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Methods for Evaluating the Potential of Renewable Energy Sources

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„Energy Planning in Selected European Regions.
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1 Introduction

1.1 Problem Statement

Over recent decades, economic development has been accompanied by an extreme increase in energy production, which has resulted in a depletion of fossil resources and has negatively affected the environment. Therefore, alternative energy resources have increasingly gained importance as a means to tackle these problems. In 1997, the European Commission set a target of doubling the share of alternative energy sources in the European Union from 6% to 12% by 2010 (EC 1997). Since this time, significant progress has been made on the White Paper goal. The latest but not last mandatory target, a 20% share of renewable energy sources in the EU's primary energy consumption, was agreed in December 2008. Clearly renewable energy sources (RES) contribute to environmental protection, fossil fuels' conservation, the diversification of the fuel supply and enhanced regional and rural development opportunities. However, although all of the positive impacts of the transition from fossil fuels to alternative energy sources are known, an intensified RES use may have negative local impacts on socio-economic or ecological systems, and the pressure on farmland has already increased under a growing biomass demand (Bergmann, Hanley et al. 2006; Gross 2007; Chiabrando, Fabrizio et al. 2009; Frondel, Ritter et al. 2010). Renewable energy sources like biomass and solar energy require significantly more land to generate energy than conventional fuels do (Seager, Miller et al. 2009; Dijkman and Benders 2010). An uncontrolled extensive increase of RES production will thus lead to significant changes in land use patterns and socio-economic activities. Therefore the risks linked to the intensified use of RES should be adequately taken into consideration because ill-conceived energy policies may adversely impact land, local ecosystems and increase growth in public and social expenditure (EEA 2006; OECD 2008). For that reason, the Directive 2009/28/EC recognizes the vital role of public authorities in this process and calls upon the Member States to define and coordinate the administrative responsibilities of the self-governments, integrating the RES technologies into energy portfolios through spatial and energy planning. The planning at a regional level plays a key role in balancing competing interests for land resources and in managing the multi-functionality of land-use (Helming, Pérez-Soba et al. 2008).

Based on the outlined problem, the following hypotheses were derived for the present work:

- All forms of energy production and generation result in environmental and socio-economic impacts and contribute to land use conflicts.
- Impact chains of renewable energy use can only be estimated at regional or local level in order to respond to them through planning instruments.
- A sustainable development of RES and an appropriate RES mix will make it possible both to exploit their opportunities and to mitigate various conflicts.
- Thus, a multidisciplinary approach needs to be developed to evaluate the diverse effects of the intensified expansion of RES.

1.2 Objectives and Scope of Study

The primary objective of this work is to develop a transparent framework to support the regional energy planning process that allows for a better understanding of the region-specific RES potential and the related land use trade-off. The developed set of methodological approaches makes it possible to explore the potentials of solar, wind and biomass energy production and the exemplary utilization technologies. In addition, the analysis, based on several local factors, is carried out to explore investors' or land-users' decisions on potential locations for renewable energy usage. The objective is to demonstrate the potential deployment of the RES from the investors' perspective and such renewable energy mix which would optimally balance the trade-off between contradictory territorial and environmental objectives.

Moreover, the sub-objective is to develop a consistent approach based on comparable types of data (statistics, digital layers etc.), so that any outcomes would be comparable at the European regional levels. Three regions that represent heterogeneity across Europe are selected to verify the methods and to evaluate the available dataset that have an influence on the methodology design and results. The Kujawsko-Pomorskie Voivodship in Poland (see Map 1) depicts the peripheral regions characterized by agricultural monostructure. European metropolises are represented by the Stuttgart Region in Germany (see Map 2). On the other hand, the

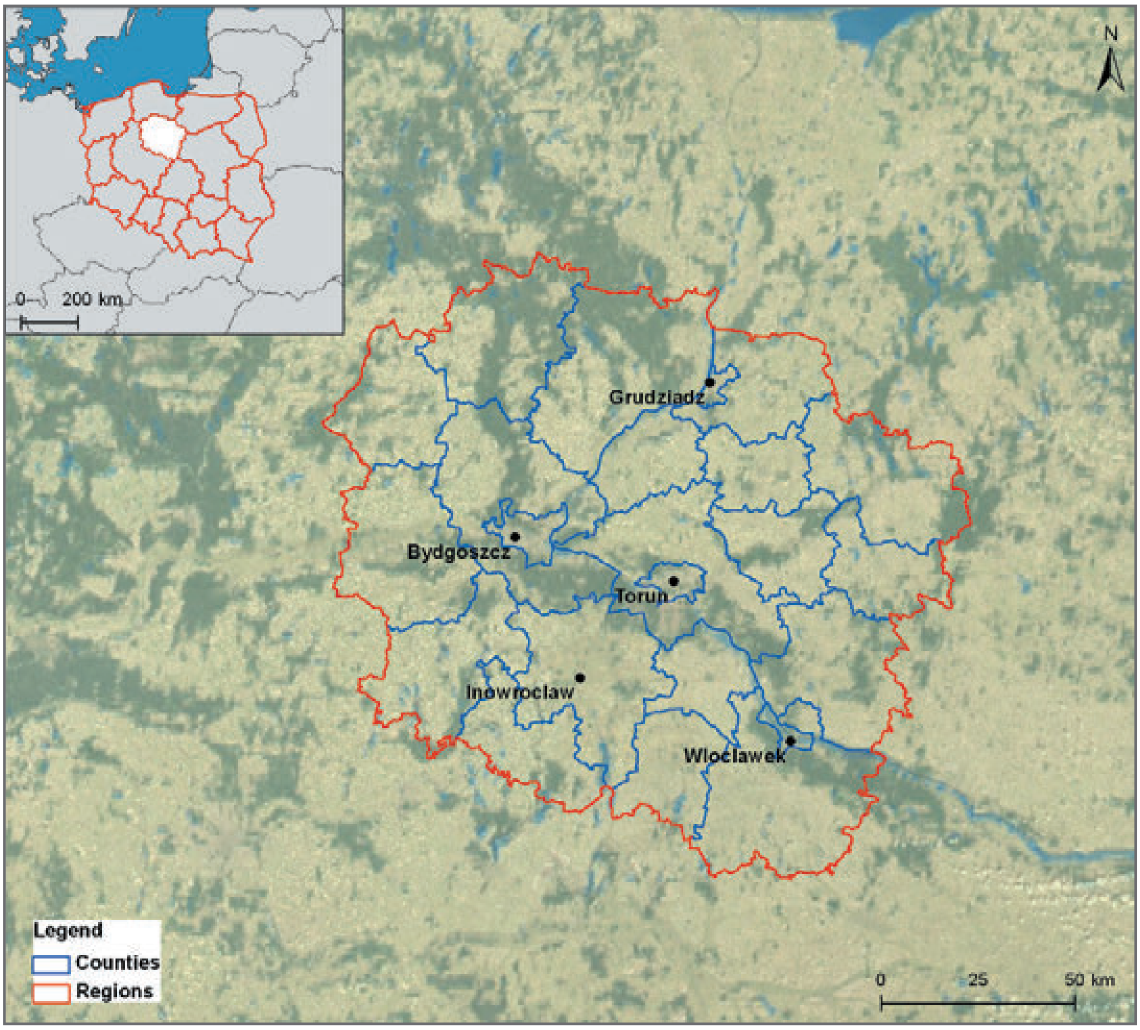
Provence-Alpes-Côte d'Azur (PACA) in France (see Map 3) exemplifies the regions consisting of urbanized territories as well as a sparsely populated areas surrounded by agricultural land and an uncultivated mountainous terrain.

The geographical information system (GIS) was chosen as a supporting instrument, as it provides a logical solution for analyzing a variety of spatially related data in a cost-effective way. Moreover, GIS allows for an integrated assessment of environmental, technical and economic potential, resulting in the determination of RES potentials and potential conflicts related to the use of cross-energy sources; wind, solar and biomass.

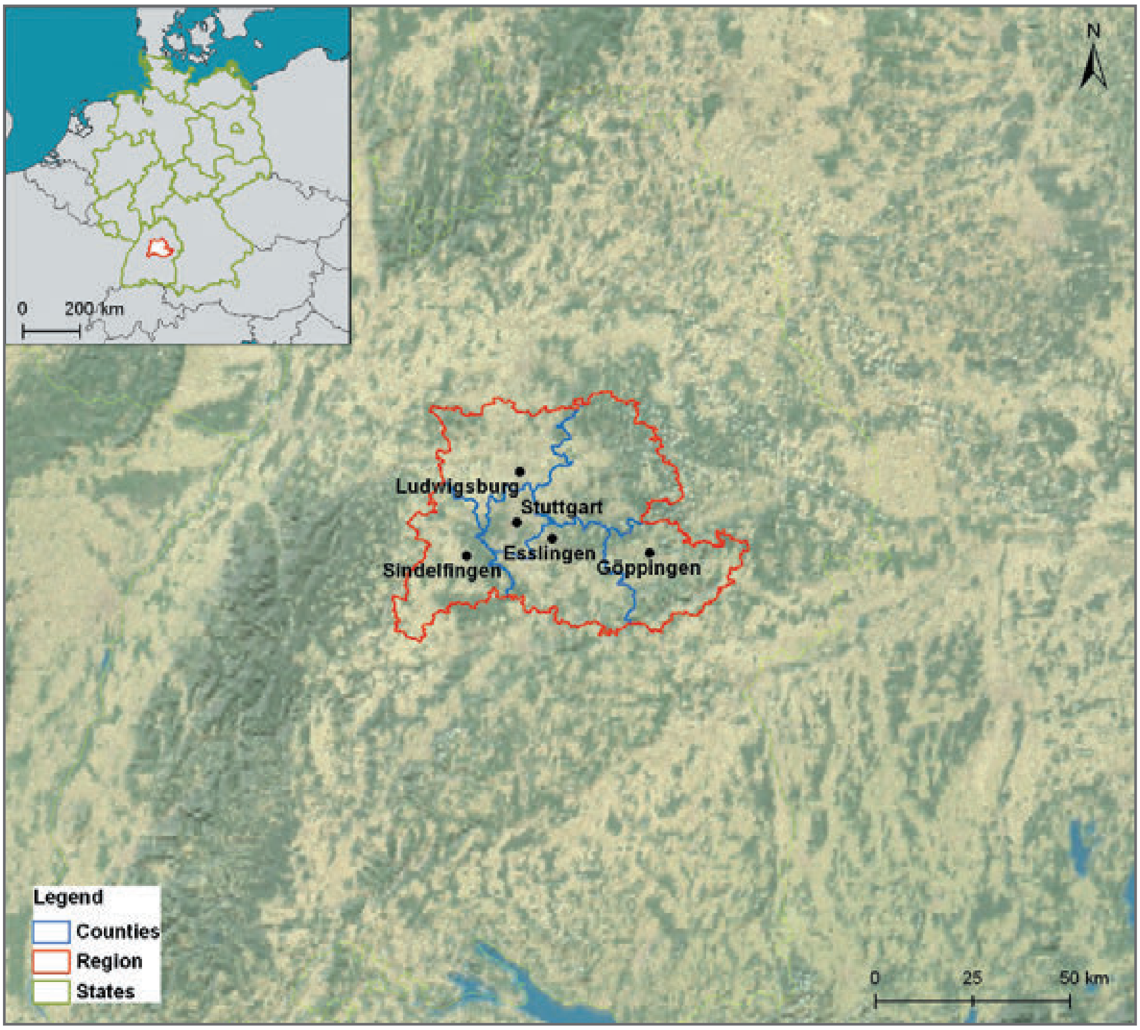
1.3 Research Question

From the hypothesis, objectives and framework conditions outlined above, essential questions were derived and will be discussed in subsequent chapters:

- Which factors determine the technical, economic and deployment potential of renewable energy sources?
- What methodical approach allows the impact of the expansion of renewable resources to be explored?
- How should this approach be designed to provide support for regional decisions?
- What conflicts and risk arise from an intensified use of RES?
- Which regional planning instruments and measures can tackle the problems?



Map 1: Topographic Overview of the Kujawsko-Pomorskie Region in Poland

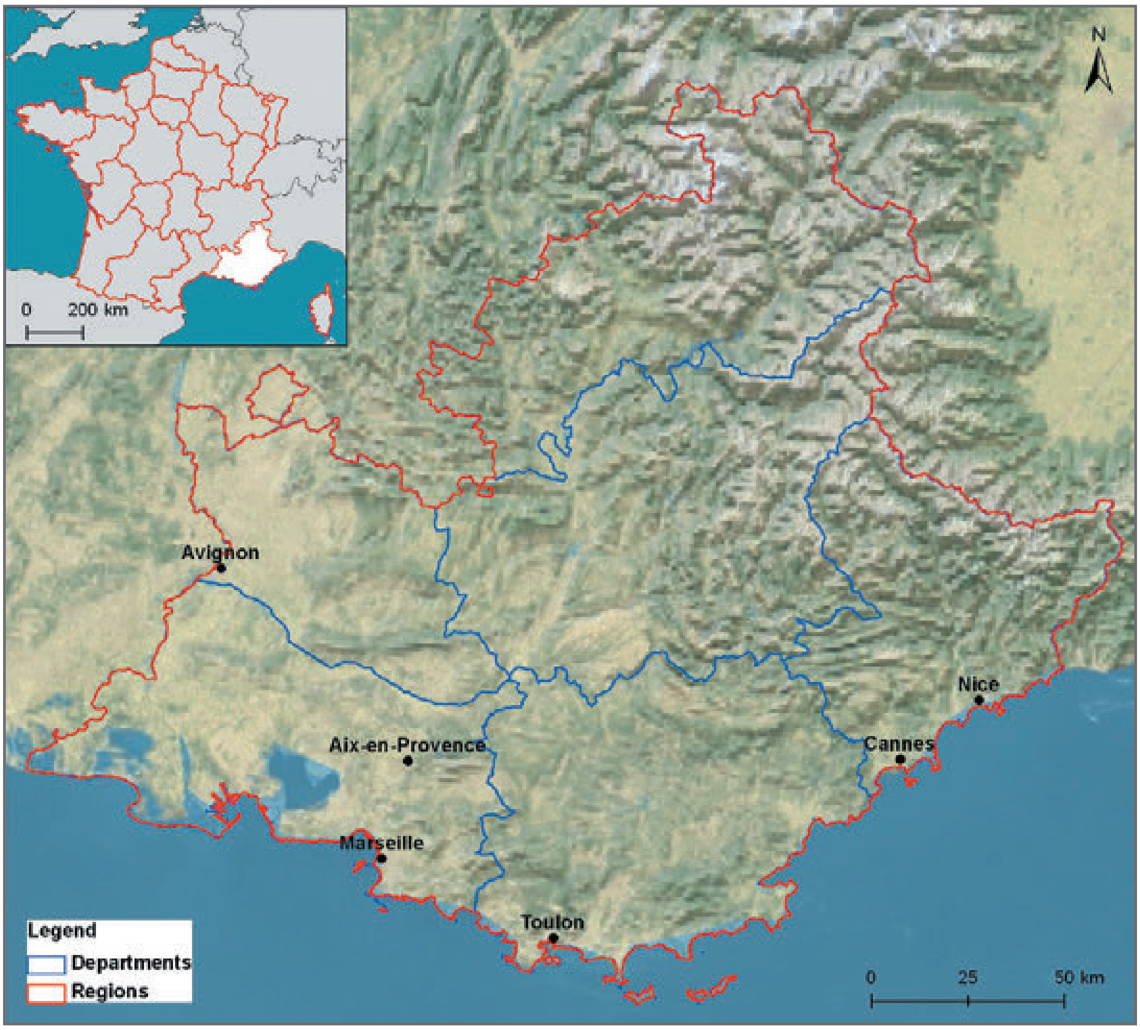


Map 2: Topographic Overview of the Stuttgart Region in Germany

- What regional specifics lead to a modification of instruments or measures?
- What spatially differentiated datasets are available and can the lack of data be supplemented by other data?
- What data is required and what are the indicators enabling RES assessment?

1.4 Outline of the Thesis

The study is structured according to the following scheme: Chapter 2 provides an overview of the current renewable energy use and policy framework at national and regional levels related to three case studies, as well as RES financial support schemes. Furthermore, it gives insight into spatial planning policies and their instruments that maintain renewable energy development and mitigate land use conflicts. Chapter 3 outlines the methods, datasets and objectives needed to carry out studies dealing with RES assessment. In addition, the deficiencies of existing studies dealing with different RES potential in selected case study regions are identified and, on the basis of this, the assessment framework proposed in this thesis is expounded. Chapter 4 describes the biomass sources concerned, the methodological approaches to assess the energy crops' cultivation potential, plus the potential of agricultural waste and woody residues as renewable sources of energy. Animal waste potential is evaluated in the context of biogas production. The technical and economic wind energy potential is evaluated in chapter 5. With respect to legal requirements and assessment conditions of technical wind energy potential, three methods were developed. In chapter 6, the focus is placed on the technical and economic potential of solar energy generated through rooftop and stand-alone photovoltaic systems. In chapter 7, different alternative energy sources and



Map 3: Topographic Overview of the Provence-Alpes-Côte d'Azur (PACA) in France

options for their exploitation in the context of land use trade-offs were assessed. The investors' decision to dedicate the land for food or non-food production is evaluated in view of the current legal and economic conditions. The potential variations in RES use from the investors' perspective demonstrates competing needs for land-resources. The assessment is carried out on the basis of several factors that were explored to appraise the likely land users' activities. In chapter 8, conclusions are drawn with respect to the development potential of energy-mixes and the instruments needed to maintain the sustainable development of alternative energy production. Finally, recommendations for further assessments are outlined as well as the limitations of the present study and the methodological set of approaches.

2 Renewable Energy Use and Policy

In March 2007, the European Council agreed on a common strategy to mitigate green house gas emissions, to boost energy efficiency and increase the use of renewable energy sources by 20% until 2020 (with 2005 as reference year). This strategy resulted in Directive 2009/28/EC on the promotion of the use of energy from renewable sources, which came into force on 25 June 2009. This legal document sets individual overall national targets on the use of energy from renewable sources for each EU member state and allows them to decide on the mix of renewable energy in their final gross energy consumption. By the end of 2010, EU member states had submitted National Renewable Energy Action Plans (NREAP) setting out the national targets for the share of energy from renewable sources consumed in transport, electricity, heating and cooling to be achieved by 2020.

2.1 Renewable Energy Use and Targets in Poland

The EU Directive 2009/28/EC set up the following indicative objectives for Poland to be implemented by 2020: 15% share of energy from RES in gross energy consumption and at least a 10% share of biofuels in the final consumption of energy in transport. According to the Polish National Renewable Energy Action Plan (NREAP), electricity generation is expected to be realized particularly through wind energy and biomass with 47% and 44% of the total electricity production respectively (see Table 1). The most significant share in reaching the target will fall to the heat sector (with over 60%), and among other fuels, solid biomass is to play the leading role in achieving the above-mentioned objectives (see Table 2).

Apart from heat and electricity production, agricultural land will be dedicated to production of bio-fuels, whose targets are outlined in Table 3. The NREAP document does not include a detailed plan on biomass exploitation or the division of sources between co-incineration and combustion. The relationship between the power capacity (10200 MW_e) and the electricity produced from solid biomass (1150 GWh) indicates a high rate of biomass combustion power plants[1], while the blended

Table 1: Estimate of the Total Contribution (as to Installed Capacity, Gross Electricity Consumption) of Selected Technology Using Renewable Energy Sources Anticipated in Poland in the Electricity Sector by 2020

	2005		2020	
	MW	GWh	MW	GWh
Hydro Energy	915	2201	1152	2969
Solar Energy	-	-	3	3
PV	-	-	3	3
Wind Energy	121	136	6110	15210
On-Shore	121	136	6110	13160
Off-Shore	-	-	500	1500
Biomass	55	1451	2530	14218
Solid (Biomass CHP)	25	1399	1550	10200
Co-Firing*	-	1236	-	900
Firing*	-	163	-	9300
Share of Co-Firing*	-	88%	-	9%
Biogas	30	111	980	4018
Liquid Biofuels (1)	-	-	-	-
Overall	1091	3787	10335	32400
from Combined Heat and Power	55	1451	1425	14383

*Own estimation

Source: NREAP (2010c)

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[1] The calculation is based on a power plant's load factor of 6000 hours per year

Table 2: Estimate of the Total Contribution of RES to the Overall Energy Consumption in the Heating and Cooling Sectors by 2020

	2005		2010	
Heat	ktoe	GWh*	ktoe	GWh*
Solar	21	244	506	5884
Biomass	3949	45919	5089	59174
Solid	3884	45163	4636	53907
in CHP*	-	1539	-	11200
in Heating Boilers*	-	43624	-	42687
Biogas	65	756	453	52907
Biogas	-	-	-	200
in CHP (with Electricity)*	-	122	882	4407
in CHP (without Electricity)*	-	634	-	861
Overall			6065	70523

*Own estimation

Source: NREAP (2010c)

biomass with hard coal is likely to account for only 9% of green electricity compared to 88% in 2005 and 82% in 2009. It must be noted that the first draft of NREAP made public in May 2010 assumed that 60% of the electricity is to be generated through co-firing processes. The current structure and support mechanisms of the Polish energy sector (with 93% of total electricity being generated through coal-fired power plants) suggest that the original scenario is more likely to be met. In Poland, there were 39 co-firing units in 2009 and 41 co-firing power plants in 2010. Among these, two operate in the Kujawsko-Pomorkie Voivodship (Świecie and Grudziądz).

In 2009, the amount of electricity generated in Poland's 39 power plants reached 4 300 GWh, that is to say 30% of the target expected in 2020. The origin of the biomass production is relevant for the share of biomass in combustion and co-combustion power plants. The Ordinance of the Polish Ministry of Economy from 14 August 2008 restricts the amount of biomass originating from forests, which therefore has to be replaced by agricultural material in co-firing processes to be eligible to obtain certificates of origin (Ministry of Economy 2008). In power plants with a power capacity exceeding 5 MW_{th}, the amount of non-forestry biomass co-fired with coal shall exceed a certain percentage of substances other than forestry biomass (from 25% in 2010 to 100% in 2017). In systems whose capacity exceeds 20 MW_{th} (for hybrid systems and dedicated biomass units after 2010) and which incinerate biomass only, a certain percentage of the biomass (20% in 2010 and 40% in 2017) must be replaced by non-forestry material (i.e. energy crops, agricultural and bio-industrial residues).

Besides these targets, another relevant objective is to strengthen the promotion of biogas for methane production decided by the Council of Ministers on 13 July 2010 and laid down in the document "Development of agricultural biogas plants in Poland in 2010-2020" (Ministry of Economy 2010). This legal basis sets a very ambitious goal of increasing the biogas power capacity in Poland from 77 MW (including the capacity of 7.5 MW of 7 agricultural biogas power plants constructed by the end of 2009) up to 2000 - 3000 MW by 2020. According to the Polish Ministry of Economy, the real potential

Table 3: Estimate of the Total Share of Bio-Fuels in RES in the Polish Transport Sector by 2020

	2005	2005	2020	2020
Biofuels	ktoe	TJ	ktoe	TJ
Bioetanol/Bio-ETBE	28	1156	451	18888
Biodiesel	15	633	1348	56454

Source: NREAP (2010c)

of biogas feedstock from agriculture and the food processing industry could generate approximately 1.7 billion m^3 of biogas per year, which after treatment would meet 10% of the country's natural gas consumption and provide an additional 125 GWh of electricity and 200 GWh of thermal energy (Ministry of Economy 2010).

2.2 Renewable Energy Use and Targets in the Kujawsko-Pomorskie Voivodship

Comparing national energy statistics (GUS 2010b) the Kujawsko-Pomorskie indicates a 5.2% rate of energy consumption in the national energy consumption, which indicator is higher than the rate of 1.9% in the national energy production (see Table 4).

Due to the favorable conditions on the Vistula River, the hydro installed capacity and production in the said region is among the highest in Poland. Also with regard to solid biomass and residue exploitation, the Kujawsko-Pomorskie Voivodship comes in the leading position (see Table 5). Moreover, the region ranks third for its amount of wind energy generation.

The use of renewable energy sources is addressed in two documents: "The Development Strategy of the Kujawsko-Pomorskie Voivodship for the years 2007-2020" (Zarząd 2005) and in "The Plan for the Protection of the Environment and Waste Management in the Kujawsko-Pomorskie Voivodship" established in 2010 (Sejmik 2010), which set up the mid-term objective by 2014 to increase RES energy production according to the national energy policy. Consequently, as there were no specific formulated RES quotas for the Kujawsko-Pomorskie Voivodship, the national targets based on the NREAP were transferred onto the region. For this, reference factors were identified like the share of installed capacity (see Table 5), the share of agricultural land or the animal population (10% in the national animal population (GUS 2009a)) as shown in Table 6.

It can be assumed that the energy consumption is approximately proportional to the population, but on the other hand, electrical energy is not necessarily produced at the place of consumption and in practice is transferred over long distances. By the same token, crop production for the generation of bioenergy is approximately proportional to the area of farmland. Unlike biofuels, which are produced exclusively from crops, electricity and heat can be generated either from crops or from wood or organic waste. Although partly inadequate, those reference factors were applied in the thesis to define regional objectives according to the national energy policy. By the calculation of heating objectives, the figures outlined in Table 6 indicate the rest of the heat generated in heat only boilers, as these figures were expressed in the agricultural land area required to meet the biomass-based regional targets (see

Table 4: Share of Installed Capacity, Electricity Production and Consumption in National Performance in % in 2009

Installed Capacity [%]			Electricity Production [%]				Consumption of Electricity
Total	Thermal Power Plants	RES	Total	Fossil Fuels, incl. Biomass in Co-Firing	RES	Hydro	Total
2.9	1.5	18	1.9	1.2	24.6	31	5.2

Source: URE (2010); GUS (2010b)

Table 5: Share of Installed Capacity in National Power Generation in % Based on RES in 2009

RES Share [%]	Wind	Hydro	Biomass Solid	Agricultural Biogas	Sludge Gas	Landfill Gas	Co-Firing Plants
	13.1	22.3	18.5	29.3	7.5	7.5	2 from 38

Source: URE (2010); GUS (2010b)

Table 6: Transfer of National Targets onto the Regional Level Through Reference Factors

	2009	Share	2020		Reference Factor
	MW	%	MW	GWh	
RES	Electricity				
Solar Energy - PV	-	-	0.2	0.2	Settlement Areas
Wind Energy	95	13	865	1977	Proportional to the Share in 2009
Biomass	Electricity				
Solid	48	19	23	156	Installed Capacity
	-	-	93	623	Agricultural Land
Co-Firing	-	-	-	14	Installed Capacity
	-	-	-	54	Agricultural Land
Firing	-	-	-	140	Installed Capacity
	-	-	-	558	Agricultural Land
Biogas	5	7	66	272	Proportional to the Share in 2009
	-	-	98	401	Animal Population
	Heating				
Solar	-	-	-	329	Settlement Areas
Biomass	Heating				
Solid	-	-	349	2911	Population
	-	-	401	3342	Agricultural Land
Biogas	-	-	269	527	Animal Population
	Biogas*				
Agricultural Biogas	2	29	250	5200**	Animal Population
Agricultural Biogas	-	-	150	3000**	Agricultural Area

*"Development of agricultural biogas plants in Poland in 2010-2020" (Ministry of Economy 2010)

**Methane equivalent in GWh

chapter 7.1). The additional target of agricultural biogas production for methane injected into the natural gas grid set by the Polish Ministry of Economy (2010) was proportionally transferred onto the regional level through two rates: animal population and agricultural land.

2.3 Renewable Energy Use and Targets in Germany

Unlike Poland, Germany has greatly advanced in the production of electricity, heat and biofuels from alternative energy sources (BMU/BMELV 2009; NREAP 2010a), exceeding by 3% the national targets set in Directive 2001/77/EC (12.5% of RES-E in 2010). Among all RES, the most important contribution to the generation of primary energy was made by biomass (74% - an equivalent of 789 PJ), whilst almost half of the electricity generated from RES was made up by wind (145 PJ).

To contribute to the overall European target of 20% of renewable energy in the EU's total energy production by 2020, the German government made a clear commitment to expand renewable energy sources with the following goals (see Figure 1):

- to increase the share of renewable energies in the country's electricity consumption to 30% by 2020,
- to increase the share of renewable energies in the country's final energy consumption to 18% by 2020,
- to raise the proportion of heat energy from renewable energies to 14% by 2020,
- to increase the share of biofuels in the net greenhouse gas reduction to 7% by 2020.

According to the German National Renewable Energy Action Plan (NREAP 2010a), the government estimates the share of alternative energies in gross final energy consumption will be 19.6% in 2020, thus exceeding the binding national target of 18% laid down for Germany in the EU Directive

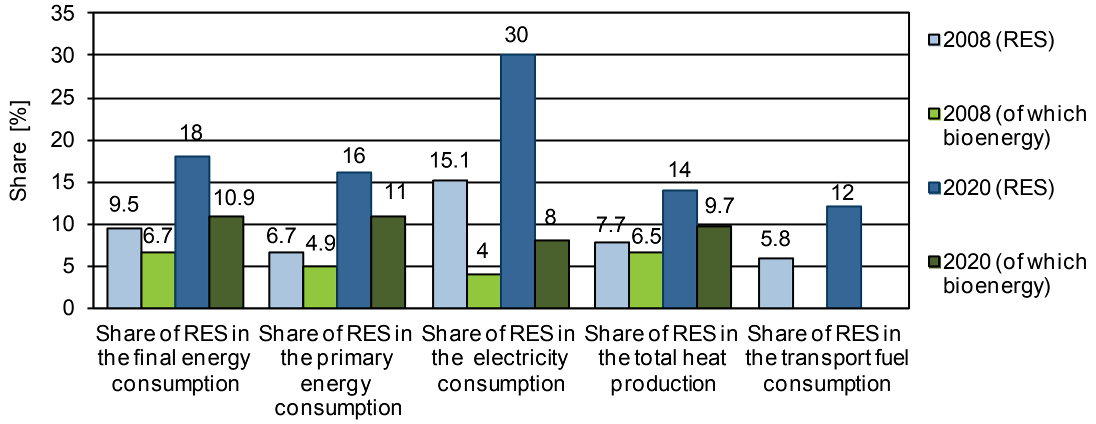

Figure 1: Status Quo in 2008 and Specific Targets for RES and Bioenergy by 2020
Source: Based on Data Derived from BMU/BMELV (2009)

2009/28/EU. Table 7 summarizes the expected contribution of RES in the German electricity sector energy-mix. Below, Table 8 and Table 9 summarize the expected contribution of RES in the energy mix by 2020 in the German heat sector and biofuels sector respectively.

To reduce dependence on natural gas imports, the German government created conditions (the Gas Grid Access Ordinance (GasNZV), Gas Grid Payment Ordinance (GasNeV) and Incentives Ordinance (AregV), all adopted in 2008) aimed at facilitating the entry of upgraded biomethane into the gas grid and its use in the transport sector. Thus, the share of biomethane used to meet the total natural gas demand in Germany should reach 6% by 2020 (6 Bn m^3 of biomethane) and 10% (10 Bn m^3 of biomethane) by 2030 in comparison with the base year 2007.

Most studies assume constant levels of food and fodder supplies and come to the conclusion that in 2020 between 2.5 and 4 million ha of arable land could be available for biomass crops for use as raw materials and in energy production (BMU/BMELV 2009). By comparison, in 2008,

Table 7: Estimation of the Total Contribution (Installed Capacity, Gross Electricity Consumption) of Selected Technology Using Renewable Energy Sources Anticipated in the German Electricity Sector by 2020

	2005		2020	
Electricity	MW	GWh	MW	GWh
Solar Energy	1980	1282	51753	41389
PV	-	1282	51753	41389
Wind Energy	18415	26658	45750	104435
On-Shore	18415	26658	35750	72664
Biomass	3174	14025	8825	49457
Solid	2427	10044	4792	24569
Waste Wood*	-	3918	1332	5634
Biogenic Solid Waste*	740	3039	1150	4500
Other Solid Biomass	-	-	2310	14435
Biogas	693	3652	3796	23438
Biogas*	-	2780	3189	21563
Landfill and Sewage Gas*	-	872	607	1875
Liquid Biofuels	54	329	237	1450
Overall	27898	61653	110934	216935

* Division based on data derived from BMU (2009)

Source: NREAP (2010a)

Table 8: Estimate of the Total Contribution (Final Consumption of Energy) of RES in the Heating and Cooling Sector in Germany by 2020

	2005	2005	2020	2020
Heat	ktoe	GWh	ktoe	GWh
Solar Energy	238	2767	1144	13302
Biomass	7260	84419	11162	129791
Solid	6794	79000	8839	102779
Biogas	154	1791	1692	19674
Bioliquids	313	3640	707	8221

Source: NREAP (2010a)

Table 9: Estimation of the Total Contribution in the Transport Sector in Germany by 2020

	2005	2020	2005	2020
Biofuels	ktoe		TJ	
Bioethanol/Bio-ETBE	144	857	6031	35891
of which Imported	0	278	0	11643
Biodiesel	1598	4443	66924	186073
of which Imported	0	2846	0	119190

Source: NREAP (2010a)

around 1.8 million ha were used for the cultivation of energy crops (DBFZ 2009). Of all energy crops, around a third of the cropland devoted to energy production will be used for biogas production (Hinrichs-Rahlwes and Pieprzyk 2009). Beyond the background of the ambitious biomass scenario, the German government launched the National Biomass Action Plan outlining a concept for increasing the bioenergy share in Germany's energy supply (Figure 1) while adhering to sustainability criteria. The Action Plan is a roadmap and not a legally binding document, agreed upon to support the effort to promote bioenergy use in the heating, electricity and fuel sectors (BMU/BMELV 2009).

2.4 Renewable Energy Use and Targets in Baden-Württemberg

The objectives regarding RES electricity production set at the state level are considerably lower - above all for wind energy - than those fixed at the national level due to structural differences in production and consumption and natural feasibilities. As presented in Figure 2, the German Federal Land of Baden-Württemberg covered 7.6% of its primary energy consumption through renewable energy sources in 2007 (WM 2009). Based on the assumption of the same amount of electricity consumption in 2020 and 2005, the German federal government fixed targets for electricity generation from RES as outlined in Table 10. The target for 2020 is 14.4 TWh of electricity from renewable energies, equaling 5.1% of the country's projected primary energy consumption (UM 2007; WM 2009). As outlined in Table 10, to achieve the goal of 20% of renewable energy sources in Germany's gross electricity generation by 2020, wind power must grow from 0.31 TWh in 2005 to 1.2 TWh in 2020. A significant increase in power could also be achieved through repowering (Hinrichs-Rahlwes and Pieprzyk 2009). In addition to this, the German government pointed out the role of regional authorities in identifying new sites for the development of wind energy plants by including them in regional plans.

Due to its geographic location, Germany has a leading position in the harnessing of solar energy and schedules a further expansion of electricity generated from photovoltaic plants from 0.27 TWh in 2005 to 2.7 TWh by 2020 (UM 2007; WM 2009).

In its Environmental Plan (UM 2007) and in its Energy Concept (WM 2009), the federal state

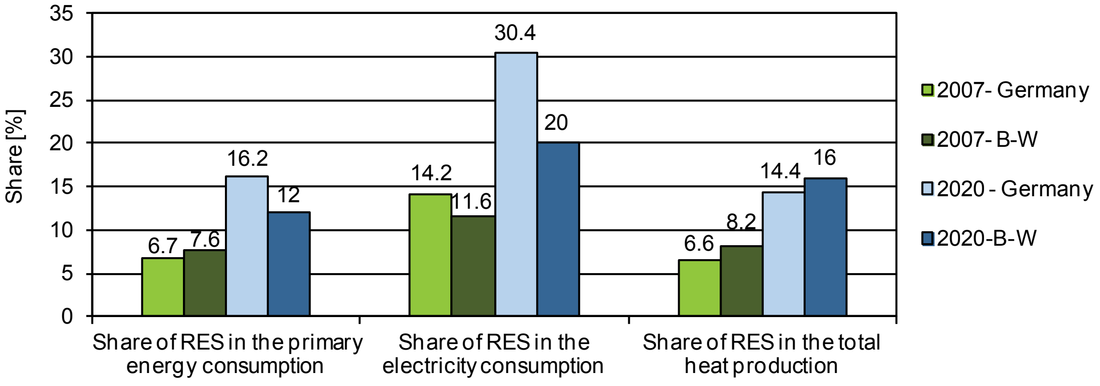

Figure 2: The German Energy Targets at National and Federal State Level
Source: Based on Data Derived from UM (2007) and WM (2009)

government of Baden-Württemberg emphasizes the major role of biomass sources in energy production. According to the Energy Concept, the use of biomass energy in Baden-Württemberg should triple (compared to the reference year 2005), thus generating 6.5% of electricity by 2020 and double (compared to the reference year 2006) in order to meet 13.2% of the federal state's energy demand for heat production.

The state government of Baden-Württemberg expects the contribution of biogas to the country's gross energy production to rise from about 0.3 TWh in 2005 to 1.5 TWh in 2020, and the share of solid fuel in energy production to step up from 1.1 TWh in 2005 to 3 TWh in 2020. In contrast, the contribution of landfill and sewage to gross energy production will be reduced from 0.25 TWh in 2005 to around 0.2 TWh in 2020 due to national legal regulations in waste management (UM 2007). The German government is aiming for an efficient use of bioenergy, thus only the power generated in cogeneration plants is eligible for incentive payments.

Assuming that the demand for space and process heat is decreasing, the target for 2020 set by the state government is to produce 22 TWh of heat from renewable energies (equaling 5.7% of the country's forecasted total primary energy consumption) (UM 2007; WM 2009). Among other RES, biomass will play a key role in the heat supply. The target is to extend heat generation from 10.9 TWh in 2006 to 18.1 TWh in 2020 (see Table 11), which is 13.2% of the predicted heat demand. In addition to bioenergy, solar thermal energy will play an important role in increasing the share of renewable energy in

Table 10: Electricity Targets on the German National Level to Be Reached by 2020

	2005	2005	2020	2020	Share in National Target of the NAREAP by 2020
RES	TWh	%	TWh	%*	%
Hydro Energy	4.9	6.8	5.5	7.7	27
Bioenergy**	1.7	2.4	4.7	6.5	9.5
Photovoltaic	0.3	0.4	2.7	3.7	6.5
Wind Energy	0.3	0.4	1.2	1.7	1.1
Geothermal Energy	0	0	0.3	0.4	18
Total	7.2	10	14.4	20.0	6.6
Gross Electricity	72	100	72	100	-

*Based on gross electricity production in Germany in 2005

**Solid and Liquid Biofuel, Biogas, Landfill Gas, and Sewage Gas

Source: WM (2009); NREAP (2010a)

Table 11: The Heat Targets on the German National Level to be Reached by 2020

	2006	2006	2020	2020	Share in National Target of the NAREAP by 2020
	TWh	%	TWh	%*	%
Biomass	10.9	6.1	18.1	13.2	14
Solar Energy	0.8	0.4	2.9	2.1	22
Geothermal Energy	0.1	0.2	1	0.7	7
Total	11.8	6.7	22	16	14
Heat Production	175.3	100	137.2	100	-

Source: UM (2007), WM (2009)

the heating sector. The state government fixed a target of increasing the heat supply from solar thermal power from 0.8 TWh in 2006 to 2.9 TWh in 2020.

With regard to national targets, the use of biofuels in the German Federal State of Baden-Württemberg will be strengthened according to the sustainability of crop production. The German government promotes the effective use of farmland for the cultivation of second-generation biofuel crops (WM 2009). However, this as yet immature technology will not make an impact before the end of this decade (WM 2009; NREAP 2010a).

2.5 Renewable Energy Use and Targets in the Stuttgart Region

To date, the Stuttgart Region in the German Federal State of Baden-Württemberg has not formulated any RES targets. Consequently, an approach for transferring national RES targets onto the regional level was applied in this study. As the Energy Concept for Baden-Württemberg provides an insufficient breakdown of different bioenergy sources in this regard, Feldwisch, Lendvaczky et al. (2010) used a scenario of expansion of renewable energy by 2050 based on Nitsch (2008). Feldwisch attempted to transfer the national targets onto the Stuttgart level, although he focused only on biomass for the electricity, heat and biofuel sectors using both the regional rate of agricultural land and the population density rate as reference factors. Those objectives expressed in the theme of agricultural land are extensively addressed in chapter 7.2.

2.6 Renewable Energy Use and Targets in France

In 2008, the overall renewable primary energy consumption in France amounted to 19 Mtoe (million tons of oil equivalent), 86% of which was made up by hydroelectricity, providing 14.5% of the French gross electricity production. The different markets for RES have developed significantly over the last few years. The national renewable energy targets for 2020 are predominantly based on wind and solar energy. Besides that, large surfaces of agricultural land is to be used to develop energy dedicated crops (EREC 2010).

The objectives presented below (see Table 12 - Table 14) envision 23% of French energy consumption to be derived from renewable sources by 2020, provided the country's energy demand in the final energy consumption will fall by at least 10% by this date. Table 12 presents a summary of the development of renewable electric energy sources in France and their share in overall electricity consumption set in the NREAP document (NREAP 2010b). The biggest contribution to electricity production (83%) is to be made by both hydro and wind sources. Biomass does not play a significant role in this sector, but it is expected to generate 11% of the electricity from RES by 2020 in France. This is to be subdivided mainly between biomass incineration plants and biogas (22% of the electricity production) (NREAP 2010b).

In the French heat sector, around 83% (16455 ktoe) of the demand is to be covered by biomass by 2020. The targets will be divided between the tertiary and the industrial sector (5200 ktoe equaling 32%), biomass combustion plants (2400 ktoe - 15%), household and industrial waste, including mechanization processes (900 ktoe - 4%) and biogas production (555 ktoe - 3%). In the heat sector, lignocellulosic material (i.e. wood) and waste will be the main fuel (NREAP 2010b).

To reduce dependence on exported fuels and to contribute to environmental protection, France has been seeking to increase the share of biofuels in the country's overall energy consumption by fixing an earlier date for the fulfillment of the targets (10% by 2015) than required by the EU biofuel Directive 2003/30/EC (Guindé, Millet et al. 2007). Hence, France is one of the main biodiesel producers in Europe (ADEME 2010) based on rapeseed oil (87% of total production) and sunflowers (7%) (Delphine, Tyner et al. 2009). In addition, wheat and sugar beets are used to produce ethanol. French ethanol production accounts for 2% of global production (Guindé, Millet et al. 2007). In 2008, the biofuels' targets for 2020 were met in 80% for bioethanol and 66% for biodiesel.

The approach whereby the national RES targets are transferred onto the region level is not appropriate in this case for three reasons. Firstly, the natural conditions of the Provence-Alpes-Côte d'Azur region are highly favorable to the development of solar, hydro and wind energy. Secondly, the rate of arable land per capita amounts to 0.05 in PACA and thus is significantly lower than the rate of 0.3 for France. Thirdly, the pedoclimatic conditions substantially affect the profitability of crop production for energy purposes. Therefore, the reference factor can neither be the available farmland nor population density, but that an adequate development of RES must harmonize environmental, social and economic aspects.

2.7 Financial Support Schemes in the Case Study Regions

How RES will contribute to energy supply at different levels and to what extent this will happen largely depends on the legal frameworks and financial aids. Most renewable energy technologies are still not economically competitive with fossil fuels, thus their development requires supportive policy drivers and financial incentives. There are two major political support schemes applied to the 27 EU member states: the feed-in tariffs (FiT) system and the Tradable Green Certificate (TGC) system. Feed-in tariffs are generation-based, price-driven incentive mechanisms. They can be designed flexibly according to the framework conditions set by national targets and the national electricity market (Jacobs 2010).

Table 12: Estimate of the Total Contribution (Installed Capacity, Gross Electricity Consumption) of Selected Technology Using Renewable Energy Sources in the Electricity Sector Anticipated in France by 2020

	2008		2020		Share of Power in RES	Share of Energy in RES
Electricity	MW	GWh	MW	GWh	%	%
Hydro Energy	25416	68324	28300	71703	46	46
Solar Energy	110	70	5400	6885	9	4
PV	110	70	4860	5913	8	4
Concentrated Systems	-	-	540	972	1	1
Wind Energy	3458	5707	25000	57900	40	37
On-Shore	3458	5707	19000	39900	31	26
Biomass	877	4391	3007	17171	5	11
Solid	755	3708	2382	13470	4	9
Biogas	122	683	625	3701	1	2
Liquid Biofuels	-	-	-	-	-	-
Overall	30116	79094	62167	155284	100	100
From CHP	422	1052	3007	17171	-	-

Source: NREAP (2010b)

Table 13: Estimate of the Total Contribution of RES to the Final Consumption of Energy in the Heating and Cooling Sector in France by 2020

	2008	2020	2008	2020	Share in RES
Heat	ktoe	ktoe	GWh	GWh	%
Geothermal Energy	114	500	1326	5814	3
Solar Energy	70	927	814	10779	5
Biomass	9365	16455	108895	191337	83
Solid	9067	15900	105430	184884	81
Biogas	81	555	942	6453	3
Liquid Biofuels	-	-	-	-	-
Overall	10024	19732	116558	229442	100
of which Biomass in Households*	6379 (64%)	7400 (38%)	74174 (64%)	86047 (38%)	38 -

Source: NREAP (2010b)

Table 14: Estimate of the Total Contribution in the French Transport Sector by 2020

	2008	2020	2008	2020
Biofuels	ktoe	ktoe	TJ	TJ
Bioethanol/Bio-ETBE	510	650	21359	27222
of which Imported	71	50	2973	2094
Biodiesel:	1887	2850	79028	119358
of which Imported	322	400	13485	16752

Source: NREAP (2010b)

Quota obligations based on Tradable Green Certificates are generation-based quantity-driven instruments. Quota-based mechanisms are technology neutral measures because all RES-based electrical energy receives the same price through the certificate price. However, it is the least costly technologies that benefit from this incentive instrument, with the result that photovoltaic, geothermal or biogas technologies are not being developed (Jacobs 2009). Therefore, in Italy and England for instance, an additional feed-in tariff scheme was implemented to support mature RES technologies like photovoltaic systems. Quota systems as the main support instrument are cost-efficient from the society's point of view, but of low effectiveness, as Poland's example demonstrates. In addition, this mechanism involves high risks for renewable electricity producers through future uncertainties regarding fluctuating certificate and electricity prices. In addition, European practice showed that quota-based mechanisms favor large players, as small energy producers have a hard time entering the market (Fouquet and Johansson 2008; Jacobs 2009). The main principle of a quota system is that RES targets are set by public authorities while certificate prices are determined by the market (Fouquet and Johansson 2008).

In the FiT scheme, electricity generators sell renewable electricity at fixed prices over some period of time and under specific conditions related to a technology and a location. Thus, the scheme can be adjusted to each RES technology and regulated on an annual basis to avoid so-called windfall profits (Jacobs 2009). A key advantage of the FiT scheme is the high degree of investment security over the lifetime of the technology, but first and foremost is the FiT scheme's ability to promote all types of RES power due to payment diversification. On the other hand, FiT mechanisms are regarded as non-competitive and thus economically inefficient due to their fixed tariffs. In addition, on liberalized markets, the mechanism is not in line with the principles of a free energy market (Jacobs 2009). Nonetheless, the FiT model supported by the German government is regarded as a highly efficient incentive instrument not only in Europe (Fell 2009). In fact, the German Renewable Energy Sources Act (and its amendments) was the main trigger for the rapid development of not just RES-electricity but also RES-heat through bioenergy and geothermic technologies, fostering the creation of thousands of new jobs in Germany and abroad in RES-related industries and allowed billions of Euros to be saved by reducing the consumption of fossil fuels (Fell 2009). On the other hand, Frondel, Ritter et al. (2010) critically review the German public support for RES, pointing out that such system imposes high costs to society and show little long-term promise for stimulating the economy, protecting the environment, or increasing energy security.

In France, despite of one of the most comprehensive FiT schemes for wind and solar energy in Europe, administrative barriers and a lack of renewable development plans have slowed down the expansion of wind power and ground-based photovoltaic systems (Resch and Ragwitz 2007; EREC 2010).

In the subsequent sections that address the economic potential of different RES resources, the support systems outlined below will be evaluated against their ability to enhance the development of sustainable RES in the three case study regions.

2.7.1 Support System in Poland - Quota System

The main legal frameworks promoting renewable energy development in Poland are:

- The Energy Law Act (Ministry of Economy 1997, 2010), which is updated every year,
- The Order on the quota system and price regulation from 14 August 2008 (Ministry of Economy 2008).

The Polish Energy Law Act amended in March 2005 introduced a certificate of origin eligible for electricity generated from RES and in 2007 for electricity produced through high-efficiency cogeneration (yellow and red certificates). With regard to the installed capacity, the so-called yellow certificates are eligible for CHP up to 1 MW_e in the case of solid fuels or fired by gaseous fuels (irrespective of the capacity installed). The so-called red certificates are eligible for CHP of installed capacity of 1 MW fired with fuels other than gaseous fuels.

Given the least costly technologies like wind turbines have benefited most from the flat aid mechanism (the so-called green certificates), quota-based mechanisms have recently been diversified to support the still relatively expensive biogas projects. Since the amendment to the Energy Law of 1 March 2010, the yellow certificates can be combined with green certificates. Moreover, the new (violet) certificate of origin for electricity produced from biomethane in a process of high-efficiency cogeneration (including methane from dump and landfill sites and coal mines) was introduced on 9 August 2010. The violet certificate may be used interchangeably with the yellow certificate regardless of the capacity of biogas plants.

Additionally, the (brown) certificate system for biomethane injection into the natural gas grid should be introduced on 1st January 2012. The amount of methane fed into the grid will be recalculated into an equivalent in electricity to then become eligible for the brown certificate support mechanism. The recalculation algorithm to convert biomethane injections into an electricity equivalent as well as the quality requirements for biomethane will be established by an ordinance to be prepared by the Polish Ministry of Economy.

According to the Ordinance regulating the quota system (Ministry of Economy 2008), electricity generators and electricity suppliers are obliged to fulfill a certain quota of certificates of origin as outlined in Table 15. Unless the companies meet this quota, they will pay a fee (Ministry of Economy 1997, 2010). The Polish energy market regulator (URE) sets the reference price of certificates for each year within a fixed range determined in the Polish Energy Law. In 2010, certificates could be purchased on the market (Polish Power Exchange) for the following prices:

- Green - 67 €/MWh,
- Yellow - not below 15% and not over 110% of the average purchase price of electricity on the Polish commercial market - 32 €/MWh,
- Red - not below 15% and not over 40% of the average purchase price of electricity on the Polish commercial market - 7 €/MWh,
- Violet - not below 15% and not over 110% of the average purchase price of electricity on the Polish commercial market - 8 €/MWh,
- Brown - as mentioned above, the market price of a brown certificate is not known.

In contrast to the feed-in tariff mechanism, the quota system is associated with a high degree of economic insecurity for the producers as outlined in

Table 15. A high investment risk is associated with income uncertainty over the lifetime of the technology, as the yellow certificate scheme is guaranteed only until 2012, after which the government will review its impact on the market and decide whether to continue the scheme or not. Consequently the violet certificates securing income until 2018 were introduced, but their purchase price is less than half that of the yellow certificates. The scheme for green certificates was prolonged from 2014 until 2017. Altogether, these incentive mechanisms imply uncertainty to RES, CHP and biogas project developers as well as to investors when it comes to taking new projects forward.

Despite various support mechanisms, RES projects remain relatively expensive in comparison with fossil fuel utilization facilities (Ćwil 2010; ENDS 2010). The still challenging economic and political conditions governing the development of the RES industry in Poland have been improved over the last several years by introducing various forms of funded subsidies, preferential loans and energy tax incentives. To transform national targets onto the regional level and to accelerate investment in technologies using RES, different support schemes and financial grants have been offered as detailed in Appendix 1. Investors can apply for subsidies from various EU funds, national environmental protection funds as well as from 16 Regional Operational Programmes (RPO). Furthermore, the Polish National Fund for Environmental Protection and Water Management (NFOŚiGW) offers additional funding for which RES projects can be eligible.

However, according to Andrzej Dejneka, the director general at the Polish Economic Chamber of Renewable Energy (PIGEO), the national targets will not be met by 2020 without introducing a feed-in tariff (ENDS 2010), a system which guarantees a foreseen revenue stream adjusted against the technological investment costs.

2.7.2 Support System in Germany - Feed-in Tariffs

In Germany, the Federal Government and the Federal States have developed and implemented a wide range of policy instruments (e.g Stromeinspeisungsgesetz StrEG, 1990; Erneuerbare-Energien-Gesetz, 2000) to create the necessary legal framework and to accelerate development of the renewable energy market. The Renewable Energy Sources Act (EEG) is the most important legal mechanism to promote electricity production from renewable sources, which has led to a massive increase in the amount of green electricity in Germany. The EEG offers fixed payments (feed-in tariffs) for every kilowatt-hour of renewable electricity supplied to the national grid. Moreover, a range of additional bonus payments are offered:

- the biomass bonus for using wood and other renewable resources that have been specifically cultivated for energy production,
- the cogeneration bonus (KWK-Bonus) for CHP plants,
- the innovation bonus for the use of innovative technologies,
- the silage bonus (NaWaRo-Bonus) to provide a special incentive for silage,
- the technology bonus (Technologie-Bonus) for fermentation of organic waste in combination with subsequent composting of fermentation waste,
- the landscape cuttings bonus.

To receive the manure or the landscape bonus, a 30% mass (slurry/manure) or 50% mass (cuttings

Table 15: Types of Certificates of Origin and their Share Required for Redemption

Year	Green [%]	Yellow [%]	Red [%]	Violet [%]	Brown [%]
2010	10.4	3.1	21.3	1.4	
2011	10.4	3.3	22.2	1.6	
2012	10.4	3.5	23.2	1.6	?
2013	10.9	?	?	1.7	
2014	11.4			1.9	
2015	11.9			2.0	
2016	12.4			2.2	
2017	12.9			2.3	
2018	?			2.5	

from landscape management) must be certified by an expert. The technology bonus of 2 €ct/kWh will be granted if new technologies are used, for example electricity generation with fuel cells, gas turbines etc. (Sakulin 2010). To make the most efficient use of existing resources, the specific bonus payments promote the use of high-efficiency systems in the biomass, biogas, and geothermal sectors. Biogas plants with a power capacity exceeding 5 MW_e receive the feed-in tariffs only if they generate heat and power. For plants which will be brought on line during the following calendar years, the tariffs and bonuses are subjected to the annual degressive rate to assure the cost-efficiency of the policy over time.

The revisions of the German EEG in 2009 and 2010 brought a reduction in the feed-in tariff for energy produced from solar power, as market prices had dropped by around 30% in 2009 (Wohlwend 2010). In addition, with respect to economic and ecological aspects, the Renewable Energy Sources Act (EEG) abolishes the incentive payment for PV ground mounted systems erected on agricultural land. By contrast, the law introduced remuneration for solar energy produced by PV installed at a distance of up to 110 m alongside highways or rail lines, brown fields and military ranges.

The FiT payment for wind energy is guaranteed over 20 years, but after 5 years the remuneration is adjusted to the referential energy yield achieved on corresponding sites. Details are explained in the document (FGW e.V. 2007).

Appendix 2 provides an overview of the German feed-in tariffs for facilities commissioned in 2010.

2.7.3 Support System in France - Feed-in Tariffs

The French policy to promote the development of renewable energies mainly relies on the following mechanisms:

- Feed-in tariffs (introduced in 2001 and 2002, and then amended in 2005 and 2010) for PV, hydro, biomass, sewage and landfill gas, municipal solid waste, geothermal, offshore wind, onshore wind, and CHP,
- A tender system for large renewable projects.

The most important instrument to promote electricity from RES is a price regulation system consisting of a feed-in tariff specified in the Décret n°2000-1196 and applying to the electricity generated from PV, hydro, biomass, sewage and landfill gas, municipal solid waste, geothermal, offshore wind, and CHP. France has introduced new feed-in tariffs in 2010 including higher rates than in 2009 for energy generated from geothermal and biomass plants as well as for building integrated photovoltaic (BIPV) systems. The tariffs are based on the type of technology used and also on the region where the technology is located. The feed-in tariffs for the single technologies are guaranteed for a 15-year period for onshore wind, geothermal power, biogas and biomass, and for 20 years for offshore wind, solar and hydropower technologies. The incentive payments are revised every year based on a national inflation index.

Due to the revision of feed-in tariffs in 2006, the energy yield from photovoltaic systems had increased from 7.6 MW in 2006 to 285 MW in 2009 thanks to new installations. The latest change to the feed-in tariff structure was made in January 2010. Within the framework of its feed-in tariff policy, the French government offers varied payments for PV installations mounted on different locations according to whether they are free-standing or building-integrated (a.k.a. BIPV), including three categories of building integration (Order 2010a). As shown in Appendix 3, higher payments are offered to PV arrays integrated onto buildings belonging to the residential, educational and health sector. Moreover, to promote multi-functionality, the policy includes a number of specifications for eligibility in each BIPV category. For instance, the PV system has to be integrated into the roof to effectively replace the roof function and projects must be larger than 3kW in installed capacity (Couture, Cory et al. 2010). The objective of higher incentive payments for BIPV is to promote the integration of solar installations into the French landscape as harmoniously as possible.

The French biogas feed-in tariff mechanism is made up of three components:

- the cogeneration rate of 0.09 €/kWh (depending on the power of the equipment),
- the anaerobic digestion bonus of 0.02 €/kWh,
- the energy efficiency bonus of up to 0.03 €/kWh_{el}, if there is a total energy efficiency of more than 75%. For biogas, the total energy efficiency (heat and electricity, sold and/or used) of the plant has to exceed 75% to receive

the maximum bonus. The heat can be sold freely on the market.

The legal tariff for the gas grid injection is under development and is expected to come into power in late 2011 (NREAP 2010b).

The incentive payment for onshore wind energy will remain constant in the first 10 years. After that, the rate will be adjusted according to the actual wind resource performance data from that particular site according to the average number of full-load hours (Klein, Pfluger et al. 2008). The full incentive payment is offered for projects that produce electricity with less than 2400 full load hours. In contrast, wind turbines that produce more than 3600 full load hours receive only 2.8 €cents between the 10th and 15th year of their running period.

2.8 Spatial Planning Policies and Energy Plans in the Selected Case Study Regions

In the European Union, the implementation of national targets regarding the promotion of RES is delegated to the respective country's local level, with the involvement of regional and local authorities. According to Directive 2009/28/EC, the authorities at all levels are responsible for implementing and monitoring RES production and utilization (EC 2009). Thus, the question is whether such spatial and energy plans and monitoring instruments do actually exist and whether they are suitable to maintain sustainable energy development. This issue was addressed through the examples of three selected case study regions in Poland, Germany and France.

2.8.1 Spatial and Energy Planning Instruments in Poland

The current spatial and energy policy in Poland has been shaped since the end of the Second World War. After the political transition in 1989, a new law on spatial planning came into force. The Act on Spatial Planning and Management was passed in 1994 abolishing the spatial plans passed before 1995 as well as the centralized planning system. As a result, local authorities received statutory autonomy in spatial planning but insufficient financial aid and know-how (Jędraszko 2005). As a consequence of the opening of EU accession negotiations, many legal documents were revised, among them the Polish Act on Spatial Planning and Management (ASPM). The revised law was passed on 27 March 2003 (Dz. U. Nr 80 poz. 717). However, the spatial planning policy with later amendments has turned out to be far from its intended role (Jędraszko 2005; Izdebski, Nelicki et al. 2007; Izdebski, Nielicki et al. 2007; NIK 2007; Radziejowski 2007; Dziekoński, Szczech-Pietkiewicz et al. 2008). The main point of critique is related to the distribution of skills and tasks between authorities at different hierarchical levels.

At the national level, there are three groups of spatial policy acts, the most relevant of which is the strategic Concept of National Spatial Development, which has mainly analytical and informative functions (Izdebski, Nielicki et al. 2007). According to the 1997 Polish Energy Law, the objective of the national authorities is to ensure the country's energy security and efficiency, the increasing competitiveness of its economy as well as environmental protection.

At the regional level (16 voivodhips), the coordinating and informative function of spatial management and development plans gains importance. The voivodeship spatial management projects and plans are internally binding planning acts at a regional level and reflect a voivodeship-based development strategy in the socio-economic field. According to the Polish Energy Law, regional self-government takes part in energy and fuel supply planning for the voivoidship area under the conditions specified in Art. 19.5 of the Energy Law.

The role of Polish counties in the spatial planning management process is rather limited. They execute specific tasks commissioned by the State and carry out unbinding spatial analyses and studies.

According to the Spatial Planning Law, a commune is the basic self-governmental entity. In Poland, 2489 communes have binding decision-making functions. A basis for the local spatial policy is "Study on the conditions and direction of the spatial management of a commune" that is binding only for municipal authorities in the preparation of local land use plans. The objective of the Study is to harmonize the sustainable development strategy of a commune with the national and regional objectives, policies, programs and statements on sustainable use of resources (COMMIN 2007; Izdebski, Nielicki et al. 2007).

The local land use plan is a legally binding document for citizens and public administrations and a basic instrument of the municipal spatial policy. Moreover, the Polish Energy Law calls on communal self-governments to prepare the planning of heat, electricity and gaseous fuels supply and to evaluate the current conditions and expected changes in the demand for heat, electricity and gaseous fuels.

Such defined relations in the field of spatial and energy planning provide local authorities with instruments to create and stimulate communal socio-economic development but, on the other hand, if improperly used or not used at all, they may lead to harmful consequences for society, the economy and the environment. However, many municipalities have not yet prepared and implemented either spatial plans or energy and heating plans (NIK 2007; Ćwil 2010).

2.8.2 Regional Energy Planning for Renewable Energy Development in Poland

The Directive 2009/28/EC calls upon the EU member states to define and coordinate the administrative responsibilities of national, regional and local self-governments, integrating RES technologies into energy portfolios through spatial and energy planning.

Under the current legal framework, the role of the regional authorities in creating energy policy and planning is rather passive (Konwent Marszalkow Wojewodztw 2008). Neither the energy generation capacity of the individual regions nor the share of the region's particular renewable energy sources are known (Sebesta 2010). Therefore, the Convention of the Heads of the Polish Regional and Local Self-Governments expressed its concern about the lack of consultation with the representatives of regional self-governments in the process of implementing the RES targets.

In addition, communes as basic self-governmental entities are responsible for shaping energy plans (Ministry of Economy 1997, 2010). However, the lack of financial resources and expertise has often been the main barrier to implement municipal land use plans and development strategies, which link the commune's mid-term development objectives with energy, environmental and infrastructural issues (MTiB 2006). This situation leads to spatial disorder (Jędraszko 2005) and slows down the development of renewable energies.

To ensure land-use as well as socio-economically and ecologically sound renewable energy growth, it is necessary to conduct a preliminary assessment at a regional scale to bridge the gap between a national-scale and a local RES potential assessment. The regional spatial and energy planning instruments would guide deployment of RES technologies over their territory and offset them with different types of land use functions (e.g. residential, recreation, agricultural, forestry, nature conservation, energy production).

2.8.3 Spatial and Energy Planning in Germany

The organizational structure for decision making and planning in Germany involves three different political levels: state, federal government and commune. Germany is a decentralized nation due to the fact that its sixteen federal states have their own authorities and legislation. The organs of local self-government are municipalities which have decisive influence on the system of spatial planning at regional and state levels. The objective of regional planning is to work out spatial development concepts (German: *Entwicklungskonzepte*) in open space areas taking into account a wide range of competitive land use functions.

In contrast to Poland, Germany has no legal framework for separate legally binding energy planning that could determine targets and strategies for the development of energy production and consumption. Nevertheless, some local and regional authorities have provided energy concepts for their planning area. Energy concepts were developed mainly in the 1980s and 1990s and focused on the extension of district heating, energy saving in local buildings and the utilization of combined heat and power (CHP). Nowadays, self-sustaining renewable energy regions or biogas village concepts are widespread in Germany owing to a wide range of incentive measures. At the national and federal state levels in Germany, spatial planning documents define basic principles, laying down the spatial requirements for a safe, environmentally sound energy supply, particularly alternative energy sources, which are specified through regional development plans and policies (Weiland and Wohlleber-Feller 2007). Regional planning is a principal instrument that influences and regulates not only spatial but also to some extent renewable energy development. The regional planning plays a key role in the balancing of RES expansion with the competing interest for land use resources (BBSR 2011).

2.8.4 Regional Planning for Wind and Solar Energy Development at the Regional Level

Alongside the incentive measures, the amendment to the Federal Building Law in 1997 contributed to rapid development of wind energy. The legal framework gave the wind turbines privileged status by promising the locations, so that regional authorities can regulate the wind park deployment by concentrating them in appropriates zones. To ensure the compliance of wind energy with environmental and spatial development objectives, the 2003 Baden-Württemberg State Planning Act (German: *Landesplanungsgesetz*) required of the regional authorities to specify priority zones for regionally significant wind turbine parks. Within those areas, other land-related uses are excluded unless they are compatible with the construction and operation of wind turbines. Outside these zones, the development of wind energy is barred.

In 2005, the Federal State Ministry of Economy stated that regional authorities may establish priority, exception and excluded zones for regionally significant PV ground applications. However, the Stuttgart Region did not take advantage of this privilege explaining that the dense urbanized region offers sufficient PV potential on roofs and façades (Günnewig, Püschel et al. 2009).

In Germany, a wide range of necessary measures and instruments at all hierarchic levels have been established and evaluated to reach the objective of 18% of renewable energy in gross energy consumption by 2020 (NREAP 2010a). However, there are no prescribed approaches or instruments that would allow for a constant evaluation of potential land use conflicts and intrusion in different systems, particularly in the biomass field.

2.8.5 Spatial and Energy Planning in France

In France, a process of power decentralization was initiated by the Act of 2 March 1982, followed by an amendment to the French Constitution on 28 March 2003 and the Act of 13 August 2004 on local rights and responsibilities. As a result, more tasks were transferred to local authorities and their role received greater recognition as the principle of local governments' financial autonomy was upheld. The authorization procedure for energy production is drafted and applied at the national level. French communes managed by Municipal Councils are responsible among other things for urban planning. The primary tasks of the regional government are coordination and planning.

Since the Grenelle II law of 12 July 2010, the development of renewable energy has been regulated by three strategic documents. The first document is the "Regional Plan for Climate, Air and Energy (SRCAE)" drawn up by national and regional authorities, which fixes targets for the development of alternative energy sources territorially. The objective of these strategic planning guidelines is to coordinate the activities of regional and local authorities (NREAP 2010b). The second document, the "Territorial Climate and Energy Plans" developed by authorities at territorial levels is binding for municipalities with more than 50000 inhabitants. The plans and measures for driving forward RES development are drawn up on the basis of regional climate, air and energy plans. The third document is the "Regional Plan for the Connection of Renewable Energies to the Grid", which regulates the connection of renewable energy technologies to the French power grid.

2.8.6 Wind Power Development Zones in France

In France, the wind power development was initiated in 1996 by the program called "Eole 2005" that set up the objective of reaching 250-500 MW by 2005. The first stage in the development of wind power zones was established in the amendment to the French energy program in 2005. A corresponding law introduced a stipulation focusing on the feed-in tariff and laying down that wind farms are allowed to be erected only within special Wind Power Development Zones (French: *Zone de développement de l'éolien - ZDE*) (Ministry of Energy 2005). The ZDEs are not however an instrument of spatial planning, rather only an instrument of electricity authorization (EREC 2010). The procedure of ZDE planning is launched by the relevant French prefect at the request of public institutions for inter-communal cooperation (Fröding 2009). In the designation of Wind Power Development Zones, the landscape has been a critical factor in the multifaceted cultural and political evaluation process (Nadaï and Labussière 2009). Whilst in 2006, around 500 planning applications were submitted, one third of the projects were rejected mainly on the grounds of landscape protection. The highest refusal rate is found in Provence-Alpes-Côte d'Azur, a region with particular environmental sensitivities (French-Property 2009). Despite the region's high wind energy potential and the existence of very strong support mechanisms, several barriers remain that hinder the growth of wind energy. Even if wind farms are exclusively located within ZDEs, this does not simplify the permission process (Fröding 2009).

2.8.7 Renewable Energy Plans in France

As a consequence of the numerous obstacles related to the development of energy from RES in France, the Programming Law No. 2009 - 967 of 3 August 2009 made it obligatory for local government prefects to act on the above-mentioned renewable planning document (French: *Schéma regional des énergies renouvelables SRENR*). This scheme outlines the region's renewable energy potential, including the national targets and the region's qualitative and quantitative objectives for developing renewable energy potential on its territory (EREC 2010). Amongst others, these regional renewable energy plans should determine the geographical zones for the development of renewable energy sources, with a specific section for wind energy (French: *Schéma Régional Eolien, SRE*). The regional climate, air and energy plans are to be adopted before 30 September 2012.

3 Methodological Approach

3.1 Discussion of Existing Methodological Approaches

Over recent years, a wide range of methodological approaches to assess renewable energy potential has been developed, and various studies provide different findings on this issue, which can be grouped after Dees (2010) as follows:

(1) according to different renewable energy source categories:
  a) wind energy
  b) solar energy
  c) geothermal energy
  d) hydro energy
  e) energy from biomass: forest biomass, energy crops, agricultural residues, organic waste
(2) according to methodological approaches:
  a) resource-focused:
    i) statistical method
    ii) spatially explicit methods
    iii) cost-supply method
  b) demand-driven:
    i) energy and economic modeling methods
  c) combined:
    i) integrated assessment
(3) according to types of potential and their different assumptions:
  a) theoretical
  b) technical
  c) economic
  d) implementation or realizable potential
(4) according to their geographical coverage:
  a) global
  b) EU-wide
  c) national
  d) regional
  e) local
(5) according to their time frame:
  a) short, medium and long term
(6) according to their different purposes:
  a) to get information about available RES
  b) for research and scientific study
  c) for policy and decision making
  d) for environmental issues
  e) for market analysis

Due to this diversity, not only the studies differ but also their outcomes and RES potentials are difficult to compare even at the same level of geographical coverage. Different methods based on different data inputs result consequently in different quantities and qualities of RES potential. The findings differ also due to the combination of several methods like statistics, digital data, remote sensing data and satellite images resulting in inaccurate data due to different scales as well as projection and pixel level errors. Consequently, there are no specific standardized recommendations or requirements for the methods and datasets applied, because none of them is error free. Plenty of studies exist and just as many will yet be carried out because there are many fields of interest, objectives and different audiences.

3.2 Deficiencies in Methodological Approaches

Research has been conducted to assess the potential of renewable energy sources, to identify geographic and socio-political barriers to development and to explore the potential effects of RES on socio-economic systems and on the environment (Kaltschnitt and Hartmann 2001; Hoogwijk 2004; BFE 2007; EEA 2007a; Berndes, Hansson et al. 2008; Hoogwijk and Graus 2008; Krewitt, Simon et al. 2008; Stangeland 2008; Igliński, Kujawski et al. 2009; Dees 2010; Bronner 2011). However, these studies do not offer an approach to evaluating the potential of three main alternative resources: biomass, wind and solar in the context of the competition for land-use and environmental burdens.

In the thesis, the considered alternative energy sources are biomass, wind and solar, as their production and utilization cross each other and lead to a change of land use patterns and various conflicts. The site assessment for the construction of wind parks, solar ground systems or biogas plants as well as sites for the cultivation of energy crops were investigated, taking into consideration the objectives of enhancing the environmental benefits and dealing with the competing needs for land resources. So far, none of the studies has addressed the above-mentioned alternative resources in such a context at the regional scale.

3.3 Methodological Approach

Supported by a geographic information system (GIS), the approach allows for locating and quantifying the potential of alternative resources: biomass, wind, solar as well as for exploring the planning issues associated with their development. The stepwise assessment is illustrated in Figure 3. In the first step, the harvesting amount of the theoretical potential, which is the total physical amount of the primary resources that are derived from site-specific natural and climate parameters, was explored.

Next, the technical potential was calculated taking into account the spatial limitations due to land-use functions and technological conditions for energy extraction and use. This potential depends on the particular efficiency of the energy utilization processes as well as on the sitting constraints of a given technology and the policy context.

Next, the economic potential was estimated, which is the part of technical potential that meets the criteria of economic profitability under a support system framework.

In the final step, the deployment potential of the alternative energy portfolio was assessed. The analysis was carried out on the basis of several factors in order to explore investors or land-users' decisions on potential deployment of renewable energy.

Alongside legal, technical and economic factors, the social acceptance determines the realizable expansion of RES (Zoellner, Schweizer-Ries et al. 2008). The social factor may be expressed in various forms: attitudes, behavior and - most importantly - investments (Wüstenhagen, Wolsink et al. 2007). In this study, the focus was on the investors and their potential investment options. In a liberalized market, land is in hands of private investors or land users, who look after their own interests (e.g. profit maximization). This often leads to competing renewable energy options and conflicting use of land. For this reason, the development of sustainable renewable energy options needs suitable guidance and management by administrative authorities, in order to balance the actions of private investors with the public interest. At the same time, regulation should not discourage potential investors and RES growth should benefit both environmental and socio-economic systems. Therefore, before designing any incentive or instruments of regulation, the first step must to be to explore investment possibilities of RES options.

The study intended to explore the potential deployment of the RES from the investors' perspective contrasted with such renewable energy

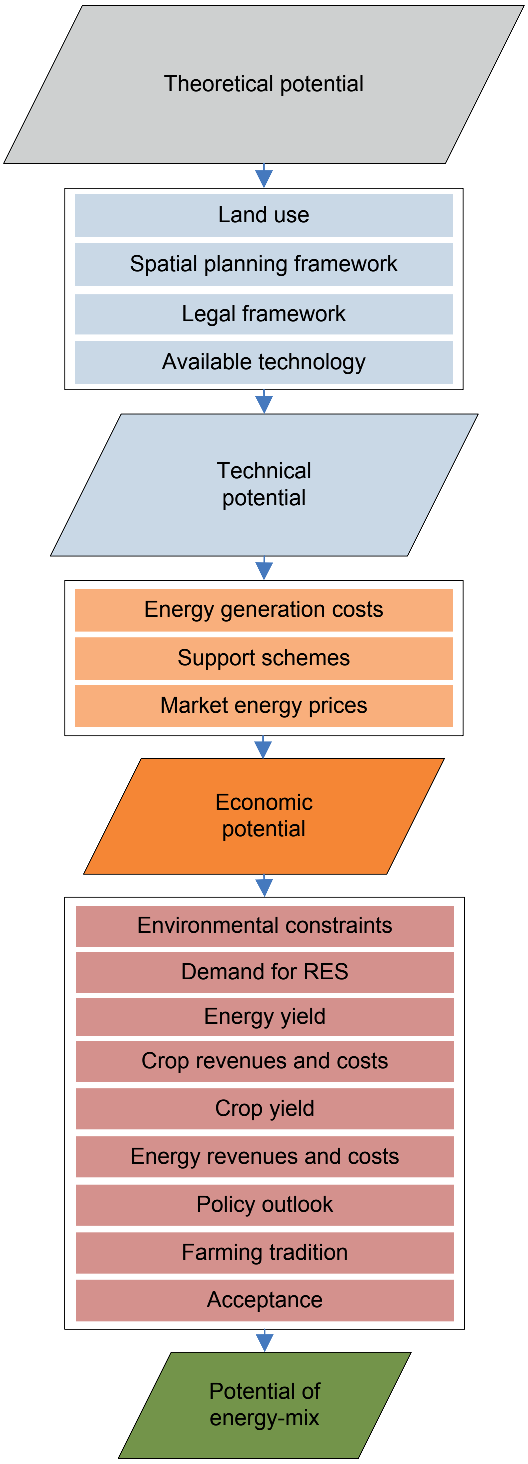

Figure 3: Overview of the Approach to Estimate the RES Potential under Various Conditions

portfolio which would balance the contradictory. The methods and findings may help to build a vision for development of an optimal RES-mix based on regionally available resources.

4 Methodological Approach for Bioenergy Potential Assessment

Biomass is expected to contribute around two-thirds of the share of renewable energy produced by EU Member States by 2020. Reaching the national targets is only possible if appropriate policies and strategies are in place. The deployment of the valuable but environmentally very sensitive resource requires particular attention because increased use of bioenergy may endanger the food security situation and affect biodiversity goods. The study demonstrates such risks based on a few examples of biomass sources.

4.1 Methodology and Scope of the Study

This study provides a comprehensive insight into the regional and local potential broken down according to the following main biomass categories identified:

(1) Energy crops
  a) Short rotation coppices SRC (willow, poplar) and perennial grasses
  b) Herbaceous crops (wheat, rye, maize, rapeseed)
(2) Agricultural residues
  a) Straw from cereals
  b) Animal manure
(3) Wood material
  a) Wood from forests
  b) Wood cuttings from orchards and vineyards, landscape management

Less-promising biomass resources were excluded from the study, such as wood by-products from building materials and industry, chemically treated wood industry by-products (i.e. from the furniture industry). With respect to the economy of scale, the potentials of this biomass origin are rather limited (Pisarek, Ganko et al. 2004). The potential of residues from the food processing industry and material manufactures were not taken into account due to a lack of data at a local level. Due to different data inputs and regional structures, different methodological approaches were developed in the Geographical Information System (GIS) environment to explore and quantify biomass sources in the case study regions considered. The assessment of biomass potentials is a complex process due to numerous fluctuating factors and political, technical and socio-economic parameters. Among others, the following issues were addressed in this study:

- the sustainability of land use maintenance,
- the maintenance of soil, organic matter and areas under water scarcity,
- the maintenance of sensitive nature conservation areas and biodiversity,
- the siting conditions of utilization technologies,
- specific technical requirements for biomass utilization,
- the economic and political framework.

In practice, a sustainable balance between the use of land for non-food and food production is impossible to determine exactly, given the global flow of commodities. Nonetheless, it is necessary to identify the present utilization pattern of agricultural products and wastes to assess the potential changes under selected aspects. For instance, the potential of growing crops for different purposes is determined by soil quality and water conditions but predominantly by economic factors and political measures. For those reasons, the study focused on the key determinants of biomass potential indicating the restrictions and opportunities.

4.1.1 Potential of Energy Crops

Due to the wide range of their applications, crops play an important role in energy generation and material use. The exploitation of herbaceous and woody plants has also been promoted by the EU members' policies. A large number of crops have been cultivated for food, feeding and energy purposes. The question is which determinants lead the farmer to choose the crop culture. Alternative crops are evaluated by farmers variously according to site conditions, the natural environment both in terms of climate and soil conditions, the patterns of land use, compatibility with policy frameworks, expected earnings and the ability to operate year-round conversion facilities. The cultivation of annual crops can easily be substituted each year by food crops depending on demand and profits, while a decision on growing perennial crops is made usually for a minimum of 20 years because of the high initial investment costs involved. The economics of short rotation crops are determined in particular by the growth performance of individual crop species that corresponds to agro-climatic conditions. The crop's productivity depends on the quality of agricultural land, climate conditions as well as on the degree of mechanization. The crop yield plays a decisive role while estimating the economical viability of a plantation. A spatial variation in natural conditions, mainly soil, water and climate represents a significant limitation regarding the choice of location for crops. Low productivity of light soils or water scarcity during the rapid growth of perennials carry the risk of a significant fall in biomass yield and may have a negative impact on the economic performance of a crop project. In addition, the political decisions affect the economics of SRC cultivation as well.

The aim of this study was to provide an understanding of regional pedoclimatic conditions and to evaluate them in the context of the growing requirements of those crops. The cropping potential was also evaluated under economic conditions and environmental constraints. Among many species of short rotation coppices and perennial grasses, the focus was placed on willow (Salix viminalis), poplar, sida (Sida hermaphrodita) and miscanthus grass (Miscanthus sacchariflorus) (see Table 16), the growing potential of which was evaluated against the annual crops; maize, oil seed raps (OSR), winter wheat and winter rye.

Table 16: Selected Crops Dedicated to Different Utilization Processes

Crops	Food	Feeding	Combustion	Biogas	Biofuels
Willow (Salix viminalis)			x		x*
Poplar			x		x*
Sida hermaphorodita			x	x	x*
Miscanthus			x	x	x*
Winter wheat	x	x	x	x	x
Winter OSR	x		x	x	x
Winter rye	x	x	x	x	x

*The lignocellulose crops in the second generation of biofuels technology

4.1.1.1 Set-Aside Land for Energy Crops

A set-aside was introduced in 1988 to limit the costly surplus production of cereals in the EU on a voluntary basis under the guaranteed price system of the Common Agricultural Policy (CAP). After 1992, the political measures became mandatory; the permanent share of 15% and then 10% was set out. The set-aside was voluntary for the new Member States, thus in Poland there was no indicative rate of set-aside land as in Germany and France. Nonetheless, in 2007, to maintain the shortage of food and feed cereals in the EU market, the set-aside requirement was reduced and two years later abolished completely. Theoretically, this land represents the first line in potential sites for growing energy crops, before replacing the current cropland pattern. However, a farmer exercising free choice would be rather motivated by economic criteria.

4.1.1.2 Energy Crops Siting Assessment

The start-up costs for the plantation of perennial crops are relatively high in comparison to annual ones. Therefore, an inappropriate and unsuitable location for the requirements of the crops could increase financial losses and may discourage farmers potentially interested in their cultivation. Climate regime and soil properties are the most important parameters influencing the cereals' productivity. That being so, in this study potential locations for crop growing were explored by matching pedoclimatic conditions with the crops' requirements in order to classify the sites according to their crop-growing suitability.

A variety of approaches have been devised to evaluate land productivity. For the past 20 years, the agro-ecological zones methodology (AEZ) has been used globally for the assessment of agricultural potentials and productivity of forest tree species (FAO 1978/1980). The method predicts crop yields or matches the agro-ecological zones with crop requirements based on globally aggregated information. Fiorese and Guariso (2010) elaborated a method to identify promising herbaceous crops based on the characteristics of geo-morphology, climate and land use. Ostrowski and Gutkowska, Ostrowski (2008) developed a computer model which links the parameters of habitat conditions of ten selected energy crops with factors required for their growth. Waldmann and Weinzierl (2008) developed a GIS-based approach for site assessment under criteria of soil moisture, annual mean temperature and agricultural bonitation. Aylott, Casella et al. (2008) developed a predictive empirical mode for yield estimation of short rotation coppices (willow, poplar) and Richter, Riche et al. (2008) for a yield estimation of miscanthus grass. Based on the relationship between miscanthus yield, rainfall variation and temperature, the linear regression model was derived from trail data in the USA to estimate miscanthus production (Delphine, Tyner et al. 2009).

However, there are as yet no studies which explore site-suitability for selected crops in the regions considered in the present work. In this study, the methodology was carried out in the GIS environment based on approaches developed by Ostrowski and Gutkowska, Ostrowski (2008; 2008) and Waldmann and Weinzierl (2008). The evaluated sites were presented in the form of maps and summary tables listing the site classification for growing crops for food and energy purposes in the case study regions.

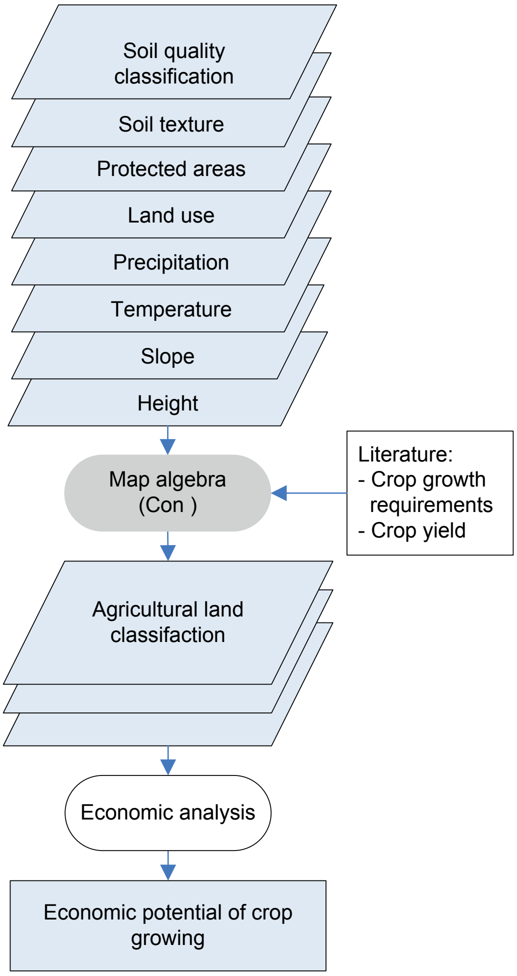

Figure 4: Workflow for Site Classification for the Growing of Selected Crops

Figure 4 illustrates the GIS-based approach toward evaluating the location for growing selected crops. In the first step, arable land is ranked according to criteria related to the agronomic needs of the selected crops such as precipitation, the elevation above sea level and the criteria of soil quality. Next, restrictions are identified by combining layers representing the arable lands on the one hand and nature conservation areas on the other hand. With respect to the cross-compliance regulation and the recommendation of the Sustainability Advisory Council of the state of Baden Württemberg (NBBW 2004) to prevent the conversion of pasture to agricultural land, grass land was excluded from the assessment.

The Map Single Algebra in the Spatial Analyst tool was used to evaluate the suitable sites with respect to humidity, soil quality, annual temperature and precipitation regime according to the following general formula:

```
if ((((ALS =  Vi or ALS =  Vi) and
    (Prec >=  Vi or Prec < Vi) and
    (Temp  >=  Vi or Temp  < Temp) and
    ( S >= Vi or S < Vi) and                    (1)
    (H  < Vi) , CS
then (((...
else YPi)))))
```

where CS are the classified sites regarding crop performance (e.g. high, average and low yield), ALS is the suitability of agricultural land, Prec is the annual precipitation in mm/m^2*y, Tem is the average annual temperature in °C, S is the slope in %, H is the height above sea level in m, Vi are the requirement criteria for crop growing derived from literature, YPi is the yield class depicting the site classification.

4.1.1.3 Data Input for Crop Siting Assessment

The sub-objective of the thesis was to elaborate a common approach based on comparable datasets for the case studies. However, due to the lack of uniform mapping schemes even on the scale of the European Union (Dobers, Ahl et al. 2009), this attempt has failed. Therefore, the assessment was carried out only for Polish and German regions. The French case study was not evaluated, due to the lack of agricultural soil-quality maps.

In the German case study region, datasets on the soil moisture capacity map (German: *Bodenkundliche Feuchtestufe*) (Lehle, Bley et al. 1995; Hauffe, Augenstein et al. 1998) and agricultural-soil land classification[2] were used. In the assessment of the Polish study region a map of complex agricultural soil indexes was used, which provides information comparable with German land quality indices (German: *Ackerlanzahl and Grünlandzahl*) (Dobers, Ahl et al. 2009).

The following spatial data was used: Agricultural-soil suitability map (complexes of agricultural suitability (CAS) at a scale of 1:100000 (Polish: *mapa glebowo - rolnicza: kompleksy rolniczej przydatnosci gleb*) was obtained from the Institute of Soil Science and Plant Cultivation (IUNG-PIB 2009). The map contains information on agro-soil suitability (called complexes) for the growth of different crops, as shown in Table 17 (Witek and Górski 1977). The information comprises 13 different categories for arable land and three categories of grass land. CAS denomination in a range of 1-100 made afterwards Witek and Górski (1977) indicates optimal land use for different crops. The complexes were defined based on the following criteria: (i) character and properties of the soil (soil type, parent rock material, texture and other basic physical and chemical properties), (ii) climate conditions in the area, (iii) land and terrain forms and (iv) hydrology (FAO 2000).

The agricultural soil quality map (German: B*odenschätzung*) at a scale of 1:25000 is a German equivalent of the Polish map of agricultural soil suitability (Dobers, Ahl et al. 2009). In addition, different mapping schemes exist for arable and grassland areas. The *Ackerlandzahl* as a complex of indexes describes the natural productivity of soil and ranges between 7 and 100 points based on predefined combinations of soil texture, the type of parent material formation, climate and the current status of soil development as shown in Table 18 (Arbeitsgruppe Boden 2005). In the same respect as the *Ackerlandzahl* for arable land, the *Grünlandzahl* for grassland ranks soil numerically from 7 to 88 based on soil texture, the stage of soil development, climatic and water conditions (Dobers, Ahl et al. 2009).

The soil moisture capacity map (German: *Bodenkundliche Feuchtestufe*) describes the moisture of soil up to a depth of 500 meters, characterizing the air-water regime and identifying the hydro-ecological growing conditions for crops. This map was used in the site assessment for short rotation coppices (SRC), which are particularly vulnerable to water scarcity over the whole year. The digital data was derived from the Water and Soil Atlas for Baden-Württemberg (WaBoA 2007). The soil texture map characterizes the soil's granulometric composition, a factor which influences the surface flow, ground moisture and soil erosion, amongst other aspects. This information was used to classify the site suitability for annual plants (KTBL 2006; Bilke 2008).

Climate data (i.e. minimum and maximum annual temperature, annual precipitation) in the form of global climate grids with a spatial resolution of one square kilometer were derived from WorldClim (2005).

The digital elevation model (DEM) of the Shuttle Radar Topography Mission (SRTM90), data consists of a 3 arc seconds resolution GRID-map, was used to generate slope and elevation layers. In the present study, the spatial resolution is fitted to CLC data with a 100m grid.

4.1.1.4 Agro-Climatic Requirements of Energy Crops

Agro-climatic criteria for each crop species were defined on the basis of the literature (Kaltschmitt and Hartmann 2001; Gutowska 2005; Jadczyszyn, Faber et al. 2006; KTBL 2006; Majtkowski 2006; Berndes and Börjesson 2007; Bilke 2008; Chołuj, Podlaski et al. 2008; CZT 2008; Ostrowski 2008; Ostrowski and Gutkowska 2008; Unseld, Möndel et al. 2008; Kuś and Faber 2009). The planting requirements for selected crops synthesized below were ranked according to site classification (c.f. Appendix 10 and Appendix 11).

- Short Rotation Coppices (Poplar and Willow)

Willow and poplars evaporate large quantities of water during the growing season, which explains their high demands on the water supply. In particular, a shortage in rainfall and overly high air

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[2] Acker-und Grünlandzahl - the indices reflect the influence of the landform, climate and groundwater level

Table 17: Complex of Agricultural Suitability

ID	CAS Description	CAS	Bonitation Classes	Characteristic
1	Very good wheat complex	95	I, II	Rich in nutrients, a neutral reaction, a deep level of humus, well structured, permeable, airy, storing large quantities of water
2	Good wheat complex	80	II, IIIa, IIIb	Periodic or regular water shortages, yield of crops dependent on weather and level of agricultural technology
3	Defective wheat complex	61	IIIb, IVa IVb	Moderately and weakly coherent soil, incapable of storing larger quantities of water; shallow soil, moderately coherent, located on the slopes and exposed to erosion
4	Very good rye complex (wheat-rye)	70	IIIb	Light soils made of sand clay; developed structure, rich in humus, appropriate water relations
5	Good rye complex	52	IVa, IVb	Soil lighter and less fertile than CAS 4; vulnerable to drought, most deeply leached and acidified. These soils are typically considered for rye-potato
6	Weak rye complex	30	IVb, V	Soil poor in nutrients, loose loamy sand, very low water holding capacity, high water infiltration water capacity: temporarily too dry, nutrients washed from soil
7	Rye-lupin complex (very weak rye complex)	18	VI	Sandy soil, poor in nutrients, too dry, only for rye and lupines
8	Cereal-fodder strong complex (mainly for wheat)	64	IIIb, IVa	Medium coherent and heavy soil, excess humidity, rich in nutrients and fertile
9	Cereal-fodder weak complex (mainly for rye)	33	IVb, V	Sandy soil, periodically wet due to a high level of ground water
1z	Occasionally flooded grassland	80		
2z	High situated grassland (not flooded)	50		
3z	Peaty and post-peat grassland	20		

Source: IUNG-PIB (2009)

temperatures between June and August certainly reduce the production of willow plants. In northern Europe, a long-time practice of SRC cultivation revealed that an average annual precipitation of at least 500 mm is required (Hall 2003). Under Polish climate conditions, the rainfall should be at least 550-650 mm, especially for willow crops. The production yield of the experimental plantations showed that both of the short rotation woody crops have moderate soil requirements (Faber, Kuś et al. 2007; Kuś, Faber et al. 2008). Willow plants can grow on soil belonging to the complexes of CAS 5 (with a high level of ground water), 8, 9, (2z) and (3z) with at least 550 mm of annual precipitation. In Germany, willow and poplar grow on soil qualities described by an *Ackerlandzahl* value from 30 to 100 (Kaltschmitt and Hartmann 2001). Both plants' agro-climatic requirements were studied in the literature (Unseld, Möndel et al. 2008).

- Miscanthus

A high yield of miscanthus and other C4 plants was obtained in locations where the annual average temperature was higher than 8°C (KTBL 2006). The cultivation of miscanthus is not recommended at levels over 700 m.a.s.l. The soil quality also has a significant impact on the production of miscanthus. On soil described by an *Ackerlandzahl* value of 65, the yield amounted to 20 t per ha, while for a value of 30 (sandy loam soil), only 8 t/ha were produced

Table 18: Classification of the Natural Production Capacity of Soil Based on Soil Evaluation

Evaluation Class of the Soil Production	Ackerlandzahl
Very low	< 28
Low	28 - 40
Moderate	41 - 60
High	61 - 75
Very high	> 75

Source: Arbeitsgruppe Boden (2005)

(Fritz and Formowitz 2009). Furthermore, cold and wet clay and loam soils are not recommended. In Poland, plant production was lower on sites characterized by a weak rye complex, permanently dry, whose production capacity is very low and the plant yield of which strongly depends on the rainfall during the growing season (Jadczyszyn, Faber et al. 2006). Under Polish climate conditions, the rainfall should be at least 600 mm for miscanthus (Kuś and Faber 2009). The highest soil production potential is represented by wheat and rye complexes of CAS 1 - 4. Fritz and Formowitz (2009) report that an annual precipitation of 700 - 800 mm leads to a high yield of miscanthus (25 - 30 t DM/ha)[3]. In locations characterized by an insufficient precipitation level, the production reached 10 - 20 t DM/ha. Water stress may reduce the crop yield by 20%, even on soils with a high available water content (Clifton-Brown, Lewandowski et al. 2001).

- Sida Hermaphrodita

The climate and soil requirements of this mallow plant are rather moderate. To obtain a high sida crop yield, the average annual rainfall should exceed 550 mm with a level of ground water under 2 m. In Poland, this plant was successfully cultivated on soils of medium and low production capacities belonging to complexes of CAS 5, 6 and 9 (Jadczyszyn, Faber et al. 2006). Due to the compact sheathing formed by miscanthus and sida plants' leaves, around 20 to 30% of rainfall never reaches the soil. In areas where annual precipitation is less than 550 mm and negative values of ground water balance range from 200 to 250 mm, larger areas of perennials would lead to a lower level of groundwater retention. Chołuj, Podlaski et al. (2008) report that irrigation leads to a yield increase of 50% in the case of willow, 34% in the case of miscanthus and 13% for Sida hermaphrodita.

- Maize Crop

Miscanthus and maize crops compete with each other due to similar pedoclimatic needs. The yield of maize crops is affected by the distribution of precipitation during the growing season rather than by thermal and soil conditions (Dubas 2003). The crop has moderate soil requirements, whereas the soil structure is of greater significance for cultivation than the soil type (KTBL 2006). On identical sites, the maize yield may vary between 13 to 34 t DM/ha depending on the precipitation regime in the growing season from 200 to 500 mm accordingly (Vetter and Strauß 2008). Cold soil is unsuitable (clay, clay loam). The yield performances associated with agricultural land suitability were taken from the study of Richter (2008).

- Winter Oil Seed Raps

Rapeseed yields are predominantly affected by soil quality and precipitation. In Poland, around 3.8 tons of rapeseed per hectare were produced on sites characterized by CAS 1 and 2, while on sites with CAS 3, 4 and 8, the potential yield of oilseed rape is lower, ranging from 3 to 3.6 tons per hectare, while on moderate soil quality (CAS 5), the yield was 2.4 t/ha and on weak soil (CAS 7), the production reached 1.6 t/ha (Stolarski and Kuś 2006). Additionally, rapeseed should be grown in a four-year crop rotation system at the same location to bring a high yield. In Germany, the highest production is obtained on loamy and clay soils. The minimum annual precipitation required is 600 mm (KTBL 2006). The lowest possible *Ackerlandzahl* is 30 points.

- Winter Wheat

Wheat cultivation brings the highest yield potential on good soils. Generally, this crop prefers fertile soils, rich in nutrients like deep loam and loess soils. However, it may be grown on practically all soil types except for very light sandy soils or peat

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[3] at 80% DM (dry matter)

soils, as long as their water requirements are satisfied and the nutrient content of the soil is sufficient. The yield structure of wheat is also affected by precipitation, which may vary in the same location from 15 dt/ha in the case of 150 mm of rainfall to 115 dt/ha in the case of 650 mm of rainfall (Heyne 1987).

- Rye

Rye and oats are the most robust and insensitive cereals with very low requirements as to location and climate (Kuś and Jonczyk 2003). The plants can be grown on all soil types, particularly on light and sandy soils. Additionally, due to their low water demand in the main growing period, rye and oat plants represent an alternative for areas unsuitable for other cereals (KTBL 2006). In Poland, rye grain is mainly grown on light soils. The plant has an increased tolerance to acidic soil and allows cost-effective water management thanks to its well-developed root system. Due to these properties, rye brings in a higher yield on weak soils than other cereals do. Thus, rye is grown on dry soil complexes: very good (4), good (5) and weak (6) and the complex of low forage corn (9) (Kuś and Jonczyk 2003).

4.1.1.5 Economic Potential of Energy Dedicated Crops

In the context of land users' decision-making on alternative uses of their land, cost analysis is a key instrument. The availability of land as a production resource is a limiting factor in the production of agricultural crops for bioenergy, food or other uses. A farmer's decision will thus not only depend on the production costs of a given crop or its yield potential, but also on its profitability for bioenergy production, food and other non-food uses compared with other crops. The cultivation of perennial crops differs from classical annual crops due to significantly higher initial investment costs, a long period of plant rotation of 20 - 25 years, irregular cash flow and variations in price and yield as well as to the lack of long-term legislation. Thus, compared to conventional cultures, the cultivation of perennial crops entails a great number of uncertainties (Sherrington, Bartley et al. 2008). For this reason, the gross margin should include compensation for the perceived higher risk of growing SRC or perennial grasses.

This study evaluated alternatives for crop productions on the basis of a gross margin indicator (Möndel 2008) that allows for annuitization of costs and revenues of crop grown over a number of years, as follows:

$$C_0 = -I_0 + \sum_{t=1} \frac{(r_t - c_t)}{(1+i)^t} \tag{2}$$

$$a = C_0 * \frac{i(1+i)^n}{(1+i)^n - 1} \tag{3}$$

where C_0 is the capital value at the beginning of investment (net present value) in €/ha, I_0 is the initial investment cost in €, r_t is the direct income in the year t in €, c_t represents the variable costs in the same year t in €, i the interest rate, a is the annuity factor[4] in €/ha and n is the length of the calculation period.

Furthermore, the economic assessment needs to include the crop rotational constraints[5] (Karlen, Varvel et al. 1994). The choice of optimum crop production for the crop rotation period determines the overall opportunity costs based on a 20-year rotation plan. Factors affecting the profitability of producing different crops can be divided into two groups. The first one refers to agro-climatic parameters that are independent of human intervention. The second group of parameters is influenced by human intervention and includes the areas under crop cultivation, the intensity and the technique of cultivation, the level of work mechanization and production costs per hectare. As it goes beyond the scope of the study to consider every possible economic configuration, a sensitivity analysis was undertaken to test the variability of gross margin against a number of chosen economic aspects such as the establishment costs, revenues and subsidy payments to establishment costs. The gross margin calculation was made on the basis of the variable costs specified in the literature. The costs of the crops' cultivation include the main group of costs related to farming operation, planting, fertilizing, harvesting and recultivation.

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[4] A mathematical figure that shows the present value of an income stream for a specified number of periods

[5] Rotation of annual crop is the practice of growing a series of different types of crops at the same site in sequential seasons for various benefits such as to avoid a decrease in soil fertility

- Field Preparation (Farming Operation)

The cost span of field preparation varies from 47 €/ha (Vetter 2005) to 265 €/ha (Möndel 2008). In Poland, as specified by Faber, Kuś et al. (2009), the costs for field preparation vary between 218 and 235 €/ha.

- Seed Stock

Depending on the unit price of the cuttings or sets and the planting density, costs may vary significantly from 880 €/ha (Hofmann 1998) up to 2340 €/ha for poplars and between 1120 €/ha (Möndel 2008) and 2025 €/ha (Pallast, Breuer et al. 2006) for willow. The cost of miscanthus seedlings exceeded those of other perennials and amounted to 1600 €/ha (Möndel 2008). In Poland, the cost of planting stocks also varies significantly from 450 €/ha for willow, 750 €/ha for sida up to 4063 €/ha for miscanthus (Faber, Kuś et al. 2009). Price variability is also connected to the uncertainty about purchase prices on markets which are still developing. The prices are thus likely to fall when farmers create their own seed stocks (Möndel 2008). The prices of seed stock in Poland and Germany are outlined in Table 19 and Table 20.

- Planting

The costs of planting spread significantly from 250 to 562 €/ha for poplar (Ohrner 2005; Pallast, Breuer et al. 2006), between 560 €/ha (Möndel 2008) and 675 €/ha (Unseld, Möndel et al. 2008) for willow and 300 €/ha for miscathus (Möndel 2008). In Poland, the lowest planting costs of 50 €/ha are associated with the sowing of Sida hermaphrodita seeds and the highest of 447 €/ha to the manual planting of seedlings of the same plant (Faber, Kuś et al. 2009). The planting costs for willow and miscanthus are 156 €/ha for mechanic planting (Kwaśniewski 2008; Matyka 2008) and up to 290 €/ha for manual planting (Matyka 2008). By employing highly mechanized operations, the costs of planting would decreased to 110 €/ha (Faber, Kuś et al. 2009).

- Herbicide Applicators

Herbicide application is highly dependent on local circumstances and depends mostly on the condition of the soil. Accordingly, there will be costs in the region of 0 - 370 €/ha (Liebhard 2007).

- Fertilizers and Field Care

As to fertilizer and field care, information about costs varies. Most authors recommend applying fertilizer for each crop cycle except the last, judging the costs to lie between 18 €/ha (Petzold, Feger et al. 2006) and 140 €/ha per cycle (Unseld, Möndel et al. 2008). Möndel (2008) fixed the costs at 100 €/ha for willow and poplar, and at 10 €/ha each year for miscanthus. In Poland, expenses for fertilizers and herbicides vary between 185 €/ha for miscanthus and 254 €/ha for willow and sida, plus the machinery costs, which can be assumed to reach 120 €/ha (Faber, Kuś et al. 2009).

- Harvesting Costs

Data for the harvesting costs varies with respect to the harvest technology and also to the authors' different assumptions regarding the harvesting processes (Table 21). While Unseld, Möndel et al. (2008) assume high expenditures, Möndel (2008) reckons with much lower costs, as do Grundmann and Eberts (2008). In Poland, the harvesting costs of willow vary between 162 €/ha (Matyka 2008) up to 603 €/ha (Faber, Kuś et al. 2009), and both references provide the same value of 162 €/ha for miscanthus and sida crops.

Table 19: Prices of Seed Stock in Germany

Poplar and willow cutting plants	0.10 - 0.25 €/unit
Poplar wood sets	2.50 - 4.00 €/unit
Miscanthus seedling	1.6 €/unit

Table 20: Prices of Seed Stock in Poland

Willow seedling	0.03 €/unit
Miscanthus seedling	0.3 €/unit
Sida seeds	1000 €/kg

Table 21: Harvest Costs

	Harvest Cost [€/t_{dry}]						
Processes	Deutschland (Burger 2004; Pallast, Breuer et al. 2006; Burger 2008)				Baden-Württemberg (Unseld, Möndel et al. 2008)	Baden-Württemberg (Möndel 2008)	Brandenburg (Grundmann and Eberts 2008)
Partly mechanisied processes	-	-	85	-	90	-	-
Wood chipper /Spliter	9 - 11	27	28	9	25 - 45	-	12
Claas Jaguar	10 - 14	10		14	25 - 50	10 - 20	17
Harvester / Chipping	-	-	59		75 - 85	-	-
Feller bunchers - Timber harvesting machine	-	-	69		80	-	-

Table 22: Transportation Costs

Authors	Distance	Costs [€/t_{dry}]
Möndel (2008)	< 10 km	5
Pallast, Breuer et al. (2006)	< 10 km	13
Pallast, Breuer et al. (2006)	< 20 km	23
Hofmann (1998)	-	15
Vetter (2005)	7 km	9
Gradziuk and Koscik (2007)	20 km	3

- Transport Costs

The costs for biomass transport depend on several parameters: biomass energy density, transport distance and means of transportation, so that the lower the energy or bulk density is, the higher the logistic costs will be. The bulk density of energy crops varies between 250 and 450 kg/m^3, as granular or baled agricultural products show a high density of approximately 650 kg/m^3. The exemplary transportation costs are outlined in Table 22.

- Storage and Drying

Many economic studies on short rotation crops ignore the cost position of storage and drying. However, those costs seem to be an essential parameter, as crops are storied and usually dried to increase their purchase price. Table 23 outlines the storage and drying costs provided in two studies.

- Recultivation

Recultivation costs vary from 100 €/ha (Pallast, Breuer et al. 2006) to 1400 €/ha (Schneider and Kaltschmitt 2002; Möndel 2008). No apparent reason for the huge differences could be found. The majority of authors however consider a cost of 1000 €/ha (Möndel 2008; Wagner 2010). In Poland, these costs seem to be four times lower and amount to 250 € /ha (Faber, Kuś et al. 2009).

- Fixed Costs

To determine the total direct expenses and subsequently the earnings, the annual fixed costs associated with buildings, machinery and land must be included. As many authors do not consider such expenses, this information was gathered from the Research Institution of the Baden-Württemberg State Ministry for Rural Areas, Nutrition and Consumer

Table 23: Costs of Drying and Storage

Authors	Storage System	Costs [€/t]
Möndel (2008)	Storage on field (rent)	5
	Indoor store with cold ventilation	17
Pallast, Breuer et al. (2006)	Field rent	5

Table 24: Annual Fixed Costs for Baden-Württemberg

Annual Fixed Costs for:	€/ha
Machinery	300
Buildings	50
Cost of land	250
Other costs	100
Total	700

Protection (LEL 2010). In Poland, only Matyka (2008) cites general fixed costs of around 350 €/ha.

- Agricultural Subsidy Payments

Under the EU's Common Agricultural Policy (CAP), different payment schemes are guaranteed to farmers by the Agency for the Restructuring and Modernization of Agriculture (ARMA) to ensure them a stable income and to influence the supply of crops on markets:

  - Complementary Direct Payments (UPO) are distributed to support farmers' income. UPO are granted for arable land sown or planted with basic or certified seed of bread wheat, rye, barley, triticale, oat, cereal mixtures, lupin (yellow, narrow leaf or white), pea, bean and potatoes (356 PLN /ha = 89 €/ha in 2009),
  - Supplementary payment for the surface area of crops intended for animal food which are grown in permanent pasture (502 PLN/ha = 125 €/ha in 2009),
  - The Single Payment Scheme (JPO) is granted to annual and perennial crops,
  - Supplementary payment to energy crops guaranteed until 2009,
  - Payment *de mimis* for rapeseed granted up to 2009.

An agricultural area maintained in a good agricultural condition without any cultivation receives a grant through the Single Payment Scheme (JPO) and since 2010 also from the Complementary Direct Payments (UPO). Until 2009, the Agricultural Market Agency (AMA) offered subsidies for the establishment of permanent plantations of willow, poplar, miscanthus and sida on the area of at least 1 ha, which was not found within a protected conservation area.

In Germany, several support payments are offered, among them MEKA (German: *Marktentlastungs- und Kulturlandschaftsausgleich*), a compensation payment to energy crops (45 €/ha) abolished in 2010 and the area payment (German: *Flächenpremie*) amounting to 285 €/ha in 2009 and 280 €/ha in 2010.

The groups of expenditures outlined above were then used to estimate the gross margin of perennial and annual crops. The annual costs were discounted by assuming a rotation of 4 years in Germany and 3 years in Poland, as well as a plant cycle of 20 years and an interest rate of 4% in both countries. Then the total costs were calculated by factoring in the additional fixed costs. In France, the market for perennial crops has been confined to a few experimental plantations; therefore, comparable economic data is not available.

Table 25: Agricultural Subsidy Guaranteed to Energy Crops in Poland

Short Rotation Crops	Estimated Fixed Costs	AMA's Subsidy to Establishment Costs		Supplementary Payment to Energy Crops	Single Payment Scheme (JPO)
Period	2007-2009	2007-2009			
Willow (Salix sp.)	2150 €/ha	50%	1075 €/ha	2009: 45 €/ha 2010 - abolished	2009: 126 €/ha 2010: 141 €/ha
Poplar (Populus sp.)	2100 €/ha	30%	630 €/ha		
Miscanthus	4500 €/ha	40%	1800 €/ha		
Sida (Sida hermaphrodita)	2550 €/ha	40%	2550 €/ha		

Source: ARIMR (2010)

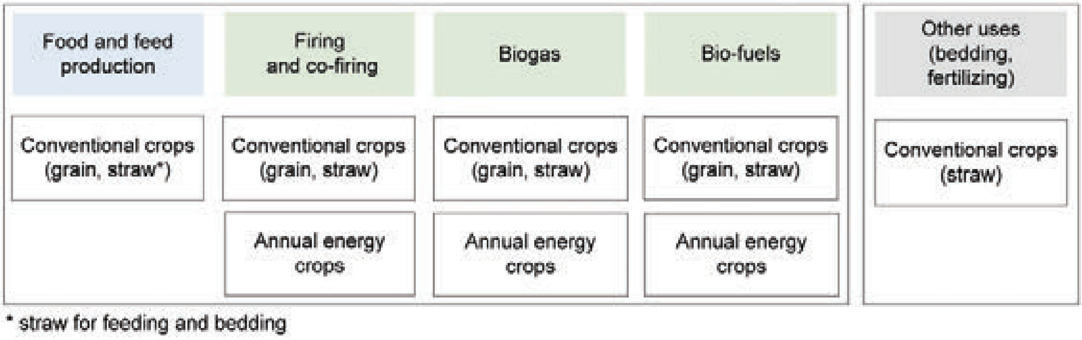

Figure 5: Overview of Feedstock for Different Processes of Energy Production

4.1.1.6 *Dual Cultivation of Energy Crops and Environmental Issues*

Although biomass significantly contribute to reducing the dependence on exported fuels and to protecting the environment, the sustainability of bioenergy crops has been questioned in recent years. Concerns over conflicts arising from the dedication of land for fuel rather than food production, as well as from the actual carbon savings such biofuel crops may generate, have been raised. Therefore, new and improved cultivation methods such as mixed or dual cultivation have been adopted to increase the efficiency per hectare of biomass cultivation and to contribute to the safeguarding and sustainability of bioenergy development.

In Germany, double-cropping[6] within one growing season has been tested in numerous field trials over the past two decades (Scheffer 1998; Karpenstein-Machan 2005). For instance, winter wheat or rye is grown in early summer followed by a spring crop like maize, sorghum, sun flower or soya bean. On sites with a long growing season and appropriate water supply, an average to high yield of maize could be achieved after harvesting the green cereals (Scheffer 1998; Karpenstein-Machan 2005). Even on pedo-climatically less-favorable sites, a double harvest per year is possible for plants with moderate climate and soil requirements such as triticale or rye. After harvesting these plants at the end of June, crops like oil radish, sunflowers and phacelia can be cultivated in the remainder of the growing season. Both crops are harvested green to produce silage for biogas. A system like this provides a number of environmental benefits, e.g. by reducing nitrate leaching and combining the production of large biomass quantities with a year-round green cover (EEA 2007b) or protection against ground erosion (FNR 2009). Nonetheless, due to the considerable complexity of the planting procedure and the comparatively high demand for water over the growing period, the dual cropping method has scarcely been used in Germany (Feldwisch, Lendvaczky et al. 2010).

4.1.2 Animal and Agricultural By-Products

Synergy effects can be obtained through the production of conventional crops, as the edible part is intended for food and fodder, and the inedible harvest residues are assigned for energy generation, as outlined in Figure 5 Due to a lack of statistics on straw quantity in many countries, the amount of crop residues was derived from a Residue to Product Ratio based on statistical information on cereals' yields and cereal-sown areas (Kappler 2008). The gross Straw to Grain Ratio differs depending on the type of cereals and also alternates from year to year, because of variations in the weather, water availability, soil fertility and farming practices. The average ratios for each cereal were collected from the literature (Harasim 1994; Börjesson 1996; Kaltschmitt and Hartmann 2001; DüV 2007). The gross production of straw residues in an administration unit was calculated according to the formula:

$$SP_a = \sum_i CA_{ia} CY_{ia} R_i \tag{4}$$

where SP_a is the gross production of straw residues in an administration unit a in t/a*y, CA_{ia} is the sown area of i cereal in an administration unit a in ha, CY_{is} is the yield of cereal i in t/ha and R_i the Straw/Grain Ratio of given cereal i.

Due to competitive usage and restrictions, not all cereal by-products identified in the region can

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[6] Production of two crops on the same land within the same year

be used for energy purposes. The gross calculated quantity can be reduced by up to 50% of the total cereal residues harvested due to straw losses during the harvesting process and because of the amount that has to be left on the field as organic fertilizer (Börjesson 1996; Pisarek, Ganko et al. 2004). Straw is also used for animal feeding and bedding, cereals' protection (used in regions with low temperatures to protect sensitive vegetables), as compost for mushrooms, as well as building material or in paper pulping (ETSU 1995). As the information on the competitive usage of cereals residues is not available in national statistics, a number of studies assumed that 25 - 50% of straw was actually used for energy purposes (ECBREC IEO 2004; Hoogwijk 2004; Pisarek, Ganko et al. 2004; Münch 2008; Scarlat, Martinov et al. 2010).

In this study, the surplus straw (SS) was calculated assuming that cereals' by-products must primarily meet the demand for animal bedding, feeding and soil organic matter reproduction as follows:

$$SS_a = SP_a - (B_a + F_a + SF_a) \qquad (5)$$

where SS_a is the annual surplus straw within administrative unit area a, SP_a is the production of cereals straw in t/a*y, B_a is the straw requirement for bedding in t/a*y, F_a is the straw requirement for feeding in t/a*y and SF_a is the requirement for straw as the soil fertilizer (humus) in t/a*y.

The annual straw quantity used for bedding in animal holdings was estimated by multiplying the animal livestock units by the required amounts characteristic of the case study regions, studied in the literature (Kuś, Madej et al. 2006; Feldwisch, Lendvaczky et al. 2010).

The maintenance of a positive or at least neutral balance of soil humus counts among the requirements of "good agricultural practices" laid down in the Polish Code of Good Farming Practice (MRiRW-MS, IUNG et al. 2004) and in the German Ordinance on Direct Payments (DirektZahlVerpflV 2004). In Poland, the humus balance was calculated based on a concept developed by the Institute of Soil Science and Plant Cultivation IUNG (2004) and Kuś, Madej et al. (2006). In Germany, it was calculated by the Association of German Agricultural Investigation and Research Centers (VDLUFA 2004). In France, the fix factor for humus balance was derived from studies carried out by the Institut National de Recherche Agronomique (INRA; (Protin 2007)).

The degradation or growth of soil humus due to crop growing was calculated in a GIS model, based on statistical data on crop production. As both straw and animal by-products were considered to be feedstock either for biogas production or for combustion, the quantity of straw necessary to balance the soil fertility was estimated at first, followed by the animal residues, as seen in Figure 6. The animal

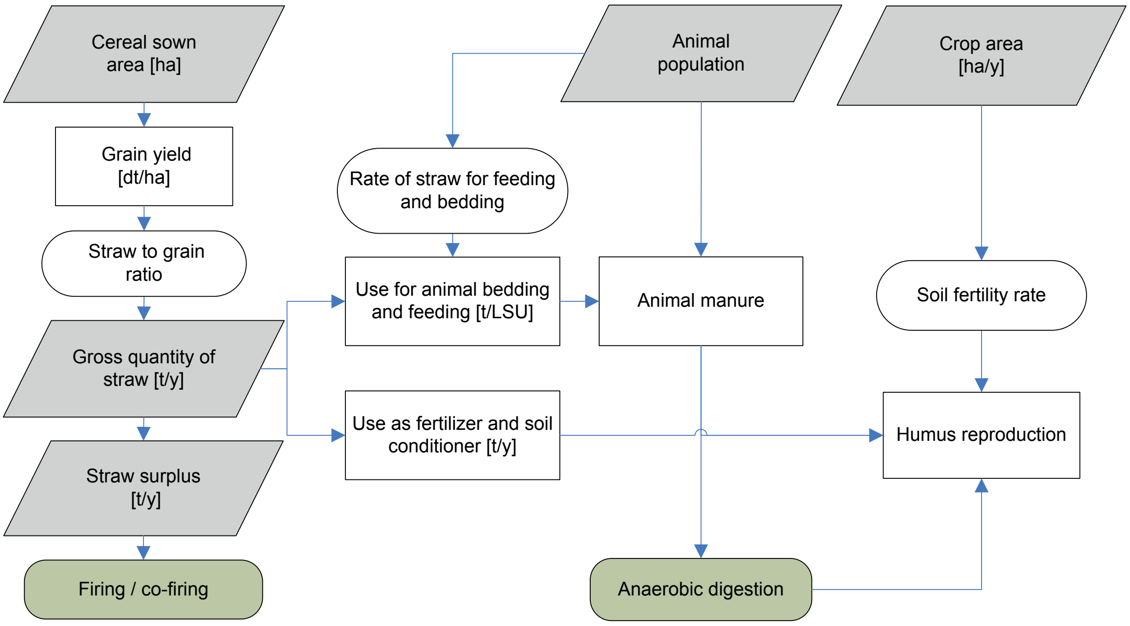


Figure 6: Overview of Utilization Flow of Cereals Straw and Animal Residues

manure used in anaerobic digestion plants can theoretically be replaced on the field by digested material from biogas fermentation and returned to the field to balance the nutrient cycles (EEA 2007b).

With regard to the low bulk density and the low heating value of straw, the long-distance transportation costs might influence the profitability of energy generation. In practice, the straw fuel is combusted locally in domestic heating boilers or local small CHP units. According to the economy of scale, the capital cost of straw-fired plants decreases as their power capacity rises, but the logistic costs increase. The spatial density of the considered residues influence the unit size and the cost of electricity generation (Edwards, Šúri et al. 2005). Another fundamental aspect is to assure supply continuity, something straw fuel struggles to achieve, given the year-on-year crop rotation.

4.1.3 Biogas Production

The anaerobic digestion of agricultural residues, bio wastes and energy crops has been of increasing interest as one of the realistic future scenarios for power and heat generation or natural gas equivalent production. By converting waste into energy, biogas plants provide valuable biomethane, transform organic waste into high quality fertilizer and contribute to the reduction of greenhouse gas emissions. A variety of organic feedstock can be used for biogas production as long as they contain carbohydrates, proteins, fats and hemicelluloses as their main components (Braun 2007). Typical substrates are harvest residues, organic wastes from agriculture-related industries, food waste, collected municipal biological waste from households and recently dedicated energy crops. Livestock residues differ with respect to their chemical and psychical characteristics depending on the animals' housing conditions, the animal type, their diets and residue removal technology. The collectable amount of animal by-products depends on many factors such as the size and structure of dairy farms or the housing period (Kozakiewicz and Nieściór 1984; Bläsing, Gerth et al. 2000).

Experience indicates that relying on waste material for the anaerobic digestion may lead to inconsistency in the feedstock and supply. Thus, in practice, to increase the methane production performance and to stabilize the production process, the manure is mixed with organic waste or energy crops. Maize crop has been widely used as a co-substrate in many anaerobic digesters due to its high biogas yields and high hectare yield (30 - 60 t/ha) under moderate agro-climatic conditions (Michalski 2005; Podkówka 2006; Braun, Weiland et al. 2009). Sugar beets (yield up to 35 t/ha) or potatoes (yield up to 50 t/ha) can also achieve a high yield, but due to operational problems these crops are rarely used (Braun, Weiland et al. 2009). Apart from maize silage, the most frequent co-substrates for fermentation are grass silage and cereals (Braun, Weiland et al. 2009; DBFZ 2009; FNR 2009). Exemplary biogas yields with respect to dry matter content and volatile solids of different biogas feedstocks are outlined in Table 26. Strong ligneous organic substances such as wood are inappropriate due to their slow anaerobic decomposition (Weiland 2010). Among agricultural wastes, cattle, pig and poultry manure are the primary feedstock for wet anaerobic digestion in the "first generation" biogas plants (DBFZ 2010; Weiland 2010). Recently, in countries like Germany and Austria, an increasing trend towards dry anaerobic

Table 26: Exemplary Biogas Yield, Dry Matter and Volatile Solids of Different Crops and Animal Manure

	Dry Matter	Volatile Solids	Biogas	Methane Content
Substrates	% DM	% VS	m^3/Mg VS	%
Maize silage	31	94	577 - 600	56
GPS rye silage	30	92	580 - 600	56
GPS wheat silage	32	92	580 - 600	56
Wheat grain	86 - 90	98	550 - 680	51
Rye grain	86	98	690	52
Grass silage	20 - 35	80 - 90	550	54
Sugar beets	23 - 25	90 - 95	600 - 800	53
Cattle manure and slurry	6 - 25	80 - 90	280 - 450	58

Source: FNR (2006a); Weiland (2010); KTBL (2010b) digesters relying on energy crops has been observed, reaching approximately 10% in Germany at the end of 2009 (DBFZ 2010). This development is driven not only by technological innovations but also by support mechanisms (e.g. German EEG). The optimal mix of biogas feedstock depends on the choice of fermentation systems, with regard to technology costs and the availability of biogas feedstock. Considering those criteria, the wet fermentation systems dominate, which are based on the typical liquid manure of pigs or cattle with co-substrates added to increase the content of organic material for achieving a higher gas yield and a total dry matter share of 10 - 20% (FNR 2006a; Braun 2007; Weiland 2010). In dry fermentation, the total dry matter content inside the digester varies between 15% and 35%, with crops the basic substrate (Braun 2007).

4.1.4 Woody Biomass

Woody residues can be divided into (i) forestry harvest residues (e.g. twigs, branches, stumps, not-commercial logs), (ii) forestry processing residues from primary wood processing (e.g. sawdust, chips), (iii) secondary wood processing (e.g. furniture manufacture) and also (iv) residues from trees grown outside forests (i.e. road side tending) as well as (v) recycled wood (e.g. demolition wood from old buildings).

The assessment of the potential of wood from forests and forest industry by-products was not carried out in the study, because these types of biomass do not directly influence agricultural land use. Nevertheless, an unbalanced supply and demand for wood affects the demand for other lignocellulosic material like short rotation coppices or combustible residues from agriculture-related sectors. Consequently, findings from existing studies and statistics on the forestry wood supply potential were addressed in the study in order to estimate the gap between demand and compensatory supply of other materials.

4.2 Bioenergy Potential in the Kujawsko-Pomorskie Voivodship

The structure of biomass production and use is related to the structure of the energy sector. Strongly centralized energy companies have invested in co-firing infrastructure and will thus mostly promote a market for lignocellulosic crops. Small district heating power plants have already driven the wood and straw market. Besides this, the Ministry of Economy's ambitious plan (2010) to install biogas plants in each commune, mentioned in chapter 2.1, is expected to be the driving force for the exploitation of agricultural residues and energy crops. Regarding the sustainability issues addressed in Directive 2009/30/EC, attention is given to second generation biofuels so as to increase land use efficiency; however, this leads to an expansion of the area under lignocellulosic crops. Nonetheless, the production of second generation biofuels is supposed to replace the other production methods by 2020 (Ministry of Economy 2009). Dedicated energy crops are expected to be the main source for the production of renewable energy in the near future, meeting around 90% of demand, while 70% should come from energy plantations (K-PBPPiR 2010). The Kujawsko-Pomorskie Voivodship is expected to contribute significantly to the achievement of biomass targets in respect of the high index of arable land per capita of 0.48 ha that is above the national rate of 0.36 ha/cap.

4.2.1 Biomass Usage Status Quo in the Kujawsko-Pomorskie Voivodship

At the current time, anaerobic digestion based on agricultural and farm manure is not widespread in Poland. By the end of 2009, only seven agricultural biogas plants were operating with a capacity per plant ranging from 600 up to 2200 kW_e and one with a capacity of 2.1 MW_e in the area of the Voivodship in Liszkowo (URE 2010). In 2009, seven biogas power plants based on dump and sewage treatment were operating in the Kujawsko-Pomorskie Voivodeship, plus four biofuel producing plants as well as numerous biomass (mostly wood) boilers (Igliński, Kujawski et al. 2009).There are also sizable companies that produce green energy, for instance the Thermal Power Plant in Świecie with a biomass boiler of 130 MW_{th} (Cecerko 2006) or the Toruń Energy Company, where 200000 tons biomass were blended annually with hard coal. There are also two straw pellet companies in Sępólno Krajeńskie and Grudziądz that were using around 24000 tons of straw annually with the objective of extending the amount to 40000 tons (Brykietowanie 2010).

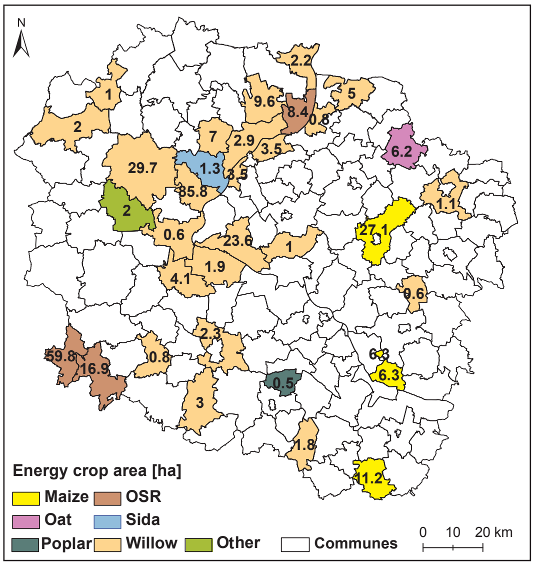
Table 27: Technical and Economic Potential of Biomass Use by 2020 in Poland

	Technical Potential (Final Energy)	Economic Potential (Final Energy)	Use of Economic Potential	
	2020		2006	
Resources	TJ	TJ	TJ	%
Biomass incl.	962950	600168	192097	32
Solid Dry Waste Biomass (for Combustion)	273044	165931	160973	97
Biogas (Wet Biomass)	175809	123066	2613	2
Forestry Wood	34931	24452	24452	100
Energy Plantation, incl.	479166	286719	4056	0.14
Cellulose	208888	145600	0	0
Sugar and Starch	81027	21501	2558	12
Rape Seed	73514	37980	1498	4
Corn Silage	116625	81638	0	0

Source: ECBREC IEO (2007)

4.2.2 Potential of Energy Crops in the Kujawsko-Pomorskie Voivodship

To fulfill the targets set up in Directive 2009/28/EC, the Polish Energy Policy aims for a demand of 334818 TJ of biomass in the country's gross final energy consumption by 2030 (Ministry of Economy 2009). By then, around 2.1 Mha of farmland should be dedicated to energy generation: 0.5 Mha of good quality soil for biodiesel production based on oil seed rape, 0.6 Mha for bioethanol (cereals, sugar beets, potato), around 0.5 Mha for the production of solid biomass and in addition around 0.5 Mha for biogas development (Kuś and Faber 2009). Whereas the Institute for Renewable Energy (ECBREC IEO 2007) indicates 3.3 Mha of farmland potential that could be dedicated to energy crops while maintaining food and fodder demand. A total technical potential of biomass sources, including bio-residues and forest



Map 4: Energy Crop Area in Kujawsko-Pomorskie in 2009
Source: Based on Data Derived from ARiMR (2010)

Table 28: The Cultivation of Energy Dedicated Crops in Kujawsko-Pomorskie in 2008 and 2009

Area under Energy Crops [ha]	2008	2009
Sugar Beet	1.15	-
Maize	49	45
Oil Seed Rape (OSR)	287	88
Willow	298	280
Poplar	-	0.5
Sida	-	1.5
Total	635	423

Source: ARiMR (2010)

Table 29: Constraints of Energy Crop Cultivation

Nature and Environment Protected Areas	Species Protection	Land-Use Competition	Other Impacts (incl. Environmental Impacts Resulting from Use of RES)
a) Natural areas: • national parks • landscape parks • nature reserves • Natura 2000 b) Protected Habitat c) Ecological Corridors d) Areas with water shortage e) Areas under Nitrates Directives*	a) Sites of agrobiocenosis - protected habitats - non-forest (plants and animals) also outside protected areas b) invasive species c) rules of growing GM crops	a) Areas planned for afforestation b) Land needed for food, fodder and raw material production c) Agricultural land needed to maintain landscape and natural values	Transformation of landscape leading to monoculture planting

*Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources

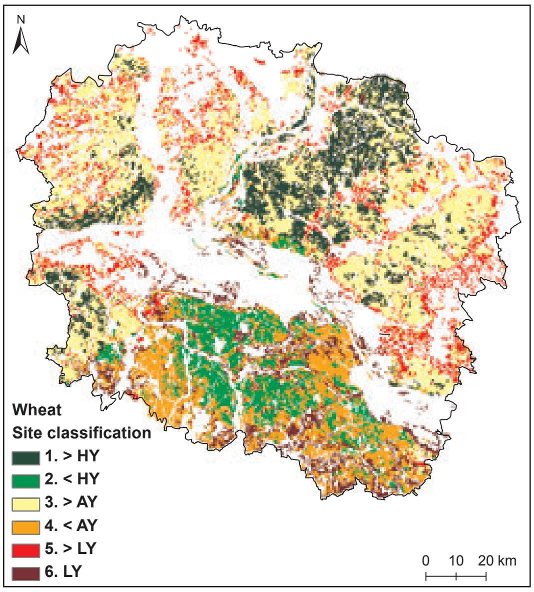
Source: ECBREC IEO (2007)

wood was estimated at 962950 TJ. As outlined in Table 27, the potential of wood from forests for energy purposes was already explored in 2006 and the supply remains thus at the same level for 2020. Over the past few years, interest in growing perennial crops has been rising steadily but demand still outstrips supply (Żmijewski 2010). According to the Polish Agency for Restructuring and Modernization of Agriculture (ARiMIR) that provided statistics on the growing area of energy dedicated crops, 61364 ha in 2008 and 52408 ha in 2009 of the arable land in Poland were under crop plantations devoted to energy (ARiMR 2010). About 10% of these plantations were located in the Kujawsko-Pomorskie Voivodship (see Table 28). Among different annual and perennial crops, 50% of the area was grown by willow crop (corresponding to 5% of the national planting area). The plantations were mostly concentrated in the northern and central part of the region as illustrates Map 4.

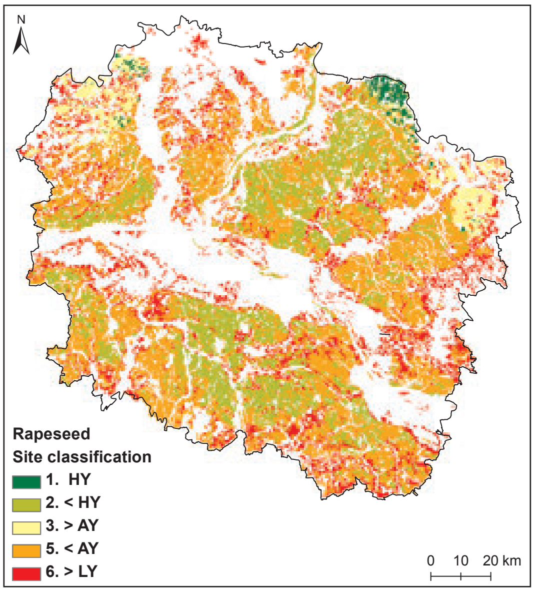
4.2.2.1 Potential of Energy Crops Cultivation

The cultivation of conventional crops is not restricted in terms of nature protection or planting technologies, but specifically by economic factors like agricultural performance. Nonetheless, Directive 2009/28/EC highlights several requirements for the maintenance of bio-fuel sustainability. Among others, energy crops should not be grown on land of great value in terms of biological diversity. Since subsidy payments for energy crops were abolished in Poland in 2010, the growing of annual crops like wheat, maize, potato, sugar beets, which can be either energy dedicated or planted for food, is no longer incentivized nor subject to any rules of sustainable maintenance for arable land planted with energy crops. Moreover, the growing of short rotation coppices and perennial grasses inventoried in the database of alien species (DAISIE 2003) is theoretically restricted on a legal basis according to Article 120 of the Environmental Law (Ministry of the Environment 2004). However, in view of the ambiguity of several legal acts that address the alien species issue in Poland, the law's violation is not seen to carry any consequences (Państwowa Rada Ochrony Przyrody 2007; Okarma 2010). Besides this, planting willow and poplar is also constrained within reclamation areas, as the roots may damage the irrigation infrastructure (MINROL 2007). The main constraints outlined in Table 29 were then considered after ranking the sites against cropping needs.

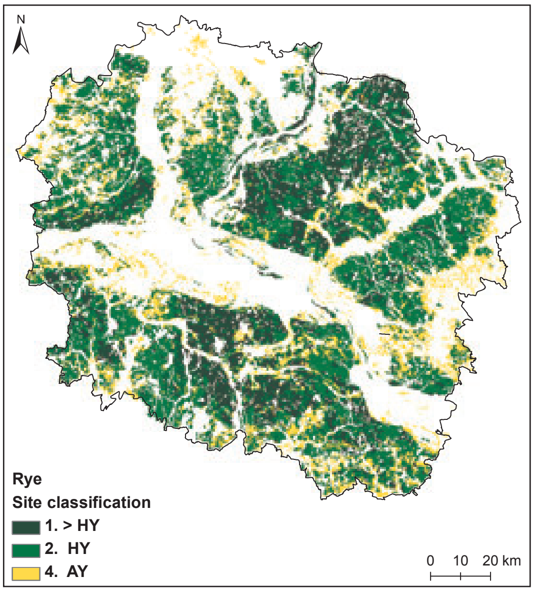
Spatially suitable pedoclimatic conditions for crop planting were identified on a regional scale through digital data, processed with the Spatial Analyst Tool and classified according to cultivation requirements. Sites for selected crops (winter wheat, winter rapeseed, rye, maize, miscanthus, Sida hermaphrodita and willow) were evaluated according to the methodology described in chapter 4.1.1.2 to gain information on the opportunity and constraints of agricultural productivity. With regard to crop growing requirements for the land, three main ranks (sites) were assigned to describe expected high,



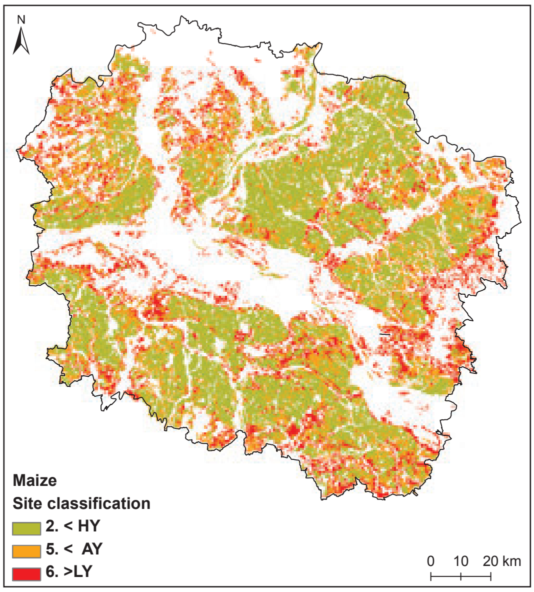
Map 5: Site Classification for Wheat Growing



Map 7: Site Classification for Rapeseed Growing



Map 6: Site Classification for Rye Growing



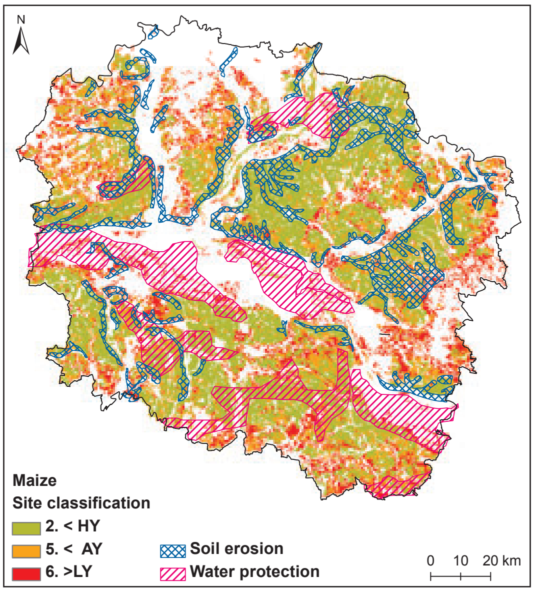
Map 8: Site Classification for Maize Growing

average and low crop productivity (yield) (see Appendix 10). In practice, yields may vary depending on farming technologies and pesticide application, two aspects whose assessment was beyond the scope of the study. The aim was to give insight into the agro-climatic characteristics of the region and likely conflicts arising from the varying land production performance of different crops.

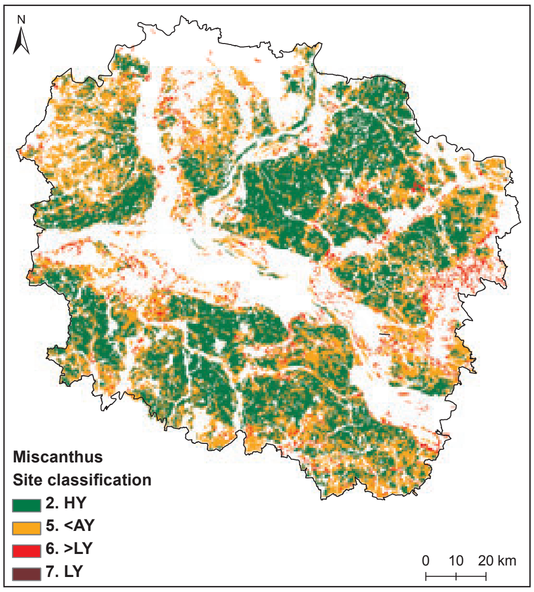
Regarding the high soil requirements of wheat crops, very good growing conditions resulting in high yields were found on around 25% of the agricultural land (239 ths. ha), which may, however, vary slightly under different rainfall regimes. In contrast, 55% of the cropping area may produce average yields (sites 3 and 4 on Map 5). In practice, rye crops are not grown at locations characterized by a very good soil quality (site 1 on Map 6). A high yield of rye is likely to be obtained within an area of 523 ths. ha (50% of the total arable land), whereas an average yield may be produced on 203 ths. ha of the total arable land. Table 30 outlines the area of ranked sites referred to on the maps. With respect to rapeseed requirements, a high yield can theoretically be expected for 239 ha of the cropping land (sites 1 and 2), while

Table 30: Classification of Growing Area of Annual Crops

Crop	Rye		Wheat		Rapeseed	
Sites	ha	%	ha	%	ha	%
>HY	239037	25	-	-	-	-
HY	523253	54	136171	14	11564	1
<HY	-	-	102866	11	227473	24
>AY	203603	21	360012	37	57181	6
<AY	-	-	163241	17	466045	48
>LY	-	-	129581	13	203601	21
LY	-	-	74022	8	-	-



Map 9: Site Classification for Maize Growing under Environmental Constraints



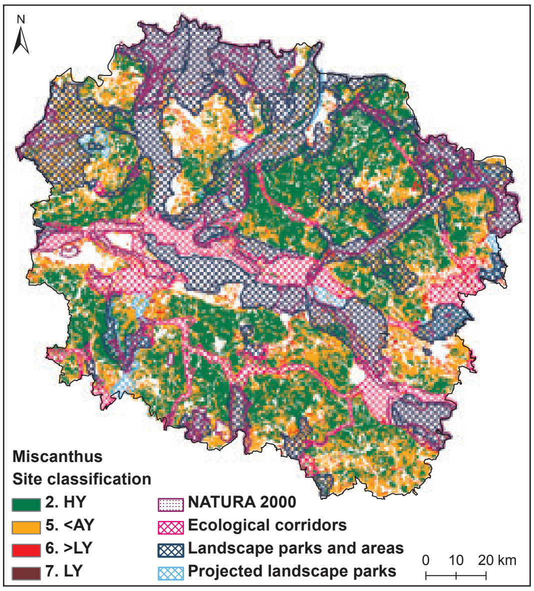
Map 10: Site Classification for Miscanthus Growing

523 ths. ha are likely to show a productivity oscillating around the average as shown on Map 7. Regarding the suitability of cropland for maize cultivation, 51% of the arable land explored shows very suitable conditions allowing for high productivity, while 27% show an average productivity (compare Map 8 and Table 31). The intensive cultivation of maize crops often leads to soil degradation through the penetration of water and wind (wind and water erosion) due to the slow growth of the plant during the initial period. Moreover, monoculture cropping leads to groundwater pollution through the application of nitrates and herbicides with a long decay, especially in the area of drinking water sources (Majchrzak and Piechota 1998). Hence, it is not recommended to grow maize crops over a certain period within areas of water protection as well as on erodible farmland, which covers around 25% of the total cropland available in Poland as illustrated on Map 9.

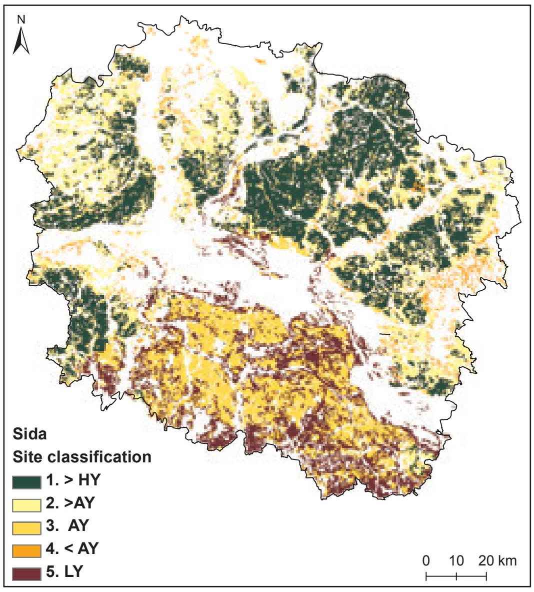
The agro-climatic requirements of miscanthus (see Map 10) are comparable to those of maize crops, but the plant's cultivation can be restricted through the above-mentioned legal regulatory measures. As shown on Map 11, 24% of farmland is located within nature-protected land, landscape parks and landscapes areas (compare with Table 31). A high productivity of Sida hermaphrodita crops can be expected on 317 ths. ha of the total cropland available in the region and at least an average yield (sites 2 - 3 on Map 12) is likely to be produced on 450 ths. ha of the farmland. Sida crop is subjected to the same restriction as miscanthus as shown on Map 13. Within an area of 317 ths. ha (site 1), a high yield of willow crops can be expected, while an area of 340 ths. ha is characterized by an average yield (sites 2 - 3 on Map 14). The area of 189 ths. ha indicates below-average productivity of willow crops. Map 15 outlines the potential area for growing willow and after blocking out the above-mentioned protected

Table 31: Classification of Growing Area of Energy Crops in Total and Outside of Protected Areas (OP)

Crop	Maize			Miscanthus			Willow			Sida		
	Total	OP	Share	Total	OP	Share	Total	OP	Share	Total	OP	Share
Sites	ha		%	ha		%	ha		%	ha		%
>HY	-	-	-	-	-	-	317591	256154	81	317591	256154	81
HY	-	-	-	498762	416096	83	-	-	-	-	-	-
<HY	498427	365224	73	-	-	-	-	-	-	-	-	-
>AY	-	-	-	-	-		268377	180235	67	268377	180235	67
AY	-	-	-	-	-	-	174649	153630	88	181772	160306	88
<AY	261509	197667	76	404200	287010	71	39796	19755	50	39796	19755	50
>LY	200479	156265	-	58829	30211	51	-	-	-	-	-	-
LY	-	-	-	181	59	33	149976	111249	74	149976	111249	74
Total	960415	719156	75	961972	733376	76	950389	721023	76	957512	727699	76



Map 11: Site Classification for Miscanthus Growing under Environmental Constraints



Map 12: Site Classification for Sida Hermaphrodita Growing

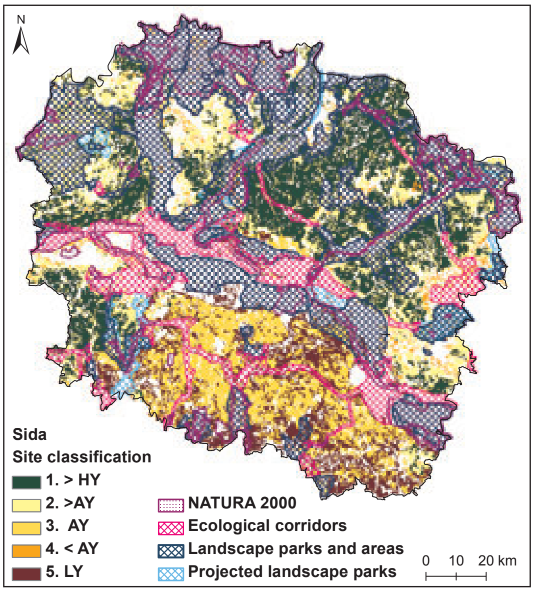
land. Although willow is not listed among invasive alien species, its cultivation might also be restricted within protected areas depending on site-related restrictions (MINROL 2007). Around 25% of the total arable land would be restricted for the cultivation of short rotation crops and maize given the risk of soil erosion over time.

Despite environmental restrictions and other constraints, there is a high theoretical potential for planting energy-dedicated crops in the region. The extent to which the arable land will be subjected to land use competition also depends on economic factors that are addressed in the next chapter.

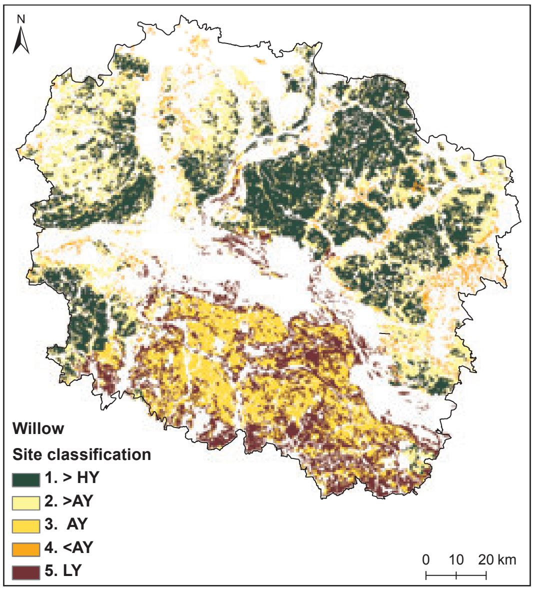
4.2.2.2 Economic Potential of Energy Crops

In this section, the economic profitability of willow, miscanthus, sida, rapeseed, winter wheat, winter rye and grain maize was analyzed. Ericsson, Rosenqvist et al. (2006) studied the economic viability of willow crop based on the plant's annual gross margin compared to traditional alternatives like wheat and barley. However, the calculation is based on the economic conditions and prices of 2003. Other studies (Kwaśniewski 2008; Matyka 2008; Faber, Kuś et al. 2009) compare the costs of perennials, wheat, raps and sugar beet without taking into account the discounted value of cash flow over the perennial rotation.

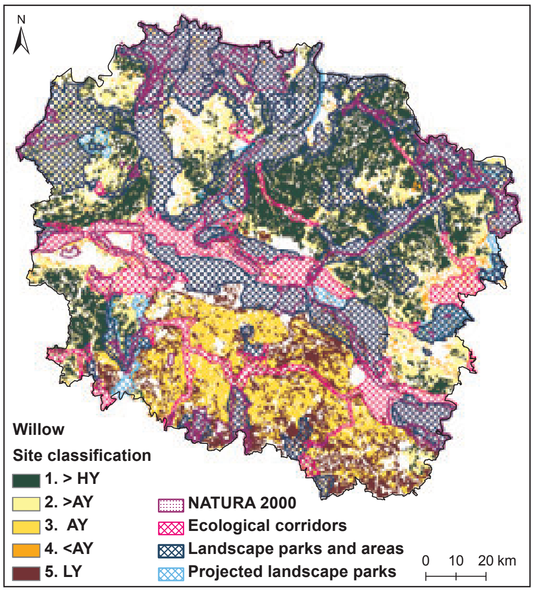
In this study, the annualized discounted profit margins were calculated for low, average and high



Map 13: Site Classification for Sida Hermaphrodita Growing under Environmental Constraints



Map 14: Site Classification for Willow Growing



Map 15: Site Classification for Willow Growing under Environmental Constraints

production levels per hectare according to the methodology described in chapter 4.1.1.5. For the willow crop, a 21-year plantation lifespan with an even, average yield after a 3-year rotation period was assumed, although yields are lower during the first rotation periods (Ericsson, Rosenqvist et al. 2006). Sida and miscantus grass are harvested each year over 20 years.

There are two strategies for operating the establishments resulting in different expenses as shown in Table 32: partially mechanized (Establishment Costs 1) and fully mechanized (Establishment Costs 2). The higher costs of the establishment for miscanthus compared with willow and sida reflect the higher costs of the seed stock as well as the elevated establishment costs, which in fact account for almost 40% of the total expenses summed up over 20 years. Nevertheless, the higher costs of miscanthus are compensated for by the plant's higher yields compared to willow and sida crops and a gross margin similar to the one of sida. Under the framework of variable costs (Harvest strategy 1) and an assumed purchase value of fresh chips of biomass of 72 €/t (Faber, Kuś et al. 2009), growing perennials is economically profitable under the conditions of average and high yields as shown in Figure 7. Moreover, the calculation of Faber, Kuś et al. (2009) includes the subsidies offered by the Agricultural Market Agency (AMA) for the establishment of permanent plantations of SRC and perennials that were abolished in 2010.

In practice, prices for the dried mass of perennial crops oscillate around the average price for wood chips. By contrast, the purchase value of fresh mass SCR and perennials is 20 - 30% lower as shown in Figure 8. In this study, the average purchase prices of fresh biomass at 50 €/t, 60 €/t and 72€/t were used to calculate the gross margin of perennials with comparison to the gross margin of conventional crops. The contribution margin was calculated for the prices of annual crops from June 2010 as presented in Figure 9. Figure 10 shows

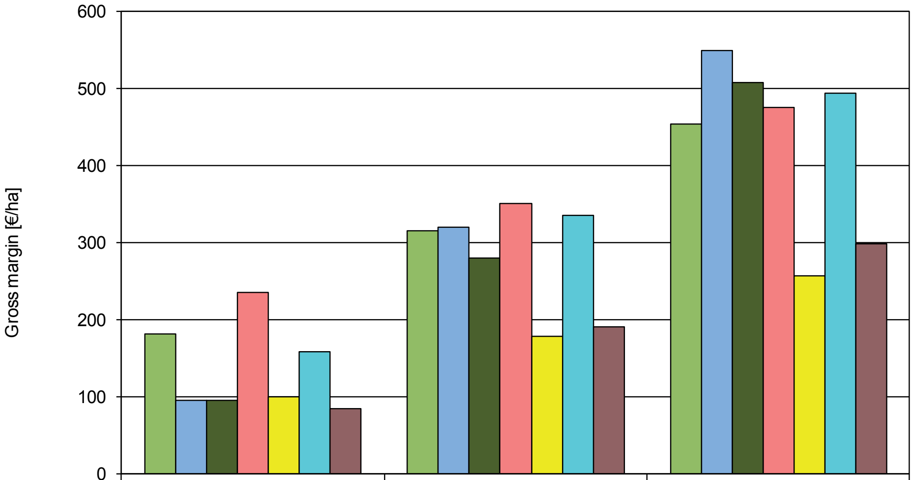
Table 32: The Average Variable Costs of Growing Perennial Crops

Crops	Willow		Miscanthus		Sida	
Costs	€/ha*y	% in TC	€/ha*y	% in TC	€/ha*y	% in TC
Establishment Costs 1	2265	24	5769	39	2529	19
Establishment Costs 2	1617	19	5134	37	1917	15
Field Operation	2632		5440		7520	
Harvest	4221		3240		3240	
Recultivation	270		245		245	
Total Costs (TC) 1	9388		14694		13534	
Total Costs (TC) 2	8740		14059		12922	

Source: Matyka (2008); Faber, Kuś et al. (2009)

the gross margin of perennial crops calculated on the basis of the June 2010 purchase prices, excluding however the subsudies for perennial crops, because the subsidy payment for perennial crops and establishment subsidies were only granted until 2009. In the case of a low yield, the gross margin for willow is about 24% lower, for micanthus 75% and sida 43% lower than those based on Faber's assumptions (see Figure 7). With greater yields, the difference in the gross margin falls, so that at high yield the gross margin is lower by 9%, 13% and 8% for willow, miscanthus and sida respectively. As shown in Figure 11 annualized discounted profit margins for SCR and perennials vary according to changes in purchase prices. Given a purchase price for fresh biomass of 50 €/t, these crops cannot be economically competitive with annual crops due to the higher gross margin of conventional crops based on high purchase prices from June 2010.

Excluding the subsidy payments for all crops, the SRC gross margin at a purchase price of 60 €/t is capable of competing with annual crops as shown in Figure 12. Maize and winter rye crops bring profits only in the case of high yields. With respect to the moderate soil requirements of short rotation crops, relatively high levels of production can be achieved at those locations where average yields of wheat and



	low	average	high
🟩 Willow [72 €/t fm], (10,14,18 t/ha*y)	181	315	454
🟦 Miscanthus [72 €/t fm], (12, 18,24 t/ha*y)	96	320	549
■ Sida [72 €/t fm], (11, 16,22 t/ha*y)	96	280	509
🟥 Winter wheat [14 €/dt], (40, 55, 70 dt/ha)	236	351	476
🟨 Maize [14 €/dt], (50, 65, 80 dt/ha)	101	179	257
🟦 Rapeseed [30 €/dt], (20,30,40 dt/ha)	158	336	494
🟫 Winter rye [9 €/dt], (20,35,50 dt/ha)	86	191	298

Figure 7: The Gross Margin of SCR and Perennial Crops at Purchase Prices of 72 €/t incl. Subsidy Payments for the Establishment of Energy Crop Plantations and Direct Payments for Conventional Crops

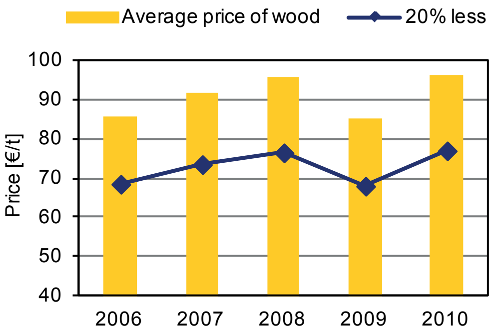


Figure 8: Average Purchase Price of Fire Wood between 2006 and 2010 (in Columns) and Exemplary 20% Less Prices of Biomass Plotted as a Curve (Assumptions: 1€ = 4 PLN and 1m^3 = 0.4 tone)

Source: Based on Data Derived from Drewno.pl (2010); GUS (2010)

rapeseed, as well as a high harvest of rye and maize, are expected. Under these local conditions, perennials might be a competitive alternative to annual crops.

Pawlak (2009) studied the relation between unit costs and the size of the growing area for a willow plantation and found that unit costs progressively decline under increasing area and an increasing mechanization level of the operation processes. With manual planting and harvesting, the unit cost for plantations of 50 hectares or more is nearly 9% lower than for a field of 0.5 ha, while in the case of entirely mechanized planting and harvesting processes, these expenses for a field of 50 hectares or more are up to 25% lower than for a field of 0.5 ha. Moreover, a likely decline in prices of seed stocks will significantly reduce the establishment costs (Möndel 2008). Consequently, Figure 12 shows the gross margin of perennial crops calculated for assumed establishment costs 20% lower than those used in the assessment above and a purchase price for fresh biomass of 72 €/t. The gross margin of perennials with a high yield potential lies above the gross margin obtained by the average production of conventional plants. Oilseed rape achieves high profits under different economic framework conditions. However, due to rotational constraints related to yield performance, rapeseed crops should only be grown at the same location once every four years. Therefore, the optimum crop production choice over the crop rotation period determines the overall opportunity costs of alternative production choices over a period of 20 years. However, the fluctuation span of crop prices on the food market is wider than the fluctuation of wood prices (compare Figure 8 and Figure 9).

Figure 14 depicts the profit relations calculated for annual crop prices obtained in 2008 and for the lower establishment costs for short rotation crops purchased at 72 €/t. This case indicates that gross margins resulting from high yields of short rotation crops cultivated on moderate-quality soil are comparable with the gross margin generated by average yields of annual crops.

The economic assessment illustrates that farmers could choose to invest in perennials and SRC especially on sites characterized by moderate quality land, where costs are reimbursed and the profits are significantly higher than those with annual crops. On the other hand, the high initial costs, the long period of a plant's rotation, unforeseen cash flows and the lack of long-term legislation are the main barriers that might not be overcome by small farmers.

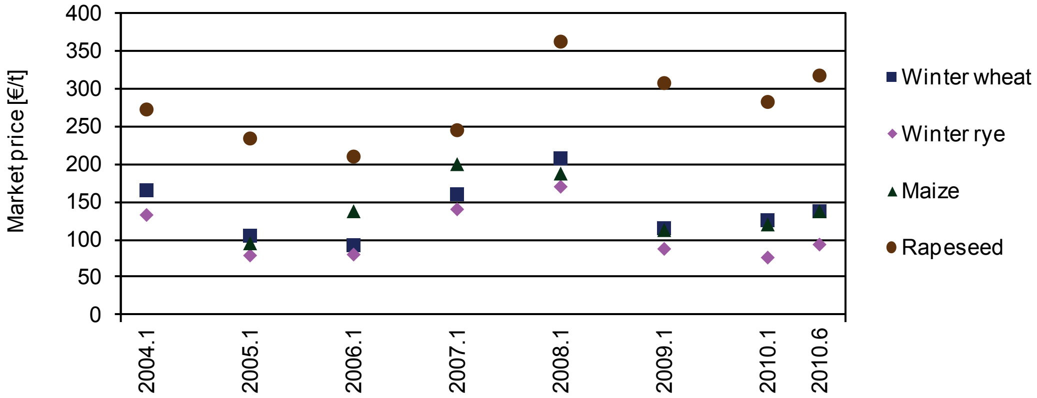
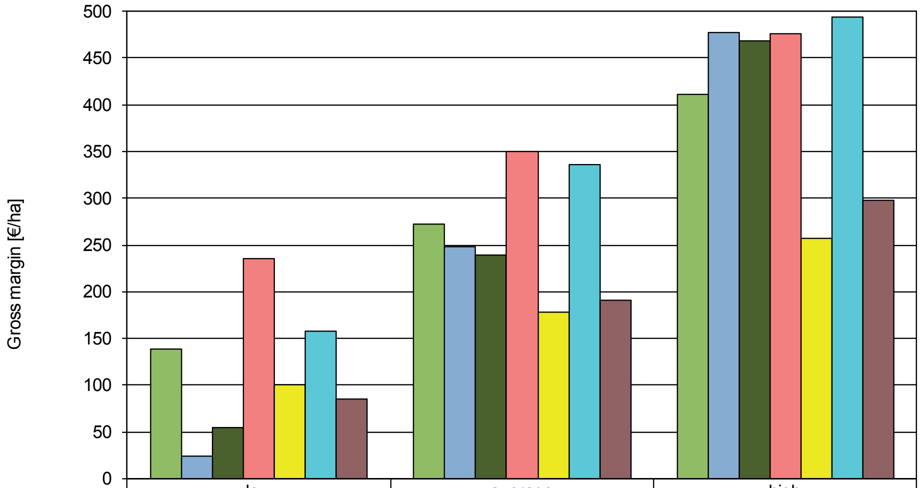


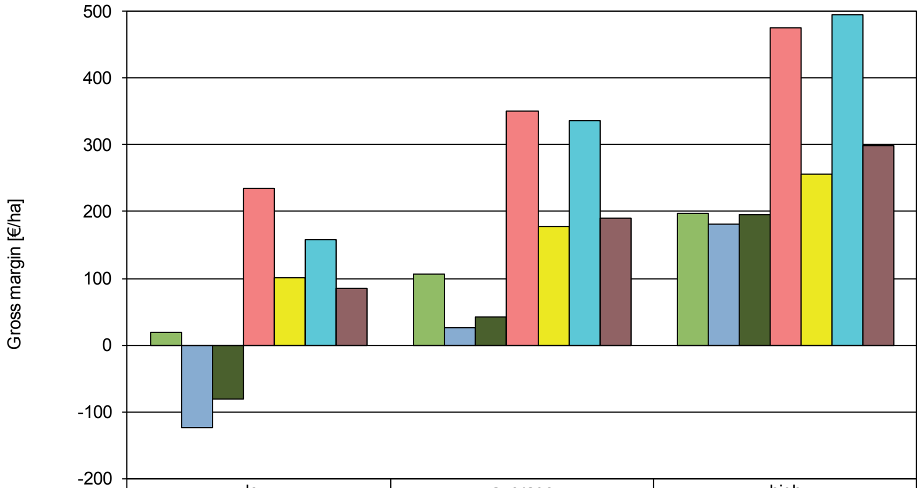
Figure 9: Selected Crop Prices between January 2004 and June 2010

Source: Based on Data Derived from ewgt (2010)



	low	average	high
🟩 Willow [72 €/t fm], (10,14,18 t/ha*y)	138	272	411
🟦 Miscanthus [72 €/t fm], (12, 18,24 t/ha*y)	24	248	477
🟩 Sida [72 €/t fm], (11, 16,22 t/ha*y)	55	239	468
🟥 Winter wheat [14 €/dt], (40, 55, 70 dt/ha)	236	351	476
🟨 Maize [14 €/dt], (50, 65, 80 dt/ha)	101	179	257
🟦 Rapeseed [30 €/dt], (20,30,40 dt/ha)	158	336	494
🟫 Winter rye [9 €/dt], (20,35,50 dt/ha)	86	191	298

Figure 10: The Gross Margin of SCR and Perennial Crops at Purchase Prices of 72 €/t and of Annual Crops Purchased at Prices from June 2010 (incl. Direct Payments for Conventional Crops)

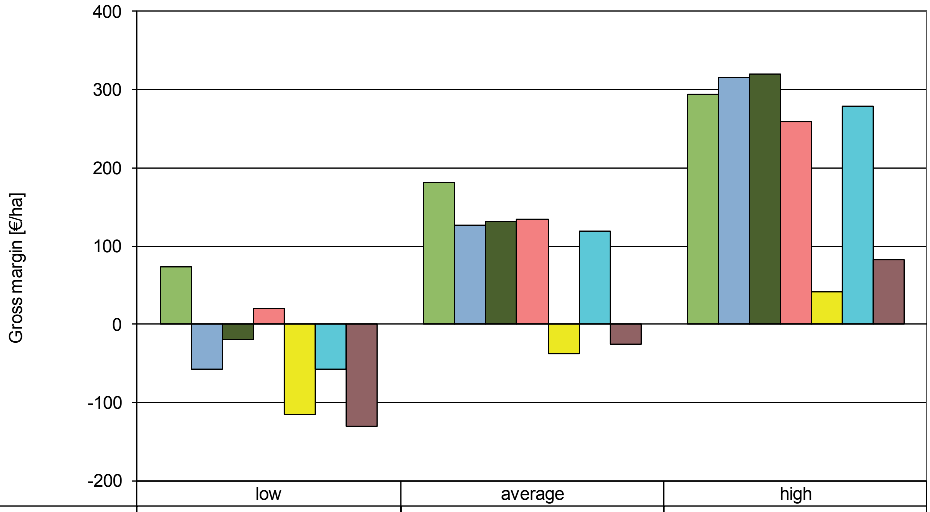


	low	average	high
🟩 Willow [50 €/t fm], (10, 14,18 t/ha*y)	20	106	197
🟦 Miscanthus [50 €/t fm], (12, 18,24 t/ha*y)	-124	26	181
🟩 Sida [50 €/t fm], (11, 16,22 t/ha*y)	-81	41	196
🟥 Winter wheat [14 €/dt], (40, 55, 70 dt/ha)	236	351	476
🟨 Maize [14 €/dt], (50, 65, 80 dt/ha)	101	179	257
🟦 Rapeseed [30 €/dt], (20,30,40 dt/ha)	158	336	494
🟫 Winter rye [9 €/dt], (20,35,50 dt/ha)	86	191	298

Figure 11: The Gross Margin of SCR and Perennial Crops at Purchase Prices of 50 €/t and of Annual Crops Purchased at Prices from June 2010 (incl. Direct Payments for Conventional Crops)

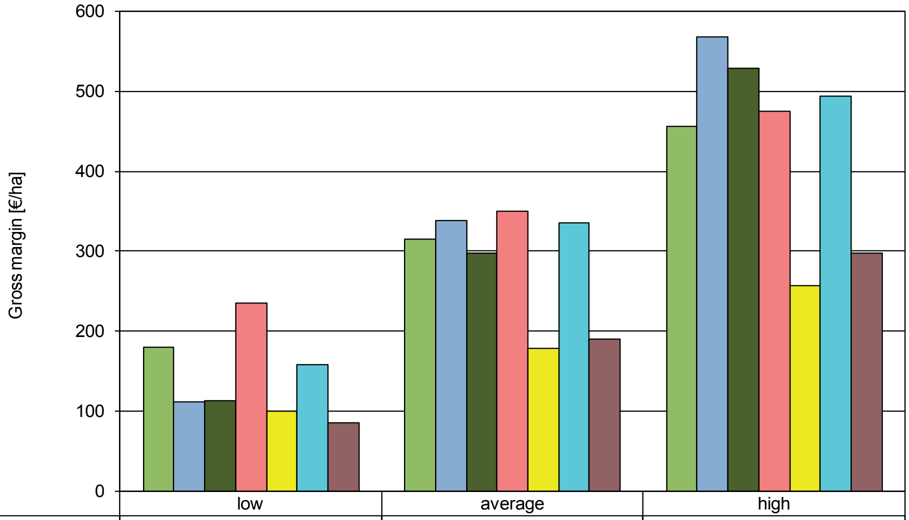
4.2.3 Potential of Bio-Residues in the Kujawsko-Pomorskie Voivodship

In this section, the potential of animal manure and agricultural residues was studied in the context of biogas production and incineration. Due to the fact that data on by-products coming from the food processing industry is largely unavailable, those biomass sources were beyond of the scope of the study.



	low	average	high
🟩 Willow [60 €/t fm], (10, 14,18 t/ha*y)	74	181	295
🟦 Miscanthus [60 €/t fm], (12, 18,24 t/ha*y)	-57	127	316
🟩 Sida [60 €/t fm], (11, 16,22 t/ha*y)	-19	131	320
🟥 Winter wheat [14 €/dt], (40, 55, 70 dt/ha)	20	135	260
🟨 Maize [14 €/dt], (50, 65, 80 dt/ha)	-115	-37	41
🟦 Rapeseed [30 €/dt], (20,30,40 dt/ha)	-58	120	279
🟫 Winter rye [9 €/dt], (20,35,50 dt/ha)	-130	-25	83

Figure 12: The Gross Margin of Perennial Crops at Purchase Prices of 60 €/t and Without Direct Payment to Annual Crops

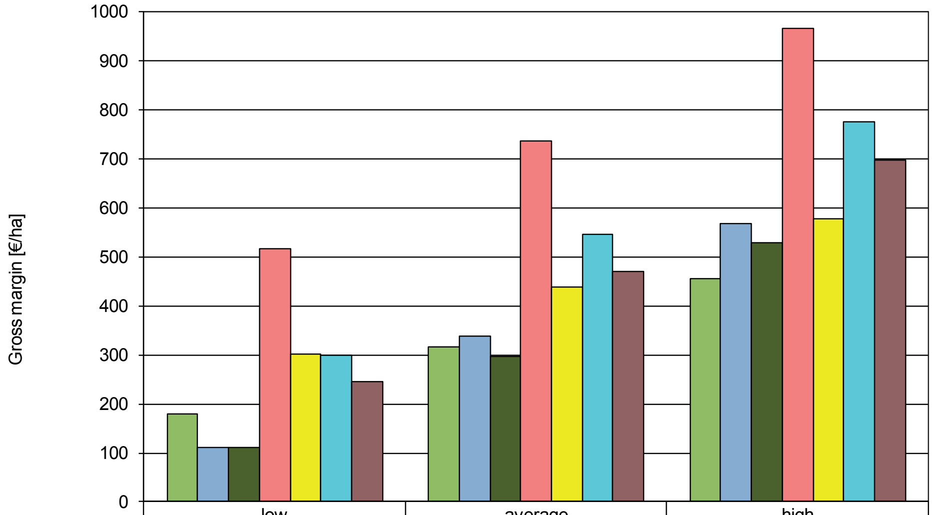


	low	average	high
🟩 Willow [72 €/t fm], (10,14,18 t/ha*y)	180	315	456
🟦 Miscanthus [72 €/t fm], (12, 18,24 t/ha*y)	112	338	568
🟩 Sida [72 €/t fm], (11, 16,22 t/ha*y)	112	298	528
🟥 Winter wheat [14 €/dt], (40, 55, 70 dt/ha)	236	351	476
🟨 Maize [14 €/dt], (50, 65, 80 dt/ha)	101	179	257
🟦 Rapeseed [30 €/dt], (20,30,40 dt/ha)	158	336	494
🟫 Winter rye [9 €/dt], (20,35,50 dt/ha)	86	191	298

Figure 13: The Gross Margin of Perennial Crops at Purchase Prices of 72 €/t and at Establishment Costs Reduced by 20% (Establishment 1) and Annual Crops Purchased at Prices from June 2010 (incl. Direct Payments for Conventional Crops)

4.2.3.1 Livestock Manure

10% of Poland's livestock population is located in the Kujawsko-Pomorskie Voivodship, with cattle and pig livestock units accounting for 94% of the total national LSU in 2009 (see Table 33). The database with the location of farms as well as cattle and pig populations was obtained from the Polish Agency for Restructuring and Modernization of Agriculture (ARiMR 2010). As shown in Table 33, the livestock population of pigs lies between the figures



	low	average	high
🟩 Willow [72 €/t fm], (10,14,18 t/ha*y)	180	315	456
🟦 Miscanthus [72 €/t fm], (12, 18,24 t/ha*y)	112	338	568
🟩 Sida [72 €/t fm], (11, 16,22 t/ha*y)	112	298	528
🟥 Winter wheat [21 €/dt], (40, 55, 70 dt/ha)	516	736	966
🟨 Maize [19 €/dt], (50, 65, 80 dt/ha)	301	439	577
🟦 Rapeseed [37 €/dt], (20,30,40 dt/ha)	298	546	774
🟫 Winter rye [17 €/dt], (20,35,50 dt/ha)	246	471	698

Figure 14: The Gross Margin of Perennial Crops at a Purchase Price of 72 €/t and at Establishment Costs Reduced by 20% (Establishment 1) and of Annual Crops Purchased at January 2008 Prices (incl. Direct Payments for Conventional Crops)

for 2007 and 2008 obtained from national statistics. Despite the fact that the ARiMR's database was not fully updated in 2009, its statistical data provided regional-level information for 2009, allowing an analysis to be undertaken at the municipal level.

Among many factors, the long term investment decisions on biogas production depend on the future livestock population. A continuous decline in the animal population is registered for sheep, goat and poultry livestock. Between 1999 and 2009, regional statistics (GUSB 2010) reported sharp nonlinear changes in the pig population as illustrated in Figure 15 . The significant drop in the pig population over the past three years was mainly associated with low pork meat prices. The R-squared for both pig and cattle population is insufficient to predict the future outlook based on historical data. Nonetheless, a slight increase in the cattle population can be assumed, while the pig population may continue to drop in the mid-term. This leads to the assumption that there is a high untapped potential for biogas generation in the region. The size of animal holdings is a key factor influencing the quantity and quality as well as the recovery amount of animal by-products. In the Kujawsko-Pomorskie Voivodship, dairy farms operating with up to 50 animals predominate (99%). Among dairy farms, 317 businesses (corresponding to 1.1%) had a livestock population of more than 100 whereas among pig farms, 3807 (corresponding to 9%) kept more than 100 animals as outlined in Table 34.

Farm structure also has an impact on the amount of straw used for bedding and feeding. In Poland, 80% of farms collect both manure and slurry, whereas 20% only collect liquid manure (MRiRW-MS, IUNG et al. 2004). These figures allow for the assumption that on farms housing more than 100 animals, the liquid manure is collected and 100% can be recovered. In dairy farms with a population over 100 animals, cattle as well as pigs are housed in barns throughout the whole year regardless of the farm's size, so it was assumed that 95% of manure could be recovered in the amounts outlined in Table 35. On smaller farms, the recovery factor is proportional to the period animals spent grazing on pasture.

4.2.3.2 *Agricultural Production*

60% of the region's total land surface of 17.9 ths. ha, around 10.6 ths. ha is agricultural land, 99% of which is maintained in a proper agricultural manner (GUS 2009a). Regarding the area under orchards registered in national statistics, the figure for the

Table 33: Livestock Units (LSU) and Population in the Kujawsko-Pomorskie Voivodship

	Livestock Population						
Years	Cattle	Pig	Horse	Sheep	Goat	Poultry	Total
2002	415371	2174203	8523	30628	8373	10880043	13517141
2007	437256	2132663	8337	22936	3848	6455382	9060422
2008	444943	1810099	11455	19415	3213	5963176	8252301
2009	482603	1724568	10626	15229	3430	5821501	8057957
2009	487157*	2022977*	-	-	-	-	-
Change	16.2	-20.7	24.7	-50.3	-59	-46.5	-40.4
	Livestock Units*						
	Cattle	Pig	Horse	Sheep	Goat	Poultry	Total
2002	332297	326130	8523	3063	670	43520	714203
2009	386082	271515	10626	2294	274	23286	657800
2009	389726*	303447*	-	-	-	-	693172*
	Share in Livestock Population in Poland [%]						Weighted Mean
2009	9	12	3.5	8	3	4.7	10

*The average livestock unit LSU of animal species is an equivalent of 0.8 LSU per cattle unit and 0.15 per pig (MRiRW-MS, IUNG et al. 2004)

Source: GUS (2009a); GUSB (2010); ARiMR (2010)

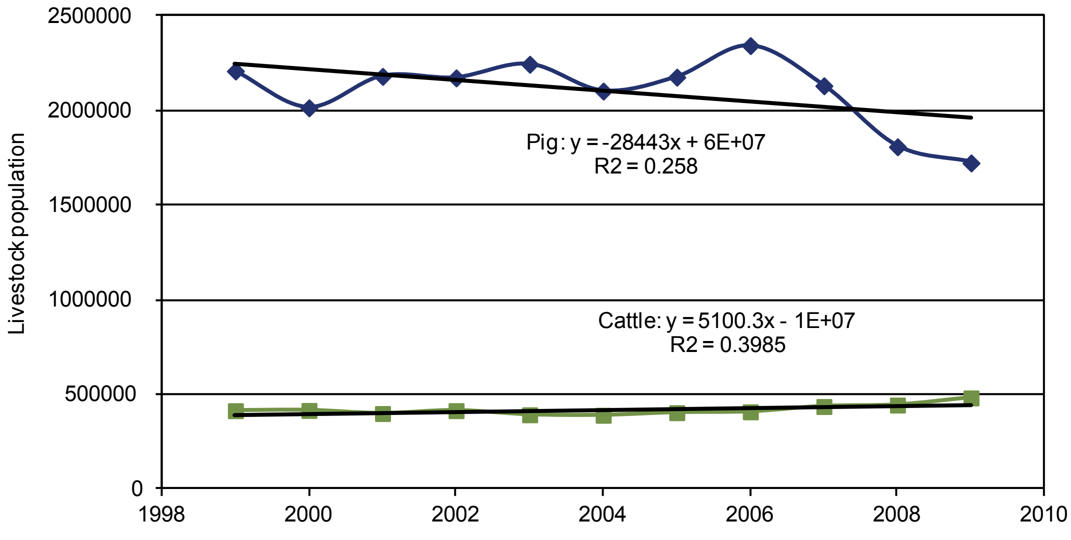


Figure 15: Historical Trend in Livestock Population for Cattle and Pigs between 1999 and 2009
Source: Based on GUS (2009a); GUSB (2010)

year 2002 differs by 13% in both ways as shown in Table 36. According to figures provided by the National Statistical Office (GUS 2009a), the area planted with orchards decreased by 15% between 2002 and 2009, whereas, according to figures derived from the Regional Statistical Office (GUSB 2010), orchard land increased by 12.5% over the same period. This discrepancy results from different definitions of the term "orchard" as well as from the minimum size of orchards recorded in the census carried out in 2002. Hence, with respect to figures recorded in previous years (GUS 2009a), the area of orchards is likely to decrease. By 2020, the total surface of arable land in the Kujawsko-Pomorskie is likely to decrease by 3% to 913954 ha owing to the expected dynamic infrastructural development

Table 34: Frequency of Livestock Population and LSU within Animal Holdings

Animal Population					
Cattle			Pigs		
Number	Farms	Share [%]	Number	Farms	Share [%]
1	4450	14	1	1326	3
10	14511	46	10	8220	20
50	11033	35	50	13762	33
100	1288	4	100	4106	10
200	226	1	200	2165	5
500	82	0	500	1163	3
1000	26	0	1000	255	1
2000	1	0	2000	90	0
5000	0	0	5000	40	0
More	0	0	More	24	0
Total	31617	-		31151	-
Livestock Units					
Cattle			Pigs		
Number	Farms	Share [%]	Number	Farms	Share [%]
1	4449	14	1	6326	15
10	16000	51	10	18829	45
50	10187	32	50	5269	13
100	767	2	100	464	1
200	127	0	200	162	0
500	71	0	500	66	0
1000	15	0	1000	19	0
2000	0	0	2000	9	0
5000	0	0	5000	6	0
More	0	0	More	1	0
Total	31617	-		31151	-

Source: Data Derived from ARiMR (2010)

(motorways, roads, settlements) and to areas subject to afforestation (1.3% of an agricultural land) (GUSB 2010). The majority (69%) of arable land in the case study region was cultivated with cereals, an area that slightly decreased between 2002 and 2009 (see Table 37), while the area dedicated to industrial and energy crops (e.g. maize for silage, rapeseed) significantly increased in the same period. Land for pasture decreased by 41% between 2002 and 2009 as a result of a drop in the animal population (see Table 36). Similarly, arable land decreased on average by 2% from 2002 to 2009 as outlined in Table 36. A significant decline in areas planted with potatoes, rye and sugar beets was noticed, while the area under maize and rapeseed has doubled in the same time, encouraged by incentive payments for energy crop cultivation paid by the Polish state.

For the ethanol production, potato and sugar beets may also be used; however, under the current economic conditions in Poland, the production of ethanol from these arable crops is relatively more expensive than ethanol production from cereals (Kuś and Faber 2009). Hence, the area under potatoes and sugar beets has dropped by more than one third since 2002. Potato and sugar beet are suitable feedstock for the production of biogas, although these crops are very rarely used in practice due to operational problems (Braun, Weiland et al. 2009). Lignocellulosic energy crops are also cultivated in the Kujawsko-Pomorskie Voivodship as mentioned in the previous section (see Table 28). However, this category has not been incorporated into the national statistics yet.

Table 35: Quantity and Quality (Dry Matter and Volatile Solid) of Animal Residues in Poland

Size	Unit	Cattle		Pig		Poultry Litter	Horses Manure	Sheep and Goats
		Slurry	Manure	Slurry	Manure			
Animal >100	t/LSU*y	15		14		-	-	-
	t DM/LSU*y	1.62		0.98		-	-	-
	t VS/LSU*y	1.30		0.78		-	-	-
Total Population	t /LSU*y	14	3	13	2	10	3	3
	t DM /LSU*y	1.12	0.75	0.78	0.40	3	1	1
		1.87		1.18		-	-	-
	t VS/LSU*y	0.9	0.6	0.62	0.32	2.6	0.8	0.8
		1.5		0.94		-	-	-
Biogas	m^3/t VS	320		350		350	350	350

Source: Kozakiewicz and Nieściór (1984); Steppa (1992); Kaltschmitt and Hartmann (2001); MRiRW-MS, IUNG et al. (2004)

With regard to the national RES targets and the development of biogas referred to in chapter 2.1, one can expect that the crop growing structure is likely to continue the outlined trend with the difference that the historical decline in pasture land will probably slow down due to the increasing demand for grass silage used for biogas production. The driving force in terms of a direct payment for energy crops was cancelled, so their production is likely to be regulated by the demand for biogas and combustion feedstock, which is associated with quota systems, as well as by the price of tradable green certificates.

4.2.3.3 Cereal By-Products

The amount of crop residues was derived from a residue-to-product ratio based on the national Polish statistics on the yield of cereals and the areas cultivated with cereals (Kappler 2008). The amount of residues generated from particular cereals remains stable due to a different straw yield. When including rapeseed and maize by-products, the amount of cereal residues increased by 10% since 2002 as described in Table 38. The table reveals a high degree of diversification in the annual surplus of lignocellulosic material tracing back to the size of the sown land and the structure and size of the farm holding. In this study, data collected during the 2002 Agricultural Census at the municipal level in Poland (GUS 2002) was used, as the national statistics only provide regional-scale information on the area of annual crops, production of the main plants, and their harvest. As outlined in Table 38, the average amount of cereals' by-products gathered in 2002 and 2009 respectively has not changed but, due to an increase in the area under rapeseed and maize cultivation, an additional amount of residue could be harvested for energy purposes.

Due to crop rotation constraints, the trend of crop cultivation might change from year to year (Karlen, Varvel et al. 1994). Therefore, the exemplary results of straw production based on historical data may fluctuate over time. The next agricultural census was conducted in 2010, so the actual data will be available one year afterwards and then the modeling

Table 36: Land Use in ha and Changes in % between 2002 and 2009 in the Kujawsko-Pomorskie Region

	Agricultural Land [ha]						Afforested Area	Other Land
	Total	Arable Land	Orchards	Permanent Meadow	Permanent Pasture	Other		
2002	1090443	961212	9389 12368(1)	85117	34725	-	408471	298058
2009	1067975	942221	10558	84893	20548	9755	427897	301297
Change [%]	-2.1	-2	12.5 /-15	-0.3	-41	-34	4.8	1.1

Source: GUSB (2010); (1) GUS (2009a)

Table 37: Area under Crop Cultivation in ha in the Kujawsko-Pomorskie in 2002, 2008 and 2009

Crop Area [ha]	Area under Cereals	incl. Basic Cereals	Maize for Silage	Maize for Grain	Potato	Sugar Beets	Rapeseed
2002	662338	554912	19703	20362	38702	54015	51285
2008	639706	551480	52487	33201	26648	30894	105451
2009	621117	537217	43265	27081	23303	35264	119399
2008/2002	-3.4	-0.6	166	63	-31	-43	106
2009/2002	-6.2	-3.2	120	33	-40	-35	133

Source: GUS (2009a)

Table 38: The Cereal Yield and Straw Production in the Kujawsko-Pomorskie Voivodship in 2002 and 2009

	Yield [t]		Crop Area [ha]		Straw to Grain (x:1)	Straw Yield [t]	
Cereals	2002	2009	2002	2009		2002	2009
Wheat	888138	8768009	211843	196409	0.90	759358	7496648
Rye	262331	2082031	100437	76418	1.20	299057	2373515
Barley	423119	3861547	127576	114311	1.13	454218	4145371
Oats	44843	356440	16048	11842	0.70	29821	237033
Triticale	364365	5350010	99008	138237	1.20	415376	6099011
Mixed Cereals	321804	2402946	106446	78168	1	305714	2282799
Total						2263544	22634376
Rapeseed	129403	3682357	51286	119399	1	122933	3498239
Maize for Grain	142534	1617606	20362	27081	1	135407	1536726
Total	2576537	28120946	733006	761865		2521884	27669341

Source: Harasim (1994); GUS (2002); Kuś, Madej et al. (2006); GUS (2009a)

could be updated. The potential surplus of harvest residues from cereals was calculated according to the formula 5 outlined in chapter 4.1.2. The straw quantity used in livestock farms was estimated under the assumption that 0.8 tons of straw are used annually for the feeding of livestock units of cattle, horses, goats and sheep and 1 t/y of straw is used as bedding for the LSU of cattle, horses, goats and sheep and pigs (Kozakiewicz and Nieściór 1984; Kuś, Madej et al. 2006). In dairy and pig farms operating with more than 100 LSU, a factor of 0.3 was applied (see Table 39).

From the sustainable agriculture perspective, agricultural residues are used after crop rotation as a soil fertilizer. Maintaining a positive or at least neutral balance of soil humus is one of several requirements laid down in the Code of Good Farming Practices published in 2004 (MRiRW-MS, IUNG et al. 2004). The balance of soil humus was estimated using a concept developed by the Institute of Soil Science and Plant Cultivation (MRiRW-MS, IUNG et al. 2004). The average reproduction or degradation rate of organic soil matter was estimated based on the formula:

$$C = \frac{\sum \%CA * c}{\%SA} \qquad (6)$$

where C is the coefficient of degradation / reproduction in t/a*y, CA is the fraction of cultivated area of the total surface of arable land within an administrative unit in percent, c is the coefficient of degradation or reproduction taken from Table 40 and SA is the grown area in percent.

As shown in Table 40, different organic materials vary in their effectiveness to generate humus depending also on the soil classification. Factors representing the level of degradation (-) and reproduction (+) correspond to the amount of humus expressed in tons per ha. Kuś, Madej et al. (2006) estimated the straw requirement for fodder, bedding and fertilizer on a regional scale. In the present study, by contrast, the humus balance was estimated at a local level considering two cases: first, the organic soil matter was balanced by animal waste and then by straw. In the second case, the humus from cereals residues was estimated to balance the shortage of organic materials after crop rotation.

The degree of degradation or reproduction of the soil's fertility after growing crops was calculated in a GIS-based model, relying on Polish census data on crop cultivation per commune. Assuming that the organic soil matter was balanced in the preceding year, Map 16 shows 129 communes that became poor in humus after a crop rotation in the year prior to 2002 in the considered study. In those communes, the humus was balanced due to manure produced by cattle, pigs, horses, sheep, goats and poultry upon the recommendation of the Code of Good Farming Practices (MRiRW-MS, IUNG et al. 2004). As shown on Map 17, manure fertilizer resolved the humus depletion in 67 of 144 communes, so that in the remaining 77 communes, the soil had to be additionally enriched by straw organic matter. In order to reach a neutral balance of the soil humus, around 78% of livestock manure and 32% of straw were used as fertilizer.

In the above-mentioned first case, 71% of the total amount of cereal by-products was required to offset the shortage of animal fertilizer and to satisfy the demand on animal fodder and bedding as outlined in Table 41. The estimate carried out at the communal level indicates an insufficient amount of both considered fertilizers in 20 communes (Map 18 and Map 19) while in total, one third of the straw remained. In the assessment of the straw potential, the agricultural holding structure should be taken into account, since harvesting and transport costs play a significant role in the economic viability of energy production.

In the second case, the straw as a basic fertilizer was considered to have reproduced the organic material after satisfying the demand for animal fodder and bedding. Mostly in communes with a significant share of root crops covering between 20 and 40% of the commune's total arable land, the humus shortage could neither be offset by cereal straw (Map 20) nor an additional animal fertilizer.

Table 39: Straw for Bedding and Feeding and Dry Matter of By-Products per Livestock Unit

Livestock Unit*	Cattle	Pigs	Horses	Poultry	Goats and Sheep
Straw for Bedding [t/LSU]	1	1	1	1	1
Straw for Feeding [t/LSU]	0.8		0.8	0.8	0.8
Total Manure [t DM/y]	1.9	1.2	1	3	1
Availability Factor	0.7*	1	0.5	0.5	0.5

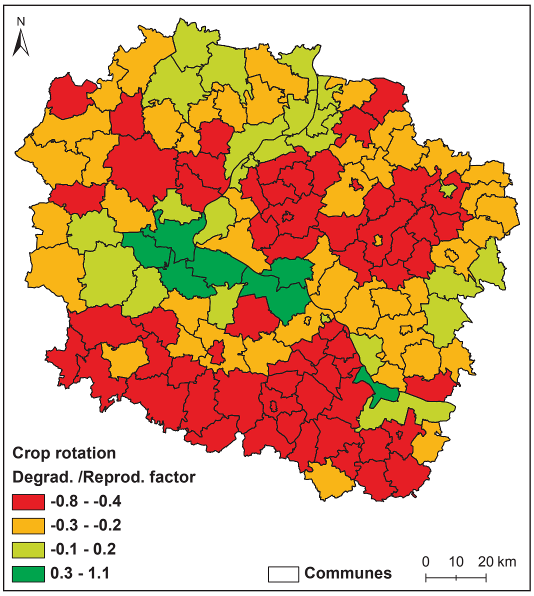
*During 5 grazing months, for 60% of a cattle population (dairy farms operated with less than 10 animals). The LSU of animal species is an equivalent of 0.8 per cattle unit, 1 horse, 0.15 pig, 0.1 sheep, 0.08 goat and 0.004 chicken

Source: ME (2004)

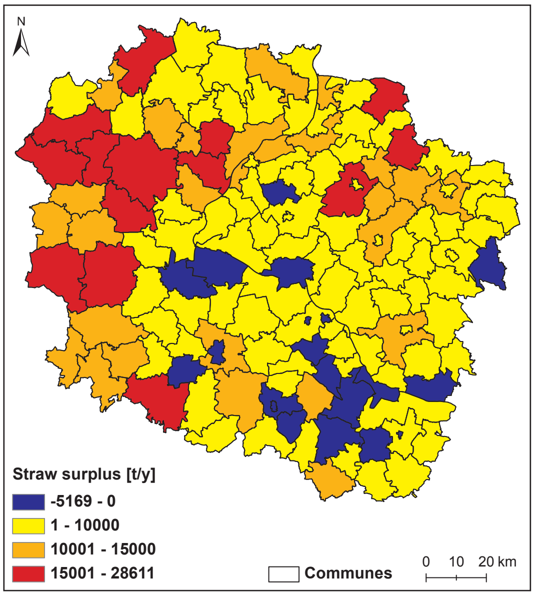
Table 40: Factors for the Degradation (-) and Reproduction (+) of Organic Soil Matter

Type of Crop/Fertilizer	Unit	Light Soil	Medium Soil	Heavy Soil
Root Plants	1ha	-1.26	-1.4	-1.54
Maize	1ha	-1.12	-1.15	-1.22
Cereals, Rapeseed	1ha	-0.49	-0.53	-0.56
Pulse	1ha	+0.32	+0.35	+0.38
Grass	1ha	+0.95	+1.05	+1.16
Legume	1ha	+1.89	1.96	2.10
Manure	10 t		+0.7	
Slurry	10 m^3		+0.28	
Straw	10 t		+1.8	

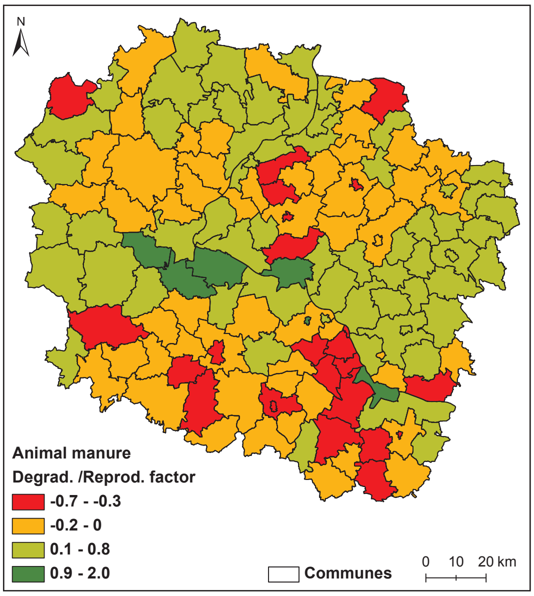
Source: MRiRW-MS, IUNG et al. (2004)



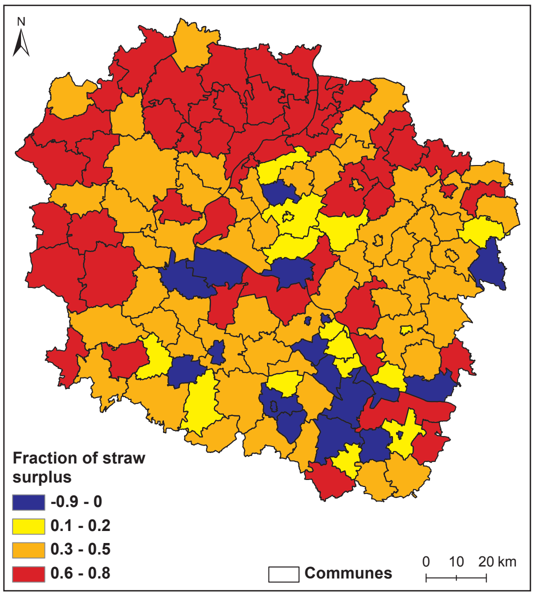
Map 16: Factor of Organic Matter Degradation or Reproduction within a Crop Rotation



Map 18: Quantity of Straw Surplus



Map 17: Factor of Reproduction or Degradation after Manure Fertilizing



Map 19: Share of Straw Surplus in Total Amount of Straw

The surplus of either animal or agricultural by-products after satisfying the primary needs is outlined in Table 41. With respect to the agricultural practice in Poland according to which livestock manure is predominantly used as a soil fertilizer, around 0.94 Mt of straw (35% of the total amount) remained in the region, concentrated foremost in the country's north-western part (see Map 18). The energetic equivalent is 6600 TJ[7].

With respect to its competitive use, 0.24 Mt of straw is already being used by the existing straw pellet companies in Kujawsko-Pomorskie and the outlook is to extend the amount to 0.4 Mt (Brykietowanie 2010). Moreover, in this region there are few heat-only boilers fed with straw in operation (K-PBPPiR 2010). Nonetheless, the amounts to be used for energy purposes depend on mobilization costs and logistical factors.

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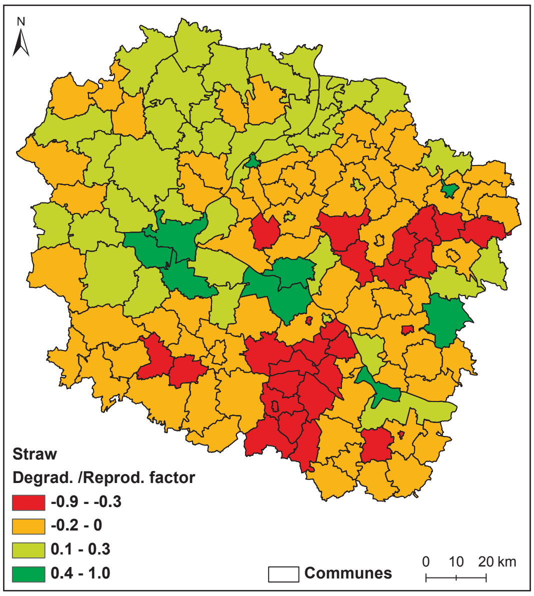
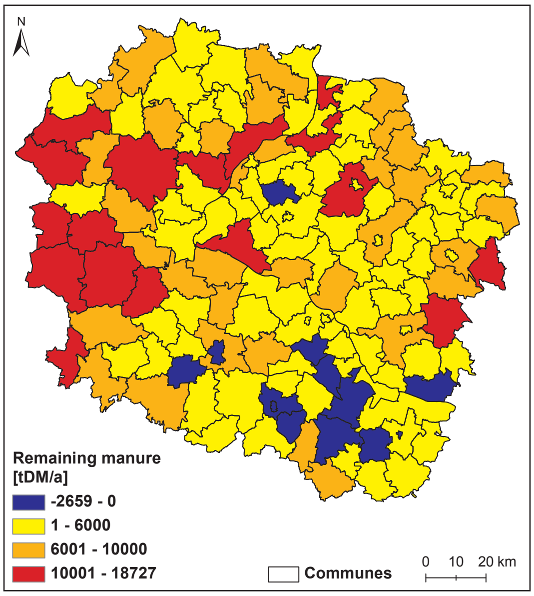
[7] Assumed calorific value of fresh straw at 7 GJ/t



Map 20: Factor of Reproduction or Degradation after Fertilizing with Straw



Map 21: Remaining Animal By-Products after Additional Fertilizing

Table 41: Balance of Animal and Agricultural By-Products

	Case One		Case Two	
	First Fertilizer	Additional Fertilizer	First Fertilizer	Additional Fertilizer
	Animal By-Products	Cereals By-Products	Cereals By-Products	Animal By-Products
	t DM/y	t/y	t/y	t DM/y
Total Potential	983918 (911907*)	2 647 323	2 647 323	983918 (911907*)
Bedding and Feeding		1015389	1015389	
Used as Fertilizer	768265	868476	1448733	270720
Remaining after Balance	215653	973865	183201	713198 (645843*)
Fertilizer Shortage	354234	24873	728057	9492
Fertilizer Remaining in Total	-136781 (13%)	948992 (35%)	-544856 (20%)	703706 (71%)

*Manure of cattle and pig populations

4.2.3.4 Biogas Potential in the Kujawsko-Pomorskie Voivodship

The study provides a means to evaluate the potential for, and geographic distribution of, biogas feedstock (animal manure and selected crops) on a regional scale and to determine appropriate sites for biogas development under ecological, technical and economic criteria. In addition, the functions developed on the basis of collected dataset allow for the techno-economic evaluation of biogas projects under a constant set of variables. A workflow chart describing the stepwise methodology is illustrated in Figure 16. The following actions were performed: first, the zones suitable for biogas development were pre-selected, considering a variety of environmental, technical and economic constraints (outlined in the next section). Secondly, the spatial density of the farm manure was calculated to identify optimal sites within those pre-selected zones. Next, the arable land within certain distances of biogas plant sites was mapped to assess the share of land required for biogas-dedicated crop planting across the total arable land area. Similar analyses were carried out for a selected number of crops. The assessment of the technical and economic potential was carried out for energy production with combined heat and power technologies, as well as for biomethane feeding into the natural gas grid.

4.2.3.4.1 Biogas Siting Location

The pre-selection criteria of sites for biogas development must fulfill certain conditions, since the aim is to enhance the environmental and economic benefits of biogas use and to mitigate conflicts related to the biogas production process and its facilities. Consequently, several selection and exclusion criteria were defined to aid the siting process in a GIS environment, as outlined in Table 42. With respect to the potential impact associated with noise, fumes, visual intrusion and an increase in local traffic, anaerobic digesters (AD) are located within a certain distance of residential areas and visually sensitive landscapes. Furthermore, in accordance with the Nature Protection Act (Ministry of Environment 2001), the construction of biogas plants is banned in nature reserve areas and other protected zones. Within landscape areas and the EU's Natura 2000 network, biogas plant projects are not entirely excluded. However, exceptions are only permitted if the environmental impact assessment reveals that the extent of the impact would be tolerable. On a regional scale in Poland, according to the precautionary principle taken in the study, the entire area under protection as well as forests, roads and wetlands are excluded from the biogas development sites, and buffer zones were defined to establish the minimum distances as outlined in Table 42. The tolerable proximity is usually determined from case to case on site, therefore the data used in the regional-scale study only serve as an example.

Aside from these exclusionary constraints, selection criteria influencing the technical and economic viability of projects were defined. In the process of selecting development zones, access to the power network or the natural gas grid play a crucial role, thus buffer zones of 2 km around the gas grid and the power network were established to determine the preferential zones. The individual maps were overlapped to extract maps, which identified restricted areas for biogas development (see Map 22) and preferential zones around the gas grid and the power network (see Map 23). Then both digital layers were overlapped and a final map of preferred development zones for biogas plants were produced.

The digital map layers at a scale of 1:750000 representing the land use (transport infrastructure, wetlands, forestlands, settlement areas), land functions (residential, nature conservation) and natural hazards like floodplains outlined in Table 42 were obtained from the Office of Spatial Planning of the Kujawsko-Pomorskie Voivodeship (KPBPP 2009). In addition, the digital data representing the road and railway infrastructure and built-up areas were complemented by the Corine Land Cover 2006 (1: 100000) data (IGIK 2009) and the Open Street Map (Geofabrik 2010).

The assessment carried out on the regional scale allowed only for a preliminary selection of preferred zones and not for the actual biogas plant planning, since digital data on the low-voltage transmission

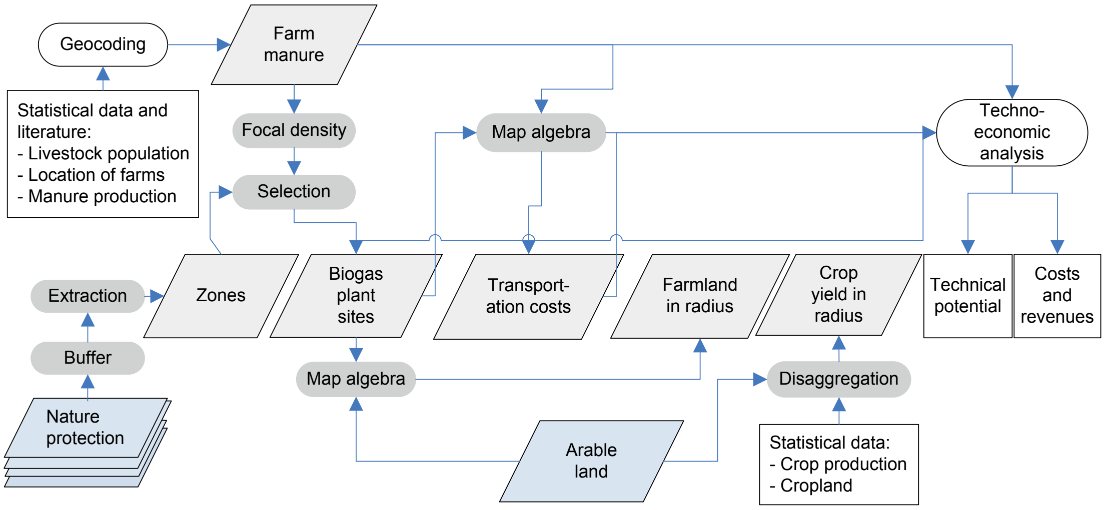


Figure 16: Flow Chart Describing Operational Steps of the Method

line and the low-pressure gas grid was not available. Finally, due to the different scales of the digital datasets, small scattered settlements units, smaller forestland, wetlands and local roads could not be taken into account in the analysis.

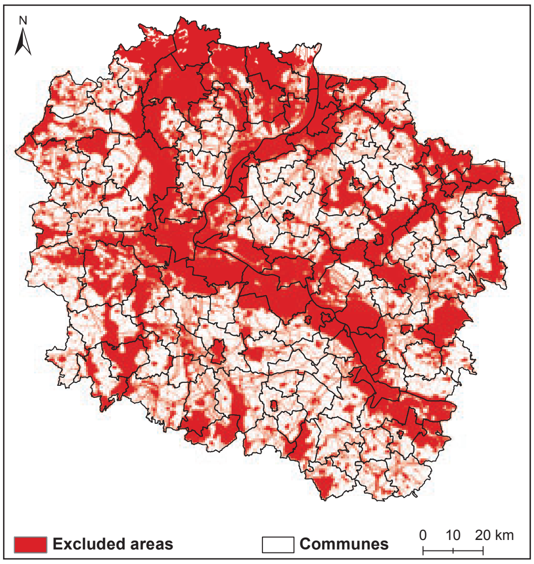
4.2.3.4.2 Feedstock for Biogas Generation

The optimal mix of biogas feedstock depends on the choice of fermentation systems with respect to economic criteria and the availability of biogas feedstock. Nonetheless, wet fermentation systems dominate with a total dry matter (DM) of up to 15%, which is mainly based on animal slurry added with co-substrates to increase the content of organic material for achieving a higher gas yield (Braun 2007; Laursen 2009; Weiland 2010). In Germany, the mass percent of manure in co-fermentation processes is, on average, 43%. The share of crops amounts to 41% and the remaining 16% are organic wastes (DBFZ 2010). In Poland, the basic biogas feedstock fed into agricultural biogas plants is animal manure, whose mass percentage varies from 60% to 100%, followed by maize silage as a main co-substrate with a mass share between 16% and 28%, the rest being organic waste (see Figure 17).

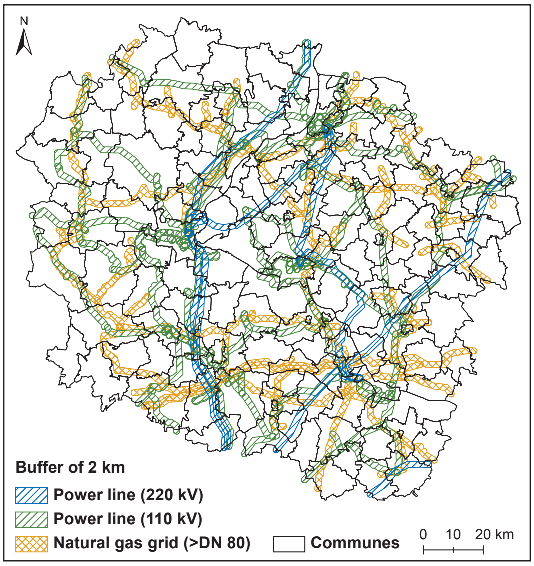
Under these conditions, the focus was placed on assessing the potential of farm manure assuming wet fermentation with 15% DM of the total feedstock mix. The required amount of co-substrates was estimated on the basis of the identified quantity of animal by-products according to the formula:

Table 42: Exclusive and Selective Criteria for Biogas Infrastructure Development Sites

Exclusive Criteria	Distance
Forests	-
Water Bodies	50 m
Floodplains	50 m
Water Protection Areas	-
Natura 2000 Network, Ecological Corridors, Landscape Parks and Areas, Nature Reserves	-
Built-up Areas	300 m
Roads, Railways	10 m
Selective Criteria	
Power Grid	2 km
Gas Grid	2 km



Map 22: Excluded Areas after Considering Areas under Protection, Water and Residential Areas



Map 23: Buffer of 2 km Around the Power Transmission Line and Natural Gas Grid

$$\sum S_{cs} = \frac{15 * S_m - DM_m * S_m}{(\sum DM_{cs} - 15) * 100} \qquad (7)$$

where S_{sc} is the annual amount of co-substrates (maize silage and cereals silage) in t/y, S_m is the quantity of animal manure and slurry in t/y, DM_m is the dry matter of animal manure and slurry %, DM_{cs} is the dry matter of co-substrates in %.

Biogas production is proportional to the dry matter and the organic matter content of co-substrates and can be calculated as:

$$BS = \sum S_i * DM_i * VS_i * MVS_i \qquad (8)$$

where BS is the biogas production in m^3, S_i is the amount of substrates i in t/d, DM_i is the dry matter in the substrate i in %, the volatile solids VS_i is the concentration of organic matter in the total solid of substrate i in %DM, MVS_i is the biogas content in the VS_i of substrate i in m^3/t VS.

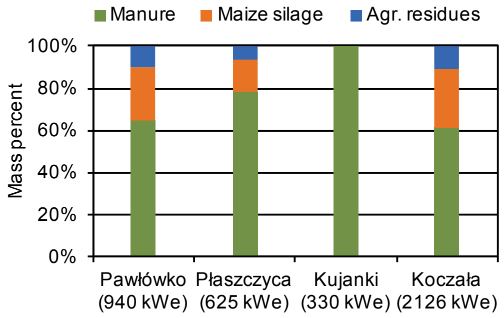
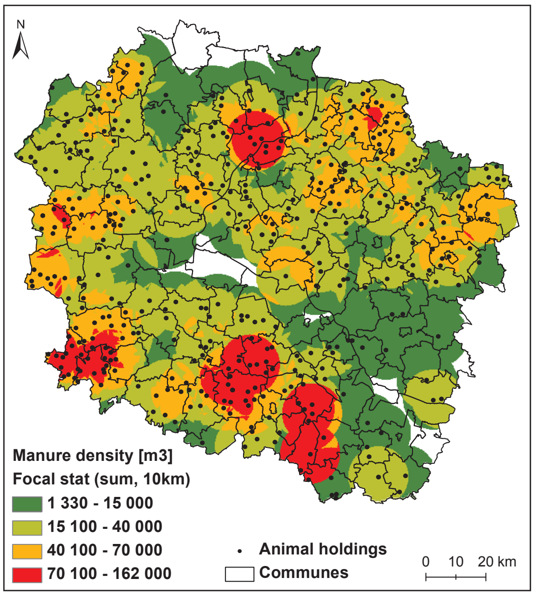


Figure 17: Mass Percent of Biogas Feedstock in Four Existing Biogas Plants in Poland in 2010

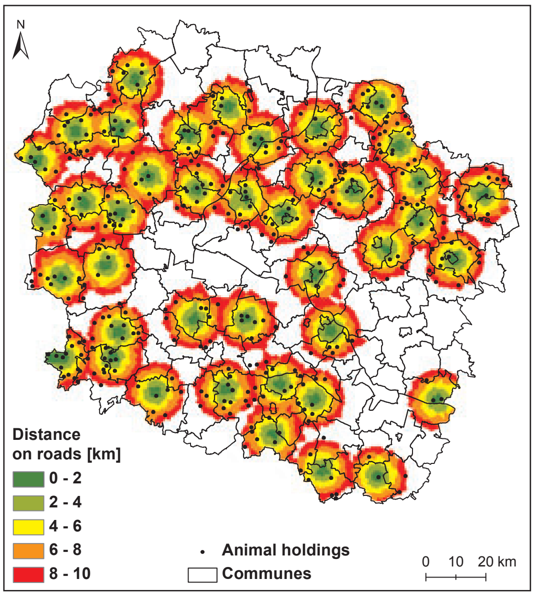
4.2.3.4.3 Site Selection Based on Animal Manure

In the case of anaerobic digesters fed predominantly with animal waste, with respect to the economies of scale, biogas plants are in practice located close to large animal farms with at least 100 livestock units (ECBREC IEO 2004; FNR 2009). Under these conditions, 215 dairy farms and 317 pig farms operating with 100 or more livestock units were taken into account in the first step analysis. Biogas yield was calculated under the assumption that cattle produce 15 tons of manure per LSU and pigs 14 tons per LSU annually (Steppa 1992; Kaltschmitt and Hartmann 2001; Schulz and Eder 2001).

Having computed the map of manure density (see Map 24) using the focal statistic sum tool in the Spatial Analyst toolbox, the sites characterized by a maximum animal waste density were identified first, taking into account the development zones. Then a buffer zone of 10 km was computed to select appropriate farms within this area. The selection was an iterative process, so that the manure density map was updated each time after extracting clusters of farms. Once the density of animal by-products was lower than an equivalent of 200000 m^3/y of



Map 24: Focal Density of Accumulated Sum of Animal Manure from Animal Holdings with at least 100 LSU within 10 km Radius



Map 25: Animal Holdings Selected in a Distance of 10 km on Roads from Potential Site for Biogas Plants Development

biogas, the iterative processed was interrupted. In the GIS-based modeling, 41 potential sites for biogas plant construction were identified as illustrated on Map 25 (see details in Appendix 5).

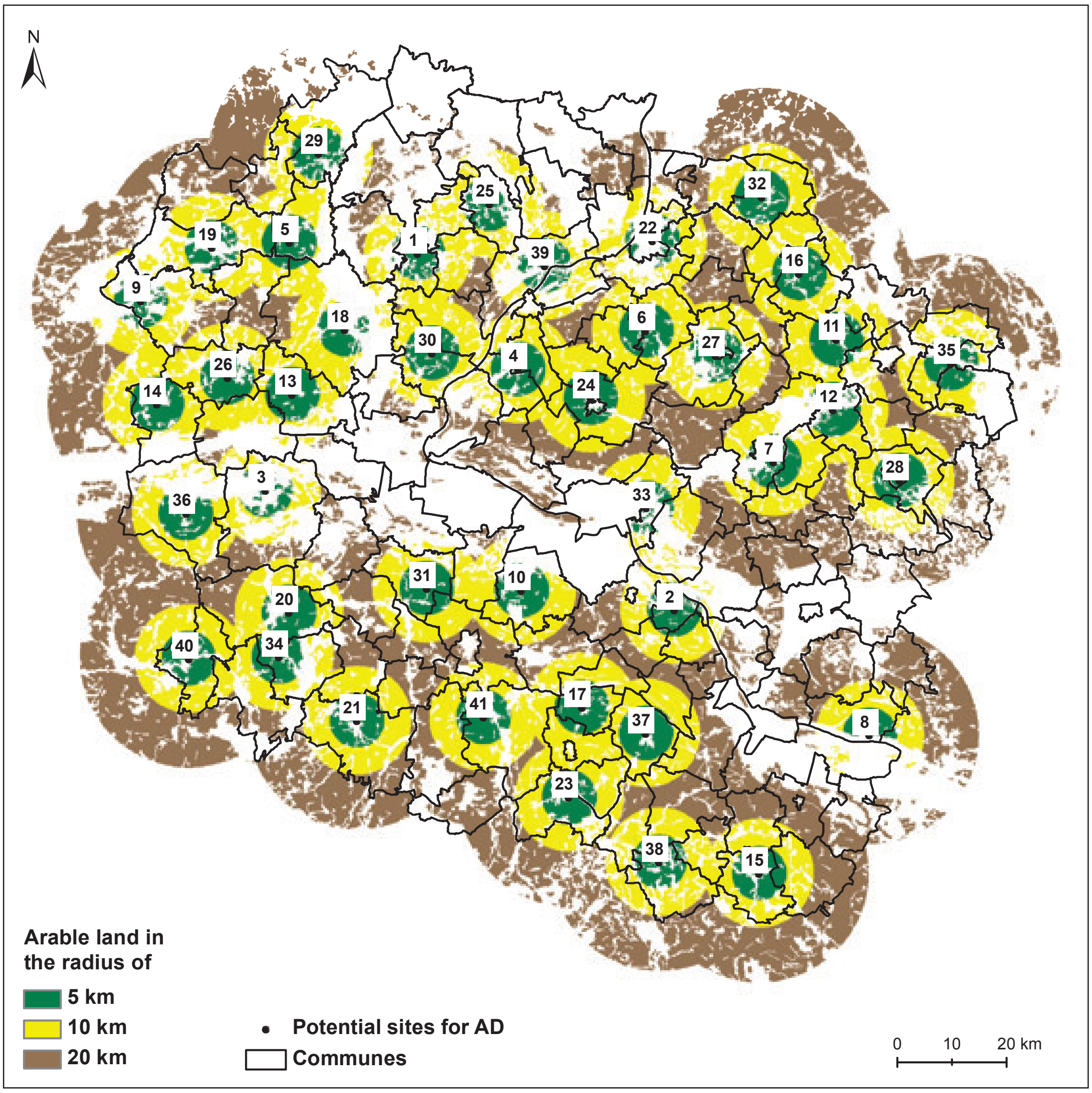
The objective of the first two steps was to identify suitable sites for biogas development under infrastructural framework conditions and the animal manure supply potential. In this study, biogas potential was estimated based on the manure quantity

Table 43: Cattle and Pig Livestock Units and Holding in the Kujawsko-Pomorskie Voivodship

	LSU*		Animal Holdings	
Animals	Amount	Share in Total	Amount	Share in Total
Cattle	48074	12%	215	0.75%
Pigs	96290	30%	317	1%

*Average livestock unit LSU of animal species is an equivalent of 0.8 LSU for cattle and 0.15 for pigs (MRiRW-MS, IUNG et al. 2004; GUS 2009a)

Source: ARiMR 2010



Map 26: Arable Land within 5, 10 and 20 km from Potential Biogas Plant Sites

produced in animal holdings identified within 41 buffers illustrated on Map 25.

4.2.3.4.4 Co-Feedstock for Biogas Generation

The availability of energy crops plays a secondary role in determining the location of ADs under the assumptions outlined above. In this phase, arable land and the production of selected crops were mapped in typical transport distances of 5, 10 and 20 km from AD sites as illustrated on Map 26. The grid cells designated as arable land were extracted from the Corine Land Cover (CLC2006) data representing 44 different land cover classes. The CLC grid format with 100 m cell size was obtained from IGIK (2009). Assuming an average yield of 35 t/ha of crop silage, a potential area of 22000 ha is required for feedstock planting, which is twice as much as the area of land set aside (GUS 2009a). With respect to the total area of arable land in the case study region, 2.2% of the area could meet the demand for co-substrate production. The above-mentioned document published by the Polish Ministry of Economy (2010) indicates that 700000 ha of farmland could be used to grow biogas-dedicated crops without harming the food and fodder supply. Since the fermentation process is primarily based on animal waste, planting the necessary agricultural co-substrates would require 3% of the total national farmland potential based on the assumptions outlined above.

Having calculated the fraction of land required for energy crop planting on the total arable land within three different ranges from biogas plants, the outcomes indicate that even a radius of 5 km around each biogas plant is sufficient. As shown in Figure 18, in three cases (sites 22, 33, 39) the demand exceeds 30% of the land.

The insight into the theoretical potential of arable land is provided in Figure 18 is supplemented by mapping data of an area in each circle of 10 km and 20 km radiuses overlapping each other as shown on Map 26. By extending the distances from biogas plants, the potential of arable land increases, but on the other hand, so does the competition for farmland for the cultivation of energy-dedicated crops.

In the next phase, the analysis was extended to crop production. The information on annual production and the grown area at a municipal level was derived from the Agricultural Census (GUS 2009b). As the data is not detailed enough to map the spatial deployment of crop yield within the three ranges cited above, the data on annual yields of maize, wheat and rye (see Table 44) was disaggregated uniformly onto the CLC2006 arable land cells using a 100 m grid according the formula:

$$CY_i = \frac{CY_a}{\sum ALCLC_a} \tag{9}$$

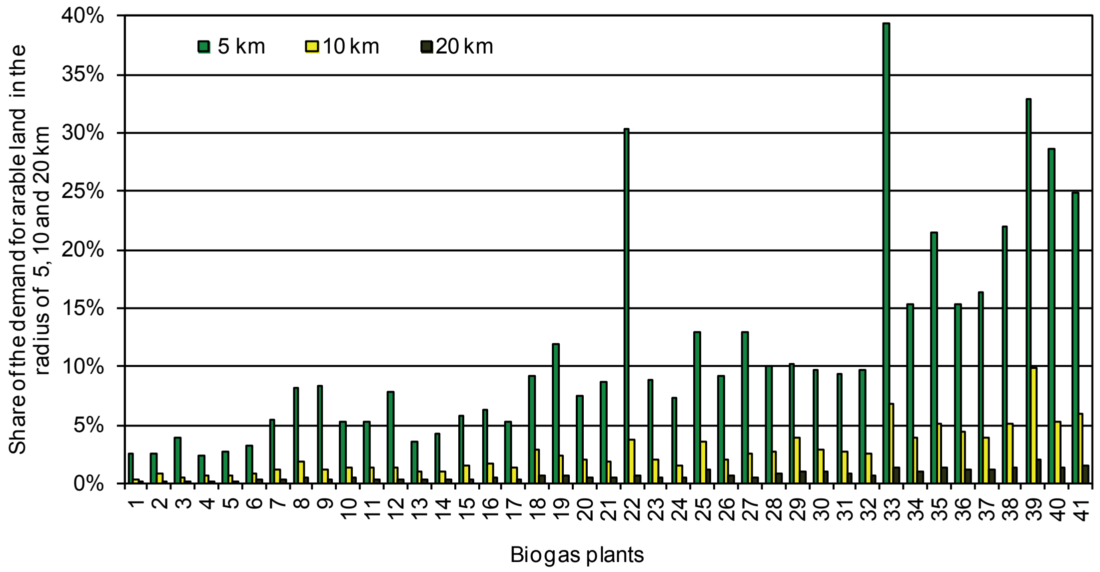


Figure 18: The Ratio of Required Arable Land for Biogas Feedstock Planting to Arable Land in the Range of 5, 10 and 20 km from Potential Sites for Biogas Plants

where CY_i is the annual crop yield in a grid mesh of 100 m x 100 m in t/ha, CY_a is the total crop yield per administrative unit a in t/a*y, $ALCLC_a$ is the sum of cells of arable land class according to the Corine Land Cover raster within each municipal unit a in ha.

The total quantity of the fresh mass of selected crops cultivated over one year was calculated through multiplying the planting area of crops by the fresh mass yield reported by Michalski (2009) and Podkówka (2006) as outlined in Table 44.

The quantity of agricultural feedstock such as maize, wheat and rye silage was calculated within distances of both 5 and 10 km as presented in Figure 19 and Figure 20. Within a 5 km radius, the quantity of the selected crops barely meets their demand (green line) at sites such as 9, 22, 33, 35 and 41. Extending the radius up to 10 km, the required amount of co-substrates can be covered by maize alone at most sites. Addressing the overlapping farmland within catchment areas of 10 km radius, Figure 21 illustrates the share of crop production computed in the adjacent circle. For instance, at site number 34, more than 50% of maize, wheat and rye yield was cultivated within a 10 km area around the biogas plants numbered 40, 20 and 21 (compare Figure 19 and Figure 20).

Due to crop rotation constraints, patterns of crop cultivation change from year to year (Karlen, Varvel et al. 1994) and it is thus impossible to predict the site and area of crop plantations over the following years. Therefore, the exemplary results of crop production based on historical data on crop cultivation patterns may fluctuate over time. Nevertheless, this approach provides an insight into the structure of agricultural production and indicates the theoretical potential of farmland for crop planting in terms of distance from biogas sites, but also takes into account the possible competition for arable land and crop resources.

Table 44: Agricultural Feedstock Quantity

Crops	Yield [t_{fm}/ha]	Grown Area [ha]	CY_a [t_{fm}/y]
Maize	30 - 50	85688	3427520
Wheat	30 - 50	192868	7714720
Rye	30 - 35	76804	2688140

Source: GUSB (2009); GUS (2009b)

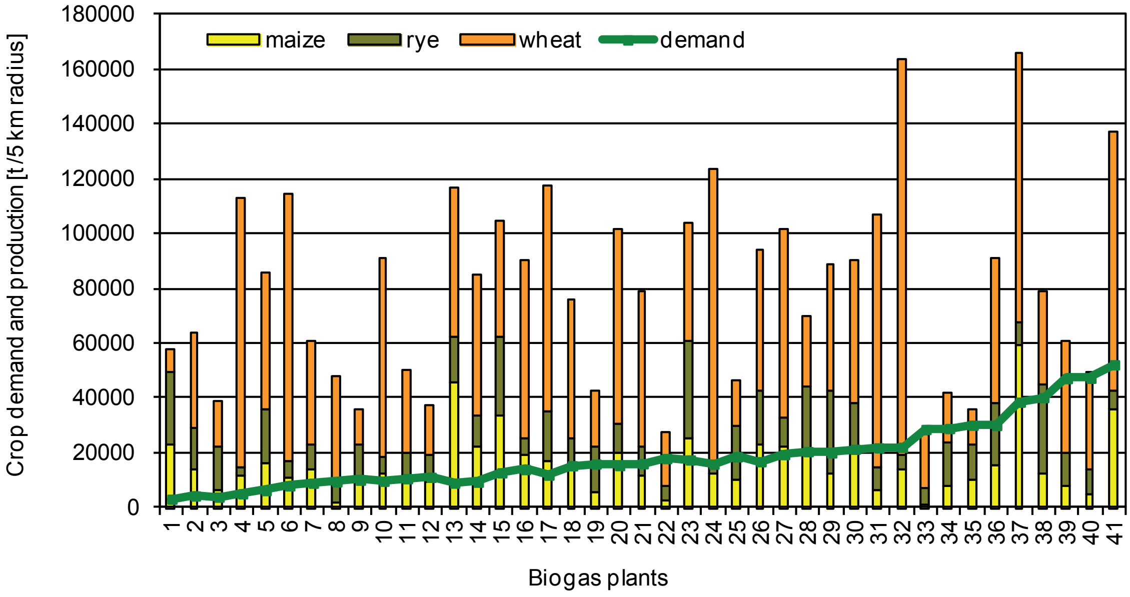


Figure 19: Crop Requirement and Production within a Catchment Area Radius of 5 km from Potential Sites for Biogas Plants

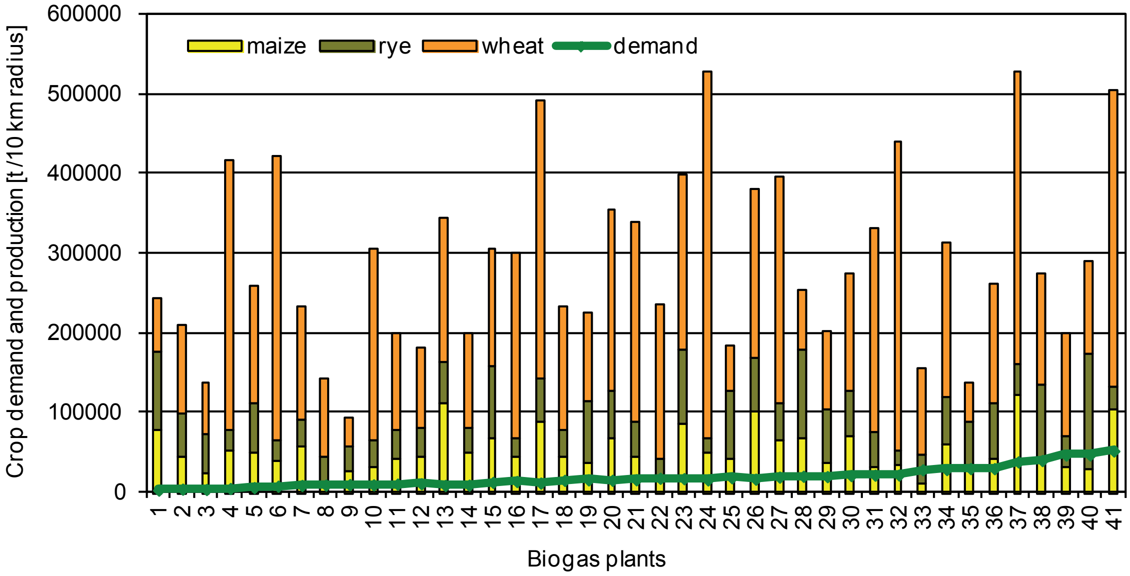


Figure 20: Crop Requirement and Production within a Catchment Area Radius of 10 km from Potential Sites for Biogas Plants

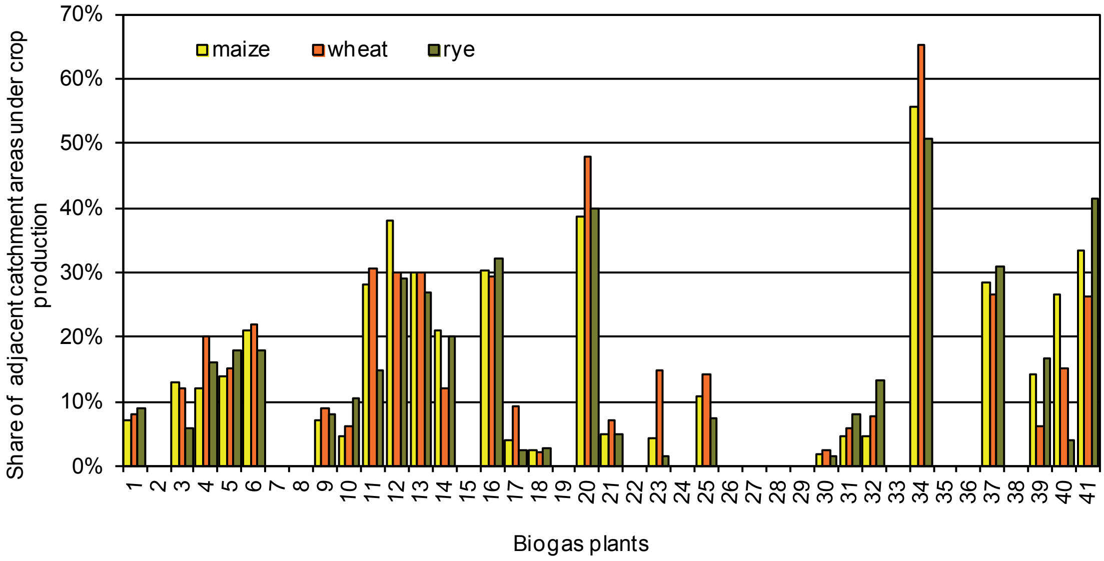


Figure 21: Share of Adjacent Catchment Areas of 10 km Radius from Potential Biogas Plants under Selected Crop Production

4.2.3.4.5 Transportation Costs of Biogas Feedtock

Due to the low energy content of liquid manure and its distributed sources, the GIS model in the present study was developed to determine the on-road distance and the costs of manure transportation to potential biogas plant sites (see Figure 22). Firstly, the road network derived from Geofabrik (2010) was rasterized at a grid size of 25 m x 25 m and then two continuous grids of distance and transportation costs to each potential biogas plant site were computed using functions of Euclidean distance and Euclidean allocation from the Spatial Analyst toolbox in the ArcGIS 9.3. Subsequently, the unit-related delivery costs of 0.024 €cents/m^{3}*m (Michalski 2009) were multiplied by the quantity of manure produced in animal holdings and the respective transport distance to potential biogas plant sites to estimate the total costs for the delivery of animal waste to biogas plants. The following formula (10) was applied to the Map Algebra:

$$TC = 0.024 * D * M \tag{10}$$

where TC is the transportation costs in €, D is the distance from animal holdings in meters, M is the quantity of animal manure in m$^{3.}$

The transportation costs of agricultural co-substrates were not calculated by the same formula as the manure, since the digital data on the spatial deployment of particular parcels for crop planting was not available for the study.

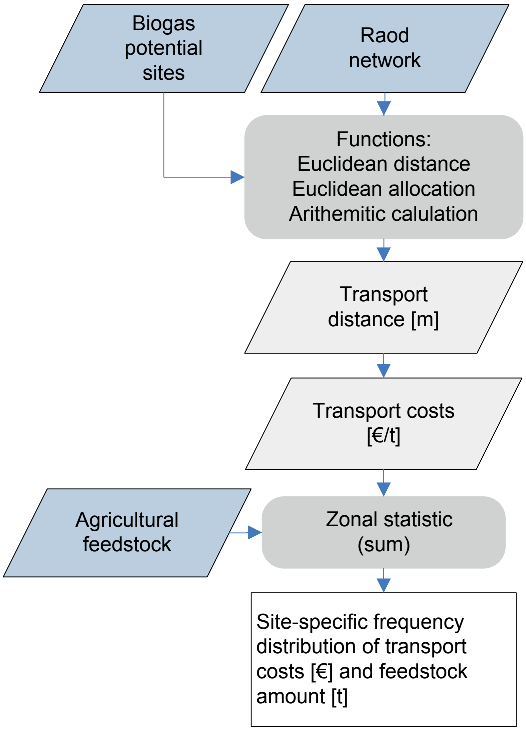


Figure 22: Model for the Calculation of Transportation Distance to Potential Sites for Biogas Plants and Transportation Costs of Animal Manure

4.2.3.4.6 Energy Production from Biogas

Biogas has mainly been utilized in combined heat and power plants (CHP) using gas or dual fuel engine to generate electricity and heat (Weiland 2010). In Germany, the leading country for biogas production, typical on-farm anaerobic digester plants range from a few kW_e installed capacity up to 3 MW_e installed capacity (350 kW_e on average) (DBFZ 2009). Due to a common problem regarding the seasonal fluctuation of heat demand from the CHPs, biomethane upgraded to a natural gas grade can be injected into the natural gas grid to increase the overall efficiency of biogas use throughout the whole year. In 2008 for instance, 15 such installations (with a total installed capacity of 80 MW_{th}) feeding biomethane into the gas grid were operating in Germany (Fritsche, Hennenberg et al. 2009).

This study of the technical potential either dealt with energy generated in CHP plants or with biomethane fed into the gas grid. The electric power output for CHPs was plotted against the hourly biogas volume stream from anaerobic digesters according to data derived from the study of Urban, Lohmann et al.(2009) as follows:

$$EP = 1.8543 * BF \tag{11}$$

where EP is the electric power of biogas plants in kW, BF is the biogas flow in m^3/h.

A basic parameter for calculating the electricity and heat generation in CHP units is the scale-dependent energy conversion efficiency (Celma, Rojas et al. 2007). The efficiency trend of electricity and heat conversion was studied on the basis of the data provided by FNR (2006a) and Urban, Lohmann et al.(2009) and fitted into a power regression function as follows:

$$EF = 19.02 * EP^{0.10} \tag{12}$$

wher EF is the electricity efficiency in % and EP is the electric power in kW.

$$HE = 50.998\exp(0.0002 * EP) \tag{13}$$

where HE is the heat efficiency in % and EP is the electric power in kW.

On this basis, electricity and heat were estimated by multiplying the efficiency factors by the gross energy. In the case of methane injection into the gas grid, the biomethane (m^3/y) generated in 41 potential ADs was converted to the electricity equivalent. The Polish Energy Law revision on 8 January 2010 introduced a certificate of origin for agricultural biogas, to be implemented from 1 January 2011 to support the injection of biomethane into the natural gas grid (Ministry of Economy 1997, 2010). However, there is as yet no ordinance regulating the calculation method for recalculating biomethane into the equivalent electrical energy value.

Furthermore, the purchase price of the certificate is still unknown. Therefore, in the present study, the amount of electricity was calculated under the assumption that 9.7 MWh is the equivalent of one cubic meter of upgraded methane.

The results from this study summarized in Appendix 5 outline the amount of animal manure, its estimated summarized on-road transportation costs, the amount of agricultural co-substrates as well as the electrical power output and energy generation. 41 biogas plants could exploit 1.9 Mm^3 of farm waste, which composes 92% of the expected amount of manure from animal farms housing at least 100 LSU. Under the above-outlined assumptions, the mass fraction of manure in co-fermentation technologies varies from 67% to 80%, the rest being crop silage. The CHP plants with an electrical power output varying between 183 kW_e and 2850 kW_e could generate 368 GWh of electricity and 442 GWh of heat. Alternatively, the biomethane produced in ADs could meet the demand for 98 Mm^3 of natural gas.

4.2.3.4.7 Costs-Benefit Analysis of Biogas Production

Investment costs vary from project to project depending on the biogas facility construction process, including for instance the land acquisition, feedstock storage, building the plant and the particular type of gas utilization and connecting systems. The objective of this study was to provide an insight into the structure of cost and benefits in order to analyze whether - and which kind of - financial subsidies suffice to enhance biogas development, and what the price limit of substrates would be, so as to keep the investment viable. Considering the economic feasibility of feeding biomethane into the gas grid, the purchase price of (brown) certificates of origin was discussed. The specific investment costs for both technical options were analyzed by means of regression functions plotted for the data studied in the literature.

Conducting an annual cost-benefit analysis, the following expenses were taken into account: (i) anaerobic digester (including the engineering and project development costs), (ii) operation and maintenance costs (including capital costs), (iii) acquisition costs of feedstock and end-use of co-digested slurry, (iv) biogas cleaning, (v) electricity and heat generation (in the CHP option) or (v) biomethane upgrading and feeding as well as (vi) potential costs associated with energy and bio-methane transmission.

The power regression of best fit data derived from the literature (FNR 2006a; Urban, Lohmann et al. 2009; KTBL 2010b) was used to estimate the investment costs of the AD from the biogas flow as follows (see Figure 23):

$$IC = 14239 * BF^{-0.2209} \tag{14}$$

where: IC is the investment cost of an anaerobic digester in €/m_n^3*h, BF is the biogas flow in m^3/h.

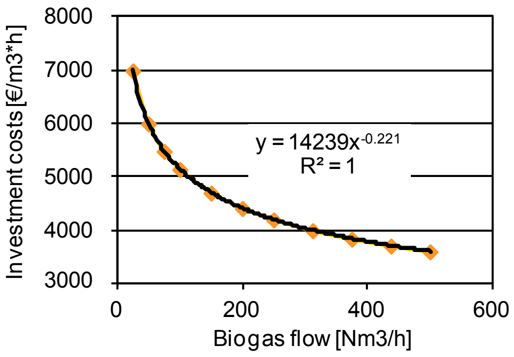


Figure 23: Relation of AD Investment Costs with the Hourly Volume of Biogas Production

In a combined electricity and heat production system, the investment includes the CHP unit costs and the costs of its operation, maintenance and connection to the power grid and to the district heating network.

The investment costs of the Otto gas engine (formula 15) and dual engine for a unit smaller than 300 kW of installed capacity (formula 16) were estimated from the power regression plotted for the data derived from FNR (2006a), which depicts the correlation of the electrical power output with specific investment costs (see Figure 24) as:

$$IC_{Oe} = 3814.8 * EP^{-0.2916} \tag{15}$$

$$IC_{De} = 7648.3 * EP^{-0.5022} \tag{16}$$

where IC_{Oe} and IC_{De} is the investment costs of the Otto gas engine and dual engine respectively in €/kW and EP is the electric power of biogas plants in kW.

The operation and maintenance costs associated with feeding, operating and repairing the plant, as well as with the storage and disposal of the substrates and its administration were defined as a constant and size-independent fraction of investment costs at 0.04 for an anaerobic digester and 0.03 for CHP (DBFZ 2009).

Additional costs of biomethane clearing (removing hydrogen sulphide, because of its highly corrosive nature and odor) were included in the economic assessment according to the costs studied by Urban, Lohmann et al.(2009). Depending on the biogas flow, the unit cost of desulphurization was calculated from the lognormal function (Figure 25) as follows:

$$DC = -0.9282 * \ln(BF) + 6.4625 \qquad (17)$$

where DC is the cost of desulphurization in €ct/m_n^3 and BF is the biogas flow in m^3/h.

Estimating the costs of biogas upgrading technologies in Poland is more speculative than for AD and CHP equipment, since several upgrading facilities are operated at agricultural biogas plants in Sweden and Germany (Fritsche, Hennenberg et al. 2009), but in Poland no such installation has so far been established. Based on costs for major biogas upgrading technologies collected by Urban, Lohmann et al.(2009), the regression functions (see Figure 26) were plotted for two exemplary technologies; the Water Wash (formula 18) and the Pressure Swing Adsorption (formula 19).

$$UC_{WW} = 233666 * BF^{-0.4723} \qquad (18)$$

$$UC_{PSA} = 7648.3 * BF^{-0.9714} \qquad (19)$$

where UC_{WW} and UC_{PSA} are the biogas upgrading costs in €/m^3 based on Water Wash and Pressure Swing Adsorption technologies and BF is the biogas flow in m^3/h.

One significant parameter affecting a project's profitability is the cost of acquiring the substrates (Szlachta and Fugol 2009). Thus, purchase prices for maize silage vary between 17 €/t and 25 €/t and cereals silage between 20 €/t and 30 €/t (MAE 2009). In this study, the transportation costs of agricultural feedstock were included in the purchase price. Farm manure is available mainly at the cost of transport alone, which varies between 1.2 €/m^3 and 1.5 €/m^3 for a distance of 5 km, depending on the

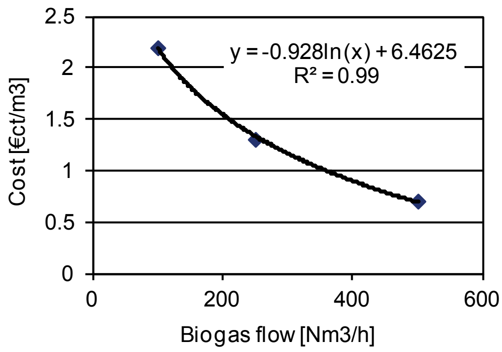


Figure 25: Log Normal Regression Function of Desulphurization Cost Depending on the Biogas Flow

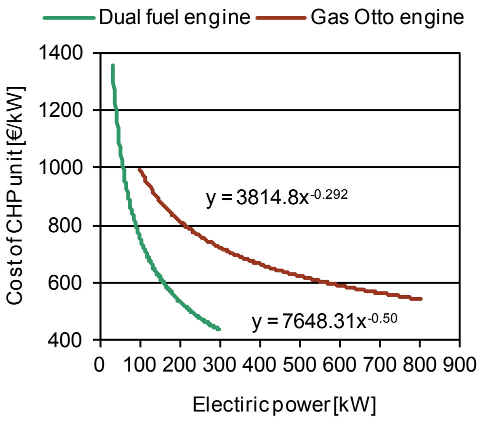


Figure 24: Relation between CHP Investment Costs (Dual and Otto Engines) and the Hourly Volume of Biogas Production

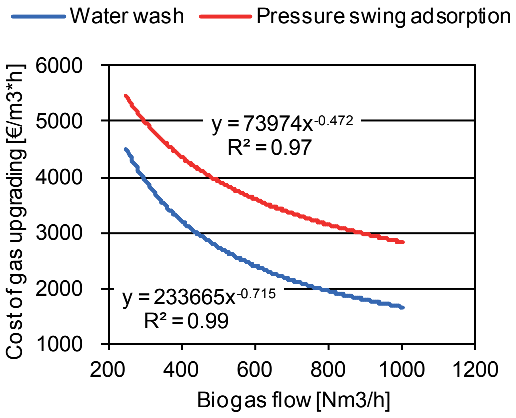


Figure 26: Regression Function of Costs of Biogas Upgrading with Relation to the Hourly Volume of Biogas Production

means of transport. For a distance of 10 km, these costs double (Michalski 2009). However, the cost of animal waste collected from external farms may amount to 10 €/t (MAE 2009; Oniszk-Popławska 2010), a price option which was included in the cost-benefit analysis. The cost of digester utilization should be calculated at 3 €/t (Józwiak 2008). Moreover, according to the Council of Ministers (2007), digested material from agricultural biogas plants, which is classified as an industrial product, must not be directly returned to farms to be applied to the land. Rather, every biogas plant making use of waste from the food and agricultural sectors is obliged to acquire a permit for the digester authorizing the waste's further reuse. Nevertheless, the Biogas Development Plan issued by the Ministry of Economy (2010) indicates a change in this legal provision in order to facilitate the direct exploitation of these wastes.

The annual costs of energy generation were estimated based on components of the investment costs annualized over the economic lifetime of a given plant. The sum of different costs under financial parameters changed in the economic analysis was divided by the sum of the annual production of electrical and heat energy as follows:

$$C = \frac{(Cm + Cf + Cc + OM + A + I * s * a)}{(Ee + Eh)} \qquad (20)$$

$$a = \frac{i(1+i)^n}{(1+i)^n - 1} \qquad (21)$$

where C is the annual energy production cost (electricity and heat or gas) in €/MWh, Cm is the feedstock mobilization cost, Cf is the cost of biogas feedstock, Cc is the connection cost, I is the sum of investment costs for an anaerobic digester, CHP and upgrading techniques, s is the subsidy to the qualified costs, a is the annualized rate, Ee and Eh are the electrical and heat energy generated per year, OM are the annual operating costs, A is the amortization, i is the interest rate and n is the economic lifetime of the plant.

A 20-year lifetime was assumed for the entire equipment and an average amortization rate of 7% of investment costs over a period of 15 years. The annuity factor was calculated over 15 years at an interest rate of 4%. The energy unit cost was derived from different fractions of costs summed up over 20 years, but only 15 years of annualized investment costs, then divided by 20.

The revenue earned from the production of electricity and heat is composed of the market price of electricity and heat as well as the price of the tradable set of certificates of origin extended by the legal framework in 2010. The unit revenues per energy generated were calculated as:

$$\begin{aligned} Re = (&En*PE+Hn*PH+ \\ &(En+En*0.09)*Pcg+Ee*Pcyv)/(Ee+Eh) \end{aligned} \qquad (22)$$

where Re is the annual revenue in €/MWh, En is the net energy fed into the power grid in MWh, Hn is the purchase price of net heat in €, Pcg is the price of green certificate in € and Pcyv is the price of yellow or violet certificates in €.

It was assumed that around 9% of the electricity and 25 - 40% of the heat are used for processes related to biogas production (FNR 2006a; MAE 2009). In 2010, the minimum sale price for electricity guaranteed by the Polish Energy Regulatory Office amounted to 45 € per MWh[8]. By feeding heat into the local district heating network, producers may increase their incomes by 8 €/GJ (2.3 €/MWh) (URE 2010). Beside this, producers of green electricity also acquire a green certificate that can be traded for 68 €/MWh[9] calculated from the gross electric energy generated. Since the amendment to the Polish Energy Law of 1 March 2010, an additional source of benefits, i.e. the yellow certificates, may be combined with green certificates. These yellow certificates of origin are awarded for electricity generated in high-efficiency cogeneration processes regardless of the power capacity of agricultural biogas. Moreover, the new violet certificate of origin for electricity produced from biomethane (and methane from dump sites and coal mines) in high-efficiency cogeneration was introduced on 9 August 2010 and may be used interchangeably with yellow certificates in biogas plants. The Polish market regulator (URE) sets the reference price of certificates for each year within a fixed range determined in the Polish Energy Law. In 2010 the purchase price of yellow certificates was fixed at

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[8] The electricity sale price is equivalent to the median market price during the previous sales year

[9] The median price in the beginning of the year 2010

30 € per MWh and at 14.8 € per MWh for violet ones (PPE 2010).

One should note that both co-generation incentive schemes are only applied on condition that the heat generated is largely used for personal needs or to be sold on the market. The amendment to the Polish Energy Law of 8 January 2010 promotes not just biogas-based combined electricity and heat production, but also the feeding of biomethane into the natural gas grid. The system of certificates of origin (brown) should have entered into force on the national energy market on 1 January 2012 (IPiEO and ARR 2010). As the reference price of the brown certificate is unknown, the annual revenue of methane injections into the gas grid was calculated as follows:

$$Rm = Em * Pm / Em \qquad (23)$$

where Rm is the annual revenue of methane injections into the gas grid in €/MWh, Em is the equivalent of biomethane expressed in MWh (overestimating that one cubic meter of upgraded methane is equal to 9.7 kWh), Pm is the price for natural gas calculated without distribution costs, which was 25 €ct/m3 (2.6 €ct/kWh).

4.2.3.4.8 Costs and Revenues from CHP Generation

Due to the common problem of seasonal fluctuations of the heat demand, the revenue structure of biogas plants may vary over the years. As seen in Figure 27 not all biogas plants are not profitable, as the annual benefits only covered the purchase price of electricity and green certificates, even if the annual costs were calculated including the transport costs of manure and the lowest price for co-substrates of 20 € per ton. When increasing the price for cereal silage up to 30 €/t, only a few biogas projects will generate profits from selling electricity and heat as well as green and yellow certificates. The unit costs react most sensitively to the additional price of 10 € per m^3 of manure added to the transportation costs, making the projects totally unprofitable.

Until March 2010, the aid mechanism in the form of green certificates benefited the cheapest technologies like wind turbines. Ever since, the quota-based mechanism has been diversified to support relatively expensive biogas projects. However, as demonstrated above, the set of certificates itself is still not sufficient to advance biogas development to reach a price level below the upper level of feedstock prices. Additionally, a high investment risk is associated with the income uncertainty over the lifetime of the biogas technology, as the yellow certificate

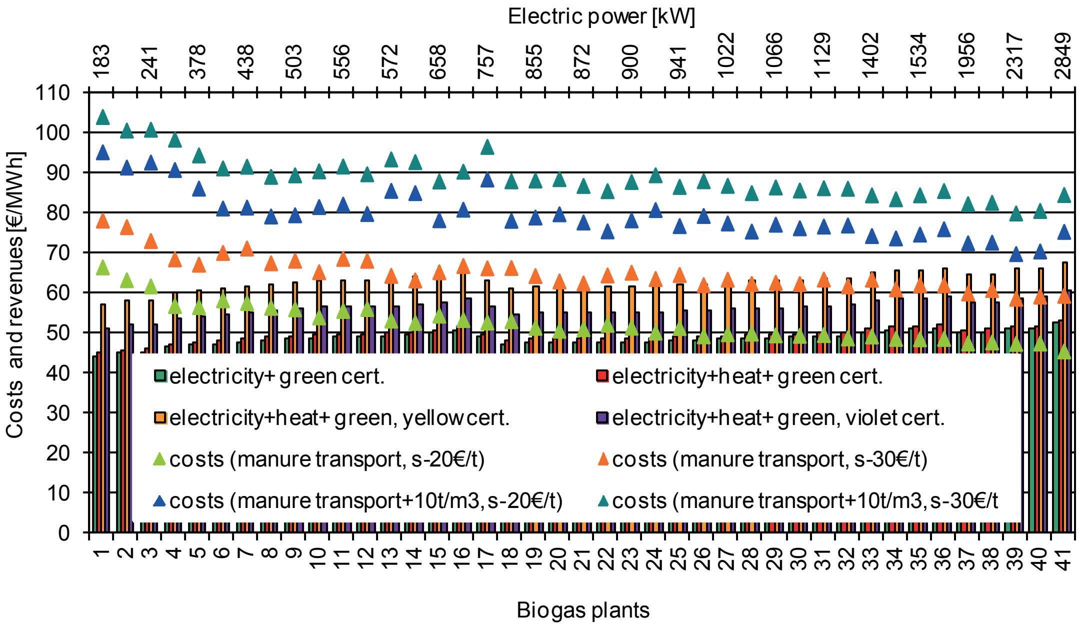


Figure 27: Annual Incomes from Four Sources (Columns) and Costs Depending on the Biogas Feedstock Costs of Acquisition. Annuity Factor Calculated Over 15 Years at an Interest Rate of 4%

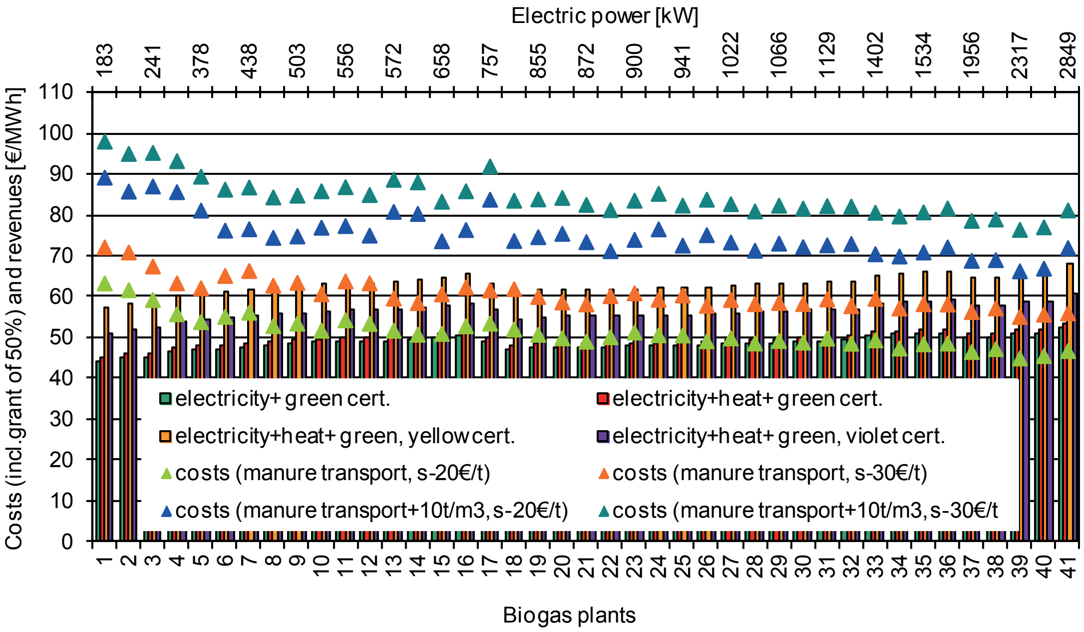


Figure 28: Annual Incomes From Four Sources (Columns) and Costs Depending on Costs of Biogas Feedstock. Annuity Factor Calculated Over 15 Years at an Interest Rate of 4% and a Subsidy Rate of 50%

scheme is guaranteed only until 2012, after which the Polish government will review its impact on the market and decide whether to continue the scheme. Therefore, the violet certificates securing income until 2018 were introduced, but their purchase price is less than half that of the yellow certificates. The green certificate scheme was prolonged from 2014 until 2017. Accordingly, to improve the ever-challenging economic and political conditions for the development of the biogas industry in Poland, apart from preferential loans and energy tax incentives, various forms of funded subsidies from regional, national and European sources have recently been launched and many others are planned (IPiEO and ARR 2010; Ministry of Economy 2010). In the most optimistic assumptions, subsidies of up to 70% of qualified costs could be granted (depending on many economic factors), though the average subsidy rate is expected to hover around 50%.

Assuming a subsidy of 50% to the investment in AD and CHP equipment, the total annual unit costs of energy generation were plotted against the same level of revenues as shown in Figure 28. In this case, plants of 2 MW and more generate benefits even without purchasing the yellow or violet certificates however for the lower level of the acquisition price at 20 € per ton of crop silage.

The calculation carried out for both options with and without grants shows that the economic viability of a biogas plant largely depends on the acquisition prices of the biogas feedstock. In addition, without the co-generation certificate support (yellow or violet, which have been obtainable simultaneously with the green certificate since March 2010), the majority of biogas projects would be unprofitable, even including grants of up to 50% of eligible costs.

4.2.3.4.9 Costs and Revenues of the Grid Injection of Biomethane

This section presents the results of a cost-benefit analysis carried out for the more efficient alternative of biomethane exploitation over a whole year. The unit costs for the grid injection of biomethane were plotted for different feedstock costs and for both usage options with and without subsidies.

As shown in Figure 29 the average price of 27 €/MWh (0.25 €/m^3) offered for natural gas without distribution fees or taxes does not meet the unit cost of biomethane production. Even the preferential interest rate of 4% and a subsidy payment of 50% to the costs of the anaerobic digester as well as to both upgrading technologies, water wash (WW) and pressure swing adsorption (PSA), do not suffice to generate benefits. Therefore, the brown certificates

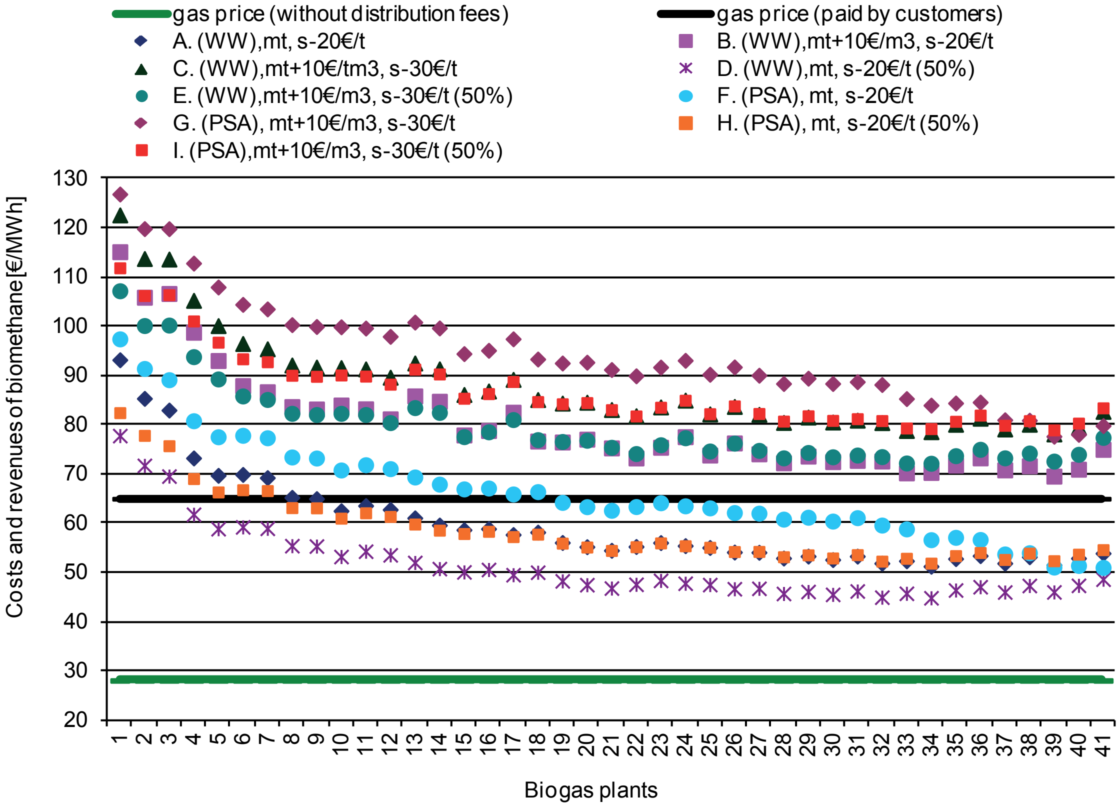


Figure 29: Costs of Methane Production Calculated under Different Feedstock Costs for the Water Wash (WW) and the Pressure Swing Adsorption (PSA) Upgrading Technologies Implying an Interest Rate of 4% (over a 15-Year Financing Period) and a Subsidy Rate of 50% to the Eligible Investment Costs. (mtc - Manure Transportation Costs, (50%) - Grant, WWW and PSA - Upgrading Technologies)

of origin are necessary to compensate for the gap between the costs and revenues of biomethane production as well as the investment risks mostly related to the costs of feedstock supply. Since the average costs for the upgraded methane supply vary from 50 € up to 90 € per MWh in the case of bigger plants, the minimum certificate purchase price of 23 €/MWh and the maximum of 63 €/MWh (the difference between 50 € or 90 € and the average price of 27 €/MWh offered for the natural gas) should be guaranteed.

4.2.3.4.10 Biogas Potential - Extended Scope of Biogas Feedstock

The most recent legal document referring to the development direction of biogas plants in Poland until 2020 (Ministry of Economy 2010) provides for the promotion of at least one biogas plant of 1 MW electrical power in each commune by 2020. Under the assumption of economies of scale made in the previous chapter (livestock unit of at least 100 taken into calculation), only one third of the Polish communes were explored. In this section, the analysis was extended to dairy and pig farms with a livestock population factor of at least 100. Under this assumption the number of cattle LSU is higher by only 8%, but in the case of pigs, the LSU number is almost doubled as Table 45 shows. In this example of the enlarged population of cattle and pigs, the biomethane production potential and the energy power capacity almost doubled compared to the potential that can be produced from manure collected in farms housing more than 100 LSU (see Table 46).

As explored in the first case (see Map 24), the spatial deployment of animal waste and biogas potential is comparable to the amount explored in the second case (see Map 27). The biomethane potential and the required area of farmland for co-substrate production were evaluated assuming 15% and 22% dry matter (DM) of biogas feedstock respectively. The technical potential findings are outlined in Appendix 7 and Appendix 8.

The biogas feedstock-mix (animal manure and maize, cereals and grass silage) with 15% DM co-

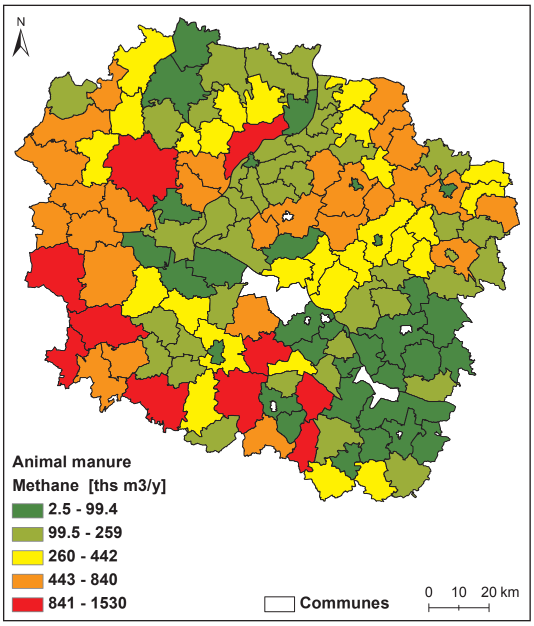
Table 45: The Number of Livestock Units in the Animal Population with at least 100 Animals in the Kujawsko-Pomorskie Voivodship

	LSU		Animal holdings	
Animals	Number	Share in Total	Number	Share in Total
Cattle	59299	15%	343	1.1%
Pigs	201370	66%	3807	12%

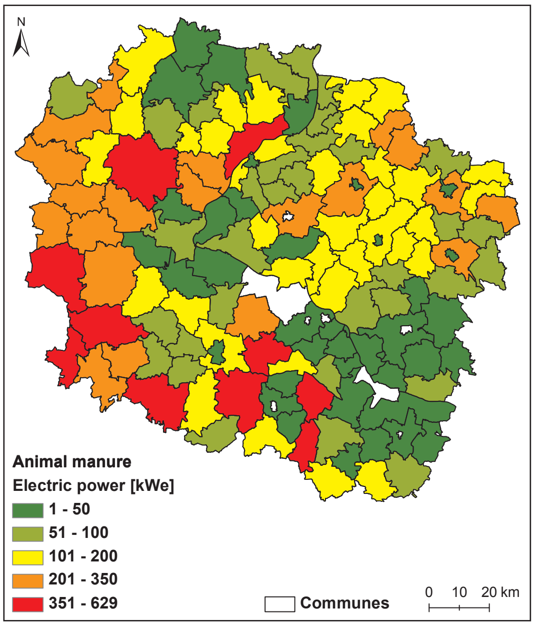
* Average livestock unit LSU of animal species is an equivalent of 0.8 LSU for cattle units and 0.15 for pigs (MRiRW-MS, IUNG et al. 2004; GUS 2009a)

Table 46: Biogas Equivalent of Animal Manure in Two Cases with LSU >100 and Livestock Population >100

		First Case	Second Case
Summury of Potential	Unit	LSU > 100	Livestock Population >100
Animal Population		132073	260669
Methane Potential	Mm^3	24	44
Gross Energy Potential	MWh	226358	405013
El. Power Based on Manure	MW	9.9	18.2



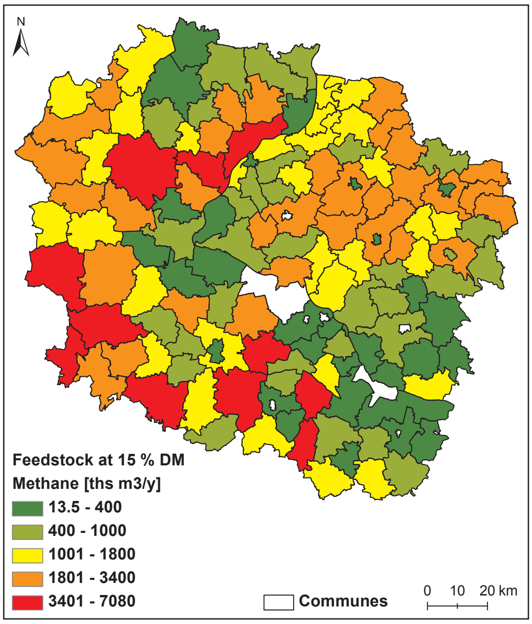
Map 27: Potential of Methane Production from Manure in Dairy and Pig Farms with a Livestock Population of More than 100 per Commune



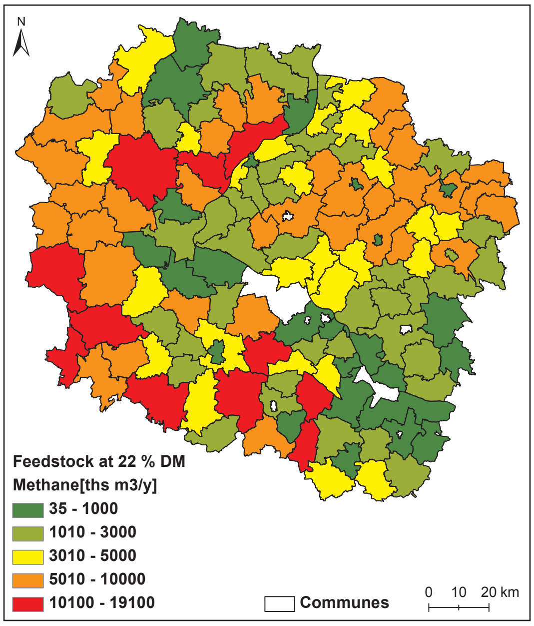
Map 28: Potential of Electric Power (kW_e) Generated from Manure in Dairy and Pig Farms with a Livestock Population of More than 100 per Commune

responds to an equivalent of 195 Mm^3 of methane (see Map 29). Increasing the dry matter fraction with maize silage to 22% DM, the methane potential increases to 566 Mm^3 (see Map 30), an amount which could meet 30% of the methane production target indicated in the Polish Ministry of Economy's document on biogas development (Ministry of Economy 2010).

By adding agricultural co-substrates (see Map 29) to animal manure, the methane potential increases from 44 Mm^3 to 566 Mm^3. As a result of the share of energy crops and grass silage in the biogas co-substrate-mix, the use of farmland areas shifts from food and fodder production to energy production. Assuming that maize silage, cereals silage (rye, wheat) and grass silage are the co-substrates, the area used for their growing was calculated as shown in Table 47. In the case of 15% DM, 5% of the agricultural land is dedicated to biogas crops whereas in the case of 22% DM, the cultivated area



Map 29: Potential of Methane Production from Manure in Dairy and Pig Farms with a Livestock Population of More than 100 per Commune and 15% of Feedstock Dry Matter in the Biogas Feedstock-Mix



Map 30: Potential of Methane Production from Manure in Dairy and Pig Farms with a Livestock Population of More than 100 per Commune and 22% of Feedstock Dry Matter in the Biogas Feedstock-Mix

Table 47: Selected Co-Substrates Required for Biogas Production under Assumption of 15 and 22% of Dry Matter of Total Biogas Feedstock Respectively

Co-Substrates		Maize	Rye	Wheat	Grassland		Share of Total Cultivable Land
Yield [t/ha]		40	30	30	23		
Share in Co-Substrate [%]		60	10	10	20	Sum	
DM [%]	% Mass	ha	ha	ha	ha	ha	%
15	66-79	24146	5366	5366	13414	48291	5
22-23	60	83445	18543	18543	46355	166886	17

more than triples to 166886 ha, covering 17% of the total cultivable land.

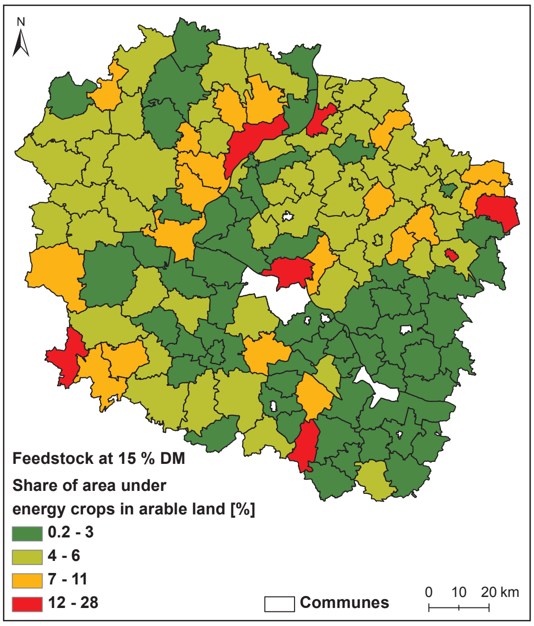
As shown on Map 31, the share of cultivable land dedicated to biogas co-substrates at the commune level may reach 28%, while an increase in demand for biogas crops may extend the share of cultivable land grown with biogas co-substrates to 85%, as presented on Map 32. The additional land required in all communes to meet the demand for co-substrates is illustrated in Figure 30.

In the first case, the expected methane production (195 Mm^3) could meet 11% of the target, requiring 7% of the cultivable surface (700 000 ha) for biogas production as indicated in the same document. In the second case, the methane production could cover 30% of the national target while requiring 24% of the cultivable area. However, as shown in Figure 30 in many communes the fraction of land used for biogas production varies around 30%, which may influence the local food and material production.

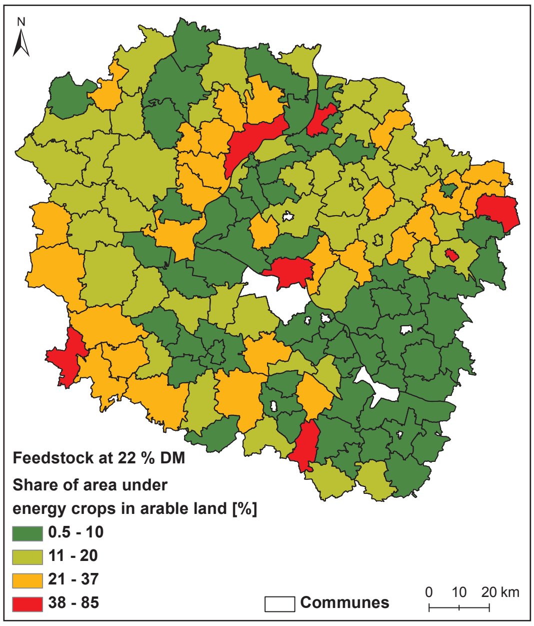
4.2.4 Woody Biomass Potential in the Kujawsko-Pomorskie Voivodship

- Wood from Forests

The area of forest in the Voivodeship Kujawsko-Pomorskie amounts to 427897 ha and 89% of it is owned by the State Treasury (GUS 2009f). The share of wood harvested in public forests is much higher than in private ones and amounts to 98% of the statistically-recorded wood supply. The wood harvest is determined in the ten-year forest management plan, which sets out the volume of wood to be harvested in pre-final and final cuts in the National Forest Districts. The annual prescribed



Map 31: Share of Area in Total Arable Land Dedicated to Energy Crops Assuming 15% of Dry Matter in the Biogas Feedstock-Mix



Map 32: Share of Area in Total Arable Land Dedicated to Energy Crops Assuming 22% of Dry Matter in the Biogas Feedstock-Mix

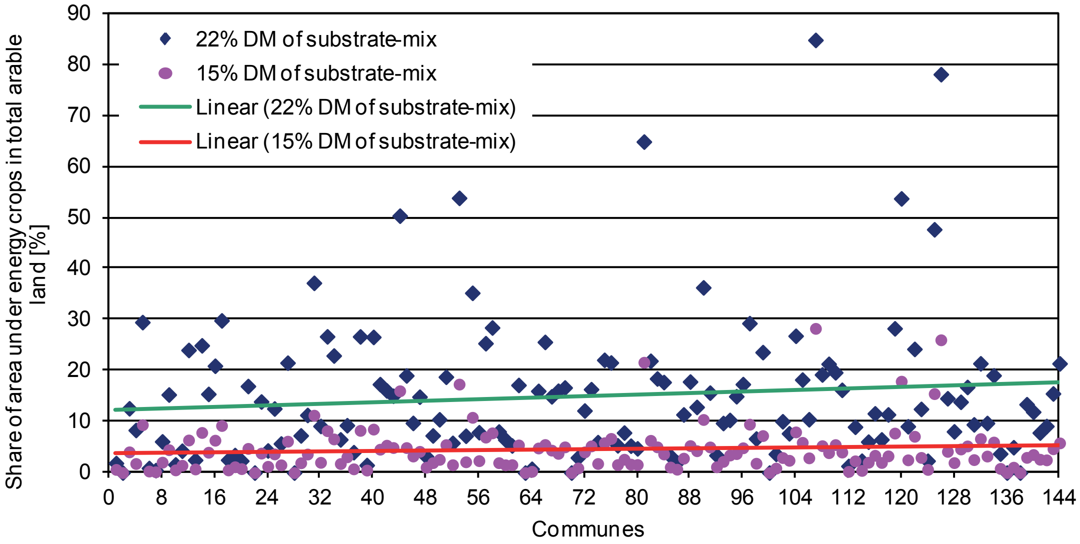


Figure 30: Share of Arable Land in Communes Dedicated to Biogas Generation Assuming Two Options of Dry Matter of Biogas Feedstock: 15% and 22% of DM

cut by volume varies from year to year depending on the forest condition and the demand for wood, but the overall harvest must balance out over the period. The theoretical potential of wood is the forest growing stock amounting to 97.6 Mm^3 in the region. From this volume, approx. 1.7 Mm^3 of wood is harvested, equaling a net annual increment of 70%. In comparison, this indicator varies between 55 and 70% in other EU countries (FRI 2006). Table 48 outlines among other data the volume of coniferous firewood, which has increased from 75 ths. m^3 to 92 ths. m^3 between 2006 and 2008, and deciduous firewood, whose volume also increased from 64 ths. m^3 to 80 ths. m^3. Moreover, a fraction of 120 ths m^3 of slash wood is used for firing. Map 33 illustrates the spatial deployment at the communal level of wood harvested in 2008. According to a legal document issued by the Polish Ministry of Environment (2003),

Table 48: Total Logging of Wood in the Voivodeship Kujawsko Pomorskie from 2006 to 2008

	2008		2007		2006	
Wood	m^3	% of Total	m^3	% of Total	m^3	% of Total
Total	1698698		1704304		1596019	
Timber, Grand Total	1578714	92.9	1584047	92.94	1461884	90
Coniferous Timber	1287822	75.8	1293169	75.88	1198908	75.1
General Purpose Large-size Timber Wood	511883	30.1	541029	31.74	507515	31.8
Special Purpose Large-size Timber Wood	2154	0.1	2292	0.13	3264	0.2
Medium-size Timber Wood, Whole-tree Length	3520	0.2	4369	0.26	5308	0.3
Medium-size Timber Wood, for Industrial Purposes	677662	39.8	660532	38.76	608344	38.1
Firewood	92606	5.4	84942	4.98	74485	4.7
Deciduous Timber	290891	17.1	290877	17.07	262973	16.5
General Purpose Large-size Timber Wood	91375	5.4	96707	5.7	84953	5.3
Special Purpose Large-size Timber Wood	2655	0.16	3835	0.23	4721	0.3
Medium-size Timber Wood, Whole-tree Length	-	-	-	-	-	-
Medium-size Timber Wood, for Industrial Purposes	116666	6.8	116587	6.8	108993	6.8
Firewood	80197	4.7	73752	4.33	64302	4
Slash	119975	7.06	120186	7.05	134117	8.4
Stump Wood	7	0	75	0	17	0

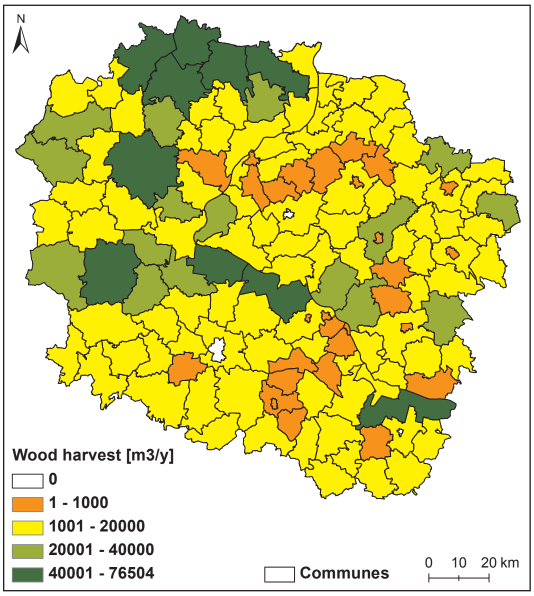
*Large-size wood with an upper diameter of 14 cm, calculated in single pieces, is dedicated for sawmills. Medium size wood (S) with an upper diameter of 5 cm and more and a lower diameter of up to 24 cm is divided into: Slash (M) - round wood with a lower diameter of up to 5 cm (excluding bark) is divided into two groups: M1 - used for industrial processes and M2 - firewood and Stump wood from non-laminated stump (foamed wood)

Source: GUS (2009f)

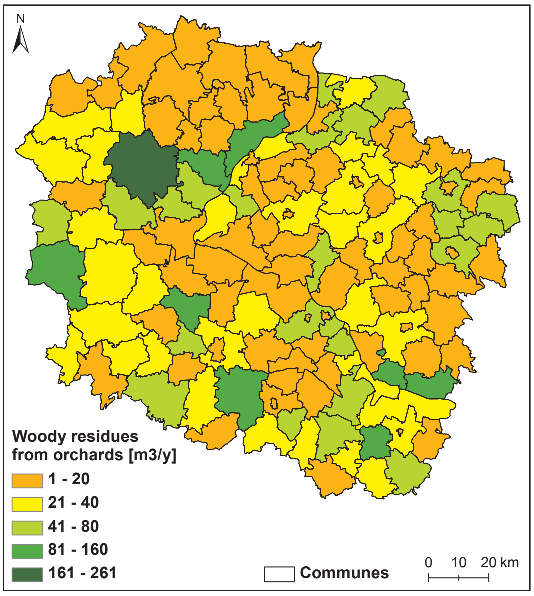
forestland should increase from 29% to 30% between 2003 and 2020, but the programme faces difficulties associated with a low supply of land for afforestation purposes (NREAP 2010c). In the period from 2001 - 2020, the national programme anticipates transforming 680 ths. ha of agricultural land (including 550 ths. ha of private land) into forest, 13100 ha (1.3% of agricultural land) of which are located in the Kujawsko-Pomorskie Region (10700 ha owned by the private sector and 2400 by the public sector). So far, less than 10% of the plan has been executed at the national level. The success of the afforestration process depends on the compensation awarded to land owners to maintain the forest plantation and on current gains from conventional or energy crop plantations. On the other hand, the restrictions linked to the extension of the Natura 2000 surface area will significantly affect the future supply of forest biomass. The area under fauna and flora habitat is to be extended into the National Park Bory Tucholskie, which is located in the northern part of the region.

- Wood Cutting from Landscape Management

According to a study published by the Regional Planning Office in the Kujawsko-Pomorskie Voivodship (K-PBPPiR 2010), wood waste from green areas and roadsides amounts to 8.5 ths. tons



Map 33: Wood Harvest from Forests per Commune in 2008
Source: Based on GUS (2009f)



Map 34: Cut Material from Orchards per Commune in 2005
Source: Based on GUS (2009a)

annually. However, the techno-economic potential of this type of biomass is clearly restricted regarding logistical aspects. In practice, bio-residues have already been recovered in larger cities like Bydgoszcz and used in district heating boilers.

- Wood Residues from Orchards

Unlike residues from green areas, wood harvested in orchards offers greater potential, as the logistical aspect of the permanent supply of raw materials from fruit trees can be organized more easily due to the orchards' spatial concentration. Igliński, Buczkowski et al. (2008) estimated the volume of wood waste from fruit crops at about 10 ths. m^3, which is approx. 6.6 ths. tons per year within an 18.8 ths. ha area of orchards. As mentioned previously, Polish national statistics recorded 11944 ha of orchard in 2005. According to assumptions made by Igliński, Buczkowski et al. (2008), an annual gain in clearing material of 350 kg/ha resulted in a total potential for wood residues of 4180 tons in 2005. The corresponding spatial distribution is illustrated on Map 34. In the region, the largest orchard surfaces occur in the communes of Koronowo (677 ha), Chocień (380 ha), Fabianki and Złotniki Kujawskie (332ha) (GUS 2009a)

- Wood Residues from the Wood Processing Industry

According to the Polish Wood Technology Institute, the treatment of 100 m^3 of raw wood yields over 60% as residues, including 10 m^3 of bark, 15 m^3 of branches, 20 m^3 of wood chips and 19 m^3 of sawdust. It is estimated that in Poland, from 7.5 Mm^3 of wood by-products produced in the wood processing industry, around 2.5 - 3 Mm^3 could be used for energy purposes (NREAP 2010c). Nonetheless, there are no statistics recorded at the regional and local level that allow this potential to be estimated in Kujawsko-Pomorskie Region.

With respect to the complexity of logistical constraints of lignocellulosic residues, their utilization strategy requires a local assessment and guidance to enhance their sustainable mobilization and use.

4.3 Bioenergy Potential in the Stuttgart Region

Concerning the aforementioned national and international climate change commitments, a further expansion of biogas and biomass production is expected in Germany. After wind energy, biomass resources subdivided between biogas, solid biomass and liquid fuels are expected to play a significant role in meeting the German national climate protection targets by 2020. The amount of green electricity generated in 2005 should grow fourfold by 2020, while the exploitation of waste as an energy resource will stagnate during the period 2010 - 2020 (NREAP 2010a).

A metropolitan region like Stuttgart, surrounded by sparsely distributed agricultural land resources, cannot be a priori excluded from achieving the national biomass targets. The study is conducted to explore both the potential of biomass sources and, furthermore, the potential increase in pressure on farmland under the growing demand not just for bio-resources, but food production and urban areas too. The indicator of agricultural land in hectare per capita of 0.05 for the Stuttgart Region depicts the scarcity of this resource, being low in comparison to 0.13 ha/cap for the federal state of Baden-Württemberg and 0.2 ha/cap for Germany as a whole (StLA 2010).

For the Stuttgart, Region, Bläsing, Gerth et al. (2000) carried out a potential analysis that covers among other things RES agricultural and wood residues. This study was complemented by Feldwisch, Lendvaczky et al. (2010) who analyzed the potential supply of agricultural residues and energy cropland at a county level in the context of the biomass demand required to meet the national targets transferred onto the regional level.

The following assessment of biomass potential refers to and complements studies of Bläsing, Gerth et al. (2000) and Feldwisch, Lendvaczky et al.(2010). The assessment was carried out at a county level based on the German Agricultural Census of 2007 (StLa, 2007). For confidentiality reasons, incomplete data at the communal level was considered only in a few cases (e.g. cereals‘ by-products).

4.3.1 Biomass Usage Status Quo in the Stuttgart Region

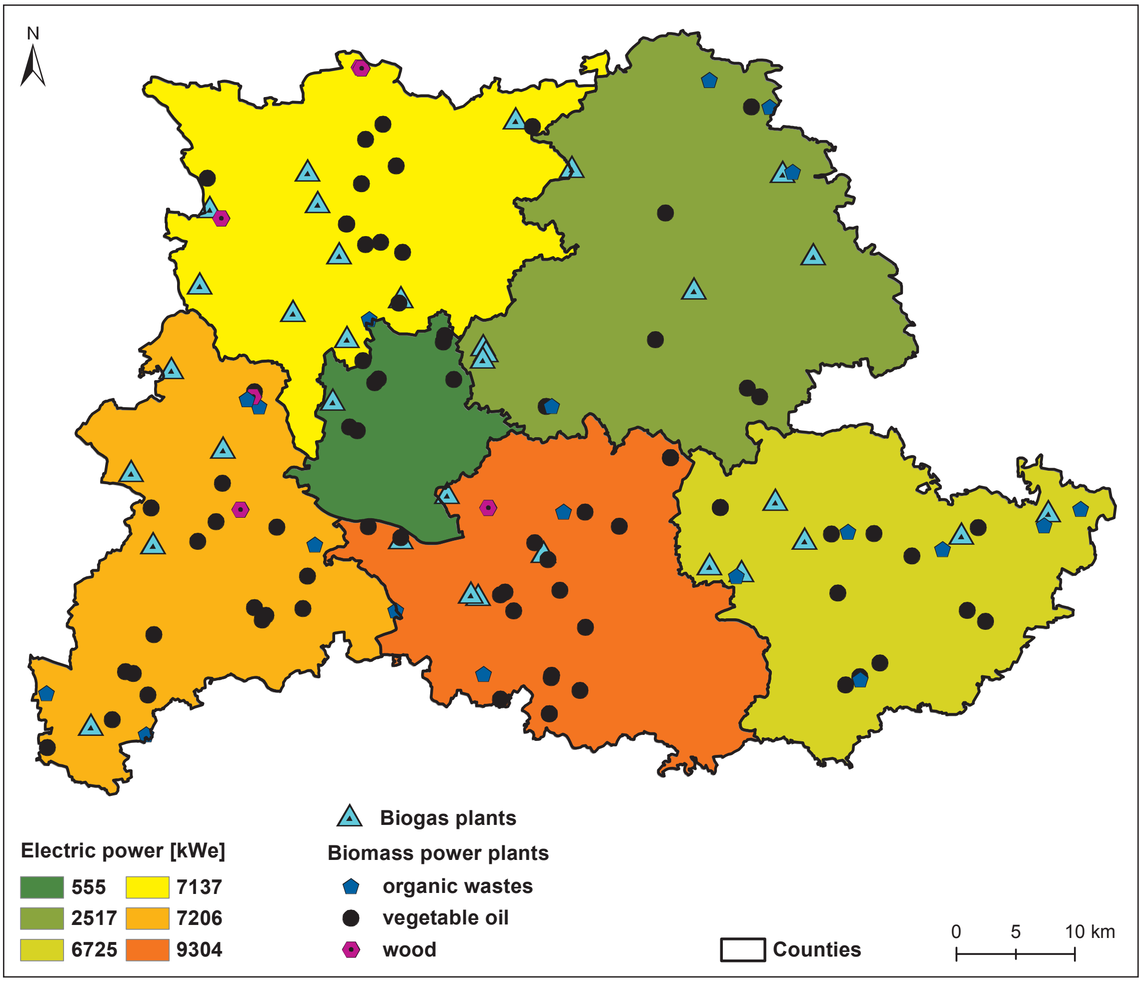
In the Stuttgart Region, around 100 biomass power plants (based on wood, bio-waste and vegetable oil) with 24 MW_e installed power capacity and generating approx. 66 GWh of electricity were operating in 2009 (EnBW 2010). Most of the power plants based on vegetable oil operate primarily in the winter season to produce heat, while electricity is the by-product, hence the low load factor. In addition, there were 29 agricultural biogas power plants with an installed electric power capacity of around 10 MW_e, generating about 68 GWh of electricity. As illustrated on Map 35, the Stuttgart Region and the Rems-Murr-Kreis have by far the lowest power capacity compared to the other four regions, not only regarding the generation of biomass, but also as to the existence of biogas power plants.

4.3.2 Production of Energy Crops in the Stuttgart Region

At the national level, arable and pasture land cultivated for energy purposes in Germany has increased within 14 years from 0.3 Mha in 1993 to over 2 Mha in 2009 (FNR 2010), covering 17% of the total arable land. Between 2008 and 2009, the land dedicated to biogas production alone has increased from approx. 0.58 Mha to 0.85 Mha (DBFZ 2010). Among those energy crops for biogas production, the share of maize silage amounted to 78%, grass silage to 11%, cereals (GPS) 6% and creels grain 4%.

In Baden-Württemberg, 50% of the maize grown on 148400 ha (18% of an arable land) and 5% of arable land under cereals were dedicated to biogas production (StLA 2008). In other words, the farmland dedicated to biogas production was shared between maize (51% of the farmland), grass land (22% of the farmland) and cereals (20% of the farmland) (Hartmann 2007).

In the Stuttgart Region, the largest area of 2733 ha (equivalent to 6% of the cereal-sown area) was dedicated to cereals (rapeseed, winter cereal grain and cereal silage) and maize (1007 ha) for generating biogas and bioethanol (Feldwisch, Lendvaczky et al. 2010; MLR 2010). Among those counties, 42% of the energy-dedicated arable area was situated in Ludwigsburg. Table 49 delineates areas under cultivation of energy crops per county in the Stuttgart Region. According to the data (MLR 2010), the energy crop grown area has increased by 30% from 2983 ha in 2004 to 3839 ha in 2007 as shown in Figure 31. At the same time, the acreage of oil crops, particularly oilseed rape for biodiesel production, dropped in the Stuttgart Region by 40% and above all in the county of Göppingen, where in 2004 there were 780 ha of rapeseed and in 2007 just 333 ha. Table 50 outlines the surface area of arable land and grassland at the county level. The greatest part of the arable land was under cereals, maize and rapeseed. The arable land dedicated to biodiesel production dropped from 2787 ha to 1733 ha between 2004 and 2007, whereas the area under biogas plants increased markedly from 150 ha to 1433 ha, foremost in the counties of Ludwigsburg and Göppingen (see Map 37). Moreover, the farmland for bioethanol production increased to 706 ha, 60% of which was located in the county of Ludwigsburg (compare Map 36 and Appendix 9). The distribution of the growing area of three



Map 35: Biomass and Biogas Power Plants / CHP and Installed Electrical Power Capacity per County in 2010

main biogas crops according to counties is shown on Map 37. In 2007, 53% and 29% of the total biogas-dedicated growing area was located within the two counties of Ludwigsburg and Göppingen respectively. According to the InVeKos database, biogas crops were cultivated in 2007 on 1433 ha out of a 3839 ha total area of energy plants in the Stuttgart Region. On the other hand, statistical data

Table 49: Area of Energy Crops in the Stuttgart Region at the County Level in 2007

	Winter Rapeseed	Cereal Grain	Maize Silage	Cereals Silage	Maize Grain	SRC*	Green Land	Other**	Total	Farmland	Share in Farmland
Counties	Crop Area [ha]										[%]
Stuttgart	19	29	10		19			2	79	2408	3.3
Böblingen	542	48	29		17	3	2	2	643	22759	2.8
Esslingen	143	79	51	8	5				284	19573	1.5
Göppingen	333	42	166	174	1		70	6	792	31506	2.5
Ludwigsburg	459	518	533	40	85			14	1649	32756	5.0
Total	1726	785	880	222	127	5	72	22	3839	140263	2.7

Source: Based on Data (MLR 2010) Aggregated by Feldwisch, Lendvaczky et al . (2010)

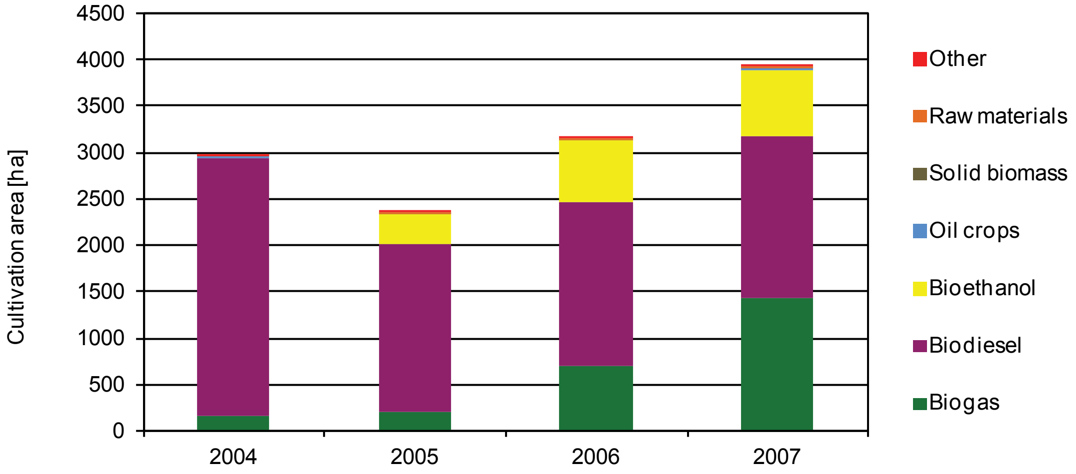


Figure 31: Area under Energy Crops Grown for Different Usage in the Stuttgart Region between 2004 and 2007
Source: Data (MLR 2010) Aggregated by Feldwisch, Lendvaczky et al .(2010)

from the Statistical Office in Baden-Württemberg (StLA 2008) reported 2565 ha of farmland cultivated with biogas dedicated crops (approximately 2% of total agricultural land). The significant divergence of 1132 ha may, amongst other causes, result from different survey periods as well as from the fact that farmers tend to take short-term decisions on the use of their crops depending on market prices.

Due to the high discrepancy of the above-mentioned data, Feldwisch, Lendvaczky et al. (2010) estimated the required farmland area for biogas production on the basis of the installed power capacity of biogas plants in 2007. The result of 1679 ha was very close to the results calculated from the InVeKos database (1433 ha). Hence, at the regional level, approx. 2% of the agricultural land and 4% of the arable land was used exclusively for biogas production. Altogether, for the above-mentioned energy carriers, almost 3% of farmland and 5% of arable land was dedicated to energy crops. Furthermore, approx. 80 ths. tons of animal liquid manure were used in biogas plants.

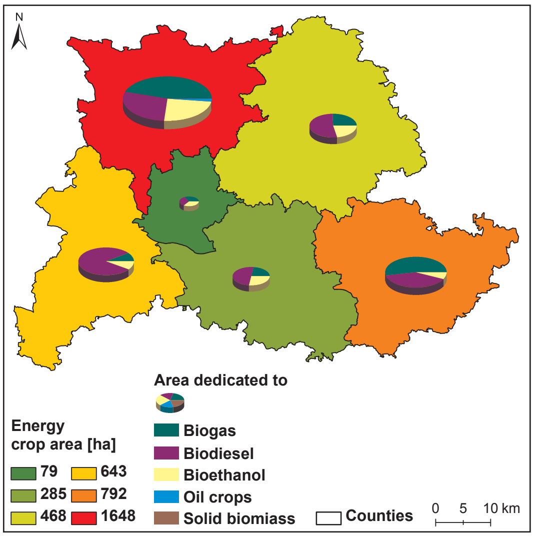
4.3.2.1 Potential of Energy Crop

The land used for biomass production is likely to grow over the coming years, covering up to 20 - 30% of the farmland available at the national level (Wuppertal Institut, IFEU et al. 2008). Concerning aspects such as population density, food demand, technical progress and land use for settlements, the demand for arable land dedicated to energy crops will be regionally and locally differentiated.

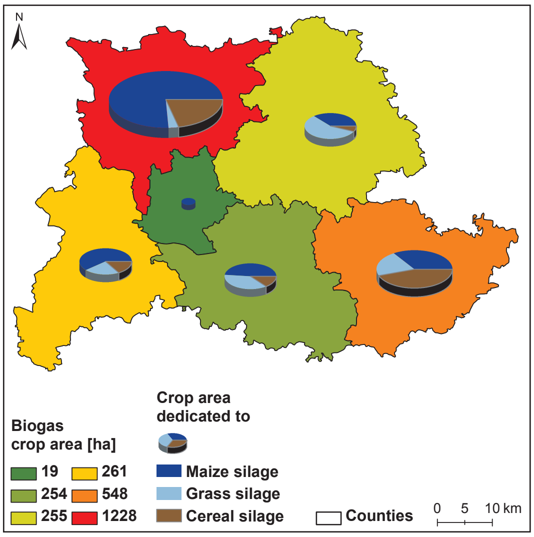
Table 50: Surface of Agricultural Land in the Stuttgart Region at the County Level in 2007

		Arable Land						
	Permanent Grassland	Total	Cereals	Share in Arable Land	Maize	Share in Arable Land	Rape Seed	Share in Arable Land
Counties	ha	ha	ha	%	ha	%	ha	%
Stuttgart	540	1538	793	51.6	343	22.3	38	2.5
Böblingen	6801	15628	10370	66.4	1485	9.5	1875	12.0
Esslingen	9319	10216	5607	54.9	783	7.7	583	5.7
Göppingen	15586	12710	7842	61.7	1936	15.2	1147	9.0
Ludwigsburg	5654	24617	14013	56.9	3293	13.4	1484	6.0
Rems-Murr	12581	11937	6456	54.1	3358	28.1	584	4.9
Total	50481	76646	45081	59	11198	14.6	5711	7.5

Source: StLA (2008))



Map 36: Area Cultivated with Energy Crops for The Production of Different Energy Carriers in 2007
Source: Data (MLR 2010) Aggregated by Feldwisch, Lendvaczky et al. (2010)



Map 37: Area Cultivated with Biogas Crops in 2007
Source: StLA (2008)

In this section, the focus was placed on the classification of sites for energy crop cultivation against agro-climatic requirements and economic profits in the context of food and fodder production. The site evaluation for selected crops (winter wheat, winter rye, winter rapeseed, maize, willow, poplar and miscanthus) was carried out according to criteria discussed in chapter 4.1.1.3 and outlined in Appendix 11.

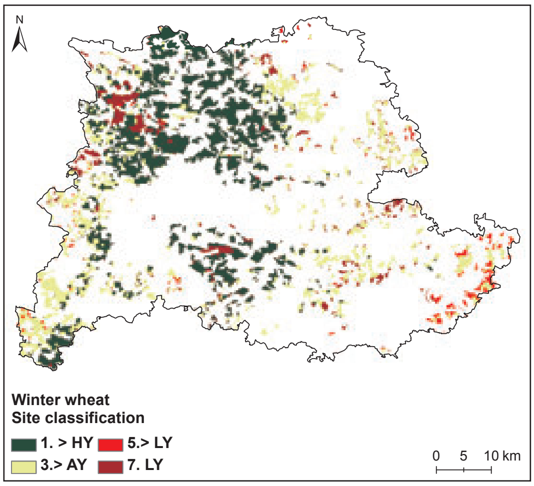
With respect to the high pedoclimatic requirements of wheat plants, very good conditions reflected in high yields are found on around 42981 ha (50%) of the cropland, while moderate conditions are met on 31514 ha (36%) of the arable land (compare Map 38 and Table 51).

Due to relatively high annual precipitation amounts, the same sites met the rapeseed growing requirements (see Map 39). The double index for low yield (sites 5 and 6 on Map 39) distinguished the arable land conditions under the same precipitation requirements (details Appendix 11).

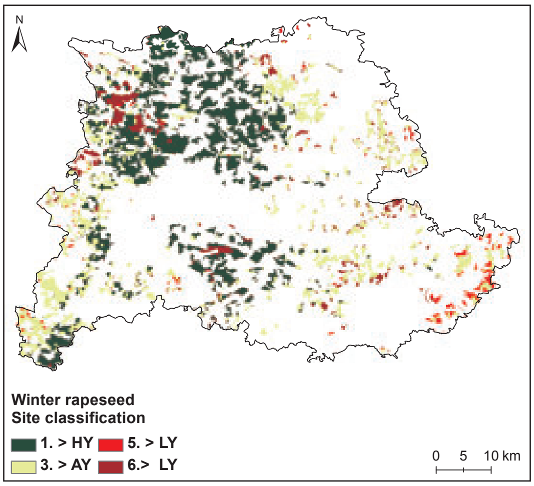
Rye crop characterized by low agro-climatic requirements is, in practice, often grown on marginal cropland (*Ackerlandzahl* and *Grünlandzahl* less than 40), where quite high yields can be expected under appropriate irrigation conditions. Under the conditions outlined in Appendix 11, on around 90% of the cropland a high yield is likely to be harvested (*Ackerlandzahl* and *Grünlandzahl* > 40) and on around 8% (6919 ha) an average yield (compare Map 40 and Table 51).

Maize yield performance depends on the precipitation (or irrigation) amounts principally in the period from May to September. High and average yields are likely to be achieved on 42422 ha (49%) and 29880 ha (34%) of the cropland, under different agricultural land quality but characterized by a water balance ranging from between 250 mm and 500 mm during the vegetation period (compare Table 51 and Map 41).

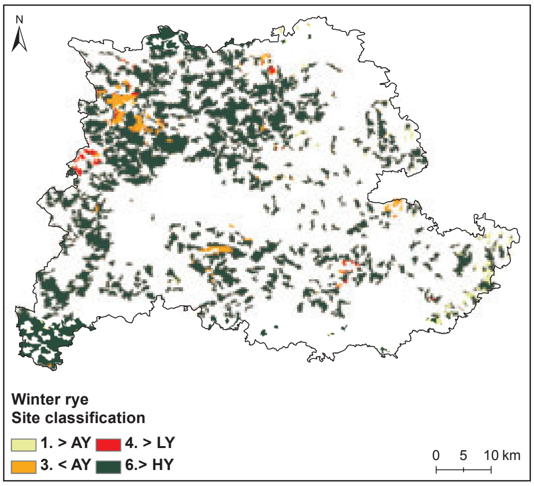
The agro-climatic requirements of miscanthus are very similar to those of maize, thus, under appropriate economic conditions, miscanthus crops may contribute to conflict with maize. Nonetheless, for



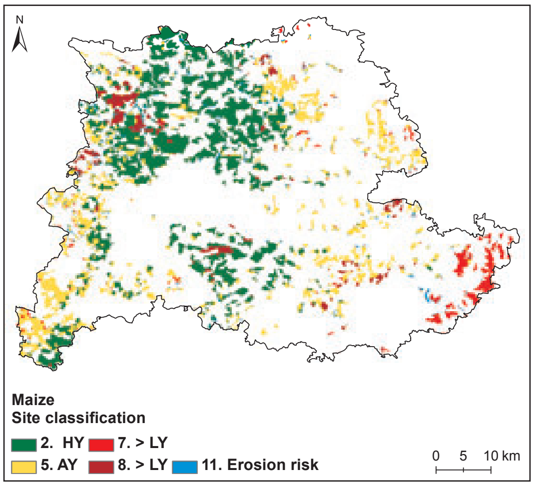
Map 38: Site Classification for Winter Wheat Growing



Map 39: Site Classification for Rapeseed Growing



Map 40: Site Classification for Rye Growing



Map 41: Site Classification for Maize Growing

this perennial grass, the annual precipitation regime was considered. In addition, as to the high risk of soil erosion in the case of intensive maize cultivation, the cropland located on slopes higher than 12° was excluded with respect to erosion risks. Depending on the water balance, a high and very high yield can be obtained on 50% of the cropland (i.e. on 10 542 ha of site 1 and 32811 ha of site 2), where the *Ackerlandzahl* value is higher than 60 points (see Table 52). A moderate agricultural land quality and appropriate precipitation conditions (*Ackerlandzahl* below 40) applied to 21971 ha (25%) of the land explored (sites 5 to 8 on Map 42).

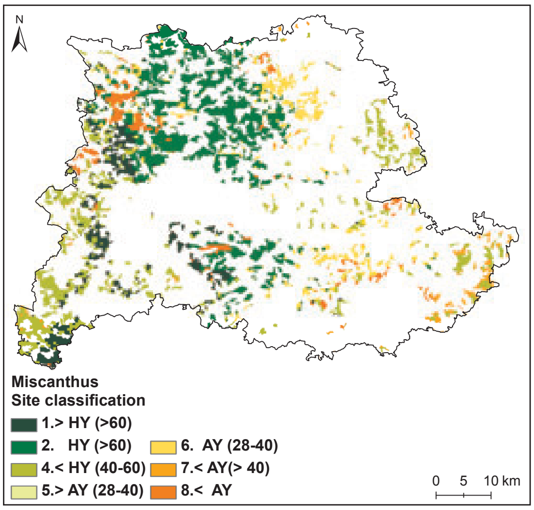
Perennial crops with moderate soil requirements planted on marginal agricultural land may result in an average yield. On the other hand, farmers have free choice of which crops to grown and, therefore, they may use land with higher production performance to produce higher returns. For this reason, sites characterized by high land performance (*Ackerlandzahl* above 40) were distinguished to explore the potential conflicts with annual crops.

For willow and poplar, the same yield performance conditions were defined. As shown on Map 43, around 60% of the areas characterized by very good conditions (sites 1, 2, 3) are located within high quality arable land (*Ackerlandzahl* > 40). As relatively high yields can also be obtained on moderate farmland, an area of 24349 ha (31% of the total arable land) was rated as offering a high yield potential (sites 4 and 5), while an area of 27807 ha (32% of the total arable land) was rated as offering an average yield potential. Those two types of site could theoretically be dedicated to willow and poplar, minimizing the conflict between conventional crops with high pedoclimatic requirements.

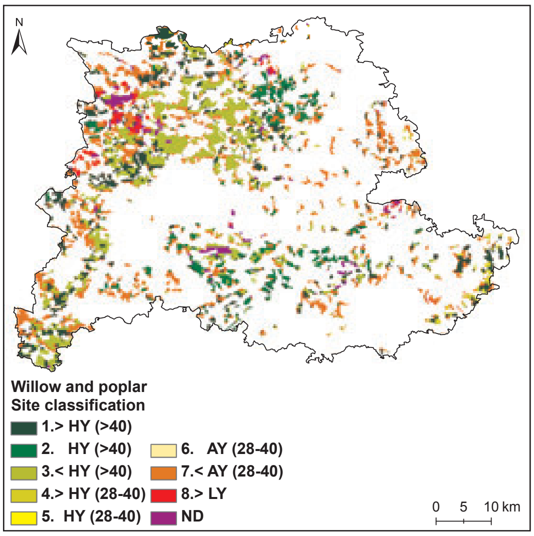
The legal framework currently in force in Germany does not necessarily exclude annual and perennial energy crops from being planted on environmentally sensitive farmland and grassland. However, there are other regulations and requirements (e.g. cross-compliance) which might hamper their cultivation. The sustainability committee of the state government of Baden-Württemberg recommended that the cultivation of short rotation crops within the Natura 2000 area of protected landscapes or water protection zones should be partially restricted to maintain biodiversity (NBBW 2008). The same recommendations may be applied to the planting of crops

Table 51: Classification of Growing Area of Annual Crops

Site Classification		Maize		Rye		Wheat		Rapeseed	
		ha	%	ha	%	ha	%	ha	%
1	> HY	-	-	77612	89.7	42981	49.7	42981	49.7
2	HY	42422	49.0	-	-	-	-	-	-
3	< HY	-	-	-	-	-	-	-	-
4	> AY	-	-	2360	2.7	31514	36.4	31514	36.4
5	AY	29880	34.5	-	-	-	-	-	-
6	< AY	-	-	4559	5.3	-	-	-	-
7	> LY	5093	5.9	1401	1.6	-		-	-
8	> LY	6272	7.2	-	-	3142	3.6	3142	3.6
9	LY	-	-	-	-	8295	9.6	8295	9.6
10	< LY	-	-	-	-	-	-	-	-
11	Not Suitable	580	0.7	580	0.7	580	0.7	580	0.7
12	Erosion	2265	2.6	-	-	-	-	-	-



Map 42: Site Classification for Miscanthus Growing



Map 43: Site Classification for Willow and Poplar Growing

for biofuels production[10] (Directive 2009/28/CE). In the Stuttgart Region, 12% of the area, which will be extended to 15% by 2020 (NBBW 2004), is under the FFH Directive, classified as protected areas (NGS) or biotopes. Currently, around 3% of arable land can be subjected to restrictions in accordance with recommendations such as 'protection before use' (German: *Schutz vor Nutzung*), or 'protection in spite of use' (German: *Schutz trotz Nutzung*) (NBBW 2004). On this basis, around 2300 ha (2.7%) of the total farmland should be protected against SRC or perennials (compare Map 44 with Table 53 and Map 45 with Table 52).

Despite environmental restrictions and other constraints, there is significant potential for the cultivation of crops dedicated to energy generation in the region. The extent to which the arable land will be subjected to land use competition depends on economic factors.

4.3.2.2 Economic Potential of Energy Crop

The economic profitability of perennial grass and SRC was evaluated against annual crops (rapeseed, winter wheat, winter rye, grain maize) which might also be grown for energy production. The profitability is related to purchase prices and the yield. The corresponding data was gathered from two sources (LEL 2010) and (Möndel 2008). The market for short rotation crops is still at an early

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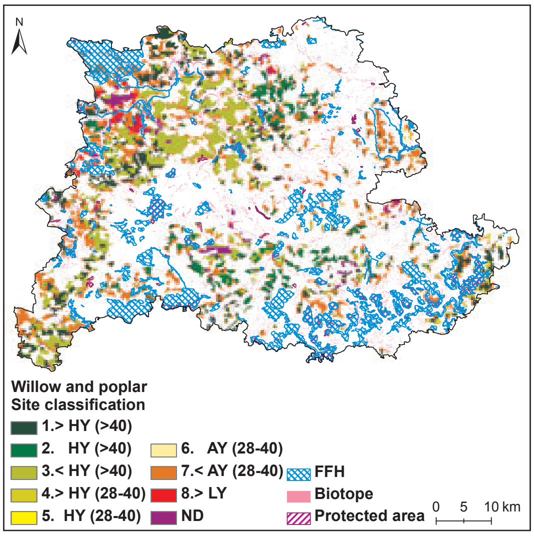
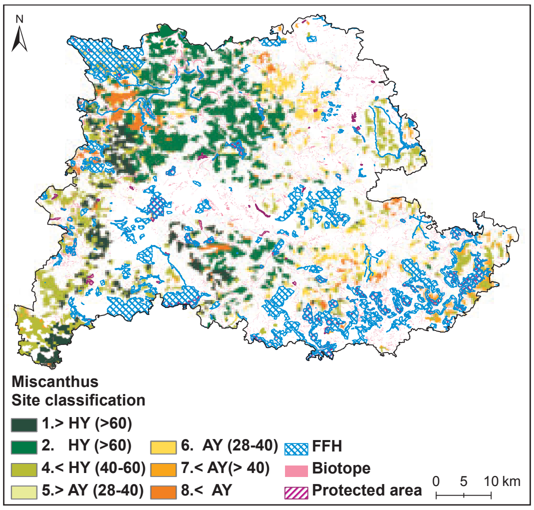
[10] The bioethanol produced from sugar beet, corn, wheat, and sugarcane and the biodiesel from rapeseed, sunflower, soybean, palm, and waste vegetable oils.

Table 52: Classification of Growing Area of Miscanthus

Site Classification		Total Arable Land		Outside of Protected Areas	
		ha	%	ha	%
1	> HY (>60)	10542	12.2	10410	12
2	HY (>60)	32811	38	32195	37
3	> HY (40-60)	-	-	-	-
4	< HY (40-60)	21146	24.4	20523	23.7
5	< AY(28-40)	3203	3.7	3073	3.6
6	> AY (28-40)	350	0.4	342	0.4
7	AY (28-40)	11671	13.5	11185	13
8	< AY	6754	8	6489	7.5
9	LY	-	-	-	-
10	Not Suitable	35	-	6	-
11	Protected Area	-	-	2289	2.6



Map 44: Site Classification for Cultivation of Willow and Poplar under Environmental Constraints



Map 45: Site Classification for Cultivation of Miscanthus under Environmental Constraints

stage of development and no valid price has been established, thus the price is based on that of forest wood chips (Fischbach 2010). In Germany, forest wood chips were sold for an average price of 80 €/t with 35% water content and 110 €/t with 20% water content over the past four years, including transportation within a radius of 20 km for 80 bulk cubic meters (C.A.R.M.E.N. 2010). According to Wagner (2010), a realistic purchase value of perennials is the price of forest wood chips reduced by 15%. Pursuant to Möndel (2008), three gross margin options for willow and poplar, which vary due to differences in the storage and drying costs, were used in the study. Willow and poplar have a dry matter (DM) of 45% directly after harvesting, while after drying, their dry matter lies around 70%. Band storage losses were estimated at 20% of DM. Miscanthus by contrast can be directly burnt after harvesting without drying, as its dry matter content is around 80%. The gross margin of willow and poplar was, thus, estimated for three options; OP1 - the crops are sold direct after harvesting with 45% of DM, OP2 - the dry matter of crops reach around 70% after outdoor storage on the field and OP3 - after indoor storage. In the study, the purchase price of fresh willow and poplar chips was assumed to be 50 €/t before and 70 €/t after drying, and in the second option, 70 €/t and 100 €/t respectively.

The gross margin of annual crops was calculated on the basis of purchase market prices inclusive of taxes (LEL 2010). As shown in Figure 32, the crop prices in 2007 and 2008 were significantly higher than in the two following years. Thus, the profitability was also calculated in the study for

Table 53: Classification of Growing Area of Willow and Poplar

		Total Area		Outside of Protected Areas	
Site Classification		ha	%	ha	%
1	> HY (>40)	17034	19.7	16609	19.2
2	HY (>40)	9410	11	9310	11
3	HY (>40)	239	0.3	226	0.3
4	< HY (>40)	25828	30	25545	29.5
5	> HY (28-40)	1706	2.0	1662	2
6	HY (28-40)	2	-	2	-
7	HY (28-40)	12	-	12	-
8	AY (28-40)	134	0.2	133	0.2
9	< AY (28-40)	27673	32	26500	30.6
10	> LY	2300	2.7	2148	2.5
11	LY	-	-	-	-
12	LY (wet)	-	-	-	-
13	ND	2174	2.5	2032	2.3
14	Protected Area	-	-	2333	2.7

annual crops including 10% higher purchase prices. The interest rate was assumed at 4%. Assuming a 20-year lifespan for the energy crops plantation, the first harvest takes place in the fourth year with three spans of years for the three considered plants.

The sale of fresh willow and poplar leaves a gross margin between 69 €/ha for an annual yield of 10 t/ha and 351 €/ha for an annual yield of 20 t/ha as shown in Figure 33. The annual gross margin of miscanthus varies from 287 €/ha (annual yield of 15 t/ha) to 587 €/ha (annual yield of 25 t/ha). The dried material of willow and poplar on a field site, sold at 70 €/t, leaves a gross margin between 97 €/ha and 408 €/ha. The much more expensive option of forced ventilation drying diminishes the gross margin to 6, 117 and 227 €/ha respectively for low, ave-rage and high yields (10, 15, 20 t/ha). In similarity with the quite low sales profits of annual crops, their gross margins are lower than those realized with perennials crops. The gross margin of the cultivation of rapeseed oil crops for food or energy production is clearly higher than the gross margin when cultivating poplar and willow, entailing steep drying and storage costs. Nevertheless, oilseed crops are usually only grown every four years. Thus, within the considered period of 20 years, the highly profitable crops may be planted only five times. Maize and wheat bring in similar gross margins provided there are sufficient

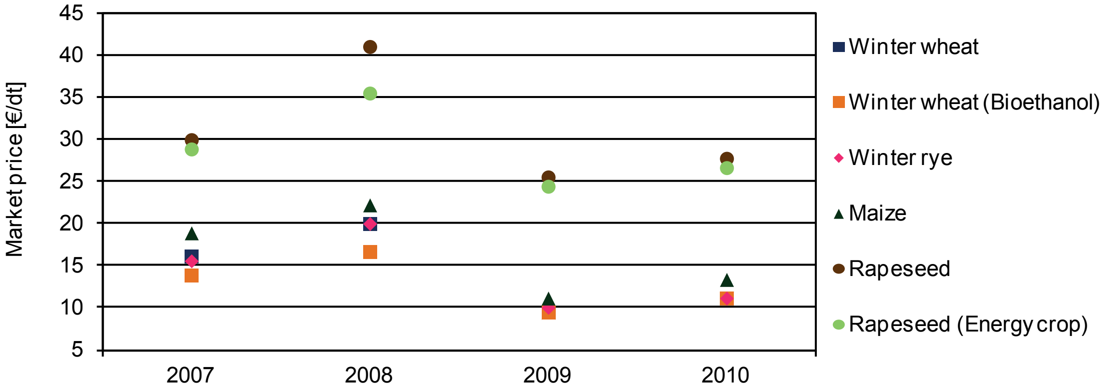
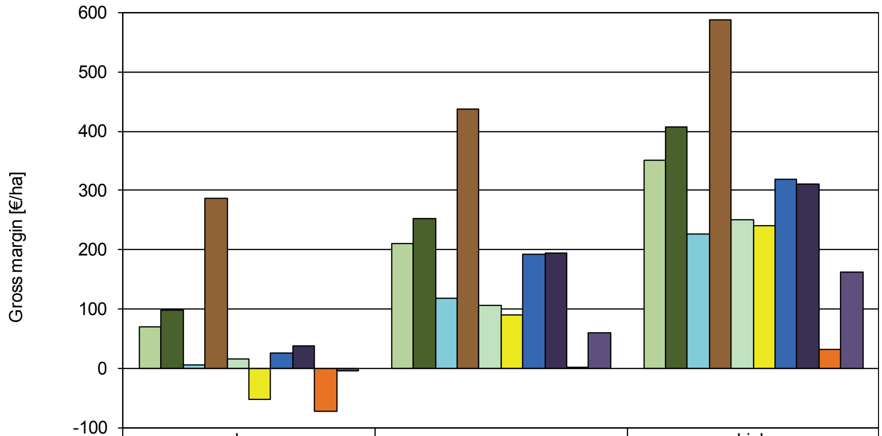


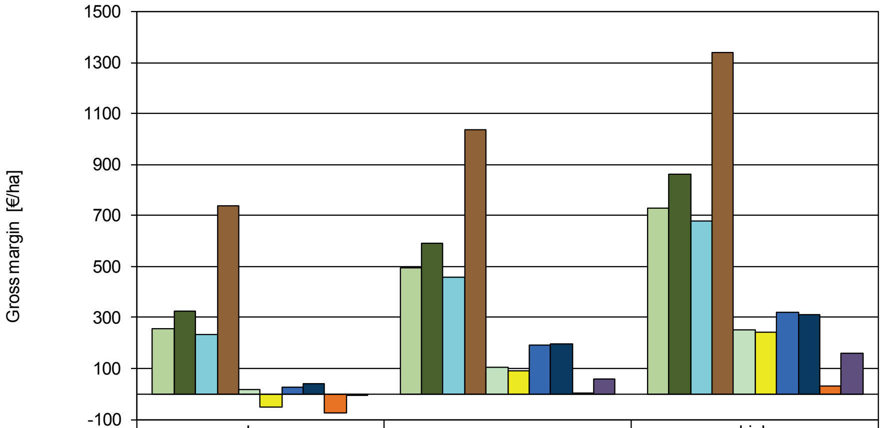
Figure 32: Selected Crop Prices between 2007 and 2010 (incl. 10.7% Tax Rate)
Source: LEL (2010)



	low	average	high
🟩 Willow, poplar OP1 [50€/t] (10, 15, 20 t/ha*y)	69	210	351
🟩 Willow, poplar OP2 [70€/t] (10, 15, 20 t/ha*y)	97	253	408
🟦 Willow, poplar OP3 [70€/t] (10, 15, 20 t/ha*y)	6	117	227
🟫 Miscanthus [70€/t] (15, 20, 25 t/ha*y)	287	437	587
🟩 Wheat [14,4 €/dt] (55, 70, 85 dt/ha)	15	106	251
🟨 Maize [13,3 €/dt] (75, 95, 115 dt/ha*y)	-53	91	240
🟦 Rapeseed [27,7 €/dt] (30, 40, 50 dt/ha*y)	25	192	319
🟦 Rapeseed, e.c. [26,6 €/dt] (30, 40, 50 dt/ha*y)	38	195	311
🟧 Rye [11,1 €/dt] (50, 65, 80 dt/ha*y)	-73	1	32
🟪 Wheat, e.c [11,1 €/dt] (60, 80, 100 dt/ha*y)	-4	59	161

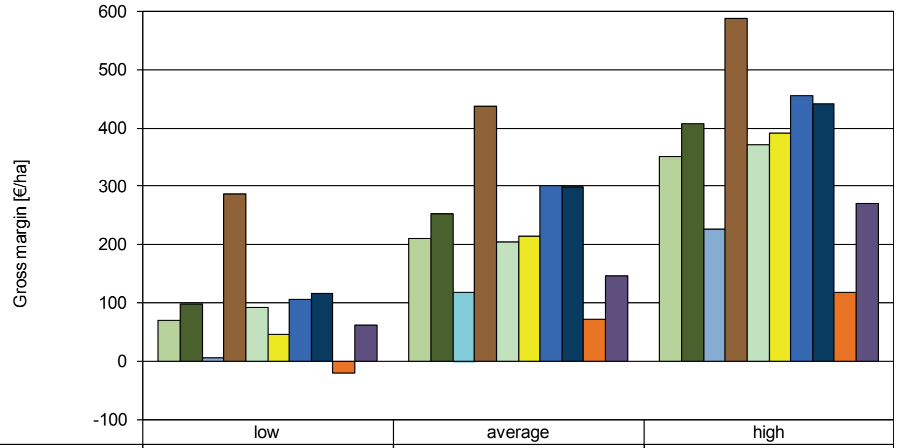
Figure 33: The Gross Margin of Perennial Crops at Purchase Prices of 50 €/t and 70 €/t and Annual Crops for Food and Energy Production Purchased at Market Prices in June 2010

agro-climatic conditions to harvest at least an average 95 dt/ha of maize grain and 70 dt/ha of wheat grain. If a producer could sell the perennial crops for a price 15% below the purchase value of forest wood chips, then growing annual crops would seem to be unprofitable from an economic point of view as shown in Figure 34. Under market conditions like this, the gross margin of an expensive



	low	average	high
🟩 Willow, poplar OP1 [70€/t] (10, 15, 20 t/ha*y)	257	493	728
🟩 Willow, poplar OP2 [100€/t] (10, 15, 20 t/ha*y)	323	592	860
🟦 Willow, poplar OP3 [100€/t] (10, 15, 20 t/ha*y)	233	456	679
🟫 Miscanthus [100€/t] (15, 20, 25 t/ha*y)	737	1037	1337
🟩 Wheat [14,4 €/dt] (55, 70, 85 dt/ha)	15	106	251
🟨 Maize [13,3 €/dt] (75, 95, 115 dt/ha*y)	-53	91	240
🟦 Rapeseed [27,7 €/dt] (30, 40, 50 dt/ha*y)	25	192	319
🟦 Rapeseed, e.c. [26,6 €/dt] (30, 40, 50 dt/ha*y)	38	195	311
🟧 Rye [11,1 €/dt] (50, 65, 80 dt/ha*y)	-73	1	32
🟪 Wheat, e.c [11,1 €/dt] (60, 80, 100 dt/ha*y)	-4	59	161

Figure 34: The Gross Margin of Perennial Crops at Purchase Prices of 70 €/t and 100 €/t and Annual Crops for Food and Energy Production Purchased at Market Prices in June 2010

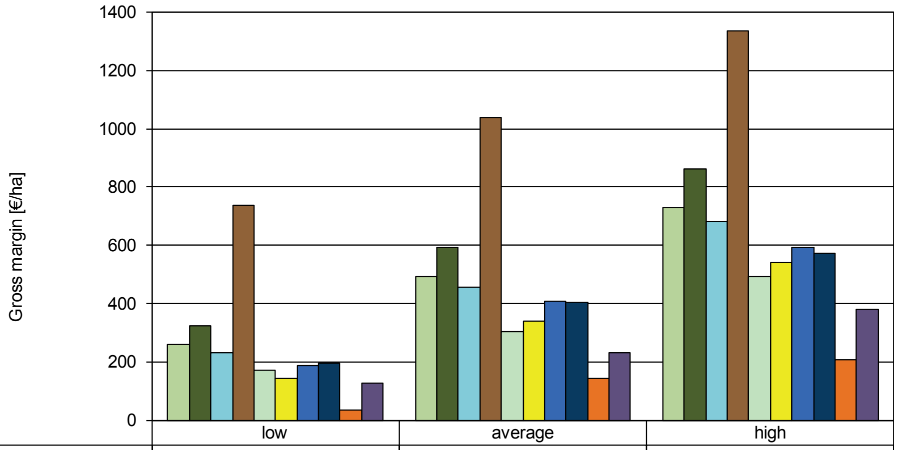


	low	average	high
■ Willow, poplar OP1 [50€/t] (10, 15, 20 t/ha*y)	69	210	351
■ Willow, poplar OP2 [70€/t] (10, 15, 20 t/ha*y)	97	253	408
■ Willow, poplar OP3 [70€/t] (10, 15, 20 t/ha*y)	6	117	227
■ Miscanthus [70€/t] (15, 20, 25 t/ha*y)	287	437	587
■ Wheat [15,8 €/dt] (55, 70, 85 dt/ha)	92	205	371
■ Maize [14,6 €/dt] (75, 95, 115 dt/ha*y)	45	215	391
■ Rapeseed [30,4 €/dt] (30, 40, 50 dt/ha*y)	106	301	455
■ Rapeseed, e.c. [29 €/dt] (30, 40, 50 dt/ha*y)	116	299	442
■ Rye (12,2 €/dt) (50, 65, 80 dt/ha*y)	-20	71	119
■ Wheat, e.c. [12,2 €/dt] (60, 80, 100 dt/ha*y)	61	146	270

Figure 35: The Gross Margin of Perennial Crops at Purchase Prices of 50 €/t and 70 €/t and Annual Crops for Food and Energy Production Purchased at 10% Higher Prices than in June 2010

drying material is around 200 €/ha higher than that of annual crops. On the other hand, the purchase prices for conventional crops may vary significantly, even by 40% as shown in Figure 32.

If the market value of annual crops increased by only 10%, the growing of willow and poplar at lower purchase values of 50 €/t and 70 €/t would be economically inefficient in comparison to wheat,



	low	average	high
■ Willow, poplar OP1 [70€/t] (10, 15, 20 t/ha*y)	257	493	728
■ Willow, poplar OP2 [100€/t] (10, 15, 20 t/ha*y)	323	592	860
■ Willow, poplar OP3 [100€/t] (10, 15, 20 t/ha*y)	233	456	679
■ Miscanthus [100€/t] (15, 20, 25 t/ha*y)	737	1037	1337
■ Wheat [17,3 €/dt] (55, 70, 85 dt/ha)	169	304	491
■ Maize [15,94 €/dt] (75, 95, 115 dt/ha*y)	142	339	542
■ Rapeseed [33,2 €/dt] (30, 40, 50 dt/ha*y)	187	410	591
■ Rapeseed, e.c.[32 €/dt] (30, 40, 50 dt/ha*y)	194	404	572
■ Rye [13,3 €/dt] (50, 65, 80 dt/ha*y)	33	141	205
■ Wheat, e.c. [13,3 €/dt] (60, 80, 100 dt/ha*y)	125	232	379

Figure 36: The Gross Margin of Perennial Crops at Purchase Prices of 70 €/t and 100 €/t and of Annual Crops for Food and Energy Production Purchased at 20% Higher Prices in June 2010

rapeseed and maize (see Figure 35). However, the gross margin of miscanthus would still be around 150 €/t higher than the gross margin of conventional plants.

The gross margin of perennial crops purchased at a value of 70 €/t and 100 €/t is still more profitable than the gross margin of annual crops sold for prices 20% above those paid in June 2010 (see Figure 36). In mid-2010, miscanthus seems to be the most profitable plant regarding its gross margin, given the assumed variable costs mentioned above.

The perennial crops could be grown on more marginal agricultural land under conditions of "sufficient" economic profits.

4.3.3 Potential of Bio-Residues in the Stuttgart Region

In this section, animal waste and straw from cereals were the objective of the analysis. The approach adopted for calculating the animal manure potential was taken from the study of Feldwisch, Lendvaczky et al. (2010) and extended in this study on the assessment of technical and economic biogas potential. Moreover, the net amount of straw was calculated according to Feldwisch, Lendvaczky et al. (2010) based on fixed rates of straw recovery. This work provides a comprehensive approach to estimate the straw used for the reproduction of soil organic matter carried out according to a concept introduced by the Association of German Agricultural Investigation and Research Institutions (VDLUFA 2004).

4.3.3.1 Livestock Manure

To calculate the potential of animal manure for biogas generation, livestock data was extracted from the German Agricultural Census of 2007 (StLA 2007) and the livestock population level was converted into livestock units (LSU) according to the factors outlined in Appendix 12. In 2007, there were 91612 LSUs in the Stuttgart Region, equivalent to 8.4% of total LSUs in Baden-Württemberg, the majority being cattle, followed by pigs (81% of LSU) (see Table 54).

Feldwisch, Lendvaczky et al. (2010) calculated the available energy potential of animal by-products based on the total amount of animal waste and the manure availability related to the period of animal housing. The average grazing period for cattle ranges

Table 54: Animal Population and its Equivalent in Livestock Units (LSU) per County in 2007

	Livestock Population				
Counties	Cattle	Pig	Poultry	Sheep	Horse
Stuttgart	889	408	2153	426	255
Böblingen	8839	20889	50998	5818	2372
Esslingen	9998	8426	72469	15210	2186
Göppingen	30089	28195	204888	10904	1831
Ludwigsburg	14126	42918	167502	3392	2318
Rems-Murr	22093	19474	152704	7878	2101
Total	86034	120310	650714	43628	11063
	Livestock Units				
	Cattle	Pigs	Poultry	Sheep	Horse
Stuttgart	666	44	9	36	272
Böblingen	6354	2468	210	498	2548
Esslingen	6878	891	290	1316	2349
Göppingen	21662	2763	820	927	1954
Ludwigsburg	9585	4948	670	299	2498
Rems-Murr	15670	2133	768	666	2236
Total	60815	13247	2767	3742	10997
Share in Total LSU [%]	66	14	3	4	12

Source: StLA (2008)

from 65 to 240 days and for sheep and horses 275 days, during which the manure is not collected. It was also assumed that 15% of the cattle population and the entire sheep and horse populations are grazed over these periods, while poultry and pigs are housed throughout year (Feldwisch, Lendvaczky et al. 2010). In addition, certain population sizes were included in the availability factor as outlined in Table 55.

From an economic point of view, dairy farms with livestock numbers of at least 60 for cattle, 100 for pigs and sheep as well as 3000 for laying hens were considered for the estimation of biogas production as outlined in Table 55 and Table 56. The data on farms with livestock broken down by herd size classes is not available at the municipal level for data confidentiality reasons. By the same token, the data for Stuttgart county is not available (NA), while in other counties the data was aggregated for two or three herd size classes. In this study, the available factors were modified and are based on the aforementioned housing periods as well as on the share of the animal population in total as outlined in Table 55. Unlike the Polish case study region, the share of big livestock holdings in the Stuttgart Region comprises 65% of cattle farms (37% among them with cattle LS >100), 90% of pig farms and 74% of sheep farms. The population of horses was not included in the statistic.

Table 55: Distribution of the Livestock Population in the Stuttgart Region in 2007

Livestock Population	Cattle		Sheep			Lying Hens
Range of Farm Size	60 - 99	>100	100 - 199	200 - 399	>400	>3000
Stuttgart	NA	NA	NA	NA	NA	NA
Böblingen	3122	2909	920		3597	20900
Esslingen	2419	3259	1560	2718	8452	41500
Göppingen	7923	13365	1305	2396	3487	107373
Ludwigsburg	4520	5487	2933			
Rems-Murr-Kreis	6510	7076	1065		4962	29980
Total	56690		32475			199753
Share in Population [%]	65		74			30
Collecting Factor of Manure	0.15 - Population 0.35 - Availability		0.25			-

*NA - no available data

Source: StLA (2008)

Table 56: Distribution of the Livestock Population of Pigs in the Stuttgart Region in 2007

Livestock Population	Pigs				
Range of Farm Size	100 - 199	200 - 399	400 - 599	600 - 999	>1000
Stuttgart	NA	NA	NA	NA	NA
Böblingen	821	3187	3230	6290	5902
Esslingen	568	1341	NA*	2788	NA*
Göppingen	2084	3490	3365	8215	8090
Ludwigsburg	1803	7089	10168	10028	11793
Rems-Murr-Kreis	2593	3211	NA**	6152	NA**
Total	109667				
Share in Population [%]	90				
Collecting Factor of Manure	0.9				

NA - data not available; NA* - a total value for both ranges is 2541; NA** - a total value for both ranges is 4918

Source: StLA (2008)

4.3.3.1.1 Biogas Technical Potential

Taking the dry matter of animal by-products outlined in Table 57, the total amount of organic dry matter of manure incurring in the Stuttgart Region is set out in Table 58. The gross energy content of biogas generated from animal wastes was calculated as follows:

$$Ew = \frac{AR * B * 0.55 * 9.17 * fa * fb}{1000} \qquad (24)$$

where Ew is the gross energy content of animal manure in MWh, AR is the volatile solid of animal wastes taken from Table 58, B is the biogas content in VS as outlined in Table 57, fa is the share in the entire livestock population, fb is the availability factor related to the housing period.

The energy produced from solid and liquid manure amounts to 418980 GJ (110 GWh), thus being slightly lower than the value of 459513 GJ estimated by Feldwisch, Lendvaczky et al. (2010). In addition, the gross energy content of manure has possibly been overestimated (at most by 3%, equal to the energy content of horse manure), as all horse farms were included regardless of their herd size. After subtracting the animal manure fed into existing biogas plants, which was around 20 GJ (Feldwisch, Lendvaczky et al. 2010), the available potential of biogas was 110 GWh (see Table 59). To get a better overview on the above-estimated potential of animal manure, Table 60 outlines the potential power capacity of biogas, electrical energy and heat production per county. The capacity of biogas, electrical and thermal power plants as well as the energy production were calculated on the assumption of 36% electrical efficiency, 42% thermal conversion efficiency and a load factor of 7800 hours per year. In total, the electrical power capacity is only 5108 kWe using animal manure. In practice, to increase the methane yield, co-substrates with an average 60% of the biogas feedstock mass are fed into anaerobic digesters (DBFZ 2010). By increasing the biogas feedstock by 40% of the manure's mass weight, gross energy production rises from

Table 57: Manure Characteristics and Biogas Yield from Animal Residues in the Stuttgart Region

Substrates	Cattle		Pig		Poultry	Horses	Sheep and Goats
Units	Liquid Manure	Manure	Liquid Manure	Manure	Litter	Manure	Manure
t /LSU*y	14.7	2.3	11	1.2	10	2.4	3.4
t VS/LSU*y	0.94	0.46	0.53	0.19	2.6	0.5	0.7
Biogas m^3/t VS	340	280	400	450	380	410	410

Source: Bläsing, Gerth et al. (2000:) FNR (2009): Feldwisch, Lendvaczky et al. (2010)

Table 58: The Organic Dry Matter of Animal Liquid and Solid Manure in t VS (VS - Volatile Solid)

	Cattle		Pig		Poultry	Sheep	Horse
Animal Manure [t VS] per County	Manure	Liquid Manure	Manure	Liquid Manure	Litter	Manure	Manure
Stuttgart	308	623	8	23	19	25	132
Böblingen	2 939	5989	466	1308	561	344	1228
Esslingen	3 201	6501	171	477	808	900	1132
Göppingen	9 999	20427	527	1484	1797	645	948
Ludwigsburg	4 495	9160	941	2619	1516	201	1200
Rems-Murr	7 242	14765	406	1134	1706	466	1088
Total	28184	57465	2519	7045	6407	2581	5728
Manure Availability Factor	0.65		0.9		0.65	0.25	0.25

Source: Feldwisch, Lendvaczky et al. (2010)

110 GWh to 491 GWh. Supposing a maize silage yield of 55 t/ha and a grass silage yield of 25 t/ha fed into biogas plants in a proportion of 70% to 30% in a co-substrate mix, the demand for arable land comes to 12622 ha (see Table 61) calculated according to the formula:

$$Acs = (\frac{Sm}{0.6} - Sm) * \frac{0.7}{55} + (\frac{Sm}{0.6} - Sm) * \frac{0.3}{25} \quad (25)$$

where Acs is the land required for growing co-substrates (maize silage and grass silage) in t/y, Sm is the annual quantity of animal feedstock in t/y.

If the total potential of manure was utilized in co-fermentation with these crops, which is commonly practiced in Germany (DBFZ 2010), 11% of the agricultural land in the Stuttgart Region would be dedicated to biogas production. If only co-substrates mixed with pig and cattle manure were considered, the area would be slightly smaller, some 12356 ha, corresponding to over 10% of the agricultural land.

Table 59: Available Energy Content of Animal Manure in MWh at the County Level in 2007

Animal Manure per County	Cattle	Pig	Poultry	Sheep	Horse	Total	Already Used	Available Energy
	MWh							
Stuttgart	962	63	12	10	74	1122	154	968
Böblingen	9225	3628	352	144	692	14040	699	13342
Esslingen	10023	1325	507	375	638	12869	439	12430
Göppingen	31441	4112	1127	269	534	37484	2053	35430
Ludwigsburg	14109	7282	951	84	677	23102	1623	21478
Rems-Murr	22739	3150	1070	194	613	27767	731	27035
Total	88500	19560	4017	1077	3229	116383	5699	110684

Source: Own Calculation Based on the Assumption Made by Feldwisch, Lendvaczky et al. (2010)

Table 60: Potential of Electrical and Thermal Power Output, Electricity and Heat Production

Counties	Power Capacity		Electricity	Heat
	kW_e	kW_{th}	MWh*	MWh*
Stuttgart	45	51	349	407
Böblingen	616	701	4803	5604
Esslingen	574	653	4475	5220
Göppingen	1635	1862	12755	14881
Ludwigsburg	991	1129	7732	9021
Rems-Murr	1248	1421	9733	11355
Total	5108	5818	39846	46487

Table 61: Demand for Arable Land for Growing Co-Substrates (Maize and Grass Silage)

Counties	Cattle	Pig	Poultry	Sheep	Horse	Total
	ha					
Stuttgart	1045	439	8	5	25	1523
Böblingen	1131	159	11	14	23	1338
Esslingen	3561	492	32	10	19	4115
Göppingen	1576	881	27	3	25	2511
Ludwigsburg	2576	380	30	7	22	3015
Rems-Murr	109	8	0	0	3	121
Total	9998	2358	109	39	117	12622

Among other factors, the potential of biogas production hinges on the future livestock population. To obtain better insight into the trend, historical data from a survey conducted in four-year cycles between 1979 and 2007 (see Figure 37 and Table 62), the number of animals was estimated for the year 2020. Due to the expected structural changes to agriculture in the region, the number of cattle herds is likely to drop by 54% (from 86034 to 39305 animals) by 2020. As a result of the decline in the number of small cattle dairy farms in the region, straw litter, which is practiced in farms with up to 200 - 300 animals, will decrease as well (Feldwisch, Lendvaczky et al. 2010), a trend which is favorable for the development of biogas. Pig and poultry manure is expected to drop by 3% and 19% respectively. At the same time, the population of horses and sheep is likely to increase; however, the availability of manure is limited during the grazing period.

4.3.3.1.2 Biogas Economic Potential

There is no doubt that the production and utilization of biogas is a lucrative business, as in Germany around 5000 installations had been constructed by 2009 (DBFZ 2010). Over the last 2 to 3 years, biogas plants have sprung up like mushrooms (Kiessling and Lingenfelser 2011), which has caused

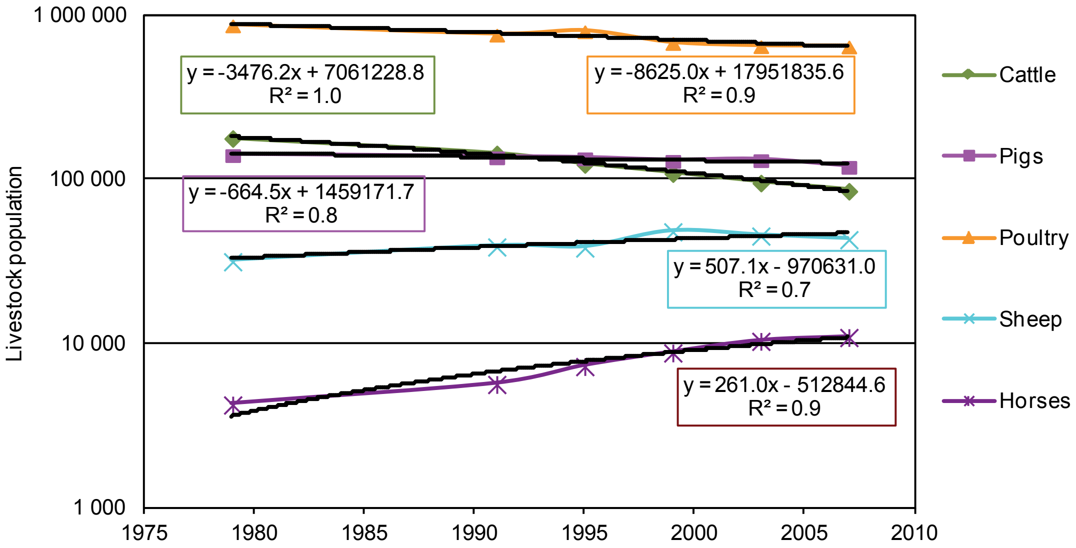


Figure 37: Historical Trend in Livestock Population in the Stuttgart Region from 1979 to 2007
Source: Processed Data (StLA 2008) after Feldwisch, Lendvaczky et al. (2010)

Table 62: Historical Data on Livestock Population and Outlook for the Year 2020

	Livestock Population				
Years	Cattle	Pig	Poultry	Sheep	Horse
1979	180214	141880	874614	32011	4296
1991	145243	137457	768021	39389	5726
1995	125213	135583	805238	38828	7359
1999	110142	130834	683263	48697	8909
2003	96508	132146	653252	45903	10486
2007	86034	120310	650714	43628	11063
Change 2007/1979	-52	-15	-26	36	158
Outlook 2020	39305	116861	529337	53711	14375
Change 2020/2007	-54.3	-3	-18.7	23	30

Source: Own Calculation Based on Feldwisch, Lendvaczky et al. (2010)

land lease rents to rise from an average price of 200 € per ha up to as much as 1000 € per ha in some regions, on average corresponding to a doubling of land lease rents between 2007 and 2010 (Gunnar and Habermann 2010; WWF 2011). The large-scale biogas producers are able to afford expensive land rents while bringing in profits of up to 3000 € per ha of land involved, compared to 340 € in EU subsidies per ha guaranteed to German farmers (WWF 2011). Due to the current set of bonus payments, investment returns may even reach 20% (Kiessling and Lingenfelser 2011). The dense and rapid construction of biogas plants and the biogas feedstock structure carries damaging consequences for the environment, agricultural structure, landscape and even social welfare. Consequently, biogas production creates jobs but at the same time endangers jobs associated for instance with milk or potato production (Agrarheute 2011; Kiessling and Lingenfelser 2011), as 60% of farmers rent agricultural land (WWF 2011).

The aim of the economic assessment in the present study was to evaluate and compare costs and revenues for exemplary on-farm biogas plants of 65, 150, 500 and 2000 kWh electrical power capacity. The investment costs of facilities and relevant annual operations and maintenance rates were outlined in chapter 4.2.3.4.6 with an annuity rate calculated at 4% over 20 years. To analyze the profitability of the power plants, two cases of biogas feedstock were considered: firstly, only manure and secondly, manure added with co-substrates at 40% mass weight (maize silage and grass silage). The 2000 kW power capacity was only analyzed in the second step. An assumption was made that there are no transport costs for on-farm plants. Furthermore, two options of co-substrate costs at 20 €/t and 30 €/t were taken into account. The annual revenue is the sum of a basic FIT and bonus payments (NAWARO bonus, manure bonus, CHP bonus, gas injection bonus) calculated in relation to the overall power capacity (BMELV 2009). Apart from the electricity revenue, additionally sold heat can generate a further 30 to 50 €/MWh. The annual revenue of generated energy from biogas was calculated by means of the formula:

$$Re = (En * (FIT + B) + Hn * HP) / (Ee + Eh) \qquad (26)$$

where Re is the annual revenue per unit of generated energy in €/MWh, En is the energy fed into the power grid calculated according to BMELV (2009), Hn is the net heat sold on the market, FIT is the base payment related to the power capacity, B are the bonus payments related also to the power capacity and energy efficiency and HP is the heat price.

The total benefit was divided by the sum of gross electricity and heat produced. In case of gas injection into the natural gas grid, the dominator is the energy equivalent of methane (gross energy).

According to Feldwisch, Lendvaczky et al. (2010), in the Stuttgart Region, the number of small biogas plants based on manure is likely to rise due to the latest amendment to the German Renewable Energy Law in 2009 that favors AD plants with electrical power up to 150 kW. Figure 38 shows the

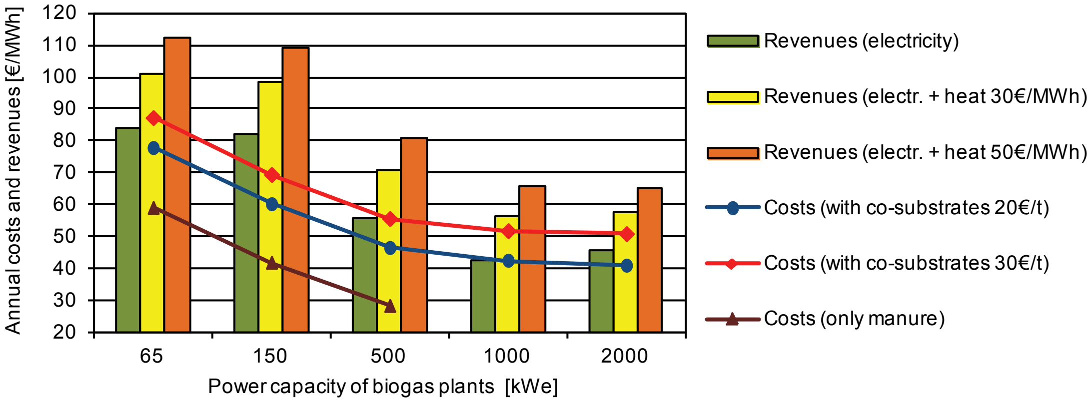


Figure 38: Annual Revenues and Costs Depending on the Acquisition Costs of Biogas Feedstock. Annuity over 20 Years at 4% Interest Rate

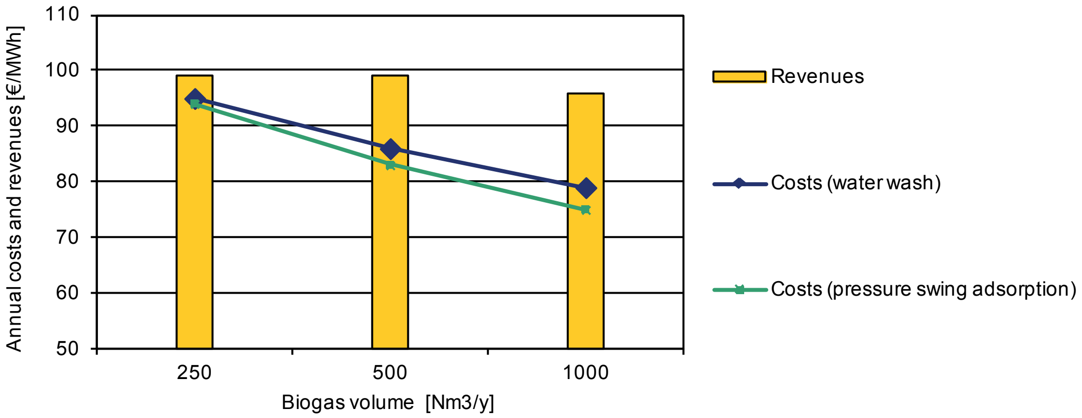


Figure 39: Costs of Methane Production Calculated under Feedstock Costs of 30 €/t for the Water Wash and Pressure Swing Adsorption Upgrading Technologies at an Interest Rate of 4% (Financing Period: 20 Years)

difference between costs and benefits primarily for smaller units, but at around 150 kW the stabilization of anaerobic digestion processes requires additional co-substrates - in practice, maize silage. Due to the scaling effect of investment costs, smaller units with a power capacity of, say, 65 kW have higher costs than units of 150 kW. However, they benefit from the same incentive measures. Therefore, biogas plants of 65 kW bring in unit revenues comparable to 500 kW biogas plants.

Nonetheless, the annual benefits produced by larger plants are clearly more attractive. Under the current support scheme framework, the possibility of combining manure and energy crop bonuses does not counteract the use of crops as co-substrates, neither in small nor in bigger AD plants. In addition, as shown in Figure 38, two options of co-substrate costs influence the production costs, but do not affect economic feasibility at all while selling both electricity and heat. This substantiates the fact that the continuing development of small and large projects is likely to fuel the demand for arable land and further inflate land lease prices. Thus, the support scheme should be revised to encourage both the conventional agricultural production and biogas production, although not regardless of price.

In the case of methane injection into the gas grid, projects like these may generate profits, which rise in accordance with the increased anaerobic digestion capacity due to high upgrading costs. The two most commonly applied gas upgrading technologies, the water wash and the pressure swing adsorption upgrading technology, only feature a slight difference as to the increase in plant capacity (see Figure 39).

Nevertheless, from an economic point of view, investment in methane generation appears less attractive than investments in heat and power generation from biogas. In addition, costs fall as the units increase, a development which may encourage producing agricultural co-substrates on site if there is no supply alternative to bio-waste, for instance, from the food processing industry.

4.3.3.2 Agricultural Production

The development of farmland is related to the development of urban areas, whereby an increase in urban land results in a decrease in the agricultural land. To evaluate crop potential and the potential of the respective residues, historical data was studied (StLA 2010). The changes in agricultural land area incurred between 1996 and 2008 allow for the assumption that the agricultural land - disregarding the development of built-up areas - will pursue its regressive trend observed until 2008 and continue to decrease by an average rate of 4% until 2020 (see Table 63).

To gain a better outlook on the potential of cereals' straw, residues from vineyards, orchards and energy crops, plus historical changes of the cropland development, were studied. Between 1999 and 2007, the area under cultivation in the Stuttgart Region dropped by an average rate of 2.4% (between 0.5 and 4.6%) (Table 64). Contrary to expectations, the area covered by permanent grassland increased

Table 63: Urban and Agricultural Land Surface in ha and its Changes in % between 1992 and 2008

Counties	Residential, Industrial and Transport Area [ha]				Change [%]	
	1992	1996	2000	2008	2008/1992	2008/1996
Stuttgart	9935	10197	10340	10644	7.14	4.4
Böblingen	12020	12359	12830	13537	12.6	9.5
Esslingen	13925	14411	14827	15635	12.3	8.5
Göppingen	9556	9817	10047	10428	9.1	6.2
Ludwigsburg	14496	14817	15411	16417	13.2	10.8
Rems-Murr	13323	13642	13993	14753	10.7	8.1
Total	63320	65046	67108	70770	11.8	8.8
	Total Agricultural Land [ha]				Change [%]	
	1992	1996	2000	2008	2008/1992	2008/1996
Stuttgart	5493	5175	5039	4791	-12.8	-7.4
Böblingen	27516	27182	26697	26025	-5.4	-4.3
Esslingen	30604	30136	29641	28766	-6.0	-4.5
Göppingen	33662	33281	32904	32428	-3.7	-2.6
Ludwigsburg	40428	39798	39154	38176	-5.6	-4.1
Rems-Murr	38673	37932	37405	36476	-5.7	-3.8
Total	170883	168329	165801	161871	-5.3	-3.8

Source: StLA (2010)

on average by almost 1% annually, while in the same period, the population of cattle and sheep dropped by 22% and 10% respectively. On the other hand, the population of horses rose by 24% between 1999 and 2007. As mentioned in the previous section, the Ludwigsburg county followed by Göppingen were leaders regarding the area under energy crops for biogas production. However, according to Feldwisch, Lendvaczky et al. (2010), only 72 ha of the total arable land of 1433 ha under biogas feedstock are covered by grassland. Changes in the extension of arable land and pasture surfaces show a common dependence, i.e. if one area decreases then the other increases and vice versa.

Considering the material from cutting and clearing treatment of orchards and vineyards, the potential of this type of biomass is likely to increase evenly over the next 10-year period, since both surfaces dropped on average by 20% from 1997 to 2007. Over the same time-frame, only the county of Göppingen recorded a rise in the orchard area (+6.4%), whilst in Ludwigsburg the vineyard surface grew by 4%.

4.3.3.3 Cereal By-Products

Among agricultural residues, wheat, rye and triticale straw were used for electricity and heat generation (Kaltschmitt, Wiese et al. 2007). So far, in the Stuttgart Region, cereal by-products have been used only for bedding or left on the field for the reproduction of soil humus. To estimate straw potential, the grain yield and growing area of cereals were derived from the national statistics. The grain-to-straw ratio was based on the factors outlined in Table 65 derived from DüV (2007).

As oil seed rape (OSR) was cultivated on 7% of the region's arable land, rape straw was taken into account in this study. The OSR straw is much higher in corrosive chloride and sulphur compounds than the conventional wheat and barley straw but has been successfully fed into biomass plants in England (Newman 2003). The entire amount of cereals' by-products with and without OSR at the county level is outlined in Table 66. The deployment of straw calculated at the commune level is shown on Map 46 and Map 47. The difference between these two maps representing the amount of straw excluding and including OSR straw is scarcely perceptible, which means that these crops are grown across the entire region. However, the secrecy obligation effective in statistical data at the communal level may lead to incomplete data sets and thus to an underestimation of the actual amount of harvest residues. For this reason, the subsequent analyses were carried out at the county level. Before estimating the potential of straw available for energy generation, the straw amount used in livestock holdings for bedding and for soil humus reproduction was calculated. The

Table 64: Area of Agricultural Land, Main Cultures and the Surface Changes between 1999 and 2007

	Agricultural Land								
	Total	Arable Land	Permanent Grassland	Orchards	Vine-yards	Arable Land	Permanent Grassland	Orchards	Vine-yards
Years	Area [ha]					Share [%]			
	Stuttgart								
1999	2556	1557	503	99	362	60.9	19.7	3.9	14.2
2003	2471	1514	464	86	370	61.3	18.8	3.5	15
2007	2542	1538	540	71	358	60.5	21.2	2.8	14.1
2007/1999	-0.5	-1.2	7.4	-28.3	-1.1	-0.7	7.6	-28.2	-0.7
	Böblingen								
1999	22997	16124	6721	120	4	70.1	29.2	0.5	
2003	22652	15759	6744	104	3	69.6	29.8	0.5	
2007	22578	15628	6801	93	3	69.2	30.1	0.4	
2007/1999	-1.8	-3.1	1.2	-22.5	-25.0	-1.3	3.1	-20.0	
	Esslingen								
1999	20473	10448	9445	278	129	51	46.1	1.4	0.6
2003	20050	10338	9260	179	127	51.6	46.2	0.9	0.6
2007	19929	10216	9319	167	118	51.3	46.8	0.8	0.6
2007/1999	-2.7	-2.2	-1.3	-39.9	-8.5	0.6	1.5	-42.9	0.0
	Göppingen								
1999	29404	12879	16365	94		43.8	55.7	0.3	
2003	28806	12756	15902	80		44.3	55.2	0.3	
2007	28454	12710	15586	100	1	44.7	54.8	0.4	
2007/1999	-3.2	-1.3	-4.8	6.4		2.1	-1.6	33.3	
	Ludwigsburg								
1999	33132	25561	5248	449	1627	77.2	15.8	1.4	4.9
2003	33474	25612	5552	446	1666	76.5	16.6	1.3	5
2007	32545	24617	5654	430	1691	75.6	17.4	1.3	5.2
2007/1999	-1.8	-3.7	7.7	-4.2	3.9	-2.1	10.1	-7.1	6.1
	Rems-Murr-Kreis								
1999	27504	12345	13310	577	1056	44.9	48.4	2.1	3.8
2003	26733	12051	12981	497	1044	45.1	48.6	1.9	3.9
2007	26231	11937	12581	524	1049	45.5	48	2	4
2007/1999	-4.6	-3.3	-5.5	-9.2	-0.7	1.3	-0.8	-4.8	5.3
	Change in Total between 1999 and 2007 [%]								
	-2.4	-2.5	0.8	-16.3	-5.2	0	3.3	-11.6	1.8

Source: StLA (2010)

surplus of straw for energy purposes calculated in different studies (BMU 2004; Leible 2004; Simon 2006) varies from 20 to 52% of the total amount of cereal by-products.

The quantity of straw required for bedding depends on the livestock population, the farming system, livestock-specific needs of straw per day and the number of grazing days. The annual amount of straw per LSU used in livestock farms was taken from the study carried out by Feldwisch, Lendvaczky et al. (2010) as outlined in Table 67. Apart from OSR straw, the annual demand for bedding material was 54944 tons in 2007, corresponding to 25% of the total straw production, however, in Göppingen for instance the demand reached 47% of the overall straw supply. Furthermore, depending among other things on crop rotation and soil quality, around 67% of straw should be left on the field for the reproduction of soil organic matter (Münch 2008).

Table 65: Average Ratio of Grain to Residue and Grain Yield at the County Level in the Stuttgart Region

Crops	Winter Wheat	Rye	Triticale	Winter Barley	Summer Barley	Oats	Rape Seed
Grain to Straw (1:x)	0.8	0.9	0.9	0.7	0.8	1.1	1
Counties	Grain Yield [dt/ha]						
Stuttgart	71.8		63.5	60.1	50.2	50.0	38.2
Böblingen	75.3	61.6	72.7	66.4	54.7	56.5	39.4
Esslingen	69	52.7	59.2	56.6	48.7	51.2	38.2
Göppingen	67.6	62.1	64.7	60.1	50.3	52.7	39.7
Ludwigsburg	72.9	50.9	62.1	64.4	53.1	51.4	38.5
Rems-Murr	65.5	49.4	58.7	54.7	46.6	45.4	35.2
Average	70.4	55.3	63.5	60.4	50.6	51.2	38.2

Source: Own Calculation Based on DüV (2007); StLA (2007)

Table 66: Cereals By-Products in t/y at the County Level in the Stuttgart Region

Crops	Winter Wheat	Rye	Triticale	Winter Barley	Summer Barley	Oats	OSR	Total (excl. OSR)	Total (incl.OSR)
Counties	Straw Production [t/y]								
Stuttgart	2050	40	40	144	954	199	145	3427	3572
Böblingen	27865	657	1450	5273	13395	4295	7388	52935	60323
Esslingen	15993	470	624	3752	3913	2408	2227	27160	29387
Göppingen	16628	348	2732	8315	4829	3482	4554	36334	40888
Ludwigsburg	43785	845	505	8637	14693	1757	5713	70222	75935
Rems-Murr	15918	339	1425	6296	2384	2388	2056	28750	30806
Average	122239	2699	6776	32417	40168	14529	21816	218828	240644

Source: StLA (2008)

Alternatively, some part of the straw may also be replaced by animal manure or by digested material from biogas plants.

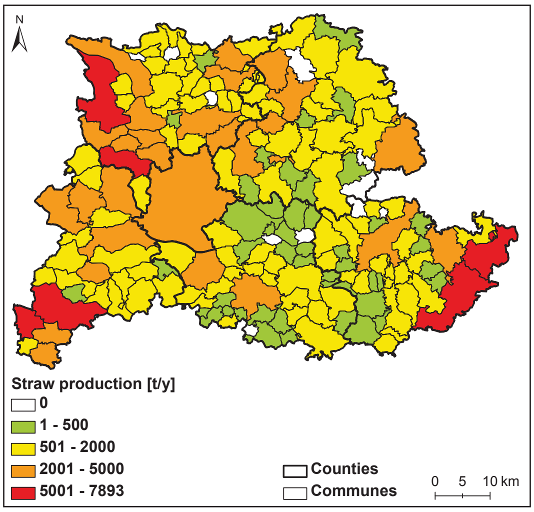
The humus balance of a crop rotation based on statistical data (StLA 2008) was calculated according to a concept compiled by the German Association of Agricultural Investigation and Research Institutes (VDLUFA 2004). The principle of humus balance is as follows (Siebert and Kehres 2008):

$$HD + HR * OM = HM \qquad (27)$$

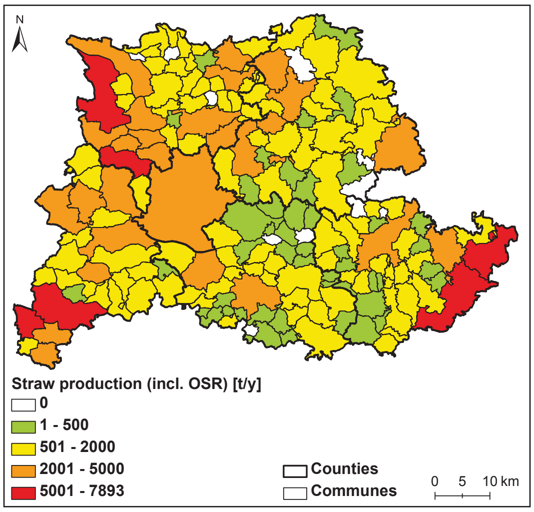
where HD is the humus demand in kg/ha*a humus-C, HR is the humus reproduction in kg/ha*a humus-C/t, OM is the amount of organic material in t/ha*a, HM is the humus nutrition in kg/ha*a humus-C. Different organic materials, which have varying effectiveness to reproduce humus, are outlined in (VDLUFA 2004).

The humus balance estimated at the county level indicates the optimal minimum values in terms of yield which range between -75 and 100 kg of humus-C/ha. Humus amounts between -76 and -200 kg humus-C/ha is tolerable at sites characterized by humus enriched soil, whereas further lower levels of humus indicate that straw alone is not sufficient, as the maximum level exceeds the optimal and tolerable shortage of organic materials.

As the basic fertilizer is in practice livestock manure, Table 69 shows the humus balance estimated based on the application of animal manure. As in the previous section, the assumption was made that the fraction of manure that may be recovered is 95% of total residues for pigs, 50% for the poultry population and 25% of the total amount of waste in the case of sheep and horse populations. For cattle, the available fraction of manure is 35% for 15% of a grazed population (Feldwisch, Lendvaczky et al. 2010).



Map 46: Annual Straw Production (excl. OSR Straw) in Tons per Commune in 2007



Map 47: Annual Straw Production (incl. OSR Straw) in Tons per Commune in 2007

This study's findings show that the soil organic matter is slightly below the optimal level indicated as null. The negative humus balance can be successfully neutralized by the application of both livestock manure and straw. If the minimum level of solid organic matter required for cultivation were restored, around 111052 tons of straw will remain as surplus, while on the other hand, a straw shortage of 5891 tons will occur if the maximum level of solid organic matter required for cultivation should be restored. In the three counties of Stuttgart, Esslingen and Ludwigsburg, the amount of straw is not sufficient to cover the shortage of manure, nor therefore to neutralize humus at the maximum level (see Table 69). On average, the straw surplus is 52580 tons , equivalent to 22% of the gross amount of straw, including rapeseed harvest residues. This finding differs slightly from the 56400 tons estimated by Feldwisch, Lendvaczky et al. (2010), who based their calculations on the average straw recovery factor. By contrast, the estimation in this study includes rapeseed straw which amounts to 21816 tons in 2007 and was neglected in Feldwisch's above-mentioned work.

Over the next few years, the straw potential is likely to remain at a level comparable to that of 2007, although the cropland area will decrease because the straw demand for animal bedding will also fall. However, due to annual crop rotation constraints, the potential of harvest residues is highly diversified in time and space. On the other hand, the low energy density of harvest residues and their high mobilization costs restrict in practice their viability within the energy sector.

Table 67: Straw Usage for Bedding in 2007 at County Level

Straw Usage	Cattle	Pigs	Poultry	Sheep	Horse	Total	Straw Used [%]	
[kg per LSU]	600	400	1000	700	600	Straw	excl. OSR	incl. OSR
Counties	Straw for Bedding [t/y]							
Stuttgart	409	17	9	26	172	633	18	18
Böblingen	3865	930	223	359	1605	6982	13	12
Esslingen	4166	342	313	948	1480	7249	27	25
Göppingen	13182	1053	894	668	1200	16997	47	42
Ludwigsburg	5818	1871	724	215	1571	10199	15	13
Rems-Murr	9517	811	669	479	1408	12884	45	42
Total	36957	5024	2832	2695	7436	54944	25	23

Source: Based on Feldwisch, Lendvaczky et al. (2010)

Table 68: Humus Balance after a Crop Rotation and Due to Straw Application in the Stuttgart Region in 2007

	Balance after Rotation		Straw		Humus*		Balance	
	Min	Max	incl. OSR	excl. Bedding	Straw	Arable Land	Min	Max
County	kg Humus-C		t/y		kg Humus-C	ha	kg Humus-C /ha	
Stuttgart	-371360	-560400	3572	2939	293916	1 538	-50	-173
Böblingen	-4348440	-6429880	60323	53341	5334050	15 628	63	-70
Esslingen	-2691720	-3943740	29387	22138	2213806	10 216	-47	-169
Göppingen	-1841120	-4262460	40888	23891	2389059	12 710	43	-147
Ludwigsburg	-8327080	-12529960	75935	65736	6573640	24 617	-71	-242
Rems-Murr	-3286280	-4833780	30806	17922	1792168	11 937	-125	-255
Total	-20866000	-32560220	240910	185966	18596639	76 646	-31	-176

*Straw is an equivalent of 100 kg humus-C

Source: Own Calculation Based on Statistical Data (StLA 2008)

Table 69: Humus Balance after Crop Rotation and Livestock Manure Application in 2007

	Humus		Balance Due to Animal Wastes		Balance		Straw Left after Neutralizing Humus Balance		Share of Straw Used in Total Amount*	
	Slurry*	Manure*	Min	Max	Min	Max	Min	Max	Min	Max
County	kg Humus-C		kg Humus-C		kg Humus-C ha		t/y		%	
Stuttgart	73924	58475	-238961	-428001	-155	-278	550	-1341	15	-38
Böblingen	882734	668144	-2797562	-4879002	-179	-312	25365	4550	42	8
Esslingen	808919	685228	-1197573	-2449593	-117	-240	10162	-2358	35	-8
Göppingen	2539388	1881270	2579537	158197	203	12	49686	25473	122	62
Ludwigsburg	1448038	1070407	-5808635	-10011515	-236	-407	7650	-34379	10	-45
Rems-Murr	1845227	1412764	-28290	-1575790	-2	-132	17639	2164	57	7
Total	7598229	5776287	-7491484	-19185704	-81	-226	111052	-5891	47	-2

* Straw used for bedding in animal barns is returned onto the field in the form of manure

Source: Own Calculation Based on the Statistical Data (StLA 2008)

4.3.4 Woody Biomass in the Stuttgart Region

- Wood from Forests

According to Dieter, Englert et al. (2001) the annual potential of firewood in the public forests of the Stuttgart Region amounts to 195175 t_{dry} (19500 t of coniferous and 177430 t of deciduous wood), which is an energy equivalent of 1450 TJ. Bläsing, Gerth et al. (2000) reported an average annual firewood potential of 1.5 t_{fm}/ha. The lack of regional statistics on wood harvest and consumption makes it difficult to estimate the real potential.

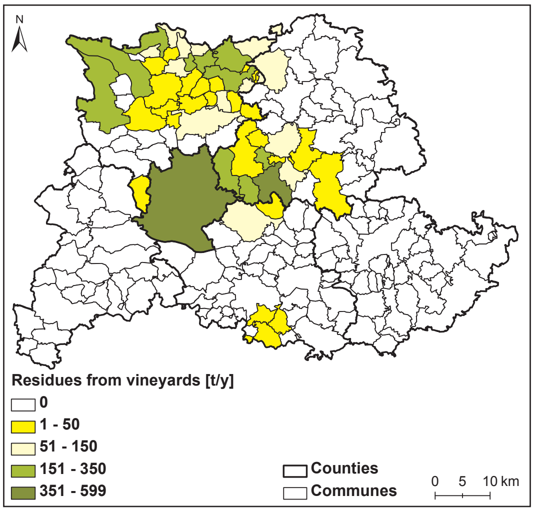
- Waste Wood from Landscape Management

A certain quantity of wood residues from green recreation areas and city parks can supplement the forest biomass. Bläsing, Gerth et al. (2000) estimated the technical potential at 22581 tons of fresh mass (energetic value of 180 TJ). However, due to the heterogeneous density of wood cutting and high mobilization costs, only a very small part of the potential has been used for energy purposes so far, like in the case of the 10 MW wood heating boiler in Geislingen-Türkheim. Nonetheless, the most recent amendment to the German Renewable Energy Law provides for an additional bonus payment supporting the use of wood residues in anaerobic digestion plants if they account for at least 50% of the overall biogas feedstock. That said, lignocellulosic material is problematic to use in biogas plants due to its slow anaerobic decomposition (Weiland 2010). Wood residues can be also incinerated in CHP units, although supply constraints in time and space considerably affect their viability.

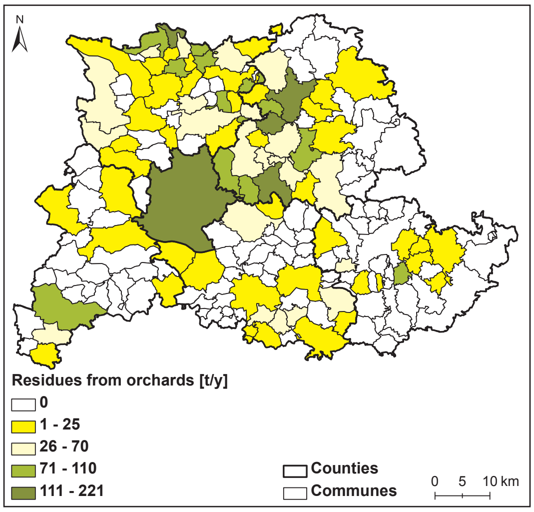
Table 70: Area and Biomass Potential of Vineyards, Orchards per County in 2007

	Vineyards		Orchards					
	Area	Clearing	Area	Cutting	Clearing	Vineyards	Orchards	Total
County	ha	t/y	ha	t/y	t/y	MWh	MWh	MWh
Stuttgart	358	537	71	57	107	1193	363	1556
Böblingen	3	5	93	74	140	10	475	485
Esslingen	118	177	167	134	251	393	854	1247
Göppingen	0	0	100	80	150	0	511	511
Ludwigsburg	1691	2537	430	344	645	5637	2198	7834
Rems-Murr-Kreis	1049	1574	524	419	786	3497	2678	6175
Total	3219	4829	1385	1108	2078	10730	7079	17809

Source: Calculation According to the Assumption of Bläsing, Gerth et al. (2000) Based on Statistical Data (StLA 2008)



Map 48: Potential of Clearing Material FromVineyards per Commune in 2007



Map 49: Potential of Clearing Material from Orchards per Commune in 2007

- Wood Residues from Orchards and Vineyards

The calculation of the biomass potential from orchards and vineyards was carried out in line with assumptions made by Bläsing, Gerth et al. (2000) based on statistical data from 2007. The clearing and cutting maintenance of viticultures and fruit trees yields around 7 tons (3 tons from clearing and 4 tons from cutting) of fresh biomass annually. Some part of the potential is also left on the field for soil humus reproduction. Bläsing, Gerth et al. (2000) assumed that for vineyards around 50% of material from clearing can be recovered, while in orchards 20% of biomass from cutting and 50% from clearing can be recovered.

Table 70 outlines the area and biomass potential of vineyards and orchards. The energy content amounted to 17.8 GWh per year in 2007. The actual utilization of the residues depends on their spatial distribution density. The spatial location of vineyards and orchards recorded at a communal level does not allow for the economic assessment of their mobilisability. Nonetheless, unlike orchards, grapevine fields are densely located, favoring the material's collection for energy purposes.

Map 48 illustrates the dispersion of vine cultures mostly in the northern part of the regions. Fruit tree plantations are more dispersed and the potential amount of residues is considerably smaller compared to vineyard biomass, presented on Map 49. As mentioned in the previous section, the area of orchards and vineyards is likely to increase over the next 10-year period, so the biomass potential will follow this trend. With respect to the complexity of logistical constraints linked to the transport of lignocellulosic residues, a local assessment and guidance are required to enhance their sustainable mobilization and utilization.

4.4 Bioenergy Potential in the Provence-Alpes-Côte d'Azur

In France, at the national level, biomass plays only a minor role in electricity generation compared to wind and hydro energy. However, biomass is expected to account for 11% (1475 ktoe) of the total amount of electricity generated from RES in the country by 2020. The biomass will mainly be employed in biomass incineration plants and biogas plants (then generating 22% of the national RES electricity production) (NREAP 2010b).

In 2009, collaborating with the French Environment and Energy Management Agency (ADEME) and the Regional Council of PACA, the Regional Directorate of Industry and Research of the Region of Provence-Alpes-Côte d'Azur launched a study to assess the potential of biomass from agriculture as well as from the food and material processing industry (Chailan, Bourgade et al. 2009). Based on the status quo of different biomass resources, an outlook was drawn up for the biomass mobilization and utilization potential in the two main sectors: combustion and digestion. The following assessment refers to and complements the study carried out by Chailan, Bourgade et al. (2009).

4.4.1 Status Quo of Biomass Usage in the Region of Provence-Alpes-Côte d'Azur

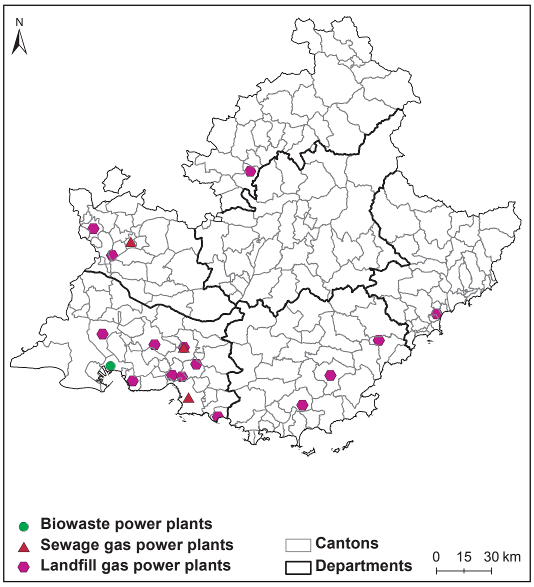
As previously mentioned, France has developed its biofuel market and is currently the European leader in biofuel production (ADEME 2010). For the production of biodiesel, rapeseed oil (87% of total production) and sunflowers (7%) are primarily used and for the production of ethanol, wheat and sugar beets (Delphine, Tyner et al. 2009). The area of arable land in France dedicated to energy crops is outlined in Table 71. For the second generation biofuels, which are to appear in France in 2017, lignocellulosic materials will replace traditional crops. Currently this biomass market is still underdeveloped, as only about 1500 ha of SRC have been established so far and plantations of herbaceous plants (reed canary grass, switch grass, miscanthus) are negligible (NREAP 2010b). The Region of PACA is characterized by Mediterranean agro-climatic conditions and is therefore neither suitable for cropping perennial grasses like miscanthus or switch grass nor for cultivating perennial coppices like willow. In fact, all trials for their adoption have so far failed (Chailan, Bourgade et al. 2009).

Compared to neighboring countries, biogas production in France is underdeveloped. By the end of 2009 there were around 20 on-farm agricultural biogas plants in France (average capacity 150 kWh), 88 industrial biogas plants, 74 biogas digester units at wastewater treatment plants which recover methane, 301 plants on landfill sites and 6 municipal digested biowastes located foremost within dense urbanized areas. In 2009 there were no agricultural biogas plants in the Region of PACA, but 17 plants on landfill sites, 4 on water treatment sites and one biowaste feeding biogas plant as shown on Map 50.

Table 71: Cultivated Areas in ha Dedicated to Energy Crops in France in 2008

Energy Crops	Main Sector of Use	Area [ha]
Plants for Biodiesel (Rapeseed Exempted)	Transport Sector	514000
Plants for Biodiesel (Sunflower Exempted)	Transport Sector	26000
Plants for Bioethanol (Wheat)	Transport Sector	4200
Plants for Bioethanol (Sugar Beet)	Transport Sector	22433
Plants for Biogas (Maize)	Heat and Electricity Sectors	302
Short Rotation Coppice and Energy Grasses (Willow, Poplar, Miscanthus, Switchgrass)	Heat and Electricity Sectors	1560
Total		568495

Source: CETIOM (2010); INRA (2010)



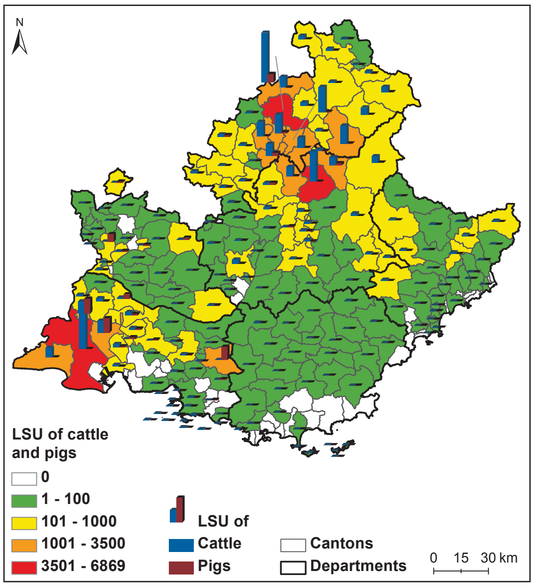
Map 50: Biogas Power Plants in the Region of PACA in 2009

4.4.2 Potential of Bio-Residues in the Region of PACA

In this section, animal waste and straw from cereals were the objects of analysis. The assessment was carried out at the canton level based on the French Agricultural Census of 2000. Data at the communal level was not considered due to a lack of figures in some communes, owing to data protection protocols.

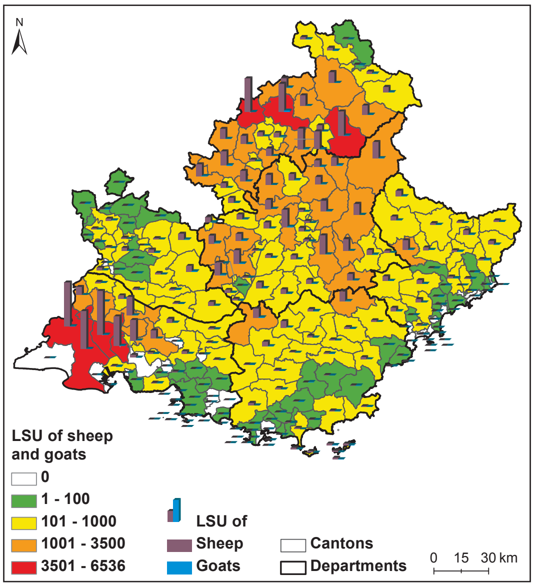
4.4.2.1 Livestock Manure

In the Provence-Alpes-Côte d'Azur region, sheep dominate among the livestock units followed by cattle. In the departments of Hautes-Alpes and Alpes-de-Haute-Provence, livestock holdings are located amid mountainous terrain (above 800 m above sea level) in the majority of cases, whereas for the department of Bouches-du-Rhone, they are located in lowland areas (compare Map 51 - Map 54 and Table 72).



Map 51: Livestock Units of Cattle and Pigs per Cantons in 2000

Source: Based on Agreste (2000)

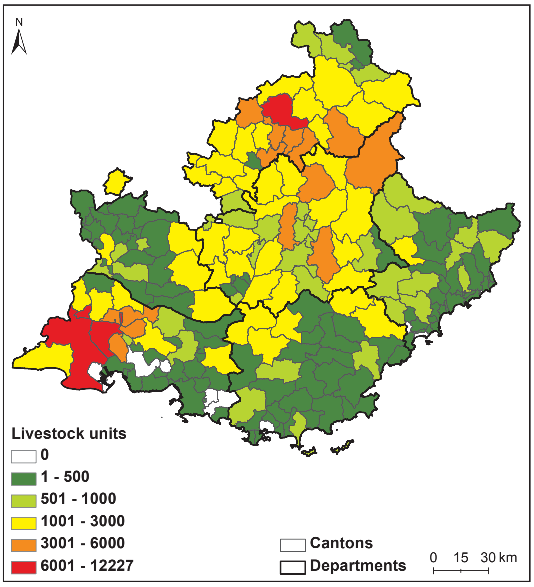


Map 52: Livestock Units Sheep and Goats per Cantons in 2000

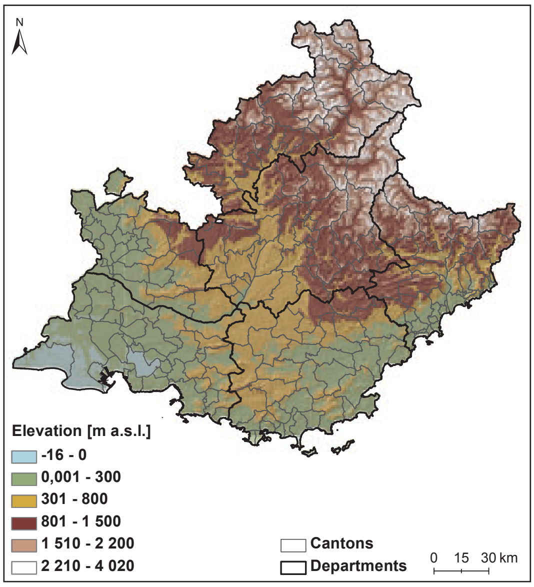
Source: Based on Agreste (2000)

The manure availability of sheep, goats and cattle depends on their grazing time; within the grazing period, animal wastes are returned directly to the ground. Moreover, the solid manure recovered is spread on agricultural land as fertilizer, and some of the sheep manure and poultry litter are bought by companies to produce compost, which is often exported outside the region (Chailan, Bourgade et al. 2009). Information on the size and structure of animal farms was not available when this study was compiled, thus the factor of manure recovery was related to the housing period and divided by half of the population (see Table 72).

To calculate the potential for biogas from animal manure, livestock data was extracted from the French Agricultural Census conducted in 2000 and converted into livestock units according to the LSU indices (Vilain 2008).



Map 53: Livestock Units of Cattle, Pigs, Sheep, Goats, Horses and Poultry per Cantons in 2000
Source: Based on Agreste (2000)



Map 54: Elevation in m Above Sea Level in the Region of PACA
Source: Based on NASA (2009)

4.4.2.1.1 Biogas Technical Potential

Based on the indicators derived from the literature (Kaltschmitt and Hartmann 2001; FNR 2009) and outlined in Table 73, the gross energy content of animal wastes was calculated as follows:

$$Ew = \frac{AW * AR * B * 0.55 * 9.17 * Af}{1000} \qquad (28)$$

where Ew is the gross energy content of animal manure in MWh, AW is the quantity of animal manure in t, AR is the volatile solid of animal wastes outlined in Table 73, B is the biogas content in VS, Af is the availability factor.

The gross energy content of animal by-products utilized in biogas plants in the PACA region amounts to 117 GWh/y. The corresponding spatial deployment at the canton level is illustrated on Map 55. One third of the gross energy can be produced on sheep farms and the same amount on dairy farms, while the contribution of horse and goat manure to energy production accounts for 1% of the calculated amount. One third of the overall biogas potential is located in the department of Hautes-Alpes (see Table 74). Map 55 reveals that around 25% of the total manure energy content is located in the three cantons of Valreas (the Vaucluse department), particularly based on poultry litter, Arles (in the delta of the Rhône in the department of Bouches-du-Rhone), where cattle waste dominates, and in Saint-Bonnet en Champsaur (in the department of Hautes-Alpes), where sheep manure dominates.

As previously mentioned, the problems regarding the consistent quality and supply of biogas feedstock are overcome in practice by adding co-substrates, which in France are bio-waste from the food processing industry and a few percent mass of energy crops. In this study, the biogas potential was calculated based on the feedstock-mix of animal manure and the two co-substrate alternatives maize silage and grass silage accounting for 30% of the mass weight. The gross energy content of biogas was calculated as follows:

$$Em = \frac{Ew + DM * oDM * B * 0.55 * 9.17}{1000} \qquad (29)$$

where Em is the gross energy content of biogas in MWh, Ew is the gross energy content of animal manure calculated according to Eq. 28, DM is the dry matter and oDM is the organic dry matter of co-substrates in %, B is the biogas content in oDM.

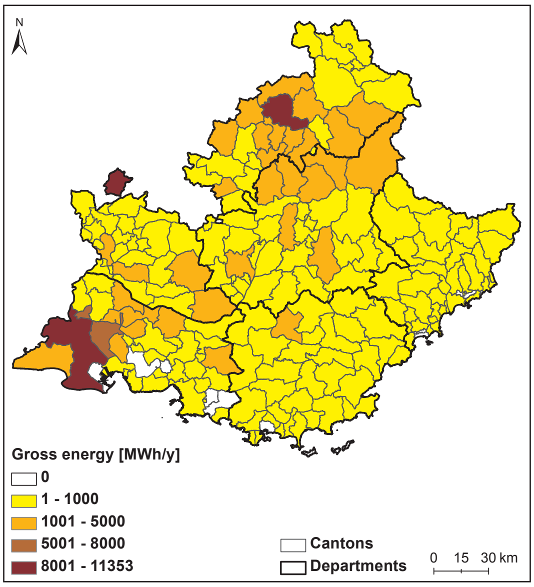
To simplify the calculation, the following assumption was made: 30% of DM, 94% of oDM, 500 m^3 of biogas/oDM. Biogas feedstock mixture like this allows the potential of biogas to increase from 117 GWh to 298 GWh generated through a power

Table 72: Animal Population and its Equivalent in Livestock Units per Department in 2000

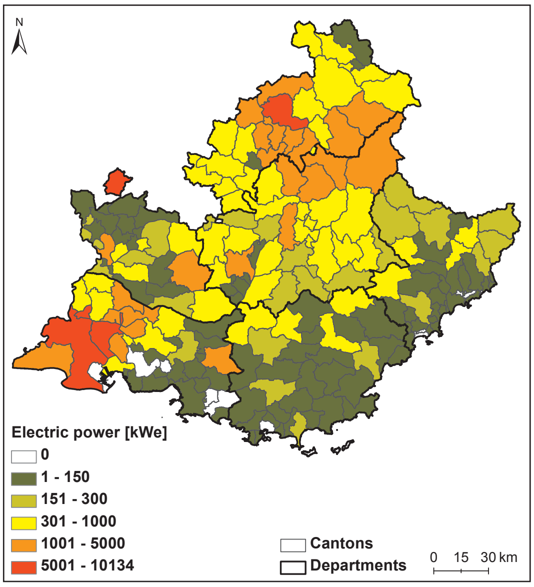
	Department	Cattle	Pigs	Horses	Sheep	Goats	Poultry*
		Livestock Population					
04	Alpes-de-Haute-Provence	12763	6192	1755	238732	8749	344339
05	Hautes-Alpes	33971	13058	2045	289469	5775	55767
06	Alpes-Maritimes	1512	216	990	58067	5681	88039
13	Bouches-du-Rhône	13936	25490	3974	209448	2906	255792
83	Var	399	476	2834	55060	5284	348859
84	Vaucluse	630	9108	1548	35671	3148	536855
	PACA	63211	54540	13146	886447	31543	720399
	Share in Total [%]	3	3	1	43	2	48
		Livestock Unit					
04	Alpes-de-Haute-Provence	9109	922	1324	33495	1393	429
05	Hautes-Alpes	23690	1986	1600	39337	902	248
06	Alpes-Maritimes	1205	42	730	8622	890	77
13	Bouches-du-Rhône	10225	4804	2981	28660	455	1105
83	Var	285	62	2047	8134	811	509
84	Vaucluse	448	1477	1149	5158	497	3443
	PACA	35852	8370	8507	89911	3557	5812
	Share in Total LSU [%]	23	5	5	62	2	3
	Availability Factor (Af)	0.4	0.6	0.1	0.2	0.2	0.5

* Including only laying hens, chickens and boiler chickens from the population of 1634000 poultry

Source: Agreste (2000)



Map 55: Gross Energy Content of Animal Manure per Cantons in 2000



Map 56: Electric Power Capacity Based on Manure and Co-Substrates per Cantons

capacity of 110 MW_e[11]. Map 56 shows the spatial deployment of electric power capacity generated by the mix of substrates. Nonetheless, a similar increase in biogas production would lead to a replacement of the farmland patterns. Considering for instance only grass silage, the area potentially demanded for co-substrate cultivation would be 8257 ha of grassland[12], which is 2.6% of the total permanent

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[11] Calculation is based on a load factor of 7500 hours per year and an electrical efficiency of 36%

[12] Yield of grass silage assumed at 25 t/ha

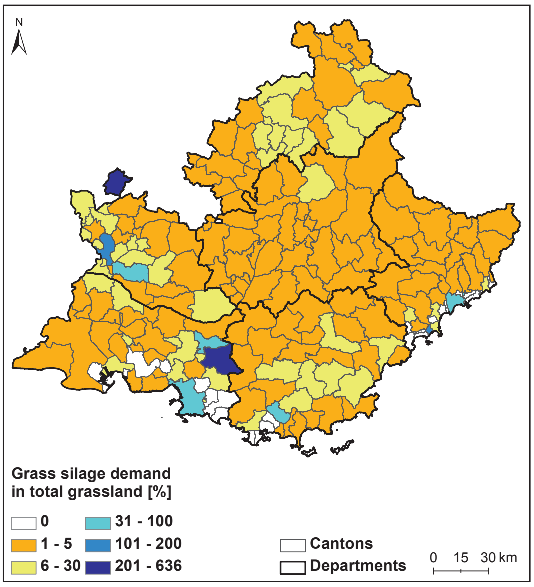
Table 73: Manure Characteristics and Biogas Yield from Animal Residues

	Cattle Manure	Pig Manure	Poultry Litter	Horse Manure	Sheep and Goat Manure
t/LSU*y	17	12	8	3	3
t DM/LSU*y	1.7	0.84	3	1	1
t VS/LSU*y	1.4	0.7	2.6	0.8	0.8
Biogas in m^3/t VS	320	400	400	400	400

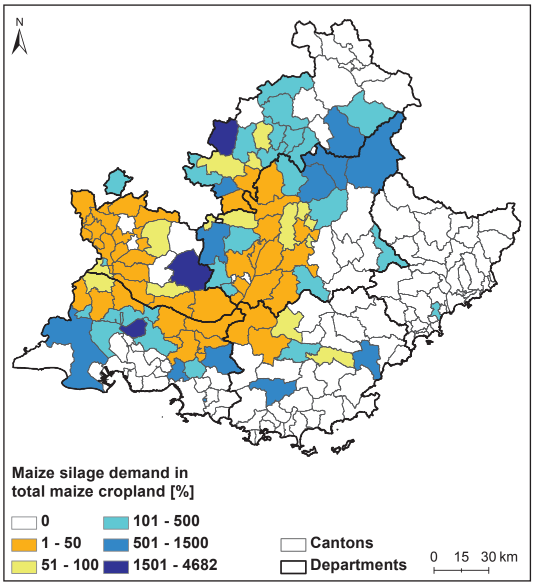
Table 74: Annual Gross Energy Content of Animal By-Products in MWh in 2000

Department	Cattle	Pigs	Horses	Sheep	Goats	Poultry	Total
Alpes-de-Haute-Provence	21411	1683	258	10812	450	2046	20836
Hautes-Alpes	1089	35	118	12697	291	650	36991
Alpes-Maritimes	9241	4070	481	2783	287	369	4682
Bouches-du-Rhône	257	52	330	9251	147	5268	28459
Var	405	1251	186	2626	262	2429	5956
Vaucluse	8233	782	214	1665	161	16418	20085
PACA	40636	7874	1587	39834	1598	25481	117009
Share in Total [%]	35	7	1	34	1	22	100

Source: Own Calculation Based on Agreste (2000)



Map 57: Demand for Grass Silage in Total Permanent Grassland per Cantons



Map 58: Demand for Maize Silage in Total Maize Cropland per Cantons

grassland available in the PACA region. Under those assumptions, the findings show that, particularly at the canton level, the share of grassland dedicated to anaerobic digestion could vary between 1 to 5%. In four cantons, the demand for pasture land exceed the supply up to six fold as illustrated on Map 57. In case of maize silage, the potential demand for biogas generation made up 75% of the region's total maize cropland[13] in 2000, and in 2006 even exceeded the available maize acreage by 40% (compare with Table 78). Map 58 shows that in 39 cantons of the PACA Region, this assumed scenario would lead to a replacement of surfaces currently used as cropland. As maize crops are predominantly grown for fodder production, each attempt to utilize them

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[13] Yield of maize silage assumed at 40 t/ha

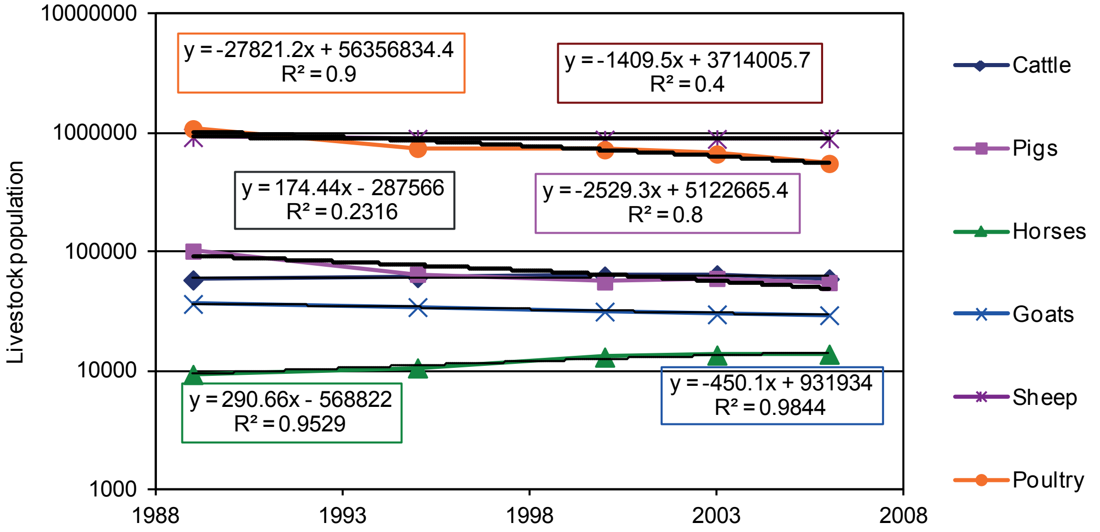


Figure 40: Historical Trend in the Livestock Population in the PACA Region from 1989 to 2006

Table 75: Historical Data on Livestock Population and Outlook for the Year 2020

Years	Cattle	Pigs	Horses	Sheep	Goats	Poultry
1989	58169	101607	9346	920590	36571	1084000
1995	60968	64933	10607	894500	34402	742000
2000	62700	56003	13085	879500	31550	722000
2003	64200	59923	13605	891415	29910	665000
2006	59359	55244	13837	898504	29405	554000
Change 2006/1989	2.0	-45.6	48.1	-2.4	-19.6	-48.9
Change 2006/2000	-5.3	-1.4	5.7	2.2	-6.8	-23.3
Outlook 2020	64803	13479	18311	866816	22732	158010
Change 2020/2006	9.2	-75.6	32.3	-3.5	-22.7	-71.5

Source: Based on Agreste (2009a)

in anaerobic digesters will increase the pressure on land use.

To obtain a better insight into the present and future potential of the animal population, and together with it, the potential of manure and biogas production, historical and current data recorded at the department level was studied. The assessment performed on the basis of the 2000 census data is overestimated, because the number of livestock has dropped ever since, that is by 25% for poultry, 5.3% for cattle and 1.4% for pigs. The linear regression curves plotted for historical data on animal population (see Figure 40) allows for the assumption that cattle and horse populations are likely to increase by 9% and 32% respectively, while the number of sheep will probably have dropped slightly by 2020. In contrast, pig and poultry populations will decrease by two-thirds (Table 75). It should be noted that the R-squared is quite low for both regression functions in the case of cattle and sheep, which affects the findings.

4.4.2.1.2 Biogas Economic Potential

In 2010, on behalf of the French Ministry of Environment, the French Environment and Energy Management Agency (ADEME) carried out a study on the economic viability of agricultural biogas plants in France and recommended increasing the electricity tariffs for biogas up to 170 €/MWh and to put up the heat recovery premium from 30 € at present to 50 €/MWh, so as to raise the economic attractiveness of biogas plants. Going even further, the French association of biogas-producing farmers (AAMF) calls for the introduction of the German support mechanism model providing for an increase in premiums to a total price of up to 260 €/MWh (Klinkert 2010).

In this study, a cost-benefit assessment was carried out for three exemplary on-farm biogas plants in the PACA region with 150, 500 and 2000 kWh of power capacity. Regarding the investment costs for technologies and relevant annual costs, the analysis was based on the assumptions already postulated for the Polish case study. The plant was annuitized for 15 years at a discount rate of 4%. To assess the economic viability of the exemplary power plants, two cases of biogas feedstock were considered: firstly, only manure and secondly, manure and co-substrates composing 30% of the mass (namely a 50 - 50 equal share of maize silage and grass silage). The power capacity of 2000 kW was only analyzed in connection with the second option, manure and co-substrates. Two options of co-substrate costs were taken into account: 20 €/t and 30 €/t. Finally, it was hypothesized that there were no transport costs for on-farm plants. The revenues brought by the on-farm biogas plants are made up of (i) the electricity price, which depends on the power capacity as outlined in Table 76, (ii) the bonus for energy efficiency related to the plants' energy efficiency and (iii) an average heat price of 25 €/MWh. The annual revenue was calculated through the formula:

$$\begin{aligned} Re = (&En*(FIT+EEB)*15+ \\ &En*MP*5+Hn*H*P*20)/ \\ &(Ee+Eh)*20 \end{aligned} \tag{30}$$

where Re is the annual revenue per energy unit generated from biogas in €/MWh, En is the net energy fed into the power grid (95%, as 5% of energy is used by AD plants), FIT is the base payment related to the power capacity, EEF is the bonus payment related also to energy efficiency, MP is the market price of electricity set at 60 €/MWh (Powernext 2010) obtained over the last 5 years of a power plant's economic lifetime, HP is the heat price and Hn is the net heat (90%, as 10% is used by AD) sold on the market.

The overall revenue achieved was divided by the sum of gross electricity and heat produced. As the FIT is guaranteed only for 15 years, in the last 5 years the electricity can be sold on the market at an average purchase price of 60 €/MWh on the French electricity market (Powernext 2010). In addition, the ADEME offers investment grants covering up to 30% of the investment sum up to a maximum amount of 10 M€, while the French Ministry of Agriculture supports on-farm AD projects with up to 375 k€ per year.

Figure 41 illustrates the maximum revenues (heat sold and EE bonus) and minimum revenues (without EE bonus and no heat sold) as well as different cost options for the three analyzed power plants. Without selling heat, the 150 kW biogas plant would not bring any profits, even with subsidies offered to offset some of the investment costs. The biogas plant is also not profitable without being subsidized at the maximum revenue level (electricity and heat) while feeding with co-substrates. Even with the investment subsidized at 30% for the option with co-substrates at the acquisition price of 30 €/t, the small biogas plant is below the threshold of profitability. Thus, already-operating agricultural on-farm biogas plants of an average 150 kWe power capacity were not fed with energy crops (Bastide and Theobald 2010). Due to the effect of scale, economic feasibility is achieved for biogas plants with a power capacity above 150 kW. However, without selling heat, the power plant of 500 kWe would not

Table 76: Feed-in Tariffs in 2010 in France and Revenues of Exemplary Biogas Plants

Power	P ≤ 150 kW	150 kW < P ≤ 2 MW	P > 2 MW
Feed-in Tariff [ct/kWh$_e$]	9.4551	FIT =-0.0009*P[kW]+9.5832	7.875
AD Bonus	2.1	2.1	2.1
EE Bonus	0 c€/kWhe (V ≤ 40%)	EE=0.09*eff [%]-3.6	-3.15 c€/kWhe (V ≥ 75%)
Revenues			
Power [kW$_e$]	150	500	2000
Min [€/MWh]	115.6	112.3	99.7
Max [€/MWh]	147.0	143.8	131.2

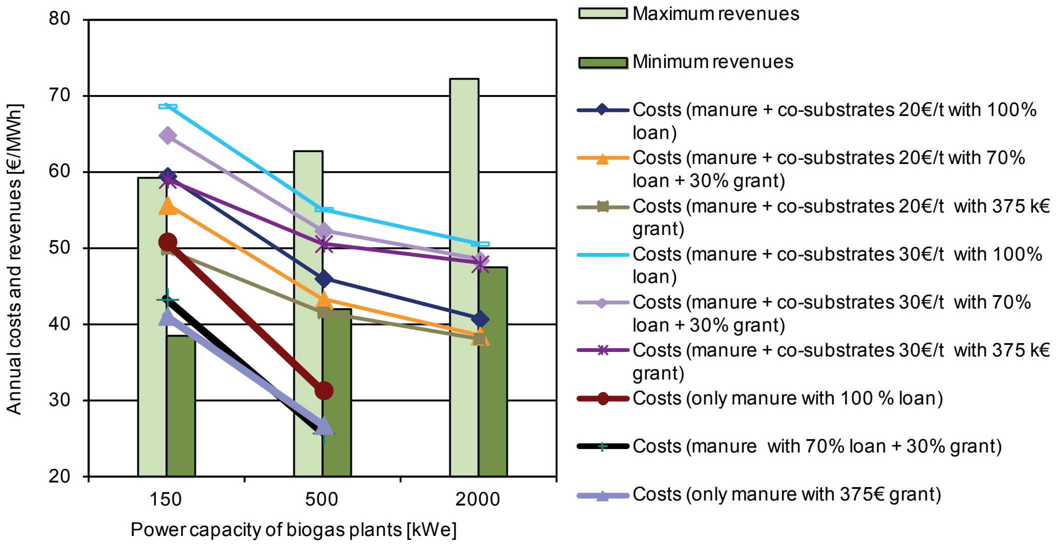


Figure 41: Annual Revenues and Costs Depending on Biogas Feedstock Costs and Power Capacity. Annuity over 15 Years at Interest Rate of 4%

be profitable in any biogas feedstock-mix scenario. At the average price of 20 € or 30 € for 1 ton of maize silage, the economic viability of plants with a power capacity of 500 kWe is questionable unless some additional subsidies are granted.

Aside from the described support scheme, the experience in France has shown that biogas plants are fed with co-substrates like bio-waste or green waste and other residues from industry in order to increase biogas performance and decrease the co-substrate costs. Bio-waste treatment in AD offers a chance to make an additional income of between 30 €/t and 70 €/t from the disposal of waste-digestion by-products (Bastide and Theobald 2010).

The option of gas injection into the grid was not considered, because at the time this study was conducted, the legal basis in France was yet to be resolved.

4.4.2.2 Agricultural Production

Concerning the agricultural land of the PACA region, the French national statistical data on land use published by Agreste (2009e) provides information on its extension and changes in use for the period from 1995 to 2006 (see Table 77). Agricultural land is divided between arable land (22%), permanent grassland (36%), vineyards (10%) and orchards (5%). While the total surface of agricultural land, particularly permanent grassland and orchard areas, drops in the decade between 1995 and 2006, the share of non-agricultural land increases. This trend is expected to continue over the following decades (2007 - 2018).

The area of vineyards and orchards can be considered in the context of potential biomass sources. The PACA region is the leading French producer of table grapes, which has a significant social impact in terms of labor demand, given that they are harvested solely by hand. The growing area of table grapes is quite stable, while the declining demand for French wine worldwide has been reflected in the decreasing area of vineyards across France. Basic cereal grain fields cover around 43% of the total arable land in the PACA region, a share which varies from 4% in Alpes-Maritimes to 56% in the Bouches-du-Rhône department. Around 5% of the farmland was dedicated to rapeseed oil crops. As outlined in Table 78, durum wheat (61% of cereal area) followed by barley and bread wheat were the most common cereals grown in PACA between 1995 and 2006. Besides cereals, vegetables and temporary grassland, arable land is dedicated to crops for the perfumery industry, textiles and material production. As the straw potential was estimated in this study at the canton level of the PACA region based on the 2000 Agricultural Census, the cropland changes at the regional level were analyzed to learn about the prospects for the current and future potential of straw. The latest data on the cropland area in the PACA region, which is reported for 2006

Table 77: Land Use in ha and its Changes in % between 1995 and 2006

	Agricultural Land						
		Arable Land					
Years	Total	Total	Temporary Grassland	Permanent Grassland	Vineyards	Orchards	Non-Agricultural Land
	Provence-Alpes-Côte d'Azur						
1995	1036606	236292	43796	396735	104222	49602	689683
2000	1026997	233099	42365	363515	101119	43442	705847
2006	996243	220789	43287	350128	102457	42211	727930
2006/1995	-4	-7	-1	-12	-2	-15	6
	Alpes-de-Haute-Provence						
1995	275592	65214	15350	109277	1100	3997	114903
2000	272602	65803	14700	93514	1050	4124	115300
2006	244837	61969	15180	82785	916	3848	118020
2006/1995	-11	-5	-1	-24	-17	-4	3
	Hautes-Alpes						
1995	249671	33295	18005	140750	205	3229	134038
2000	252871	33808	18935	140750	160	2970	133810
2006	249056	32413	19000	141750	164	2717	137942
2006/1995	0	-3	6	1	-20	-16	3
	Alpes-Maritimes						
1995	110517	2862	905	34453	166	1395	77209
2000	103898	2172	640	30907	146	1920	81878
2006	102634	1825	637	31153	138	2010	81074
2006/1995	-7	-36	-30	-10	-17	44	5
	Bouches-du-Rhône						
1995	172499	71665	4150	78670	12155	20147	207369
2000	171590	67699	3260	65120	11613	16647	209914
2006	159988	63134	3550	61790	11545	17175	220744
2006/1995	-7	-12	-14	-21	-5	-15	6
	Var						
1995	94317	18996	2386	18110	33896	5479	84810
2000	93770	18797	2380	17610	31870	5209	90609
2006	104333	18415	2500	17400	32027	5301	92932
2006/1995	11	-3	5	-4	-6	-3	10
	Vaucluse						
1995	134010	44260	3000	15475	56700	15355	71354
2000	132266	44820	2450	15614	56280	12572	74336
2006	129364	43033	2420	15250	57667	11160	77218
2006/1995	-3	-3	-19	-1	2	-27	8

Source: Agreste (2009e)

at the department level (see Table 79), shows that changes in the cultivated area of individual cereals observed at regional level differ from those observed in six departments.

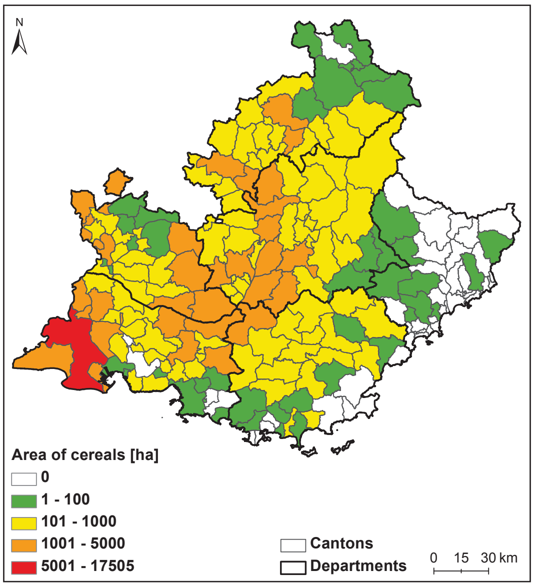
Apart from rye and oats (characterized by low pedoclimatic requirements), the cropping area of other cereals, namely maize and rapeseed oil crop, has dropped by almost half in the period from 2000 - 2006. The turnover after 2000 has mainly been determined by three factors: yield performance, sales price and subsidy payments. Due to its unfavorable pedoclimatic conditions, the PACA region is unlike others in central France where crops are dedicated to biodiesel and bioethanol production. For instance, high temperatures and rainfall scarcity make attractive returns from the cultivation of rapeseed and sunflowers impossible (Chailan, Bourgade et al. 2009; Dworak, Elbersen et al. 2009; Elbersen, Startisky et al. 2010). Particularly in the case of rapeseed oil crops, wind conditions strongly affect the yield performance (Chailan, Bourgade et al. 2009), so that in the PACA region, the profits from rapeseed oil crops are lower than those obtained from other cereals.

The heterogeneity in the drop of cropland areas observed across different French regions also results from the subsidies paid to durum wheat (around 71 - 111 €/ha depending on the region) and to rice (411 €/ha in Bouches Rhone) which are comparatively higher than those paid to crops in other regions. Therefore, the future crop-mix in PACA will mainly depend on the agricultural support scheme and the crop prices. In this context, the promising straw potential in the PACA region is due to durum wheat production. 25% of the total durum wheat area of 62560 ha (59720 ha in 2006, corresponding to 14% of the cereal area) is concentrated in the Rhône delta and the Durance valley (in the three cantons

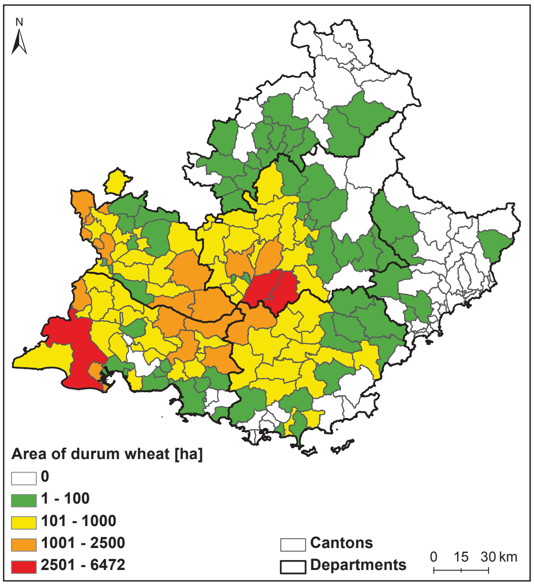
Table 78: Crop Production and Changes in the Cultivation Structure between 1995 and 2006 in the PACA Region

Years	Bread Wheat	Durum Wheat	Rye	Barley	Oat	Maize	Rice	Total Cereals	Rapeseed Oil	Sun-flower	Oilseed Crops
	Area [ha]										
1995	11734	51171	341	12625	1713	7450	18980	107396	3770	8040	12509
2000	7697	62560	415	10110	1625	6951	13840	107373	4667	9380	15003
2006	4705	59720	440	8940	1992	3625	11760	96456	2445	6365	8978
	Change [%]										
2000/ 1995	-34	22	22	-20	-5	-7	-27	0	24	17	20
2006/ 2000	-39	-5	6	-12	23	-48	-15	-10	-48	-32	-40
	Share in Arable Land [%]										
1995	5	22	0.1	5	0.7	3.2	8	45	1.6	3	5
2000	3.3	27	0.2	4	0.7	3	6	46	2	4	6
2006	2.1	27	0.2	4	0.9	1.6	5	44	1.1	3	4

Source: Agreste (2009c)



Map 59: Surface of Cereals Grown per Cantons in 2000
Source: Based on Agreste (2000)



Map 60: Share of Durum Wheat in Total Area of Cereals
Source: Based on Agreste (2000)

Table 79: Quantitative Changes in Crop Production [ha] in Six Departments of the PACA Region between 1995 and 2006

Years	Bread Wheat	Durum Wheat	Rye	Barley	Oat	Maize	Rice	Total Cereals	Rape-seed	Sun-flower	Oilseed Crops
	Area in Alpes-de-Haute-Provence [ha]										
1995	3200	15790	110	4230	470	3165	0	28005	1145	350	1795
2000	2100	19750	100	3200	400	2750	0	29650	1200	1100	2655
2006	1300	17500	135	3340	450	1270	0	25190	690	930	1755
	Change [%]										
2000/1995	-34	25	-9	-24	-15	-13		6	5	214	48
2006/2000	-38	-11	35	4	13	-54		-15	-43	-15	-34
	Area in Hautes-Alpes [ha]										
1995	3260	140	110	5525	980	475	0	12065	175	150	375
2000	2890	425	120	4780	930	320	0	11320	270	280	813
2006	1940	285	180	3800	1350	304	0	10368	30	180	225
	Change [%]										
2000/1995	-11	204	9	-13	-5	-33		-6	54	87	117
2006/2000	-33	-33	50	-21	45	-5		-8	-89	-36	-72
	Area in Alpes-Maritimes [ha]										
1995	44	15	6	120	50	3	0	278	0	0	0
2000	22	5	5	90	25	1	0	178	0	0	0
2006	15	0	0	30	2	0	0	62	0	0	0
	Change [%]										
2000/1995	-50	-67	-17	-25	-50	-67		-36			
2006/2000	-32	-100	-100	-67	-92	-100		-65			
	Area in Bouches-du-Rhône [ha]										
1995	610	18590	50	840	110	1870	18980	41320	880	3730	4874
2000	400	22380	10	600	130	1880	13840	39510	1750	3530	5540
2006	340	21670	5	310	30	830	11760	35335	740	2190	2935
	Change [%]										
2000/1995	-34	20	-80	-29	18	1	-27	-4	99	-5	14
2006/2000	-15	-3	-50	-48	-77	-56	-15	-11	-58	-38	-47
	Area in Var [ha]										
1995	520	6036	15	710	53	842	0	8283	370	210	630
2000	315	6800	20	490	60	700	0	8605	587	330	960
2006	300	5975	20	360	60	280	0	7505	200	435	635
	Change [%]										
2000/1995	-39	13	33	-31	13	-17		4	59	57	52
2006/2000	-5	-12	0	-27	0	-60		-13	-66	32	-34
	Area in Vaucluse [ha]										
1995	4100	10600	50	1200	50	1095	0	17445	1200	3600	4835
2000	1970	13200	160	950	80	1300	0	18110	860	4140	5035
2006	810	14290	100	1100	100	941	0	17996	785	2630	3428
	Change [%]										
2000/1995	-52	25	220	-21	60	19		4	-28	15	4
2006/2000	-59	8	-38	16	25	-28		-1	-9	-36	-32

Source: Agreste (2009c)

of Arles, Riez and Valensole), as shown on Map 60. Since 2000, the area of durum wheat has mainly increased in the three mountainous departments of Alpes-de-Haute-Provence, Hautes-Alpes and Alpes-Maritimes (see Table 79). In those departments, the largest share of arable land is dedicated to animal fodder, barley and oats, the straw of which is recovered for animal bedding and more rarely for animal feed (Chailan, Bourgade et al. 2009).

4.4.2.3 Cereal By-Products

As with the previous Polish and Germany case studies, the amount of cereal straw was estimated from the residue-to-grain ratio based on the statistics on cereals' yield and cereal-sown areas. The yield of wheat is strongly influenced by irrigation facilities and may reach around 5-6 tons of grain per hectare, while without irrigation, around 3 tons of grain may be harvested (Agreste 2009c). The average grain yield per department varies from 35 to 42 dt/y (see Table 80). Currently, durum wheat straws are either buried or exported so that it is impossible to define its amounts exactly (Chailan, Bourgade et al. 2009).

Beyond conventional cereals, rice occupied more than one third of arable land in the Bouches-du-Rhône department and accounted for 70% of French national rice production with a yield of 85808 tons in the year 2000. Compared to other cereals, rice straw has different components (50% cellulose, 25% hemicelluloses, 10% lignin and 15% water), meaning it is slow to biodegrade in soil and of lower absorbance. Thus, it is not used for animal bedding. In practice, the residue is burnt on the fields after harvesting (Chailan, Bourgade et al. 2009). The removal rate of residues is related to the amount of residues left on the field, which depends

Table 80: Average Ratio of Grain-to-Residue and Grain Yield in dt/ha

Grain to Straw	Bread Wheat	Durum Wheat	Rye	Barley	Oat	Sorghum	Triticale	Rice	Total Cereals
(1:x)	0.8	0.9	0.9	0.7	1.1	1	1	0.7	
Departments	Grain Yield [dt/ha]								
Alpes-de-Haute-Provence	42	35	35	44	28	51	42	0	43
Hautes-Alpes	44	42	35	38	30	55	55	0	43
Alpes-Maritimes	38	38	30	40	30	0	40	0	38
Bouches-du-Rhône	42	40	25	40	25	50	40	62	49
Vaucluse	34	38	24	42	22	52	30	0	40
PACA	41	37	30	40	29	51	49	62	44

Source: Agreste (2009c)

Table 81: Net Straw Residues in t per Department and their Availability Factor

	Bread Wheat	Durum Wheat	Rye	Barley	Oat	Sorghum	Triticale	Rice	Total Cereals
Removal Rate	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.1	
Departments	Straw Production [t]								
Alpes-de-Haute-Provence	3940	42605	168	6563	748	184	2787	0	56994
Hautes-Alpes	7072	1132	271	8884	2175	73	6915	0	26523
Alpes-Maritimes	4	9	0	18	6	0	8	0	45
Bouches-du-Rhône	946	56398	17	1190	258	739	134	52331	112011
Vaucluse	701	14722	38	964	100	217	196	0	16939
PACA	16444	146619	693	19541	3417	2139	10248	52331	251432
Share [%]	7	58	0	8	1	1	4	21	

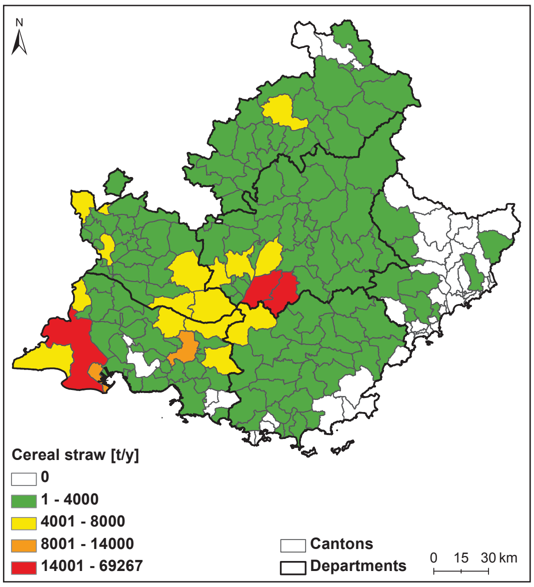
amongst other aspects on crop rotation, existing soil fertility and tillage practices (Delphine, Tyner et al. 2009). Studies carried out by the Institut National de Recherche Agronomique (INRA) found that the average removal rate in France was around 33% (Protin 2007; IWU 2010). Based on this factor, the net amount of straw (70%) produced in the PACA region was 251432 tons, made up of 70% durum wheat and rice residues (see Table 81).

Apart from the removal factor, a certain quantity of straw is used for animal bedding. For estimating the straw potential at the canton level, the same indices on straw for bedding as in the Stuttgart Region was applied to the algorithm, as the figures for France had not been made available. From the total amount of 342576 tons of cereal straw, 91144 tons were excluded for soil fertilizing and 132253 tons for animal housing (see Table 82). The potential surplus of the biomass is 119179 tons, which is 35% of the gross production in 2000. This gross amount of cereal by-products varies from canton to canton as presented on Map 61, while the deployment of the potential surplus was illustrated on Map 62.

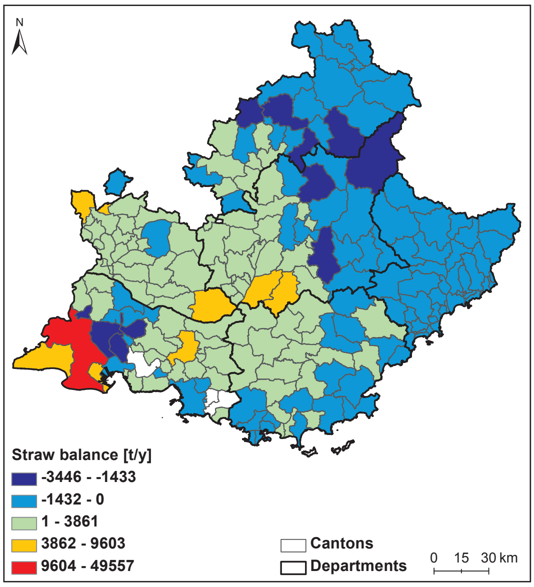
The straw balance is negative in 98 cantons of the PACA region, lacking 51373 tons of harvest residues, principally in the departments of Alpes-de-Haute-Provence and Hautes-Alpes, characterized by a large population of production animals (see Map 53) but a low area of cropland (see Map 59). In 87 cantons the straw surplus amounts to 171242 tons, of which almost 30% is produced in the canton of Arles (Bouches-du-Rhône) and 27% in 7 other cantons. With respect to the mobilization constraints and economic point of view, the potential uses of straw residue would theoretically be considered in those eight cantons.

Table 82: Projected Annual Demand for Straw in t for Animal Bedding

Straw for Bedding [t/LSU*y]	Cattle	Pigs	Horses	Sheep	Goats	Poultry	Total
	0.6	0.4	0.6	0.7	0.7	1	
Departments	Straw for Bedding [t/y]						
Alpes-de-Haute-Provence	5466	369	794	23446	975	429	31480
Hautes-Alpes	14214	795	960	27536	632	248	44384
Alpes-Maritimes	723	17	438	6035	623	77	7913
Bouches-du-Rhône	6135	1921	1789	20062	319	1105	31331
Var	171	25	1228	5694	568	509	8195
Vaucluse	269	591	690	3611	348	3443	8951
PACA	26977	3717	5899	86384	3465	5812	132253



Map 61: Cereals' Straw per Cantons in 2000



Map 62: Balance of Cereals' Straw per Cantons in 2000

4.4.3 Woody Biomass Potential in the Region of PACA

In the PACA region, the forest area covers 1.3 Mha with a forestation rate of 42% of the territory (the second most forested French region). The forest volume grows each year by up to 3% with an annual production of 3.6 Mm^3 in the region (Ninon, Guibaud et al. 2009).

Amongst all biomass sources, wood is the main energy feedstock, consumed particularly in households for heat production (Agreste 2007). Around 0.75 Mm^3 of wood are used per year for heating in the PACA region, divided between firewood, timber and industrial wood. Of this amount, 0.15 Mm^3 of logs are used mainly for domestic heating (see Map 63). Currently, the consumption of wood in forest wood boilers amounts to 3500 GWh/y, but by 2013 the annual demand for fuel wood for local boilers is expected to increase to 10000 GWh/y (Ninon, Guibaud et al. 2009).

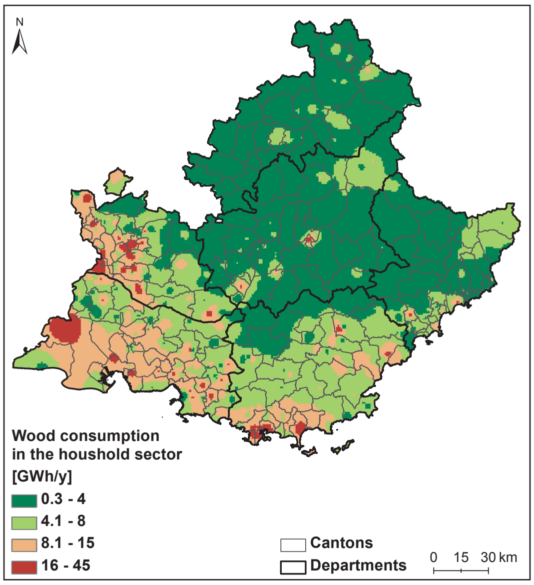
- Wood from Forests

The potential of forestry biomass was studied by ADEME, Solagro et al. (2004) and Levesque, Vallet et al. (2007). ADEME considered the potential of wood residues assuming an intensified forest exploitation (55% of wood increment) as well as the mobilization potential of wood depending on accessibility to the forest land. The total wood potential evaluated for the PACA region was estimated at 1.7 Mm^3/y (around 0.375 Mtoe/y). From this amount, around 55% of small wood could be easily accessible according to the assumed level of workability as presented on Map 64.

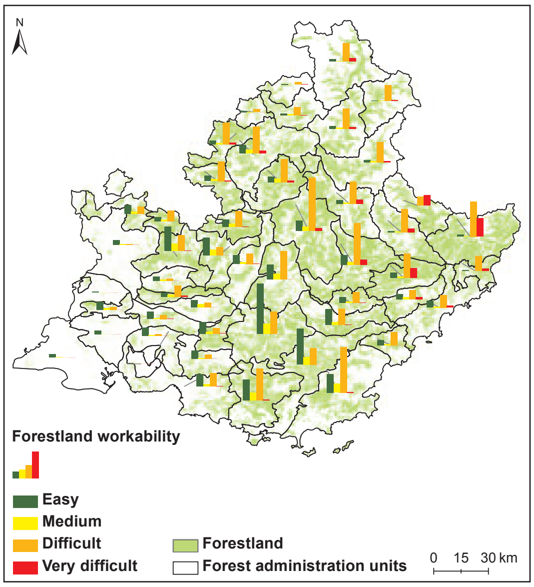
In 2007, the Agricultural and Environmental Engineering Research Institute (Cemagref) published a study about available forestry biomass for energy and industry purposes (Levesque, Vallet et al. 2007). The analyses were carried out for four types of forest silviculture. Unlike the ADEME study, this study included domestic and by-products from sawmill consumption and branches with a 7 cm diameter or bigger. As in the ADEME study, the crown quantity was estimated based on the CARBOFOR study (Granier, Balesdent et al. 2004). The results are broken down by sylviculture type (sustainable or temporary), property class (private, public) or by species (conifer, leafy trees). The total theoretical potential of wood was estimated at 1.5 Mm^3 and the technical potential of wood residues at 0.2 Mm^3. Both studies provide slightly different findings on the theoretical results, probably because of the different assumptions made.

- Wood Residues from Orchards and Vineyards

As mentioned above, 102 ths. ha of vineyards and 43 ths. ha of orchards may constitute an interesting potential source of biomass material. In the PACA region, apart from traditional fruit trees (i.e. plum, cherry, apple), olive trees make up 20% of the orchard area.



Map 63: Wood consumption in the Domestic Sector in the PACA Region in 2007
Source: Based on Data of Energies Demain (2008)



Map 64: Forestland and Classified Workability
Source: Based on Data of IFN (2007)

To calculate the residue potential, factors of 1.6 tons per year for vine trees and 2 tons per year from orchards were applied (Bläsing, Gerth et al. 2000; Chailan, Bourgade et al. 2009). The energy content of fresh material from vineyard maintenance amounts to 362 GWh and from fruit and olive trees to 190 GWh (see Table 83 and Table 84).

In practice, the utilization of biomass material can be considered in three departments with respect to

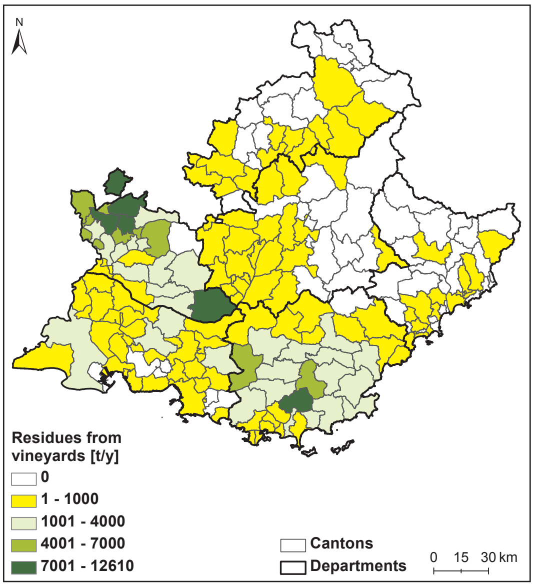
Table 83: Area and Biomass Potential of Vineyards per Department in 2000

	Vineyards	Residues	Energy Contents*	
Departments	ha	t/y	GJ/y	MWh/y
Alpes-de-Haute-Provence	921	1474	11789	3275
Hautes-Alpes	159	254	2035	565
Alpes-Maritimes	107	171	1370	381
Bouches-du-Rhône	11399	18238	145907	40530
Var	31653	50645	405158	112544
Vaucluse	57611	92178	737421	204839
PACA	101850	162960	1303680	362133

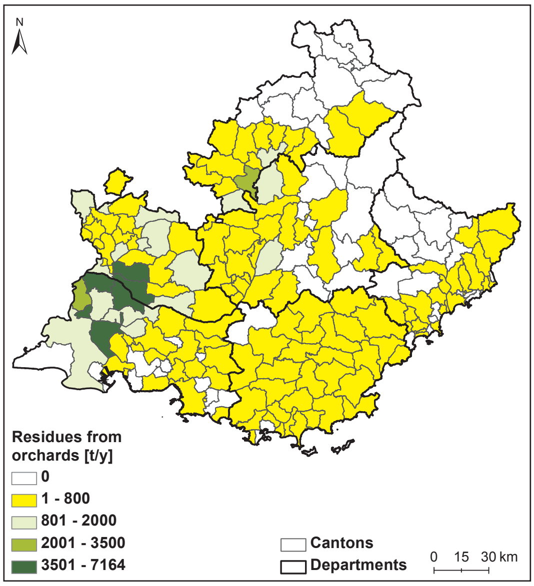
*Assuming a calorific value of fresh mass of 8 GJ/t

Table 84: Area and Biomass Potential of Orchards per Department in 2000

	Basic Fruit Trees		Olive Tress		Orchards	Residues	Energy Contents	
Departments	ha	%	ha	%	ha	t/ha	GJ/y	MWh/y
Alpes-de-Haute-Provence	2976	66.6	995	22.3	4470	8940	71520	19867
Hautes-Alpes	2872	94.7	1	0.0	3033	6066	48528	13480
Alpes-Maritimes	64	5.1	1053	83.5	1261	2522	20176	5604
Bouches-du-Rhône	13467	79.5	3082	18.2	16950	33900	271200	75333
Var	306	7.3	2538	60.3	4211	8422	67376	18716
Vaucluse	11024	85.4	879	6.8	12913	25826	206608	57391
PACA	30709	71.7	8548	20.0	42838	85676	685408	190391



Map 65: Potential of Clearing Material from Vineyards in 2000
Source: Based on Agreste (2000)



Map 66: Potential of Clearing Material from Orchards in 2000
Source: Based on Agreste (2000)

logistical and economic constraints. In the case of grapevines, almost 90% of residues are produced in the two departments of Var and Vaucluse and more than half of this material in just 10 cantons as illustrated on Map 65. Residues from orchards are predominantly produced in Bouches-du-Rhône and also in the department of Vaucluse, amounting to 70% of the material. Among all cantons, the potential for biomass material is spatially most strongly concentrated in seven cantons (dark green and light green color on the Map 66) which account for 36% of the total clearing material.

However, the proportion of this potential which may actually be exploited for energy production depends on economic costs. The study of the FD-CUMA (Departmental Federation of Cooperatives for the Exploitation of Agricultural Material) and the Gard Chamber of Agriculture indicate that the dry material could have a market value equal to the price of wood chips (80 to 120 €/t). In contrast, a 2 m^3 bucket of vine cuts costs between 100 and 150 € (Chailan, Bourgade et al. 2009), which is at the threshold of profitability after drying. Furthermore, the spatial dispersion of wood demand illustrated on Map 63 partially matches the densely located residues in some cantons in Vaucluse, Bouches-du-Rhône and Var.

4.5 Summary and Conclusion

The bienergy studies provide an insight into the regional and local potential of energy crops, agricultural residues and wood material. Due to the varying data content available for the three regions as well as the political and legal frameworks, different methods were developed in the GIS environment. The GIS-based approaches offer flexibility in processing different datasets and allow the techno-economic potential of bio-energy in three regions to be quantified.

In the Polish region, the findings point to a significant biomass potential with respect to the high rate of arable land per capita of 0.48 ha (the national average being 0.36 ha/cap), suitable pedoclimatic conditions and strong potential for animal by-products. The potential use of animal manure with a co-substrate mix would meet 5% of the 2020 target set by the Polish Ministry of Economy. Taking an assumed share of crops in the biogas feedstock-mix, in general 2.2% of the regional agricultural area would be required to meet the demand, but in some of the 5 or 10 km catchment areas the share would even reach 40% of the farmland, putting pressure on the conventional agricultural production. Furthermore, the analysis of pedoclimatic conditions shows that perennial energy crops (predominantly miscanthus) would be a viable investment alternative to conventional crops on at least a moderate quality of arable land. Nonetheless, the economic assessment points out that the main investment obstacles are associated with unforeseen incomes (quota system, subsidies to energy crops etc.) over the lifetime of investment in biogas plants and short rotation crop plantation.

Although the Stuttgart region is characterized by a low index of agricultural land per capita of 0.05 ha, compared to 0.2 ha/cap nationally, and comparable pedoclimatic conditions to the Polish region, the present production and use of biomass and biogas is higher than in the Kujawsko-Pomorskie Voivodship. The main reason for this is the favorable economic conditions due to the feed-in tariff support system. Although animal manure represents an attractive option in the Stuttgart region, its sustainable exploitation should be managed in space and time to mitigate the increase in land rent prices and food and fodder supply security. Under the current legal framework, the planning and legal instruments are unable to influence farmers' decisions on whether to dedicate their land to conventional or energy crop production.

Unlike the German region, Provence-Alpes-Côte d'Azur is not densely urbanized across the whole region, but pressure on land use for biomass sources would strongly affect the food, fodder and industrial crop cultivation mainly owing to its geographic and agro-climatic conditions. Therefore the indicator of agricultural land in hectare per capita of 0.23 is half that found at the national level. Moreover, for the same reasons the production of energy crops in PACA has turned out to be unprofitable. The utilization of animal by-products is also hindered due to logistical and economic aspects, as a significant part of the biogas potential is located in sparsely populated and mountainous terrain.

5 Methodological Approach for Wind Energy Potential Assessment

Wind energy is expected to play a central role in the transition process from fossil fuels to alternative energy sources. Despite the large interest in wind energy development driven by various benefits, there is an increasing concern about the possible impact of wind turbines on local ecosystems, natural scenery and the socio-economic system (Krewitt and Nitsch 2002; Nadaï 2007). Therefore, strategies for the development of wind energy should be systematically addressed within the framework of spatial planning policies so as to reduce the adverse impact of wind-exploiting facilities and to ensure its harmonization with various local systems (Śliż-Szkliniarz and Vogt 2011).

5.1 Methodology and Scope of the Study

Different approaches were developed to explore suitable sites for wind energy development and to assess the technical and economic potential on both a global (Hoogwijk 2004; ECBREC IEO 2007; EEA 2007b) and regional scale (Bläsing, Gerth et al. 2000; Krewitt and Nitsch 2002; Kubicz, Wojcieszyk et al. 2003; Hailer, Jeurink et al. 2004; Juchnowska and Olech 2006). Moreover, wind power zones have already been explored in France and Germany through regional spatial planning procedures, but recent national targets in both countries have created a need to draw up new sites for wind energy development.

In this study, a methodology was proposed to identify conditions for the expansion of wind power by taking regional-specific characteristics into consideration. Technical and economic potential was estimated to indicate the preliminary regional wind energy potential. In addition, the objective of this study was to develop an approach to support the policy and decision-making process of site selection for potential wind energy development zones that meet criteria reflecting the spatial and ecological policy, regulations and socio-economic welfare. A general methodological procedure was developed, which was subsequently adjusted to the three case studies with respect to different datasets and requirements derived from legal regulations.

5.1.1 Site Classification for Wind Turbines

As the harnessing of wind energy is perceived to be associated with various negative impacts, this kind of energy source should be systematically addressed by relevant spatial policy instruments to ensure its harmonization with infrastructural, ecological and socio-economic systems. The selection of appropriate locations for the construction of wind parks must fulfill certain conditions, since the aim is to enhance environmental benefits and to prevent conflicts related to the wind farm's location. The general procedure presented involves as a first step the investigation of areas unlikely to be available for wind energy development because of their cultural, historical or ecological importance. Siting constraints are most often related to land use functions which are either mutually exclusive or compatible, like the dual use in the case of agricultural land that can combine the functions of crop cultivation or keeping cattle and energy generation (EEA 2009; Hoogwijk 2004). Generally, one expects wind turbines not to be installed in areas such as wetlands, settlements and industrial areas, network infrastructure sites, nature reserves, sensitive landscape conservation areas, protected areas, special protection areas according to the EU fauna and flora directive, forests, parks plus a wide range of different biotopes and sites of cultural heritage. Proximity to specially-protected bird areas or other habitats is usually determined on site, thus, in the regional-scale study, this serves only as an example. The criteria represented by digital data and minimum proximity distances defined separately for each case study are listed in Appendix 14, Appendix 15 and Appendix 16. In some areas, for instance landscape protected areas, wind turbine constructions may not be strictly excluded. Such exceptions are only permitted if the environmental impact assessment demonstrates that the expected impact is tolerable. However, in such cases, additional environmental compensation measures would be required to compensate any possible impact of the wind turbine's siting (WM 2003). Given the large scale of digital datasets available, small settlement units and sites of scattered rural buildings, individual objectives for cultural heritage, smaller forests as well as wetlands were left out at the regional level when assessing possible locations for wind parks. For the same reason, the assessment on a regional scale allows for only a preliminary selection of available site locations, but not for the actual wind farm planning.

5.1.2 Technical Potential of Wind Energy

Once suitable locations are identified, technical potential is assessed based on the wind regime. In Germany, the Renewable Energy Sources Act (EEG) introduced the regulation of power generated by wind energy and the term 'reference yield'[14]. To be eligible for feed-in tariffs, operators of wind parks need to achieve at least 60% of the reference yield at the intended site. For this reason, the German Weather Service (German: *Deutscher Wetterdienst*) created a map of wind power potential on a 200 m x 200 m and 1 km x 1 km grid (DWD 2006) based on the reference yield criterion according to the methodology described by FGW e.V. (2007). The grid layer enables the pre-selection of appropriate sites regarding their technical potential. Additionally, the raster data of wind speed at 10 m and 80 m heights above ground is provided by the German Weather Service at a spatial resolution of 200 m x 200 m and 1 km x 1 km (DWD 2006).

For the Region of Provence-Alpes-Côte d'Azur, a wind atlas is available (DIREN 2009b), which encompasses (i) the annual mean wind speed, (ii) the annual mean power density, (iii) the Weibull parameters of mean wind speed distribution, (iv) the annual mean turbulence intensity and (v) the distribution of wind speed and direction (every 20°) at an 80 m height. The high-resolution (250 m) surface of wind speed data at three different heights above ground of 10, 50 and 80 m were calculated on the basis of wind speed values collected in 14 weather stations over 20 years. The methodology is described in the publication of Delaunay, Louineau et al. (2009).

In Poland, a digital map of wind speed that could be used to evaluate wind energy potential is as yet unavailable (Energoprojekt 2006). To date, several wind atlases have been prepared. However, the maps present only the zone of wind speed or wind energy potential at 30 m height above the ground (Lorenc 1991; Lorenc 1996).

Due to the different availability of heterogeneous datasets and diverse legal requirements for the assessment of wind energy in the three case study regions, this step of methodology was developed individually for each case study region.

5.1.3 Economic Potential of Wind Energy

Besides the technical feasibility, economic profitability influences the readiness to invest in wind energy projects. Thus, the monetary value of the technical potential of wind energy was included within the scope of the methodology.

Aspects that influence the growth of wind energy exploitation are primarily market and policy factors which play a significant role in promoting the development of any renewable energy project (Madlener and Stag 2004). In this case, electricity tariffs, the country-specific level of subsidies to green electricity as well as administrative project-related policies, were considered. Any wind farm project's feasibility is determined by the size of the investment costs, which may vary significantly, since the economic merit of wind energy depends on different site-specific conditions. The average cost of wind energy investment per kW is estimated to be around 1000 €, reaching up to 1600 € in extreme cases (Baj 2009; EEA 2009; EWEA 2009; Marcinkowski and Sztuba 2009). At this price, the expenditure towards the auxiliary and road infrastructure as well as to the grid connection may reach up to 15% of the total costs. Annual operation costs include debt service costs, insurance, property tax and land leasing, and maintenance charges which may amount to 3% of the initial capital costs. The additional expenses vary from project to project depending on different site-specific conditions. Nevertheless, for onshore wind energy, the cost of a generator is still around 75 - 85% of the total expenses. Table 85 lists the share of single components in the total investment cost for onshore wind turbine construction. The average annual cost per kilowatt-hour of electricity generated by a wind turbine were derived from the sum of total annual investments, the operating costs and the turbine's annual energy yield. The unit costs of energy were calculated using the following formula:

$$CE_j = \frac{I * P * R_{O\&M} + a * I * P}{E_j} \tag{31}$$

---

[14] Amount of energy for each wind turbine type, including the respective hub height, that this type would produce during five years' operation when erected at a reference site, calculated on the basis of a measured performance curve.

Table 85: Overview of Investment Costs According to Component Estimated for Onshore Wind Farms

Cost Components	Typical Share of Investment Cost [%]
Turbine	75 - 85
Foundation	3 - 5
Installation	1 - 9
Grid Connection	2 - 9
Road Construction	1 - 5
O&M	3 - 10
Consultancy	1 - 2
Land Lease	1 - 3
Debt Service Costs	1 - 5
Total Approx. Investment Costs	1000 - 1600 €/kW

Source: Baj (2009); EEA (2009); Marcinkowski and Sztuba (2009)

$$a = \frac{i(1+i)^n}{(1+i)^n - 1} \qquad (32)$$

where CE_j is the cost of electricity expressed in €/MWh generated in a grid cell j, I is the initial investment cost depending on the turbine size P in €, E_j is the energy yield per grid cell j in MWh, n is the economic life time of the turbine (20 years), $R_{O\&M}$ is the rate of operation and maintenance costs, i is the interest rate (assumed at 5%) and a is the annuity factor estimated according to the equation 32.

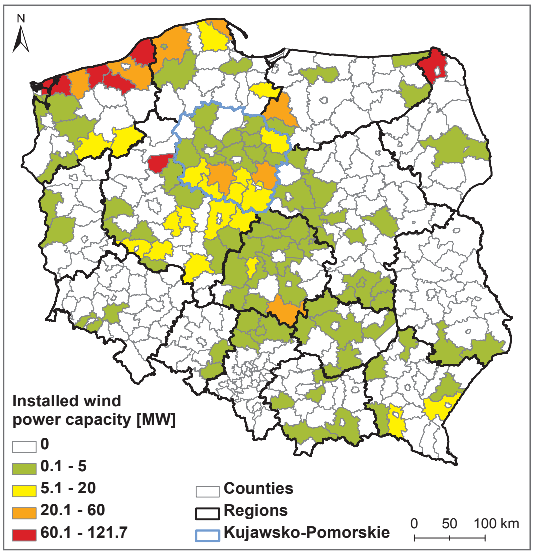
The operation and maintenance costs were assumed to represent a constant rate of 0.03 of investment over the lifetime of installation (Hoogwijk, de Vriesb et al. 2004b).

Revenues obtained through selling wind energy are either feed-in tariffs as in Germany and France or the market price of electricity and the price of the tradable green certificates as in Poland.

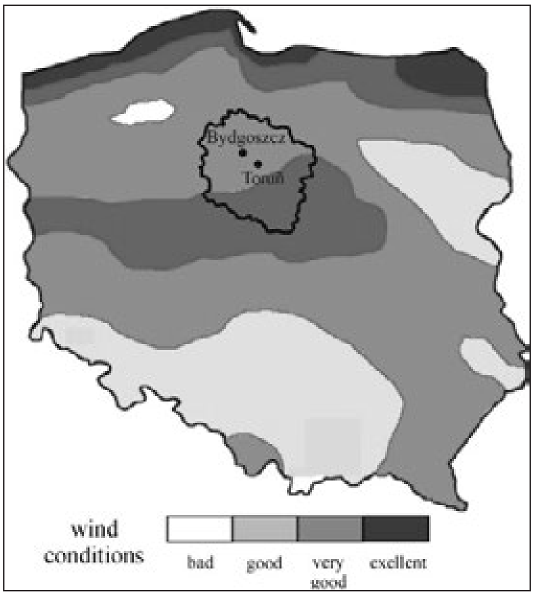
5.2 Wind Energy Potential in the Region of Kujawsko-Pomorskie

In Poland, wind energy is expected to play a major role in achieving the recent targets set out by national policy (NREAP 2010c). The Kujawsko-Pomorskie Voivodeship is the third most favorable region with regard to wind regime conditions and can be subdivided into good and very good zones according to the amount of wind energy harvested at a height of 30 m above ground, as classified by Lorenc (2005). By the end of the year 2010, 155 wind turbines with a total power capacity of 166 MW were operating in the Voivodeship (URE 2011). Most of them were located in four counties: Inowrocławski, Radziejowski, Włocławski and Aleksandrowski, the area of the latter crossing the "very good zone" in terms of wind regime (compare Map 67 and Map 68). The favorable wind and terrain conditions make the region suitable for the development of wind projects (Lorenc 2005).

The wind energy potential at the national level was assessed by the Institute for Renewable Energy (ECBREC IEO 2007) and at the regional level by the Office of Spatial Planning of the Kujawsko-Pomorskie Voivodeship (K-PBPPiR 2010) based on



Map 67: Installed Wind Power Capacity in MW in Poland by the End of 2010
Source: Data Derived from URE (2011)



Map 68: Wind Energy Zones in Poland
Source: Igliński, Kujawski et al. (2009)

a statistical approach and theoretical assumptions; the economic potential is 30% of the technical potential, which indicates the necessary share corresponding to a very good zone classified by Lorenc (2005) and the realizable potential was assumed at 30% of a given economic potential.

The complexity of the wind power development strategy calls for harmonization in spatial plans and energy concepts at different levels to mitigate harmful impacts on environmental and socio-economic systems, but also to link development objectives with infrastructural issues like power lines, a fact that has been neglected in the past. Therefore, very often suitable sites characterized by wind utilization potential at a high level of energy efficiency are not exploited due to a lack of primary infrastructure. As mentioned in chapter 2.8, a preliminary regional assessment is required to identify the production potential of wind and other RES sources

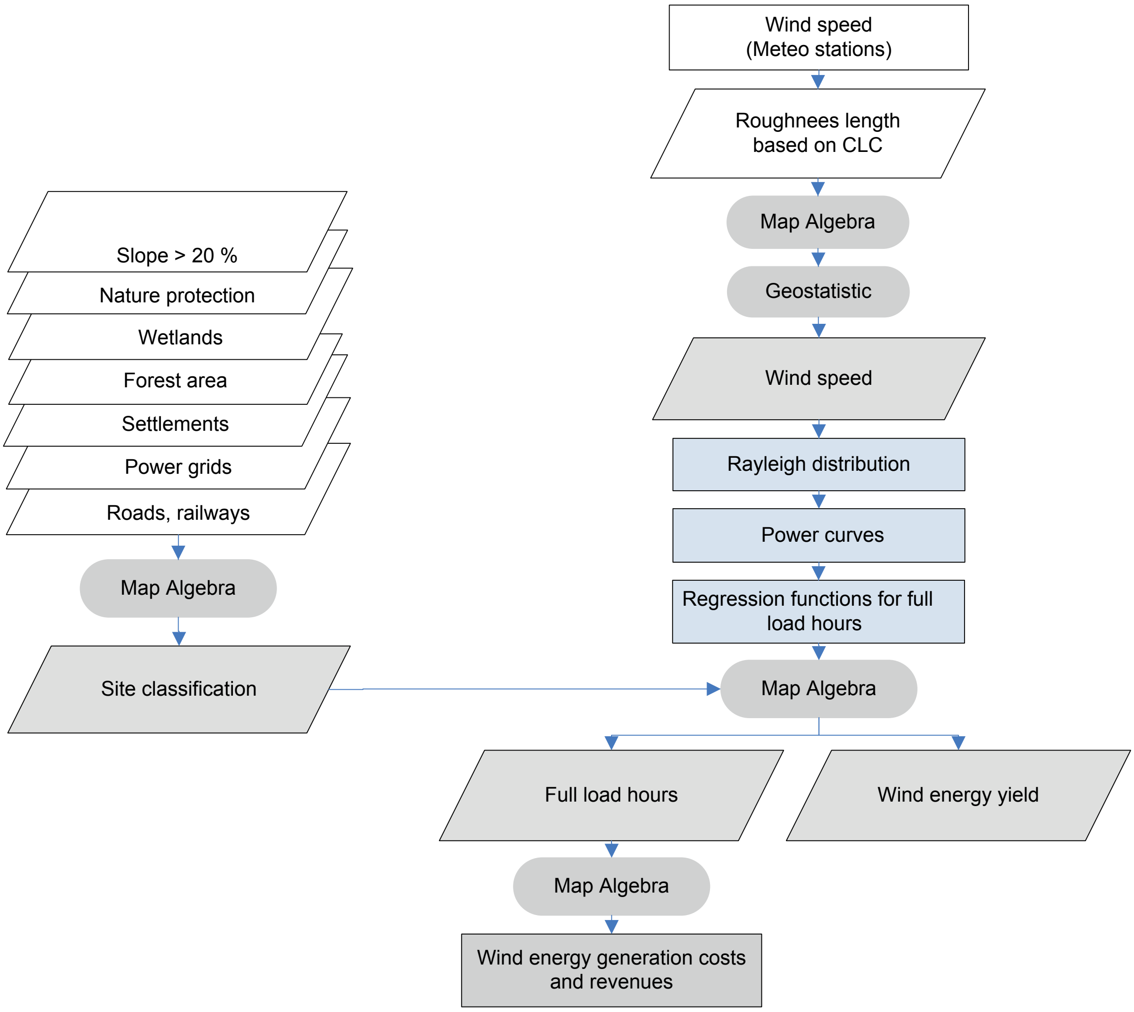


Figure 42: Overview of the Stepwise Approach for Wind Energy Potential Assessment

(Sebesta 2010) in order to guide their integration into a communal spatial, infrastructural and energy planning strategy and to avoid spatial disorder. In this study, a methodology was proposed to identify conditions for wind power expansion by taking into consideration regional-specific characteristics. The technical and economic potential was estimated to identify the preliminary regional wind potential.

5.2.1 Approach to Assessing Wind Energy Potential

The methodology developed to evaluate wind energy potential is a set of sequential steps incorporating the technical and geographical characteristics of a region as well as the existing restrictions on wind energy exploitation. The following actions were performed: first, available locations for wind energy plants were investigated according to the defined criteria reflecting local spatial and ecological policy. Secondly, datasets from weather stations on measured wind speeds were horizontally and vertically interpolated to produce the continuous surface of wind speed at rotor blade heights. Then, the number of full load hours was estimated for three differently-powered turbines based on the Rayleigh probability distribution parameters and power curves. Next, the layer of available locations for a wind farm construction was overlaid with the layer of full load hours to determine the technical potential of wind energy in the case study regions. Finally, to evaluate the economic viability, wind energy costs in the grid cell were estimated. The steps are presented in Figure 42.

5.2.2 Site Classification for Wind Energy Development

To date, there is no specific mandatory recommendations relative to the site assessment of wind farms in Poland. The related criteria and constraints were derived from relevant Polish legislation, among which the Law on Nature Protection, and from two Polish and German studies (Kubicz, Wojcieszyk et al. 2003; Hailer, Jeurink et al. 2004; Juchnowska and Olech 2006). Appendix 14 lists the criteria applied as well as the suggested appropriate distances to surfaces of sensitive ecological forms, infrastructure and socio-cultural components. The digital map layers representing the land use and functions was obtained from the Office of Spatial Planning of the Kujawsko-Pomorskie Voivodeship (KPBPP 2009). A proximity to the territory of special protection of birds or other habitats is usually determined on site, thus, in the regional-scale study, this serves only as an example. Landscape areas are a type of protected area with less stringent restrictions on development and economic use compared to national parks. Therefore, within such areas, wind turbine construction may not be strictly excluded. Such exceptions are even permitted within the Natura 2000 network (Marcinkowski and Sztuba 2010), provided the environmental impact assessment demonstrates that any arising impact would be tolerable.

Table 86: Constraints for the Siting of Wind Turbines

Land Use Functions	Constraint Level
Nature Protection	
Nature Reserves	High
Projected Nature Reserves	High
Areas of Special Protection of Birds (Natura 2000)	High
Areas of Special Protection of Habitats (Natura 2000)	High
Ecological Corridors	High
Water Protection Zones	Moderate
Landscape Parks	Moderate
Landscape-Nature Complexes	Moderate
Protected Landscape Areas	Moderate
Projected Landscape Parks	Low
Projected Protected Landscape Areas	Low
Protective Zone of Landscape Parks	Low
Projected Extension of Landscape	Low
Natural Hazard	
Floodplains	High

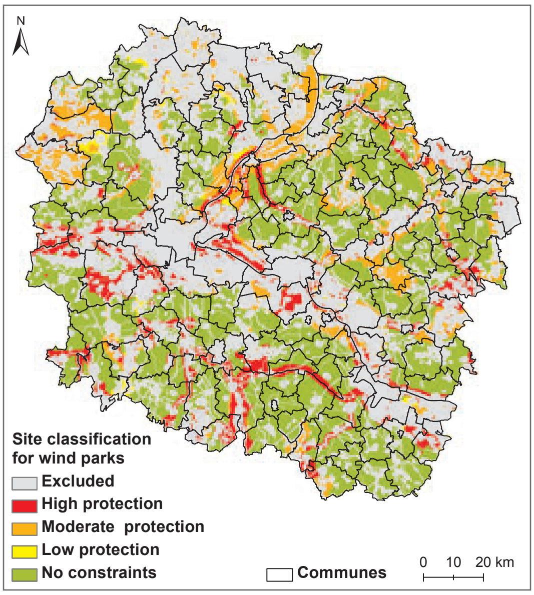
Śliż-Szkliniarz and Vogt (2011) applied the precautionary principle in the wind potential assessment, so that all areas under protection were excluded from wind siting to avoid any detrimental impact on sensitive areas. In this study, the nature and landscape conservation areas were ranked according to their sensitivity to adverse impact as outlined in Table 86. The floodplain area was also included.

The rasterized layers were processed in the Spatial Analysis in ArcGIS9.3 using the conditional statement through Map Algebra to evaluate sites for wind construction as follows:

```
if ((Excluded_land =  Y),
    Excluded,
        if ((High_protection = Y ),
            High protection,
            if ((Moderate_protection = Y),          (33)
                Moderate protection,
                if ((Low_protection = Y),
                    Low protection,
                    No constraints)))
```

where Excluded_land are grid layers representing land use functions not compatible with wind energy as outlined in Appendix 14. Next, the three classes of nature protection areas (high, moderate and low) were ranked according to their sensitivity to adverse impacts as outlined in Table 86.

The spatial deployment of the sites classified for potential wind energy development is shown on Map 69, while their area is outlined in Table 87. From almost 1.2 Mha of agricultural space in the Kujawsko-Pomorskie region, 0.62 Mha (34% of the region's total area) would remain available for the potential construction of wind turbines. This surface is larger than the area of 0.54 Mha identified in the K-PBPPiR study (2010), a difference stemming from the statistical approach and differing assumptions applied in the Polish Wind Energy Association report (PSEW 2008). Apart from the excluded land, which is not compatible with wind development, 14% of the area is located within high, moderate and low nature protected areas.



Map 69: Site Classification for Wind Parks Development

It must also be noted that due to the scale of the digital dataset (1:750000), small settlement units and sites of scattered rural buildings, individual objects of cultural heritage or smaller forests as well as wetlands were not taken into account in this analysis. For the same reason, the assessment on a regional scale offers only a preliminary selection of available site locations, but not the actual planning of wind farm sites.

5.2.3 Technical Potential of Wind Energy

The accurate determination of annual wind regimes requires the recording of anemometer data at a rotor height of 10 m or higher for at least 12 months, while site-specific decisions on particular investments are made. However, for the preliminary decision-making, annual values of average daily

Table 87: Area of Site Locations Evaluated for Wind Energy Development in the Kujawsko-Pomorskie Region

Site Classification	Area [ha]	Share in Total Area [%]
Excluded	922279	51.3
High Protection	110305	6.1
Moderate Protection	133481	7.4
Low Protection	11508	0.6
No Constraints	619016	34.5

wind speed were used as an indicator for the wind energy potential of certain sites. In the following section, the load hours and energy yield from three exemplary power turbines were calculated on the basis of information derived from the measured wind speed dataset.

5.2.3.1 Wind Sped Data

As previously mentioned, several wind atlases are available in Poland, which represent zones of wind speed or wind energy potential at 30 m height above the ground (Lorenc 1991; Lorenc 2005). As wind turbine capacity is rapidly growing, the wind speed data must be corrected to a hub height of 80 or 100 m for an average capacity of 2 - 2.5 MW onshore (EEA 2009). For the purpose of preliminary assessment and to draw up the characteristics of the wind regime, a dataset was derived from the National Climatic Data Centre website (NCDC 2007) maintained by the US Department of Commerce. Based on this data, the EEA has evaluated the wind energy potential for Europe (EEA 2009). The dataset for this study included the average daily wind speed collected by 28 meteorological stations over a period of four years (2005 - 2009). The minimum and maximum distances between the measurement stations are 12 km and 395 km respectively. The elevation of the considered surface differs between 0 m and 332 m and the highest measurement point is located at 195 m above sea level. The average annual wind velocity ranges between 2.5 and 4.5 m/s at 10 m above ground in the considered area.

5.2.3.2 Wind Speed Extrapolation to Hub Height

As the relative wind speed is related to the rotor height, the wind velocity from meteorological stations must be corrected based on the rule that wind speed profiles vary with roughness length for the complex terrain according to a logarithmic pattern. For the quantitative description of vertical profiles of wind changes, the following mathematical formula has often been chosen (Sathyajith 2006; Kaltschmitt, Wiese et al. 2007; Hau 2008):

$$V_{ZR} = V_z \frac{\ln(Z_R/Z_O)}{\ln(Z/Z_O)} \tag{34}$$

where V_{ZR} is the wind speed extrapolated at at hub heights in m/s, V_z is the wind data collected at the anemometer height of Z, V_{ZR} is the wind velocity at hub heights Z_R of 50, 80 and 100m and Z_0 is the roughness length that was derived from the CORINE Land Cover Data (CLC2006). The CLC database version of 2006 (at 100 m x 100 m resolution) reflects 44 land cover classes. The data was disaggregated to 12 main classes, reflecting similar land use types (see Appendix 13).

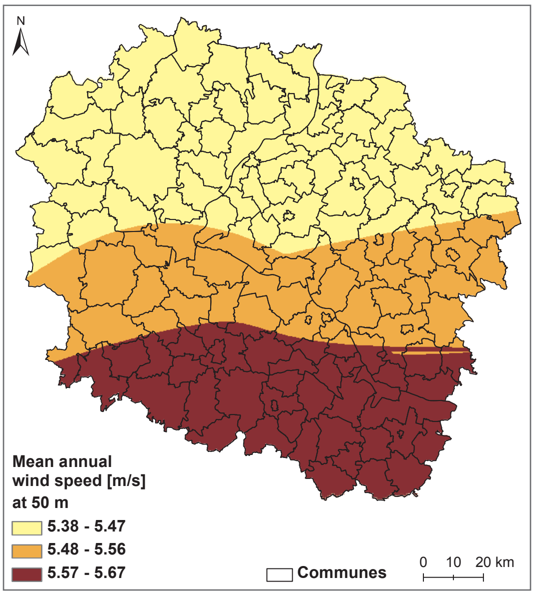
5.2.3.3 Wind Speed Interpolation

Once the wind speed had been extrapolated to hub heights, a spatial interpolation technique was used to predict the wind speed at locations where data is unavailable. A variety of deterministic and geo-statistical methods exist for interpolating the values of meteorological phenomena (Tabios and Salas 1985; Phillips DL 1992; Collins and Bolstad 1996; Price, McKenney et al. 2000; Tveito and Førland 2001). Luo, Taylor et al. (2008) assessed seven methods used to estimate the daily mean wind velocity surface. This appraisal confirmed previous results of Tabios and Salas (1985) and Robertson (1987) that kriging methods produce the most accurate results compared with deterministic techniques. As the accuracy of results is not only affected by the choice of method but also by the data sampled, its density and spatial distribution (MacEachren and Davidson 1987) in the study, the validity of the following methods was tested based on the Inverse Distance Weighting (IDW), Polynomial Interpolation Method (PIM), the Ordinary Kriging and the Ordinary Cokriging procedures.

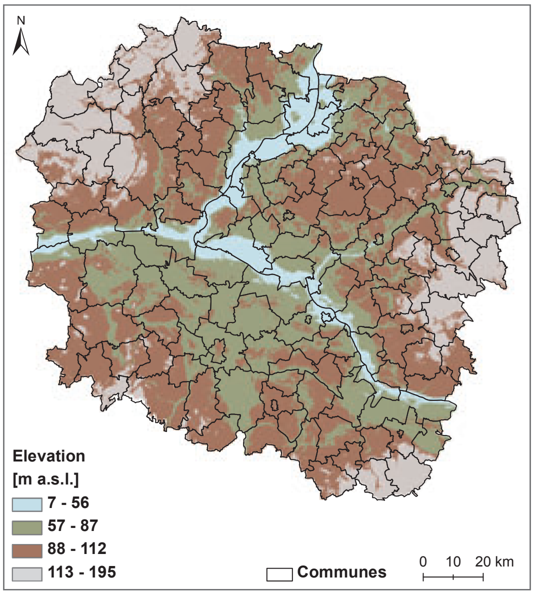
Geo-statistics is effective if data exhibit a Gaussian distribution, otherwise the data must be transformed to adapt it to a normal distribution. Before applying the interpolation methods, the distribution of data was analyzed by means of the explanatory data analysis (EDA) in order to look for local trends and to examine outliers and non-homogeneity of the sampled points and spatial correlation. The common rule-of-thumb normality test is the parameter of skewness and kurtosis that suggested in this case deviation from a normal distribution. To check this presumption, the Shapiro-Wilk test was chosen, which deals with a small number of variables. However, the test confirmed the null hypothesis of normality for the wind data. In addition, information derived from explanatory analysis pointed out trend effects. With increasing longitude, a small trend is noticeable and with increasing latitude, the yearly mean speed exhibits a trend in the north-south direction, which is likely to depict differences in elevation between the data points or the roughness length of surface (see Map 70). A Voronoi map was created to investigate possible outliers. Based on a normally distributed dataset without any outliers, the wind velocity was interpolated at different levels of 50, 80 and 100 m above ground level. The methods of ordinary kriging, ordinary cokriging as well as IDW and PIM procedures were applied through the Geostatistical Anlyst extension of the ArcGIS 9.3 software.

With respect to the trend, which should only be removed in the case of significantly improving results (Krivoruchko and Gotway 2004) and to satisfy stationarity assumptions (Luo, Taylor et al. 2008), the procedures for data with removed trend were performed in the process of a Trend Analysis. The first step in the kriging procedure was to compute the empirical semi-variogram from the set of points to measure the degree of correlation of spatial random variables, after having fitted the suitable mathematical model to the empirical semivariogram and covariance. The fitting of the model into the semivariogram is a fundamental step on the way towards determining optimal weights for interpolation (Burrough and McDonnell 1998). To verify the interpolation's accuracy and the validity of models before producing the final surface, a cross-validation tool, provided through the ArcGIS Geostatistical Analyst toolbox, was applied. The Spherical model for the ordinary kriging method resulted in the most accurate projections, producing the smallest mean standardized error and the mean error closest to zero compared to other models. Next, the surface for wind speed was interpolated using the cokriging procedure by taking into account the digital elevation model in the subsidiary variable. Cokriging requires an additional estimate of the autocorrelation for each variable and the cross-correlation of both models.

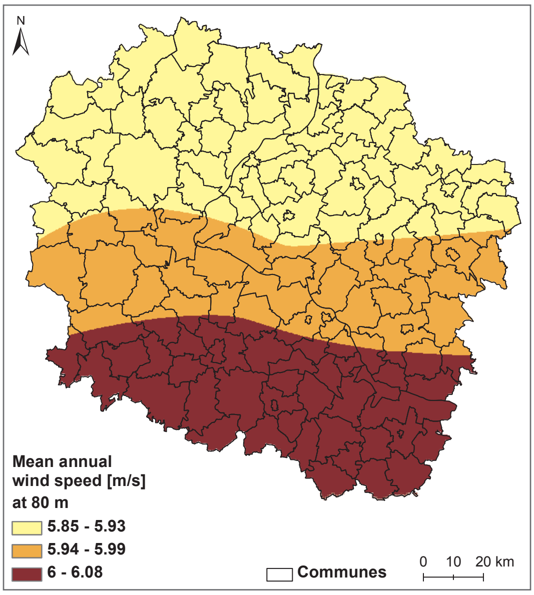
The correlation analysis performed for the wind speed and elevation variables suggested a very weak linear correlation (R = 0.1), probably due to



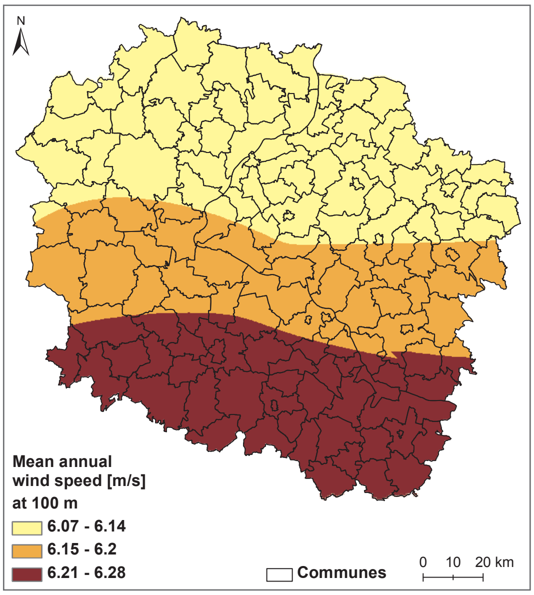
Map 71: Interpolated Surface of Annual Wind Speed at 50 m above Ground



Map 70: Elevation above Sea Level



Map 72: Interpolated Surface of Annual Wind Speed at 80 m above Ground



Map 73: Interpolated Surface of Annual Wind Speed at 100 m above Ground

relatively insignificant elevation differences among the measurement stations (between 7 and 195 m a.s.l. as shown on Map 70), a fact that conformed the cross-covariance procedure. In this case, the cokriging technique did not provide prediction maps any better than the ordinary kriging. The IDW and PIM methods have also been rejected as the Root Mean Square and Mean Error were not as good as in the ordinary kriging.

Once models and the interpolation techniques had been validated, the wind speed surfaces were generated. The wind speed at a height of 50 m, 80 m and 100 m above ground, as presented on Map 71 - Map 73, rises from the northerly direction, which suggests that the data produced is fairly consistent when compared with the zones illustrated on Map 68.

5.2.3.4 Wind Energy Assessment

The wind energy harvest is determined by three main parameters: the wind speed, its frequency distribution and the characteristics of the power curve of a wind turbine. Since a range of wind turbines is available on the market, different combinations between swept area, rated power, conversion efficiency, cut-in, cut-off velocity and wind regime are possible, leading to different numbers of load hours and energy yield, three types of turbines were thus considered. Their technical characteristics are outlined in Table 88. Based on a trade-off between increased power due to the higher turbine power capacity on the one hand and the additional cost caused by a larger turbine on the other hand, the energy yield was calculated for different wind turbines with a rated power of 600 kW, 1.65 MW and 2.5 MW respectively. The power curves were calculated following the formula:

$$P_n = \frac{1}{2} q * A * C_p * V_m^3 \qquad (35)$$

where P_n is the power curve for a wind turbine in MW, A is the rotor diameter in m, C_p is the curve of rotor efficiency for wind speed intervals of 1m/s, V_m are mean wind speed intervals and q is the air density in kg/m^3 calculated at an anemometer height based on equation 36.

Air density varies significantly with pressure and temperature, thus, for different heights this parameter was corrected by the following equation (Patel 2006):

$$q = qo - (1.194 * 10 - 4 * h) \qquad (36)$$

where q is the air density in k/m^3, qo is the normal air density, h is the site elevation in meters.

For the energy generation assessment, not only wind speed strength but also its probability of occurrence over a certain period of time is important. This being so, Weibull and Rayleigh are commonly used functions of statistical distribution for

Table 88: Technical Specifications of Selected Wind Turbines

Wind Turbines	Rated Power	Hub Height	Rotor Diameter	Cut-in	Cut-off
Bonus	600	50	44	4	25
Vestas 82	1650	80	82	3.5	25
Nordex N80	2500	100	80	3	25

Source: WWWT (2009)

representing wind regime from an average mean value of wind velocity with an acceptable accuracy level (Hennessey 1977; Sathyajith, Pandey et al. 2001; Hau 2008). The Rayleigh probability density function is a simplified case of the Weibull function with a constant shape parameter (k) that ranges from 1.5 to 3.0 for most wind conditions (Akpinar and Akpinar 2003) and is given by:

$$f(V) = \frac{\pi}{2}\left(\frac{V}{V_m{}^2}\right)\exp\left[-\frac{\pi}{4}\left(\frac{V}{V_m}\right)^k\right] \qquad (37)$$

where f(V) is the Rayleigh probability density function, V_m is the average wind speed in m/s, k is the shape parameter, V is the wind speed interval in 0.5 m/s.

The annual energy yield for a wind speed was calculated based on the formula:

$$E = 8760\sum_{t=1}^{t=n} P_n f(V) \qquad (38)$$

where E is the annual energy in MWh generated by a wind turbine with a power curve P_n, f(V) frequency distribution of wind speed f(V) calculated with the shape factor k = 2 as recommended by IEC (1998)

In the GIS-based approach, the calculation of the energy harvest was automated based on the relation that the energy output is characterized by the rated power and the number of full load hours. In the model, findings from different studies (Abed and El-Mallah 1997; Hoogwijk, de Vriesb et al. 2004b) were applied, that full-load hours is a function of a power curve and the average wind speed calculated on the basis of the Rayleigh function. To depict a linear relation between the duration of wind speed intervals and the average annual wind velocity as presented in Figure 43, the regression functions were plotted for three power curves. The number of

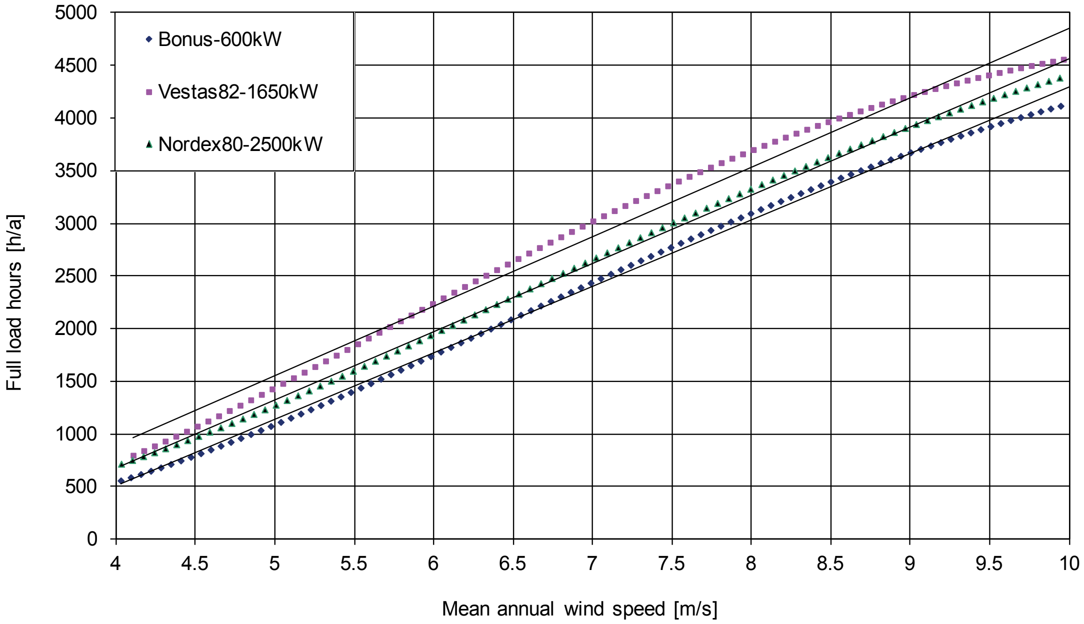


Figure 43: Linear Regression Function of the Duration of Wind Velocity within a Wind Speed Interval of 0.5 m/s

Table 89: Linear Regression Function for Three Turbine Types

Turbine Type	Regression Function
Bonus	$FLH_i = 631.47\ V_i - 2018.5$
Vestas 82	$FLH_i = 660.74\ V_i - 1754.4$
Nordex 80	$FLH_i = 648.91\ V_i - 1924.1$

load hours for grid cells over the surface was calculated using a Single Map Algebra tool in the ArcGIS 9.3, applying the functions presented in Table 89. The continuous surface of corrected wind speed at hub heights per grid cell is reflected by the V_i parameter in the regression functions. In practice, a number of full load hours are lower than the calculated ones due to two main reasons: firstly, the efficiency of wind farms is reduced if turbines are sited close to each other; secondly, it is reduced in the event of maintenance work and periods when the turbine is on standby during calms and very strong winds (Hoogwijk 2004). Thus, the full load hours (FLH) should be multiplied by a parameter ranging from 0.83 - 0.9 for onshore wind parks (EEA 2009).

Wind slows down as it passes through the blades and reduces the available power to downwind machines. Therefore, the following distance between turbines in the form of a rectangular array is recommended to be sufficient: 3 to 5 rotor diameters between towers in a row and 5 to 9 diameters between rows (Hailer, Jeurink et al. 2004; Kaltschmitt, Wiese et al. 2007).

In this case study, the land area occupied by a turbine is estimated based on the square array of six rotor diameters according the following formula:

$$LAT_i = 6D_i * 6D_i = 36D_i^2 \qquad (39)$$

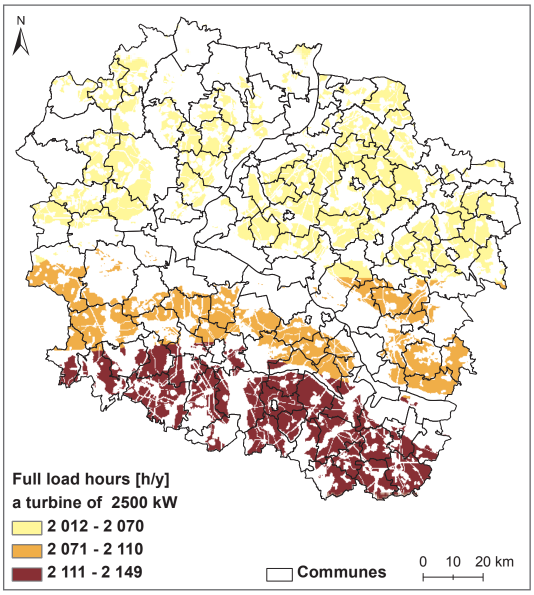
where LAT_i is the land area occupied by a turbine i in ha, D_i is a rotor diameter of a turbine i.

The turbines of either 1650 kW or 2500 kW power capacity occupied a 24 ha area, since the rotor size is similar. A small turbine with a power capacity of 600 kW with a 44 m rotor diameter takes only 7 ha, as shown in Table 90. Finally, the wind energy potential in grid cells (of 7 ha or 24 ha) was derived from the multiplication of rasters representing the usage time of wind turbines, their rated power and the correctness factor as follows:

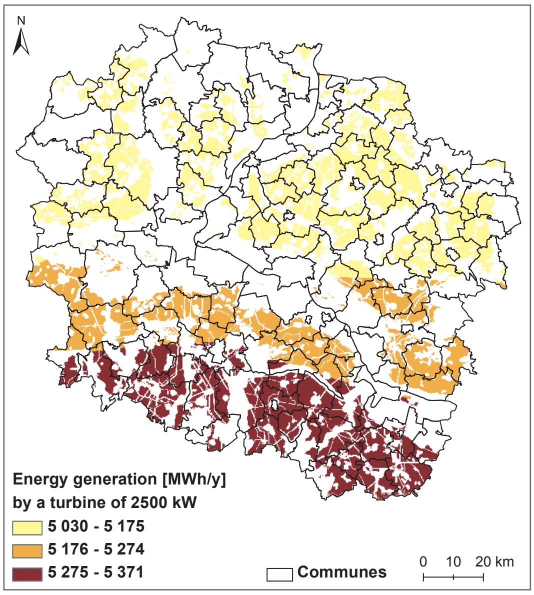
$$E_{ij} = Pr_i * FLH_{ij} * n \qquad (40)$$

Table 90: Land Area Occupied by Turbine and Power Density

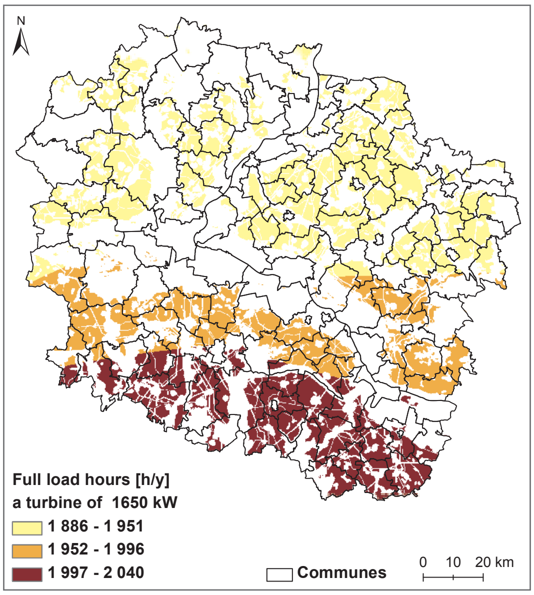
	Power	Rotor Diameter	Area under Turbine	Turbine Density
Wind Turbines	kW	m	ha	No. per km^2
Bonus	600	44	7	14
Vestas 82	1650	82	24	4
Nordex 80	2500	80	23	4



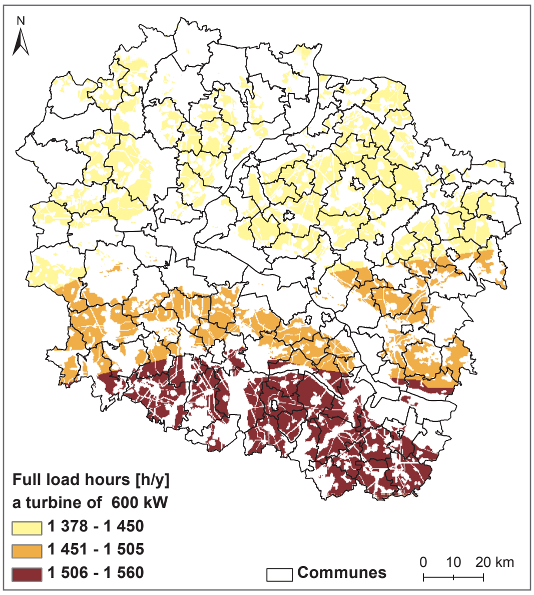
Map 74: Annual Number of Full Load Hours for a Wind Turbine of 2.5 MW



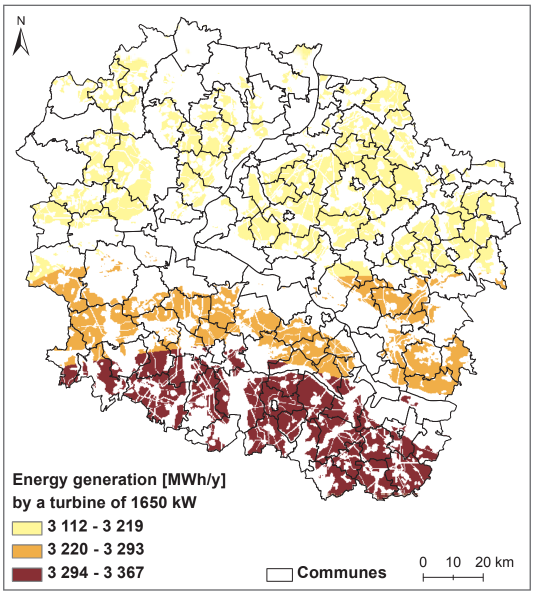
Map 75: Annual Energy Produced by a Wind Turbine of 2.5 MW



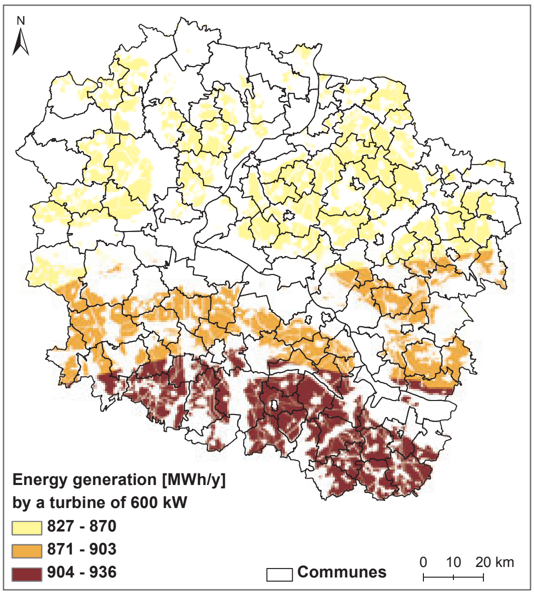
Map 76: Annual Number of Full Load Hours for a Wind Turbine of 1650 kW



Map 78: Annual Number of Full Load Hours for a Wind Turbine of 600 kW



Map 77: Annual Energy Produced by a Wind Turbine of 1650 kW



Map 79: Annual Energy Produced by a Wind Turbine of 600 kW

where E_{ij} is the wind energy generated by a wind turbine i in grid cell j expressed in in MWh, Pr_i is the rated power of considered turbines i, FLH_{ij} is a number of full load hours for a turbine i in a grid cell j derived from regression function and n is a factor (0.89) used to correct full load hours.

The spatially spread out time of a working turbine and the annual amount of energy generated by three selected turbines are presented on Map 74 - Map 79. The annual wind energy harvest varies most strongly with respect to the working time of a turbine and its power capacity.

The layer representing site classes was overlaid with layers of the number of full load hours in order to assess the wind potential within areas classed according to those with no constraints and low protection as outlined in Table 86. The results revealed that in the southern part of the study's region, the technical potential is higher with respect to the wind regime conditions. The approximate finding is concordant with the status quo of wind energy development in the Kujawsko-Pomorskie Voivodeship.

Assuming a power density of 1 MW per 10 ha, an area of 1663 ha has already been occupied by wind turbines (equaling 0.26% of the unconstrained land and an area under low protection) and 0.62 Mha would be considered for further local assessment of wind power development. As derived from the study, the technical potential still remains untapped. Having compiled a clear picture of the quantity of wind energy, local actors have considerable influence in deciding on which part of the potential can be utilized. The additional, essential factor influencing a project's viability is the willingness of the community to integrate these installations into their energy portfolio.

5.2.4 Economic Potential of Wind Energy

In the complex process of harmonizing the alternative energy projects with the spatial and energy plans of municipalities, economic factors also play a significant role. The commune will benefit from the investment due to tax revenues, while local communities will do so when leasing the land. As applied in the economic assessment of biogas in the Kujawsko-Pomorskie Voivodeship, the total price earned by wind energy producers in this region is composed of the market price of electricity at 45 € for each MWh and the price of the tradable green certificates at 68 €/MWh, which comes to 113 €/MWh in total. The costs of energy generated for three turbines according to the number of full hours are compared in Figure 44.

The minimum electricity cost based on the average cost of wind energy investment (1000 €/kW) amounts to 48 €/MWh generated by a turbine with 2500 kW power capacity, whereas the maximum of 77 €/MWh is produced by a 600 kWh turbine. Comparing the production costs with the total energy sale price of 113 €/MWh, the technical potential seems to be very attractive from an economic point of view. At this assumed level of investment costs, all those installations would be considered viable. Assuming a maximum level of investment costs (1600 €/kW), the energy production costs would range from 77 €/MWh to 121 €/MWh. Even in the case of the highest investment costs, wind projects with a power capacity of 1.65 and 2.5 MW would generate financial benefits. The calculated economic potential corresponds to a 4% discount rate and an investment lifetime of 20 years. One significant factor in estimating a project's profitability is the capital cost. In Figure 45, a sensitivity analysis based on an interest rate of 10% indicates the significant shift of curves by one third of energy production costs.

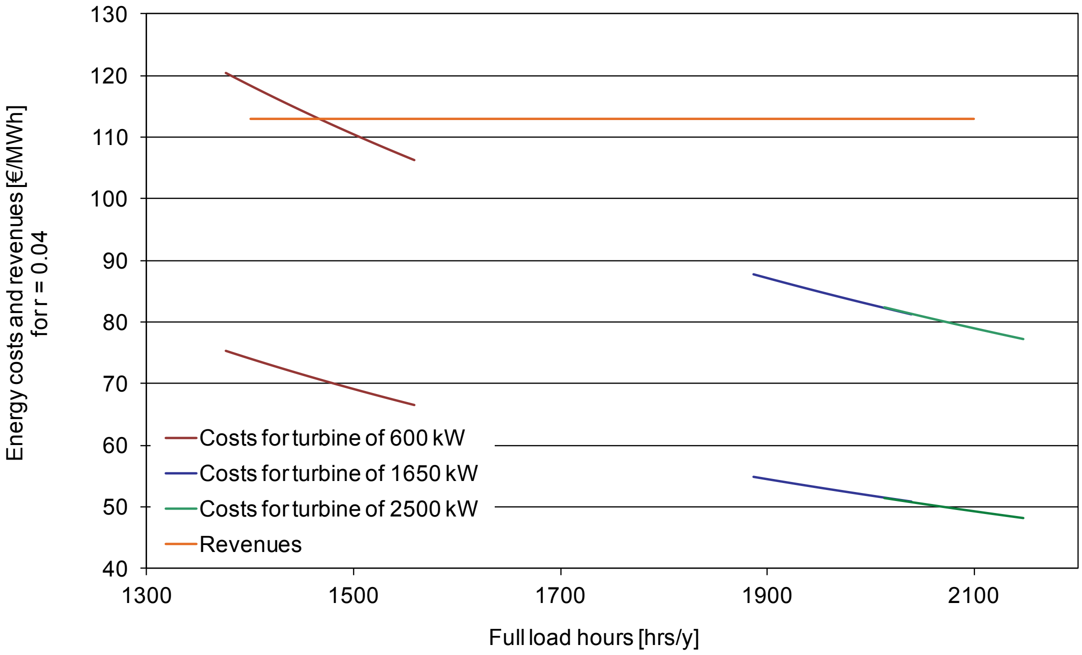


Figure 44: Electricity Generation Costs of Three Exemplary Wind Turbines with an Interest Rate of 4%

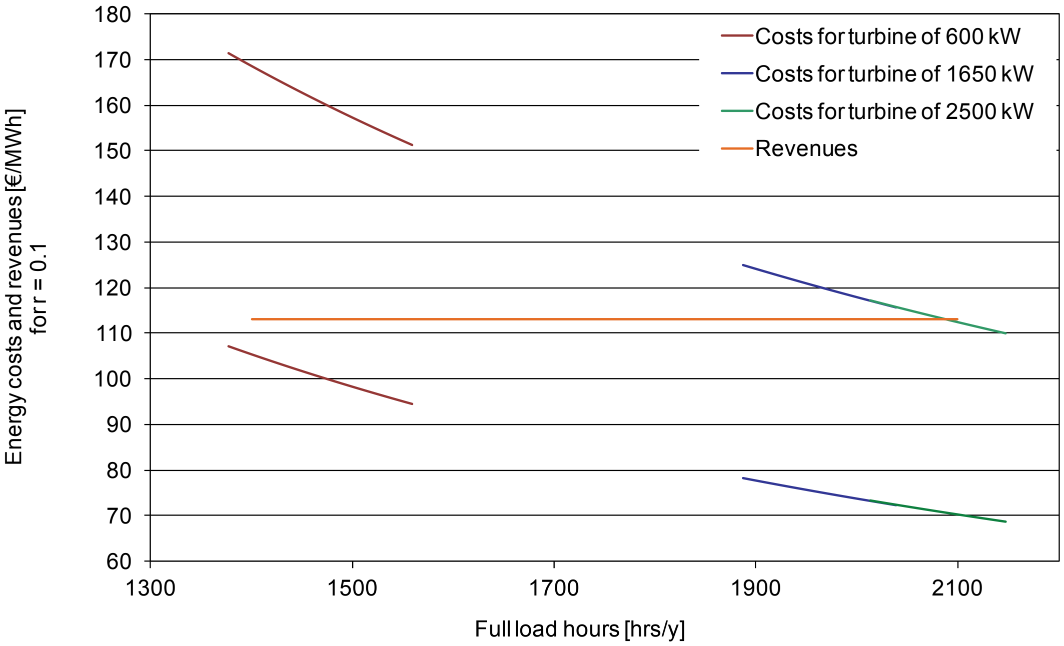


Figure 45: Electricity Generation Costs of Three Exemplary Wind Turbines with an Interest Rate of 10%

Assuming the highest investment costs of 1600 €/kW and an interest rate of 10%, the costs would exceed the benefits up to 2100 full load hours, which is at the threshold of the economic feasibility of a project. In the case of 1000 €/kW capital costs, three wind turbines would remain cost-effective (below 108 €/MWh).

The monetization of the technical potential has revealed that the Kujawsko-Pomorskie Voivodeship offers favorable economic conditions for investors thanks to the current sales prices and the level of subsidies. Being the cheapest technology compared alongside biogas or PV installations, wind turbines have recently sprung up like mushrooms. The lucrative wind energy business in Poland has even attracted western investors, whose high profits are paid for by Polish consumers.

5.3 Wind Energy Potential in the Stuttgart Region

Wind energy represents the main instrument towards meeting the targets fixed in the German NREAP, accounting for nearly 50% of overall electricity generated from RES aimed at by 2020 (NREAP 2010a). In fact, 40% of the 104 TWh target has already been fulfilled.

In 2004, the Verband Region Stuttgart established 9 preferential zones (covering 0.06% of the total area of the Stuttgart Region) located in: Alfdorf Brend, Hummelberg, Bad Ditzenbach, Lange Fäule, Böhmenkirch-Steinige, Böhmenkirch/Geislingen, Stöttener Berg, Geislingen-Aufhausen, Funkturm, Ingersheim, Holderweg, Stuttgart-Weilimdorf, Grüner Heine, Welzheim-Aichstrut, Nähe Wasserturm, Wiesensteig, Raller. Within these zones, 24 wind turbines of 29 MW installed capacity generate about 58 GWh, which made up 0.14% of the total wind energy generated in Germany in 2009.

Due to the dynamic expansion of wind energy parks in recent years, the availability of new sites is limited. Thus, apart from the construction of new wind farms, repowering has gained in importance for the further expansion of wind capacity, backed up by improved repowering incentives laid down in the EEG. Nonetheless, as the repowering measures are not sufficient to fulfill national and state targets, the highly urbanized Stuttgart region with its limited wind resources has pledged to establish additional preferential wind zones.

In 2010, the Green Party put forward at least 10 additional priority sites and proposed potential locations for wind development in Schopfloch, Erkenbrechtsweiler, Aufhausen, Treffelhausen, Drackenstein-Hohenstadt, Reussenstein-Gruibingen-Mühlhausen and Geislingen-Türkheim (Die Grünen 2010).

5.3.1 Approach to the Assessment of Wind Energy Potential

The following assessment gives insight into potential priority sites in the Stuttgart region. Priority areas for the use of wind energy are mapped out to avoid possible conflicts of wind energy plants with other regionally significant land use functions. Figure 46 shows the methodological approach for evaluating wind energy potential in the Stuttgart Region. As a first step, suitable locations for wind energy plants were examined through processing layers representing different land use functions. Unlike the Polish case, at the second step a continuous surface of wind speed was vertically interpolated using Map Algebra to obtain the wind speed at a given rotor blade height. Furthermore, the number of full load hours was estimated using a reference turbine of 2.5 MW power capacity based on the Rayleigh pro-bability distribution parameters and power curves. Next, the layer of available locations for wind farm construction was overlaid with the layer of full load hours to determine the technical potential of wind energy in the case study regions. Finally, to evaluate the economic viability, wind energy generation costs were estimated.

5.3.2 Site Classification for Wind Energy Development

The selection of appropriate locations for the construction of wind parks was carried out based on recommendations made by the Baden-Württemberg Ministry of Economy published in 2003 (WM 2003). Appendix 15 outlines criteria and suggests minimum distances to surfaces of sensitive social and ecological components and infrastructure. The digital datasets were obtained from different sources (DWD 2006; ESRI 2007; WaBoA 2007; LUBW 2009; NAVTEQ 2009; Geofabrik 2010). All data were processed using a 100 x 100 m grid.

Within some of the nature and landscape protection areas, the construction of wind energy plants is not strictly excluded. However, exceptions are only permitted if the environmental impact assessment demonstrates that any arising impact would be tolerable and in many cases specific environmental compensation measures are required (WM 2003). Landscape conservation areas, nature parks,

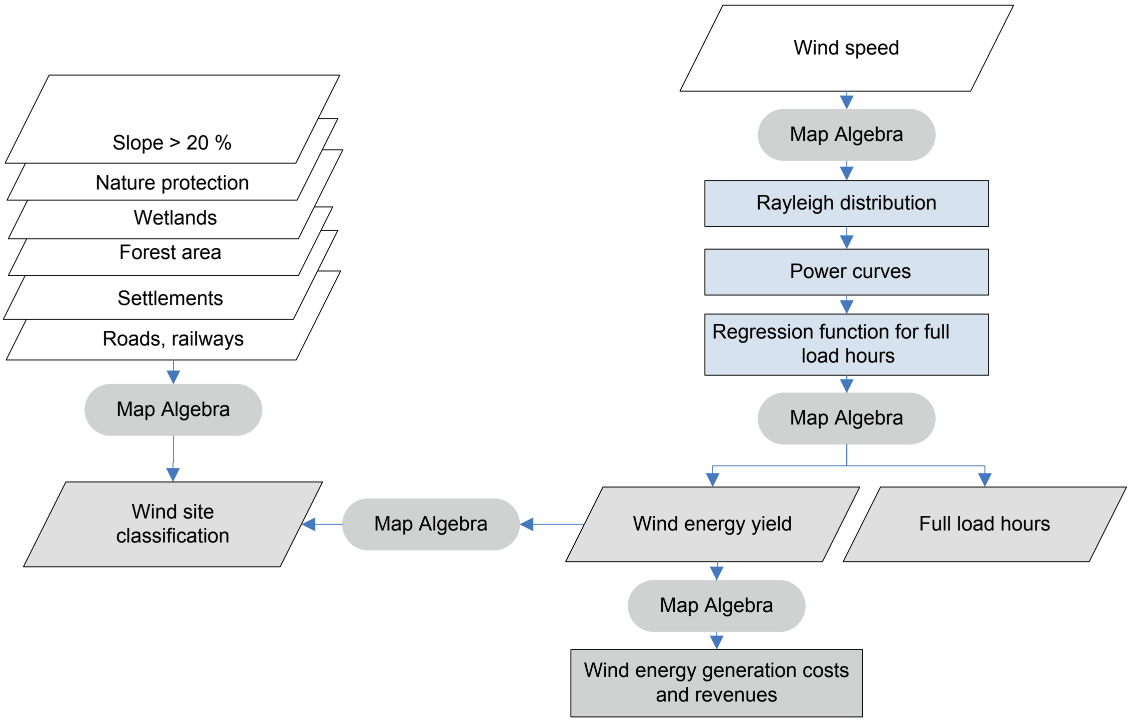


Figure 46: Overview of the Stepwise Approach to Assess Wind Energy Potential

Table 91: Constraints for Wind Turbine Siting

Nature Protection	Constraint Level
Nature Reserves (NSG)	High
Water Protection Zones (I)	High
Floodplains	High
Biotopes	High
Natura 2000 (FFH, SPA)	Moderate
Landscape Parks	Low
Nature Parks	Low

flora and fauna habitat areas (FFH) are subjected to a site-specific impact assessment. Hence, four of the existing wind parks (Aldorf, Bad Dizenbach, Welzheim, Wiesenstieg) are located in landscape protection areas and nature parks. Other forms of land use and conservation areas, which are not compatible with wind energy generation, were excluded. In the Map Algebra function in the Spatial Analysis toolbox, the rasterized layers were processed to classified sites for potential wind construction as follows:

```
if ((Excluded_land =  Y),
    Excluded,
    if ((High_protection = Y ),
        High protection,
        if ((Moderate_protection= Y),                (41)
            Moderate protection,
            if (( Low_protection =Y),
                Low protection,
                No constraints)))
```

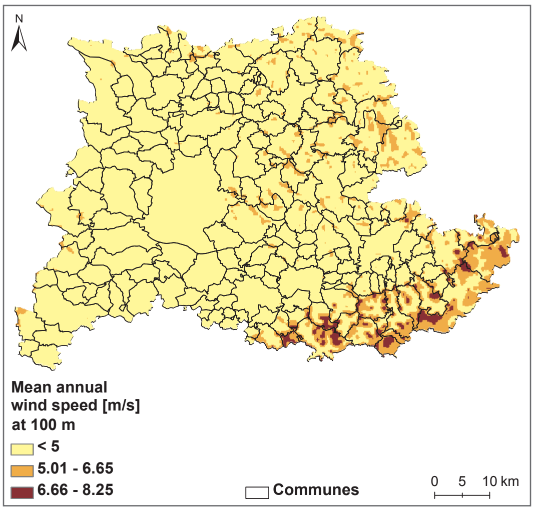
where Excluded_land is a grid layer representing land use functions not compatible with wind energy (outlined in Appendix 15). Three classes of nature protection areas (high, moderate and low) were ranked according to their sensitivity to adverse impacts as outlined in Table 91.

5.3.3 Technical Potential of Wind Energy

Wind speed is a significant factor in drawing up preferential zones, since the Renewable Energy Sources Act has introduced a regulation on the reference wind energy yield. To be eligible for feed-in tariffs, every wind park investor needs to demonstrate that there is at least 60% of the reference yield[15] at the intended sites. According to the German Renewable Energy Law, "the reference site shall be a site determined by means of a Rayleigh distribution with a mean annual wind speed of 5.5 m/s at a height of 30 m above ground level, a logarithmic wind shear profile and a roughness length of 0.1 metres" (EEG 2010).

An exemplary wind turbine Nordex N80 with 2.5 MW power capacity and a hub height of 100 m was considered to establish a reference yield calculated by the FGW (German: *Fördergesellschaft Windenergie*) that amounts to 4885 MWh. Calculation details can be found in the Fördergesellschaft Windenergie report (FGW e.V. 2007).

As the continuous surface of wind speed at 10 m above the ground obtained from the State Institute for Environment, Measurements and Nature Conservation Baden-Württemberg (LUBW 2009) is available for the study, this data was extrapolated to 100 m according to the equation 34 with a roughness length of 0.1 m as proposed in Annex 5 to EEG (2010).



Map 80: Mean Annual Wind Speed in m/s at 100 m above Ground

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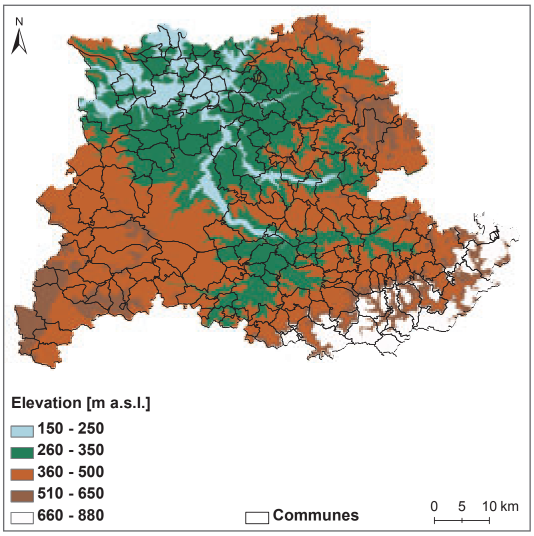
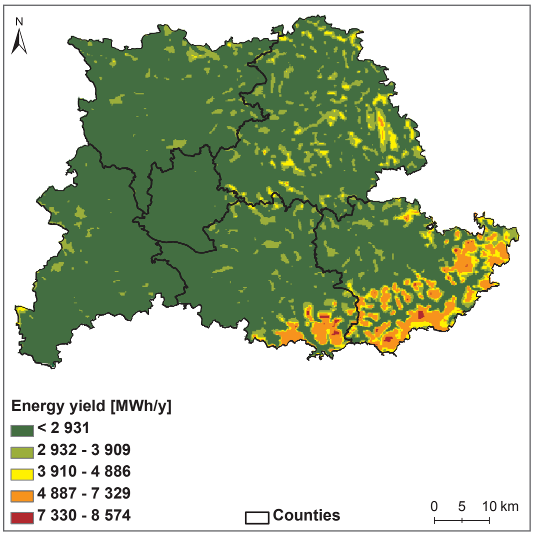
[15] Amount of energy for each wind turbine type, including the respective hub height, that this type would produce during five years of operation when erected at a reference site, calculated on the basis of a measured performance curve



Map 81: Elevation above Sea Level



Map 82: Annual Energy Yield Harvested by a Wind Turbine of 2.5 MW at a Hub Height of 100 m

The power curve, the Rayleigh distribution function and the energy yield were calculated according to steps described by the equations 35 - 40 (see chapter 5.1.2). As with the approach used in the Polish case study for wind power development described in the previous section, the regression function (see Table 89) was used to estimate the continuous surface of full load hours.

The interpolation of the aforementioned wind speed, the reference yield of which is estimated, resulted in a mean annual wind speed of 6.66 m/s at a hub height of 100 m. As presented on Map 80, suitable sites characterized by sufficient wind regimes are foremost located in the Swabian Alb, a region that features mountains with heights exceeding 1000 meters above sea level. In addition, large parts of the highlands in the middle and west of the Swabian Alb are situated over 800 m above sea level (see Map 81). Map 82 illustrates the annual energy harvested by wind turbines, varying from values less than 60% up to 175% of the reference yield. Finally, potential locations for preferential sites were evaluated against the energy yield in the Map Algebra based on the following formula:

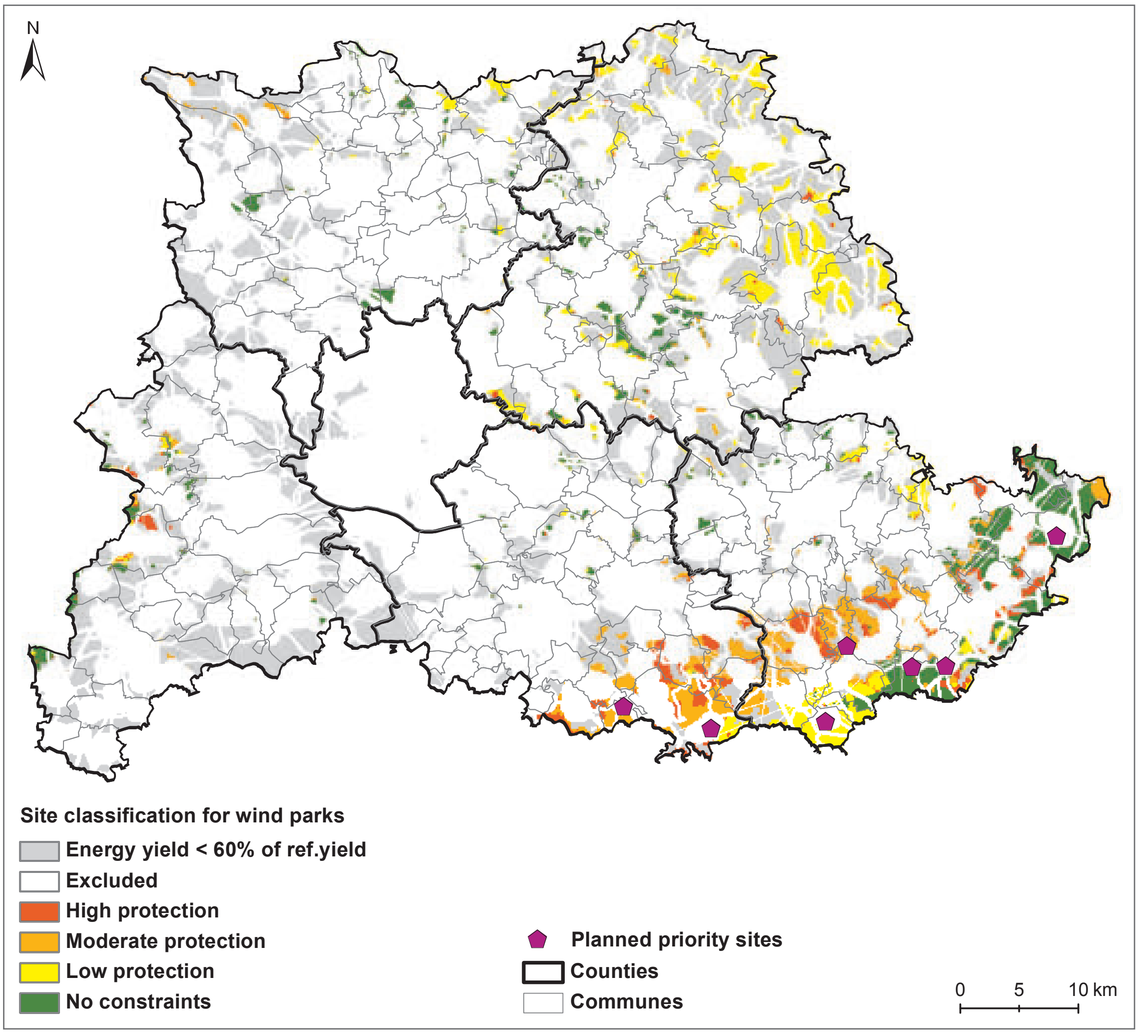
```
if (wind_sites =  Excluded),
    Excluded,
    if(wind_sites = High_prot and
        EY >= 60% of RY),
        High protection,
        if(wind_sites = Moderate_prot and
            EY >= 60% of RY),
            Moderate protection,                        (42)
            if(wind_sites = Low_prot and
                EY >= 60% of RY),
                Low protection
                if(wind_sites = No_constraints
                    and EY >= 60% of RY),
                    No constraints,
                    Reference yield < 60%))))
```

where wind_sites is the grid representing site classification for wind turbine produced through formula 41, EY is the energy yield of the referential wind turbine.

Map 83 shows the classification of sites regarding their potential to become zones of wind energy development, the areas of which are outlined in Table 92. The new priority sites proposed by the Green Party (2010) match the sites explored in this study as illustrated on Map 83. However, two of them were identified on land with moderate protection restrictions related to the Natura 2000 network. The area of 8836 ha without constraints explored at the regional level is predominately located in the mountains. Moreover, the sites classified as Low protection areas (representing nature parks and landscape protection areas) can be designated for preferential zone development after having passed through a local environmental impact assessment. In addition, to avoid a thinly-dispersed, unnecessary sprawl of wind turbines across the landscape, potential priority zone locations can only be considered where at least three turbines could be constructed (VRS 2008).

Table 92: Site Classification and its Area for Potential Development of Wind Parks

Site Classification	Area [ha]	Share [%]
Reference Yield < 60%	73917	20.23
Excluded	260131	71.19
High Protection	4295	1.18
Moderate Protection	7266	1.99
Low Protection	10934	2.99
No Constraints	8836	2.42



Map 83: Site Classification for Wind Parks (WP) Development and Planned Priority Sites

5.3.4 Economic Potential of Wind Energy

The profitability of wind energy turbines depends on the annual energy generated, feed-in tariffs, investment and annual operation costs. The costs of energy generated by the reference wind turbine were calculated according the methodology outlined in chapter 5.1.3. The initial tariff paid in the first five years for electricity generated by wind turbines commissioned in 2010 amounted to 9.11 ct/kWh, including a 1% digression rate (EEG 2010). According to the most recent amendment to the EEG (2010), the basic payment (9.11 ct/kWh) in the standard period shall be extended by two months for each 0.75 per cent of the reference energy yield by which the yield of the installation is less than 150% of the reference yield as outlined in Table 93. The basic tariff after this period was calculated at 4.97 ct/kWh.

Table 93: The Reference Yield of the Nordex N2500/80 Turbine and Payment Duration of the Initial Tariff

Percent of Reference Yield	Reference Yield	Payment Duration of Initial Tariff	Revenue from Initial Tariff	Revenue from Basic Tariff	Total Revenue over 20 Years	Mean Annual Revenue
%	MWh		€	€	€	€cent/kWh
175	8574	5 years	3905457	6391917	10297374	6.01
150	7329	5 years	3338172	5463462	8801634	6.01
140	6840	7 years, 3 months	4517659	4334347	8852005	6.47
130	6351	9 years, 5 months	5448638	3340806	8789444	6.92
120	5863	11 years, 8 months	6231250	2428207	8659457	7.38
110	5374	13 years, 11 months	6813579	1624874	8438453	7.85
100	4886	16 years, 1 month	7158524	951047	8109571	8.30
90	4397	18 years, 4 months	7343977	364231	7708208	8.76
80	3909	20 years	7121433	0	7121433	9.11
60	2931	20 years	5341075	0	5341075	9.11

Figure 47 shows that the payment received by investors brings in a high surplus, compensating the energy generation costs calculated for the option of investment costs of 1000 per kW at the 5% discount rate (minimum costs - green curve). By contrast, in the case where investment costs are 1600 € per kW, a profit may only start to be made on an energy yield more than 150% above the reference value. Figure 48 shows cost curves calculated for both investment options for an extreme case with a 10% interest rate, which would certainly influence the project's economic viability through higher investment costs. Nevertheless, supposing real costs of 1000 € per kW, the investment would bring profitable returns at less than 80% of the reference yield.

The assessment confirms that the region offers favorable economic conditions for investors thanks to the current payment schemes and energy yield. On the other hand, in the most optimistic case, only 5% of the regional surface can be considered for

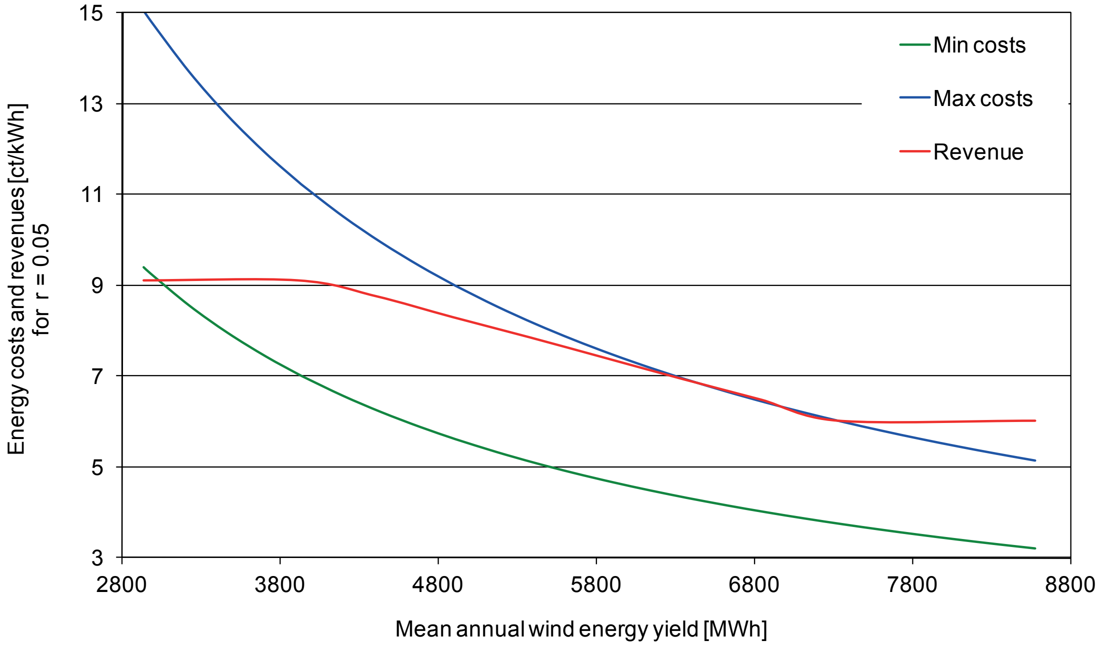


Figure 47: Electricity Generation Costs and Revenues Calculated with an Interest Rate of 5%

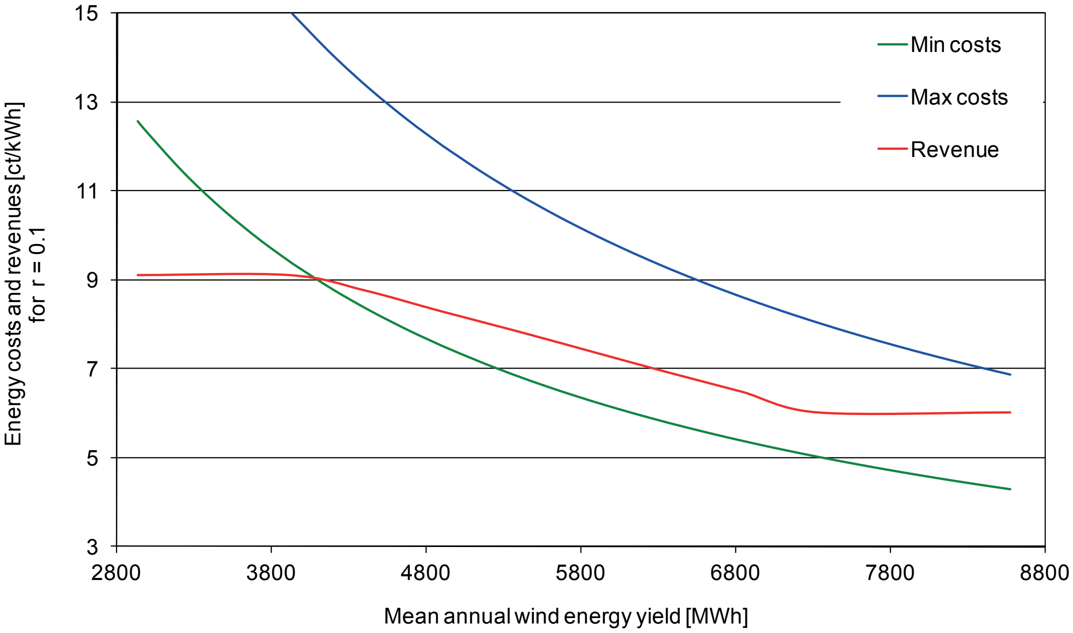


Figure 48: Electricity Generation Costs and Revenues Calculated with an Interest Rate of 10%

further site evaluation regarding the establishment of preferential wind power zones.

5.4 Wind Energy Potential in the Region of Provence-Alpes-Côte d'Azur

Apart from hydro energy, wind energy is expected to be the second major instrument to meet the national targets set by Directive 2009/28/EC, supplying 37% of renewable electricity by 2020. From the national target of 25 GW of wind power (including 6 GW off-shore), 5.3 GW (21%) have already been installed.

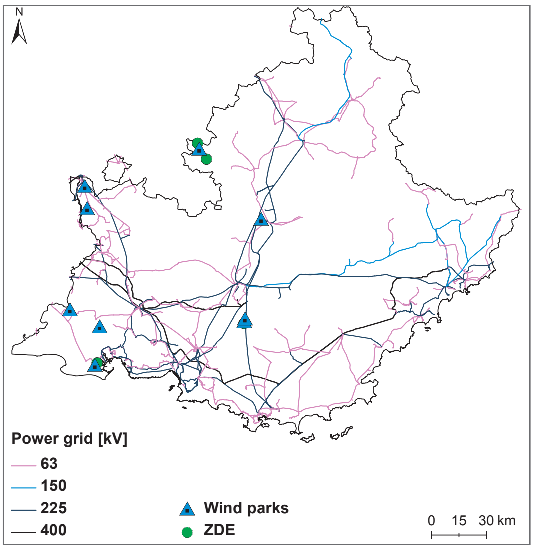
The French Renewable Energy Association (*SER - Syndicat des énergies renouvelables*) made an attempt to transfer the national targets onto regional levels based on historical patterns of wind energy development and region-related planning documents (SER-FEE 2009). The proposed allocation of wind power capacity in each region indicates for PACA a 160 MW wind power capacity in 2012 and 420 MW of wind power capacity (equaling 160 wind turbines) by 2020, corresponding to a tenfold increase compared to the installed capacity in 2009.

In 2010, in the PACA region, there were four wind development zones (French: *ZDE - zones de développement de l'éolien*) and 14 wind turbines of 47 MW installed capacity (CGDD 2010) located in seven wind parks (see Map 84).

As previously mentioned, the regional renewable energy plans currently underway are intended, among other purposes, to determine geographical zones eligible for the development of renewable energy (*Schéma Régional Eolien, SRE*). The assessment proposed here aims to provide a better understanding of the potential sites for the development of wind power plants as well as of the energetic and economic equivalent of the wind harvested in this region.

5.4.1 Approach Toward Assessing Wind Energy Potential

The methodological approach toward exploring the potential wind power development zones was carried out according to steps outlined in the Stuttgart region case study (see Figure 46). In the techno-economic analysis of wind energy, the available grid data on wind speed at a height of 80 m (DIREN 2009b) was used to calculate the full load hours from a regression function for a reference wind turbine (Nordex 80) and subsequently the cost-benefit relationship.



Map 84: Wind Development Zones and Wind Parks in the PACA Region

5.4.2 Site Classification for Wind Energy Development

Site classification for the development of wind energy plants was carried out according to the same GIS-based approach applied to both the Polish and the German case studies, postulating however a different conditional framework summarized in the ADEME document (2004). Table 94 outlines various protected environmental features, rated according to their susceptibility to potential impact from wind turbines. In addition, according to Article 10-1 of the Law on the Modernization and Development of the Public Electricity Service (Ministry of Energy 2000), the mandatory criteria in the site identification process are (i) wind speed at a height of 50 m that must be at least 4 m/s, (ii) an ability to connect to the grid and (iii) the preservation of sensitive nature, landscape and historical areas. Under different functions of land use related to nature and landscape conservation, wind energy projects may be excluded or allowed if the local impact assessment suggests such exceptions.

Layers obtained from different sources (ESRI 2007; NAVTEQ 2009; Sandre 2009; DIREN 2009a; DIREN 2009b; RTE 2010) were rasterized and processed at a 100 m grid in the Map Algebra according to the formula:

```
if ((Excluded_land = Y),
    Excluded,
    if ((High_protection = Y
        or Landscape = Y),
        High protection,
        if ((Moderate_protection = Y),                (43)
            Moderate protection,
            if ((Low_protection = Y),
                Low protection,
                No constrains)))
```

where Exclude_land represents merged buffered land use functions that are incompatible with wind energy turbines (outlined in Appendix 16), and High_protection, Moderate_protection, Low_protection and Landscape represent the grid layers outlined in Table 94.

5.4.3 Technical Potential of Wind Energy

As mentioned in the previous section, wind potential plays a significant role in the final determination of wind power development zones (ZDE), so that the wind speed must be higher than 4 m/s at 50 m above ground (or corresponding to wind speeds of 4.3 m/s or 4.5 m/s for the respective altitudes of 80 m and 100 m) (Fröding 2009). In this step of the analysis, potential wind sites were overlapped with both rasters representing the minimum and maximum annual wind speeds at 50 m above ground, data that was obtained from (DIREN 2009b) and processed based on the formula 44.

```
if((Wind_sites = excluded ),
    Excluded
    if((Wind_sites = High_prot  and
        WS50 >= 4 m/s),
        High protection,
        if((Wind_sites = Moderate_prot  and
            WS50 >= 4 m/s),
            Moderate protection,                      (44)
            if((Wind_sites = Low_prot and
                WS50 >= 4 m/s),
                Low protection,
                if((Wind_sites = No_constraints
                    and WS50 >= 4 m/s),
                    No constraints,
                    Wind speed < 4m/s))))
```

where Wind_sites is the grid illustrating the site classification for wind development produced according

Table 94: Wind Energy Development Constraints in the PACA Region

Land Use Functions	Conditions	Constraint Level
Landscape and Monuments		
Classified Sites (Sites classés)	Installation of wind turbines is restricted and in most cases prohibited	High
Listed Sites (Sites inscrits)		High
Historic Monuments (Monuments historiques classés ou inscrits)	Very strict constraints. Any turbines projected to be located within a radius of 500m must receive the ABF's authorization	High
Protection zone under the 1930 Act (Zone de protection au titre de la loi de 1930)	Requires the ABF's authorization	High
Urban and Architectural Heritage and Landscape Protection Zone (Zone de protection du patrimoine architectural urbain et paysager, ZPPAUP)	The installation of wind turbines within ZP-PAUP is subject to individual assessment	High
Coastal Area	French coastal law refers to coastal towns and lakes (Etang de Berre Ste-Croix, Serre-Ponçon) and wind projects are not permitted	High
Nature Conservation Areas		
National Park	Wind turbines are excluded in the central zone. In the peripheral zone, authorization may be looked into by the management structure	Central zone - Excluded; Peripheral zone - Low
Regional Nature Park (Luberon Verdon Queyras, Camargue)	Individual assessment required	Moderate
Nature Reserves (national, regional) (Réserve naturelle)	Wind projects strictly excluded	High
Prefectural Biotope (APPB)	Strong constraints, excluded	High
Biosphere Reserve (UNESCO)	Three zones distinguished: (central, buffer, transition). Wind projects less restricted in buffer and transition zones	Central, Buffer -Moderate; Transition - Low
Biologic Reserves (Réserve biologique RBG)		High
Natura 2000	Environmental impact assessment required	Moderate
ZNIEFF (Natural Area of Ecological, Floristic and Faunistic Interest)	Mostly identified in the Natura 2000 SPA, thus, a local impact study required	Moderate
RAMSAR (Wetlands of International Importance)		Moderate
Sensitive water land to pollution (Zone sensible)		Low
Natural Hazards		
Flood Area (AZI)		High
Other Land Use Functions		
Water Lands		High
Settlements		High
Roads, Power Grids		High
Forest Land		High

Source: Derived from ADEME (2004)

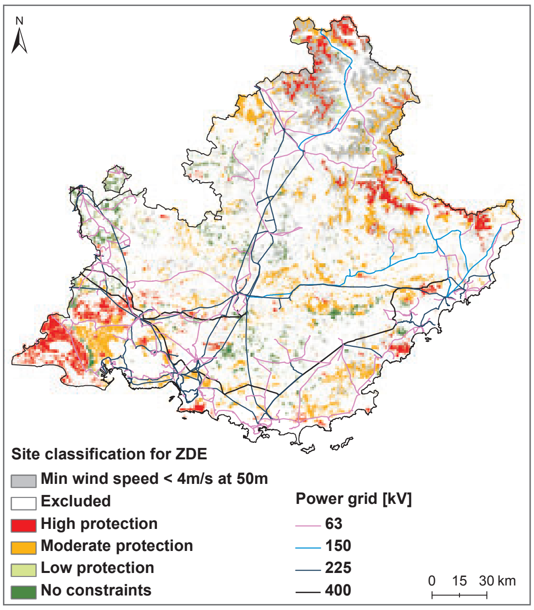
to the formula 43 and WS50 are the grid layers of maximum and minimum wind speed at 50 m above ground.

In practice, the chances of harvesting wind at heights above 2000 m are very slim, due to the lack of power grids and to the obvious construction difficulties entailed. Thus, areas located above 2000 m above sea level were taken out. Eligible sites for the potential development of wind energy plants (ZDE) are shown on Map 85 (minimum wind speed) and Map 86 (maximum wind speed). In the case of the minimum wind speed data layer, and supposing all the considered constraints are absent, a 65876 ha area would be eligible, whereas 85511 ha would be eligible in the case of maximum wind speed requirements, as outlined in Table 95. Furthermore, the area under low protection, which amounts to either 3 ths. ha or 6 ths. ha depending on the wind speed, can be also subjected to an individual local assessment.

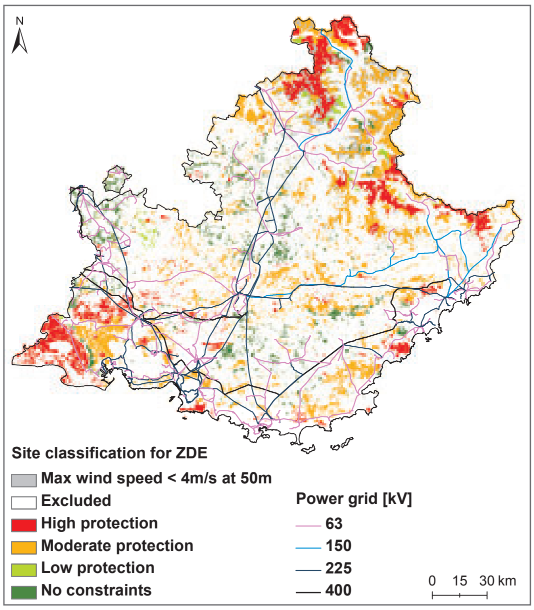
Assuming a power density of 1 MW per 10 ha, the power potential ranges between 6587 MW and 9196 MW, which is 15 to 21 times more than the than the regional allocation target identified by SERFEE (2009). However, an additional constraint in the establishment of wind power zones is the need for a nearby power network and connection possibilities, factors which are beyond the scope of the regional assessment. Also, the explored sites require subsequent evaluation in view of site-specific environmental, landscape and socio-economic impacts. Then, according to the Grenelle II law (2010), only

Table 95: Site Classification and its Area for the Development of Wind Power Zones (ZDE)

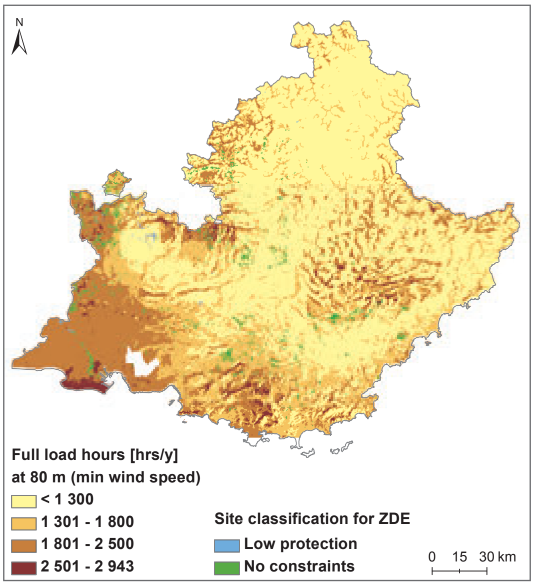
	Total Area				Area Less Than 2000 m above Sea Level			
	Min Wind Speed		Max Wind Speed		Min Wind Speed		Max Wind Speed	
Site Classification	ha	%	ha	%	ha	%	ha	%
Wind Speed < 4 m/s	242321	7.55	63183	1.97	120276	3.8	31605	1
Excluded	2457252	76.60	2457252	76.60	2356492	74	2356492	74
High Protection	156560	4.88	202719	6.32	91737	2.9	103733	3.3
Moderate Protection	273222	8.52	375390	11.70	200672	6.3	254322	8
Low Protection	10130	0.32	17516	0.55	3064	0.1	6445	0.2
No Constraints	68424	2.13	91849	2.86	65867	2.1	85511	2.7
Above 2000m					332097	10.5	332097	10.5



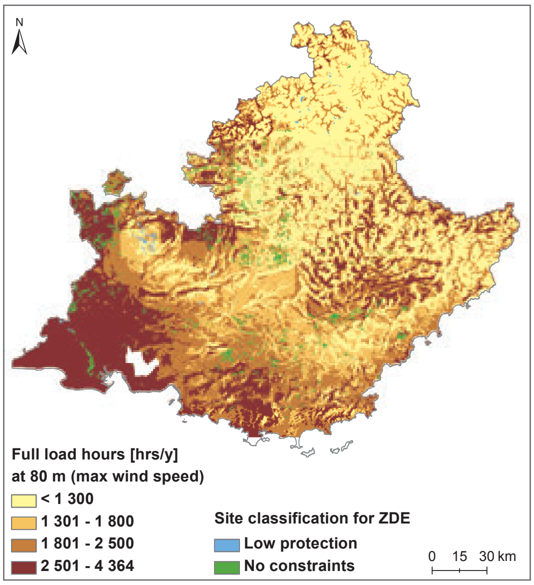
Map 85: Site Classification for Wind Development Zones Evaluated According to a Min Annual Wind Speed of 4 m/s at 50 m above the Ground



Map 86: Site Classification for Wind Development Zones Evaluated According to a Max Annual Wind Speed of 4 m/s at 50 m above the Ground



Map 87: Full Load Hours for a Wind Turbine Nordex 80 at 80 m above Ground for Min Wind Speed and Selected Sites for ZDE



Map 88: Full Load Hours for a Wind Turbine Nordex 80 at 80 m above Ground for Max Wind Speed and Selected Sites for ZDE

such areas can be chosen where at least 5 turbines may be constructed to avoid scatter development.

Map 87 and Map 88 illustrate the potential number of full load hours (calculated from the regression function shown in Table 89) and the potential sites classified in the previous step as being without constraints, plus those within low protection areas, reflecting either transition zones of Biosphere reserves and National Parks or water areas sensitive to pollution (French: *Zone sensible*). Appendix 19 and Appendix 20 outline the zonal statistics for the number of full load hours calculated on these sites within the cantons' administrative borders.

5.4.4 The Economic Potential of Wind Energy

In contrast to Germany, which applies a reference energy yield, the French support mechanism adjusts the wind tariff after 10 years according to the average annual number of full load hours during which wind turbines at a particular site produce electricity (Klein, Pfluger et al. 2008; Couture, Cory et al. 2010). The formula below illustrates the degression of payment after the first 10 years' operation for onshore wind energy plants:

$$\begin{aligned}&\text{If } (FLH < 2400),\ FIT = 8.2\\ &\quad \text{if } (FLH >= 2400 \text{ and } FLH <= 3600),\\ &\qquad FIT = -0.0045*FLH + 19\\ &\qquad \text{else } FIT = 2.8\end{aligned} \tag{45}$$

where FLH are the number of full load hours and FIT are the unit costs in €cents paid for kilowatt-hours of wind electricity.

Between the 10th and 15th year of their running time, projects that generate electricity for less than 2400 full load hours per year receive the full tariff amount estimated according to the formula 45, whereas projects generating energy for more than 3600 full load hours receive only 2.8 cents per kWh. After this period, energy from an amortized wind turbine can be sold on the electricity market Powernext at a price that currently varies between 5 and 7 cents per kWh (Powernext 2010).

The costs of wind energy generated by a reference wind turbine with a power rate of 2500kW were calculated according to the approach outlined in chapter 5.1.3 and plotted against the number of full load hours to better illustrate the FIT payments. The investment costs were annuitized over 15 years and after this period, only the operation and maintenance costs were assumed at a constant rate of 0.03% of investment costs.

Figure 49 reveals that lower investment costs (1000 €/kW) are compensated by the feed-in tariffs even at around 1500 full load hours, whereas in the case of high investment costs (1600 €/kW), a project is profitable if the wind turbine works at least 3000 full load hours per year, which is feasible on the costal

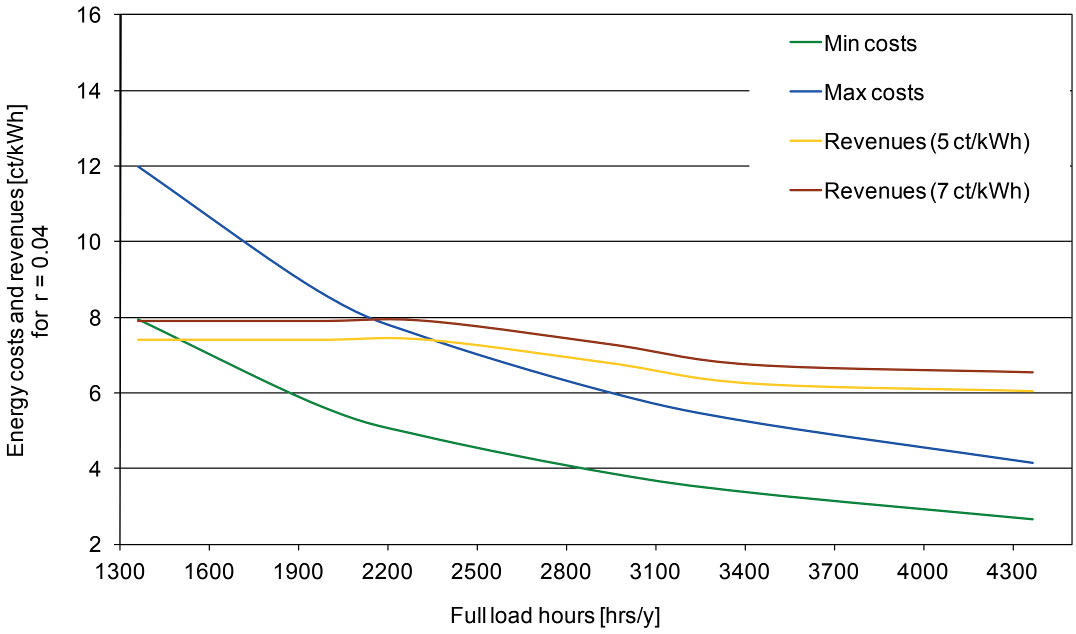


Figure 49: Electricity Generation Costs and Revenues Calculated at an Interest Rate of 4%

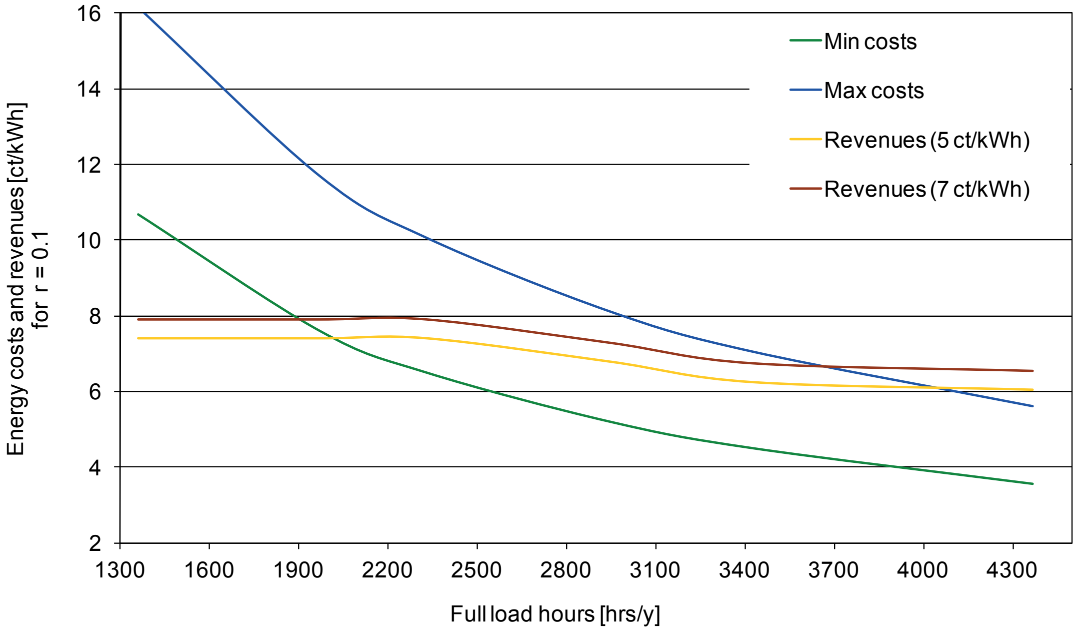


Figure 50: Electricity Generation Costs and Revenues Calculated at an Interest Rate of 10%

sites of the Bouches-du-Rhône department. The electricity purchase price after 15 years of FIT payments has only a moderate impact on the profit level. Increasing the interest rate from 4% to 10% would shift the profitability threshold of a wind turbine by approximately 500 working hours (see Figure 50).

The economic assessment indicates that the French support schemes are favorable for investors especially in the PACA region due to good wind regime conditions. Despite this fact, the lack of regional plans including wind power zones has turned out to be the main barrier slowing down the wind energy development in the region (Resch and Ragwitz 2007; EREC 2010). In addition, the French policy framework makes investors more dependent on the local community acceptance than in Germany (Jobert, Laborgne et al. 2007).

5.5 Summary and Conclusion

This study proposed methods to identify conditions for the expansion of wind power and to support the policy-making process of site selection for potential wind energy development zones. As with the previous case of biomass assessment, a uniform approach could not be developed owing to different data input availability and the requirements and constraints derived from legal regulations.

Given that the potential sites for a wind power development are foremost associated with the availability of agricultural land and environmental constraints, the findings indicates the substantial and still untapped technical and economic potential in the Polish agricultural region. On the other hand, a successful expansion of wind energy in the Kujawsko-Pomorskie Region would require local spatial and energy plans to enhance harmonized spreading of wind turbines over their territory.

The siting potential for wind parks in an urban agglomeration exemplified by the Stuttgart region is significantly limited. Unlike in Poland, an additional techno-economic constraint is the required reference yield for wind turbines at their potential locations, which increases efficient land-use. German communities can regulate the implementation of wind energy in their regions by concentrating it in appropriate places through designation of preferential zones for wind projects. This procedure enhances the social acceptance, as it reduces the fear of landscape fragmentation and uncontrolled growth of wind parks.

In Provence-Alpes-Côte d'Azur, the potential zones for wind energy development are limited not only by geographical conditions but also notably by the nature and landscape conservation constraints. For the designation of wind power zones across France, the landscape factor is a critical aspect in the cultural and political-making process. Much more in France than in Germany the policy framework makes investors dependent on the local community acceptance.

As stated in the previous sections, the outcomes of these three studies indicate the potential of preliminary wind power zones where a local environmental impact assessment is subsequently required. The additional, decisive factor influencing wind development feasibility is the willingness of the residence and other involved stakeholder to integrate these installations into their energy portfolio.

6 Methodological Approach to Assess Solar Energy Potential

In efforts to diversify the energy supply, solar energy has increasingly gained importance over recent years. Although photovoltaic (PV) facilities still lack the economic edge to compete with other power-harnessing technologies, the investment costs of PV systems will systematically decrease in the future, while oil prices will continue to rise (EPIA 2010). Compared to fossil fuels or even biomass sources, solar energy seems to be an endless resource. The solar energy can be exploited by a wide range of applications, but in most cases, the utilization of this type of energy is associated with thermal or photovoltaic systems mounted on roofs or façades of buildings. Large ground mounted PV parks have also received considerable attention for economy of scale resulting in lower investment costs and higher energy generation efficiency compared to small applications (IE 2010; Dinçer 2011). On the other hand, the space available for PV units on buildings and infrastructure might be more significant for their deployment than ground-based solar farms, because of their minor conflicts with space needed for other RES and other competing land uses. For that reason the acceptability of large freestanding PV systems is more problematic (Chiabrando, Fabrizio et al. 2009). The methodology presented in the section provides an insight into the technical and economic potential of photovoltaic systems and related land use trade-offs.

6.1 Approaches and Datasets for Assessing Solar Energy Potential

When speaking about approaches to assess solar energy potential, the area being studied should be differentiated according to its size. Due to incommensurable framework conditions, the datasets and methodologies used on a strictly limited local scale cannot be applied to studies focusing on large regional or national scale areas. Generally, datasets and analyses for the latter are rare because compiling them is very expensive. Therefore, when assessing solar energy potential in large-scale studies, less expensive, obviously inaccurate though nonetheless economically viable data is used (Sorensen 2001). The decisive factor to estimate the technical potential of solar energy for large scale territories is the identification of suitable roof areas among existing buildings and of other dedicated areas (Castro, Delgado et al. 2005), for which there is often unfortunately no direct data. Thus the roof orientation, inclination, shading, as well as the historical value of buildings must be left out in most analyses, as it is in this study.

Facing a lack of digital data on building characteristics, many developed approaches strive to estimate the available and suitable building surfaces on the basis of supplementary datasets. Against this background, Izquierdo, Rodrigues et al. (2008) developed a methodology to estimate the technical potential of roof-integrated photovoltaic devices based on data such as land use, population and building density. The approach involves a stratification method on the basis of the assumption of average building topologies in the case study region in Spain. Lehmann and Peter (2003) plotted a roof and façade area per capita versus population density in several German cities. They found that the non-residential roof area per capita ranges from 9 m^2 per capita in low-density regions to 4 m^2 per capita in high-density regions, while residential roof areas range from 7 to 4.5 m^2 per capita respectively. In 2002, the Photovoltaic Power System Programme (PVGIS 2006) was launched by the International Energy Agency in order to estimate the building-integrated photovoltaic potential across Europe on the basis of the average architectural design of roofs and façades, the population density and the solar regime (IEA 2002). Among others, the main findings of the project indicate that the roof utilization factor is 0.4 and 0.15 for façades including construction, shading and constraints related to architectural heritage protection. Although there are many studies concerning solar power systems on buildings, those for PV systems on land have so far been neglected.

In addition, various databases (Meteonorm, ESRA, NASA SSE, HelioClim) and computation models have been used to simulate the solar irradiance on an inclined surface of any orientation. There are, however, many models and many stations that measure solar irradiance and irradiation, but neither outputs from tools nor measured values are error-free (Súri and Hofierka 2004).

6.2 Methodology and Scope of the Study

Photovoltaic modules can be installed on roofs and façades of buildings and industrial constructions. The integration of solar power systems into urban construction projects brings added value by optimizing the use of space and enables the generated electrical energy to be consumed in the surrounding area without transmission losses. In contrast to ground-based PV applications, the synergy effect is obtained by mounting PV systems or thermal systems on roofs, as there is no other productive purpose of roofs (IEA 2002). On the other hand, free-standing units are economically more profitable due to the economies of scale and higher energy efficiency and yield, as they are not limited to the size of a roof (Dinçer 2011; ADEME and AXENNE 2009).

The objective of this study was to develop an approach toward evaluating the technical and economic potential of ground-mounted PV systems under the respective political framework conditions including policy incentives, spatial planning instruments and spatial confinements linked to land use prioritization. Alternative surfaces for energy development, such as building roofs, were also incorporated into the study. The focus was centred on the potential of available roof surface and economic attractiveness compared to free-standing photovoltaic systems. With the Polish and German case study regions, the existing information on roof surface potential is incomplete; an approach was developed in the present work to deal with this.

6.2.1 Theoretical and Technical Potential of Ground-Based Photovoltaic Systems

The selection of appropriate locations for ground-mounted PV plants must fulfill certain conditions, since the aim is to enhance environmental benefits and gain financial profits. PV systems mounted on land do not usually damage the land they occupy, but they compete with other land use purposes, namely crop production or natural beauty. Beside this, large-scale solar energy systems may negatively affect wildlife and sensitive natural ecosystems (Tsoutsos, Frantzeskaki et al. 2005; Günnewig, Püschel et al. 2009).

The methodology developed to evaluate site suitability for land-based PV system constructions is a set of sequential steps that incorporate the analyses of slope and orientation, land use constraints (woodland, wetland, infrastructure etc.) and natural and environmental constraints (biodiversity, natural hazards, etc.) as outlined in Figure 51. The analyses carried out at the regional scale allow for preliminary classification of sites under technical constraints and land use function aspects. The analyses were carried out on the basis of the Corine Land Cover Data (CLC2006) and region-specific datasets (WorldClim 2005; ESRI 2007; WaBoA 2007; KPBPP 2009; NAVTEQ 2009; DIREN 2009a; Geofabrik 2010).

Since the introduction on 1 July 2010 of the legal framework excluding the eligibility of PV ground-mounted systems on arable land for feed-in tariffs, in Germany favorable sites are brown fields, former

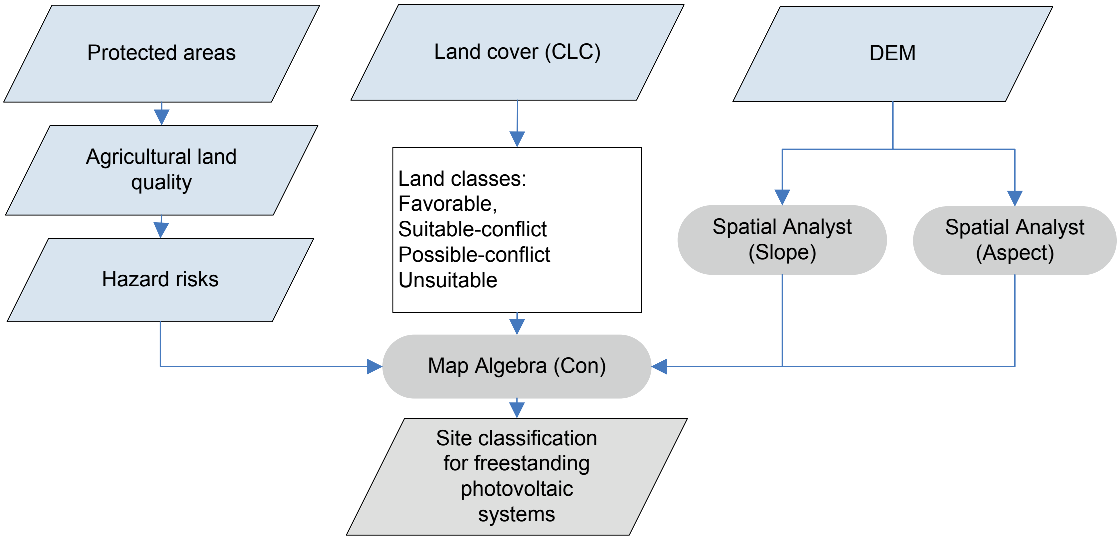


Figure 53: Overview of the Approach Toward Site Classification for Large Ground-Based PV Systems

Table 96: Land Use Classification based on CLC 2006

Classes	Land Use
Favorable (F)	Mines, dump sites, mineral extraction sites, bare rocks and burnt areas
Favorable (F-roads)	Land along railway lines and motorway Land previously used for economic, transport and military purposes
Suitable-Conflict (S-C)	Arable land, pasture
Possible-Conflict (P-C)	Fruit and berry plantations, vineyards
Unsuitable (U)	Urban areas, forestland, wetland

military ranges, mining areas or highway verges. Regarding legislative regulations in Poland and France, arable land was taken into account in the analysis in both countries, given that Polish and French land owners are free to decide on the use of their land, as long as the local legal framework does not prevent it. Furthermore, possible sites for the installation of PV systems include agricultural areas covered by orchard plantations that offer the chance to convert the area into arable land at a later date. Unlike orchards, it is difficult to adapt forestlands, urban areas and wetlands to solar power constructions, and therefore they are identified as unsuitable sites as indicated in Table 96. Details on the land use classification for the case study regions are listed in Appendix 21.

How PV installations are arrayed and their orientation towards the sun represent the basic factors affecting plants' performance. Unlike the ground-mounted modules in a fixed position, the sun-tracking systems are land inefficient, because they generate more shadow effects; however, they harvest far more energy. In other words, one-axis PV sun-tracking systems produce less electricity per area but more per installed capacity (Aste and Del Pero 2010). The Ground Cover Ratio varies from 10 to 45% depending on the number of axes (Jäger-Waldau 2007). Another type is a concentrated solar PV system, which is economically feasible at sites where solar irradiation of at least 1900 kWh/m^2 can be harvested (JRC 2010). As such, these particular PV applications are considered in the south of France in Provence-Alpes-Côte d'Azur but not in Poland or Germany (NREAP 2010a; NREAP 2010b; NREAP 2010c).

Taking into account the technical aspects of solar energy use and the optimal tilt angles for different PV arrays, the following conditions for the slope and orientation were defined (ADEME and AXENNE 2009):

- areas where the average slope is less than 3° (flat area) and regardless of orientation - condition 1,
- areas where the average slope varies from 3° to 6° oriented to SE, S and SW (90° - 270°) - condition 2,
- areas where the average slope varies between 6° and 15° and which are south oriented (135° - 225°) - condition 3,
- areas where the slope varies between 15 ° and 35° and which are south oriented (157.5° - 202.5°) - condition 4,
- other areas - condition 0.

The NASA digital elevation model (2009) was processed to evaluate sites using the tool Map Algebra provided through the Spatial Analyst toolbox. Suitable sites with regard to slope and array were assessed according to the formula:

```
if ((Slope < = 3 and Aspect >= -1 and
  Aspect <=  360) ,
  Condition_1
  if((Slope > 15 and slope <=  35) and
    (Aspect >=  157 and Aspect <=   202),
    Condition_4,
    if((Slope> 6 & Slope <=  15) and          (46)
      (Aspect >=  135 and Aspect <= 225),
      Condition_3,
      if((Slope > 3 and  Slope <=  6) and
      (Aspect >=  90 & Aspect <=  270),
      Condition_2,
        else Condition_0))))
```

Areas with land use functions like nature conservation, biodiversity and landscape protection were divided into three classes according to the degree of protection they have been given: high (areas precluded from PV development); moderate and low, where the permitted types of construction are determined on site. Areas under hazard risks such as flood plains were also excluded from PV development sites. Unlike wind parks, ground-based PV applications are not very compatible with farming, thus the agricultural land quality was also assigned three levels of constraints: high, moderate and low. The land under different forms of nature and soil protection, suitability classes of land use function and suitability classes of slope and aspect were evaluated through the Map Algebra. Three different conditional statements were developed for the three case studies due to different constraints and datasets.

6.2.2 Technical Potential of Roof-Mounted Photovoltaic Energy Systems

The objective was to estimate the roof area that could be used for PV modules or thermal collectors. As mentioned above, a wide range of approaches has been developed so far to identify different surfaces suitable for the installation of PV modules based on available datasets. Thus, in this study, two approaches were developed to match available data input, as no specific statistical dataset about roof surfaces is available. Since vector data on built-up surfaces was only available for some parts of the Polish case study region, the method proposed makes it possible to extrapolate the mean roof surface in the residential sectors across the entire region. The details are outlined in chapter 6.3.3. In case of the German region, vector point data on the buildings' age and typology was used to estimate the potential surface for the installation of rooftop photovoltaic modules. The details are given in chapter 6.4.2.

The characteristics of the sloped roof (slope, azimuth, available surface) determine the performance of the solar installation. The optimal roof-pitch is about 30 - 45° in Europe (Klärle and Ludwig 2006), though in practice the angle varies between 20° and 50° (Scheffler 2002). A deviation up to 70° may reduce the available roof surface by 20%.

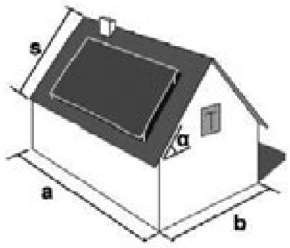


Figure 51: Area of Solar Installation on a Sloped Roof
Source: Kaltschmitt and Wiese (1993)

In this calculation of the available roof area based on the building footprint, an average angle of 35° was applied (Kaltschmitt and Wiese 1993).

The roof slope angle was calculated from a formula after Lödl, Kerber et al. (2010):

$$\cos\alpha = \frac{1}{2} b * \frac{1}{s} \tag{47}$$

where b is the verge and s is the roof length (see Figure 52).

Then the area of one roof side was calculated from the equation:

$$A_R = a * s \tag{48}$$

where A_R is the roof area in m^2, a is the length of eave in m and s is the roof length in m.

The reduction factor 0.8 (including chimneys, antennae and satellite dishes etc.) was applied to estimate the useful surface (Scheffler 2002):

$$Au_R = A_R * 0.8 \tag{49}$$

The area of PV modules or solar collectors was estimated from the building footprint area and equations 47 and 49 as follows:

$$A_I = \frac{1}{2} * a * b * 0.8 * \frac{1}{\cos\alpha} \tag{50}$$

where A_I is the available area for PV modules or solar collectors on a roof in m^2.

Assuming an angle of 35° in accordance with Kaltschmitt and Wiese (1993), the surface A_I occupies almost half of the building footprint (BF) (Hübert 1995):

$$A_I = 0.488 * a * b = 0.48BF \tag{51}$$

The exposure of a roof surface to either east or west reduces the energy harvest by around 20% (Klärle and Ludwig 2006), which can disqualify the roof's suitability in the economic context. Frequently, PV arrays are mounted on flat roofs in multifamily houses, or commercial, industrial and agricultural buildings. To harvest the highest amount of solar energy, modules should be optimally positioned and the inclination angle adjusted (around 30° at Central European latitudes). At sites with space restrictions, a trade-off between energy yield and the tilt angle of PV arrays is achieved if the system is mounted at an angle of 10° (Hofmann 2010). The utilization surface is derived from two exploitation factors defined as module width (l) and module row distance (d) as shown in Figure 53. With a low tilt angle (β), the area can be efficiently exploited due to it creating less shade. The distance (d) between the module rows depends on the module width, the tilt (β) and the shading angle (α) (see Eq. 52). In general, half of the total surface can potentially be exploited (Hübert 1995; Bayod-Rújula, Ortego-Bielsa et al. 2010) according to the formula 53:

$$d = \frac{l * \sin(180° - (\beta + \alpha)}{\sin \alpha} \qquad (52)$$

$$A_I = 0.5 * BF \qquad (53)$$

where A_I is the available area in m^2 and BF is the building footprint in m^2.

With respect to the shadowing effects, inclination and roof construction constraints, (Kaltschmitt 1990) assumed that 15% of sloping roof areas and 25% of flat roof areas are suitable for solar energy harvesting. However, the IEA (2002) indicates a roof utilization factor of 0.4. In the Polish case study, a utilization factor of 0.25 was assumed, being the average of the above-mentioned indices, as it is not possible to distinguish between flat and sloping roofs. For the German research region, the findings of Kaltschmitt (1990) regarding the suitability of sloping and flat roofs for solar energy harvesting were applied.

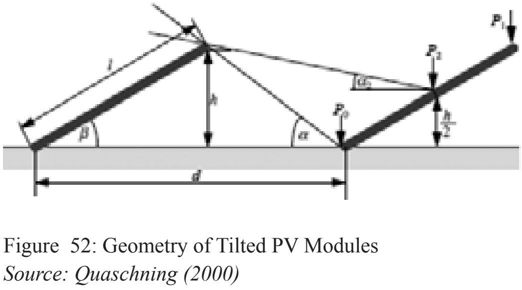


Figure 52: Geometry of Tilted PV Modules
Source: Quaschning (2000)

An additional constraint to the construction of PV installations is thermal systems which compete for the same surface. According to Quaschning (2000), the total available potential of roof surfaces for PV installations should be reduced by 34% due to their dedication to solar thermal systems. Nonetheless, the demand for roof surface depends on the respective economic attractiveness of both applications beyond the background of the local framework conditions.

The amount of energy generated through PV systems depends on the installed peak power, the performance of the system and the radiation received by the modules and is calculated as follows:

$$E = Gi,h * h * A_I * f * PR \qquad (54)$$

where E is annual energy output in kWh/kW_p, Gi,h is the annual mean global irradiation on a horizontal/inclined array module in kWh/m^2, h is the conversion efficiency, A_I is the available area (see equation 53), f is the corrector factor depending on the roof pitch (0.9-1.15) (Klärle and Ludwig 2006) and PR is the performance ratio of PV equipment.

The technical potential of solar energy installations depends on the efficiency of the installed PV cells that ranges between 8% and 17% according to the PV system type (see Table 97). These different degrees of efficiency also vary in response to the outdoor temperature, radiation during the day, etc. so that measured efficiency values do not represent the installation's actual overall efficiency. This study assumes a conversion efficiency of 12%.

The performance ratio (PR) reflects the efficiency of the installation in real working conditions and takes into account (i) the dependence of efficiency on temperature, (ii) the efficiency of the cables, (iii) losses due to dispersion of parameters and dirt, (iv) losses due to errors in monitoring the maximum power point, (v) the energy efficiency of the inverter etc. In fact, the system losses are quite difficult to approximate; based on Súri, Huld et al. (2008), the present study departs from an overall performance ratio for well-maintained systems of approximately 0.75.

Table 97: Parameters of Selected Solar Cells

Solar Cell	s-Si	pc-Si	a-Si	mc-Si	CdTe
Efficiency [%]	17	11-15	5-9	15-20	6-10
Power Peak [kW_p/m^2]	0.12	0.10	0.08	0.12	0.1

a-Si - amorphous silicon, pc-Si - polycrystalline silicon, s-Si - scandium-silicon, mc-Si - monocrystalline silicon, CdTe - Cadmium telluride

Source: Corradini and Wagner (2006)

The PV module performance per area is derived from the available roof area and power peak and was calculated as follows:

$$A_{PV} = A_I * PP \qquad (55)$$

where A_{PV} is the module performance per area in kW_p/m^2, A_I is the available roof area in m^2 and PP is the power peak kW_p.

The installed power peak depends on the cell types as outlined in Table 97. In the study, it was assumed that the installation of a 1-kW_p PV system with an array of solar modules requires about 100 W_{el}/m^2 of free roof area.

6.2.3 Economic Potential of Solar Energy

Once the technical potential has been evaluated, the next aspect to be considered influencing the development of solar energy utilization is the profitability of PV projects, which is determined by the project's anticipated electricity production, its price and the availability of financial support schemes. In the following, the economic potential of solar energy was elaborated for common applications; free-standing PV and roof-top facilities.

The electricity production costs of PV systems were calculated based on the investment costs (both module cost and the Balance of System) and operational and maintenance costs for two options: rooftop and ground applications. The annual costs of solar electrical energy generation were estimated using the following formula:

$$CE = \frac{a(M + BoS) + R_{OM}(M + BoS) + L}{E * pc} \qquad (56)$$

where CE is the annual costs of solar electrical energy in €/kWh, a is the annuity factor, L is the annual land lease in the case of free-standing PV units, M are the investment costs of PV modules, BoS are costs that refer to all components of PV systems apart from the module (e.g. inverter, electrical cabling, electrical protections and array support structure), R_{OM} is the rate of operation and maintenance costs, which are a fraction of the total investment costs, E is the annual generated electricity calculated online through the PVGIS tool (JRC 2008) and pc is a mean yearly performance degradation coefficient assumed at 0.5% (Aste and Del Pero 2010).

To determine the present discounted value of future payments accruing for investment costs, the annuity factor is calculated from the formula:

$$a = \frac{i(1+i)^n}{(1+i)^n - 1} \qquad (57)$$

where a is the the annuity factor, i is the interest rate and n is the economic lifetime of the PV systems assumed to be 20 years.

The operation and maintenance costs range between 0.01 and 0.1 €/kWh depending on the PV technology, although in practice they are correlated to the capacity system representing 1 - 1.5% of the total hardware costs (Lenardic, Petrak et al. 2009). Land rental costs for ground-mounted PV systems differ according to the potential suitability of the land for agricultural purposes.

Module costs represent approximately 40 - 60% of overall PV installation costs, while the remaining costs fall upon the BoS (IEA 2007; Lenardic, Petrak et al. 2009). The share of both main components may vary significantly due to different site preparation costs (roof, land), system design or construction permit fees. The total investment costs decrease with the size. In the case of rooftop applications in Germany with a range of nominal power between

1.5 and 12 kW_p, the mean reduction rate with increased size was on average 0.046 €/W_p (IEA 2007). The average costs of those PV systems amounted to 5.2 €/W_p installed peak power but the range varies between 2.93 €/W_p and 7.24 €/W_p depending on the size and technology. In France, investment costs varied between 6.2 €/W_p and 7.3 €/W_p for PVs installed in residential and non-residential buildings in 2008, while for large ground applications, investment costs were around 3.78 €/W_p (ADEME and AXENNE 2009). Generally, in 2009, the cost of systems up to 100 kW_p installed on roofs dropped sharply from around 4.2 to 3.1 €/W_p due to an decrease in PV installation production costs (EuroObserv'ER 2010). According to a prognosis of the European Photovoltaic Industry Association (EPIA 2010), investment costs will gradually decrease, making solar energy much more competitive compared to other RES investment costs.

Lenardic, Petrak et al. (2009) studied costs of electricity production related to investment costs and annual yields of energy per kW_p achievable in European countries. The average annual yields of 900 kWh/kW_p can be attained in central Germany and in Poland through fixed mounted systems, while an average of 1500 kWh/kW_p is possible in southern France using PV tracking systems. Electricity prices were calculated at a 4% discount rate and a 20-year system lifetime for different yield rates, assuming annual maintenance costs of 1% of the total investment costs. These findings are presented in Figure 54.

In the present study, the investment costs of module and BoS were assumed at 3 - 3.5 € per W_p in the case of roof-mounted installations (polycrystalline silicon) and at 2 - 2.5 € per W_p for ground-based PV applications of 1 MW_p (CdTe technology). It was assumed here that the annual energy production of the PV systems was entirely sold to the central power grid.

6.3 Solar Energy Potential in the Kujawsko-Pomorskie Region

In Poland, the total installed power capacity of PV cells was 370 kW_p on-grid and 1.08 MW_p off-grid (URE 2011). A major obstacle to the extension of PV solar installations is the lack of feed-in tariffs to drive PV growth, as the PV module prices are too high to become a real alternative to wind energy or co-firing installations.

In the strategic document issued by the Polish Ministry of Economy entitled "Energy Policy of Poland until 2030", the role of photovoltaic installations compared to other RES is only marginal, giving the prospect of 2 MW in 2010 and 32 MW by 2030 of PV installed capacity. In the draft National Renewable Action Plan, besides the base minimal scenario, the government proposed two scenarios:

- *scenario of maximum growth* - 1.8 GW_p of installed power capacity by 2020 and 10 GW_p by 2030 due to the introduction of feed-in-tariffs since 2010. The scenario takes into account an

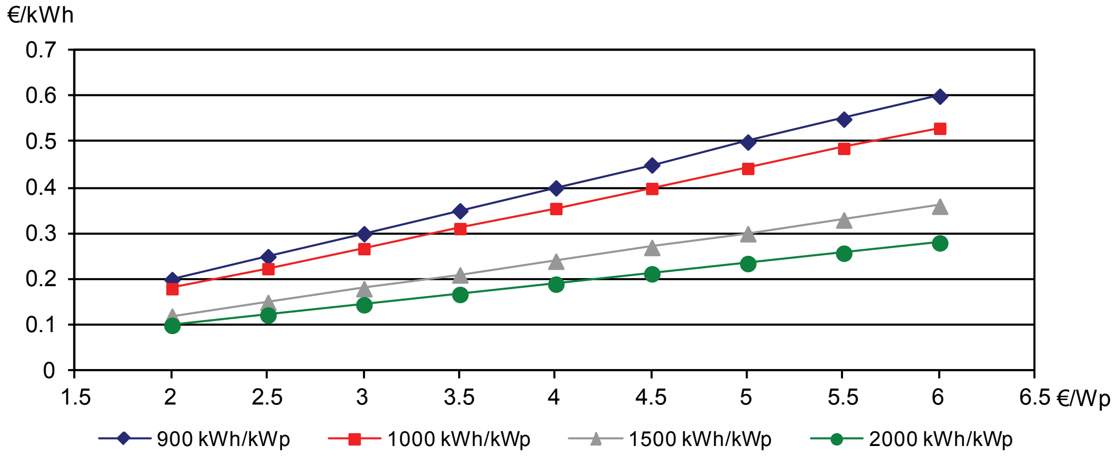


Figure 54: Costs of Electricity Generated in PV Installations Depending on Investment Costs and Solar Radiation
Source: Lenardic, Petrak et al. (2009)

eligible programme within EU energy policy called Solar Industry Initiative (SEEII),

- *scenario of moderate growth* - the most likely annual growth scenario for an installed PV capacity of about 50 MW_p (reaching up to 450 MW_p in 2020) assuming feed-in tariffs introduced in 2012 but lower incentive payments than those offered by the EU.

Unlike PV systems, solar thermal systems garnered more interest in Poland due to lower investment costs, which are around seven times lower than PV installations (ECBREC IEO 2009). In the so-called likely scenario, the Polish National Renewable Action Plan reckons with an increase in the area dedicated to photovoltaic collectors from 126 m^2 up to 14.7 Mm^2 by 2020, an equivalent of 21168 TJ[16] (588 GWh), corresponding to a per-capita increase of 0.5 m^2 over the same period (NREAP 2010c). However, this index will still be lower than the figure of 2 - 8 m^2/cap recommended by the European Solar Thermal Technology Platform (ESTIF 2009).

The objective of this study was to evaluate the technical and economic solar energy potential generated by ground-based PV systems and by roof-mounted solar installations under the current legal framework and support conditions.

The theoretical solar energy potential of the Voivodship is slightly below the national Polish average and the region's annual solar radiation varies between 1100 and 1160 kWh/m^2 (JRC 2008), conditions which are comparable to central Germany. The average annual solar radiation on optimally inclined surfaces that can be harvested in the Voiovodship is slightly below the national average, ranging between 1140 and 1180 kWh/m^2 (JRC 2008). The difference of 4% between the minimum and maximum figures is insufficient to determine a specific regional ranking of favorable conditions for solar energy development. Besides, the photovoltaic energy harvest performance also varies with respect to the module orientation and arrays of PV systems as outlined in Table 98. Under the optimum inclination of 33°, the total annual electricity generated by crystalline silicon systems is 843 kWh/kW_p under a south-facing exposition to the sun, whereas the performance of west or east-oriented plants drops by 20%, which may significantly influence a project's economic viability. By the same token, compared to the above-described optimum inclination of 33° and south exposition, the energy yield produced from horizontally aligned PV arrays is lower by 13% and from vertically aligned PV arrays by 29%. These differences were incorporated into the economic analysis.

Table 98: Illustrative Performance of Grid-Connected PV in Bydgoszcz

Orientation	Units	Inclination					Optimum
South (0°)		0°	20°	35°	60°	90°	33°
Electricity production from PV system	kWh/kW_p	740	824	843	794	600	843
Avg. global Irradiation	kWh/m^2*y	1010	1130	1160	1090	812	1160
SW/SE (45°)		0°	20°	35°	60°	90°	31°
Electricity production from PV System	kWh/kW_p	740	794	799	739	556	801
Avg. global Irradiation	kWh/m^2*y	1010	1090	1100	1020	762	1100
West/East (90°)		0°	20°	35°	60°	90°	0°
Electricity production from PV System	kWh/kW_p	740	718	688	596	423	740
Avg. global Irradiation	kWh/m^2*y	1010	986	950	831	600	1010

*Nominal power of the PV system: 1.0 kW (crystalline silicon), estimated losses due to temperature: 10.2% (using local ambient temperature), estimated loss due to angular reflectance effects: 4.4%, other losses (cables, inverter etc.): 14.0%, combined PV system losses: 26.2%

Source: PVGIS (2006)

6.3.1 Solar Radiation and Energy Potential

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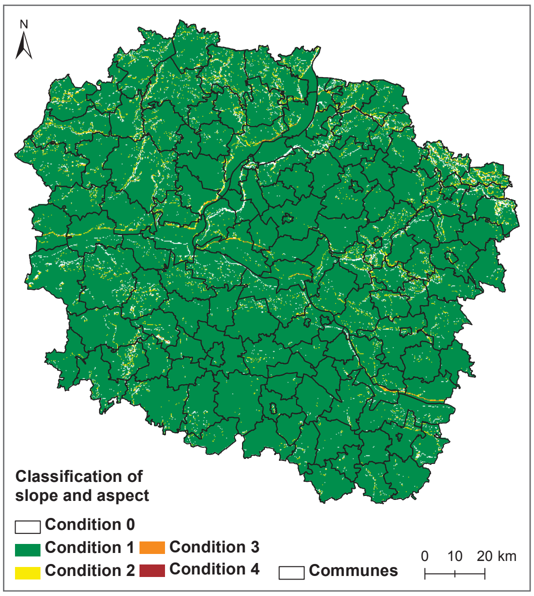
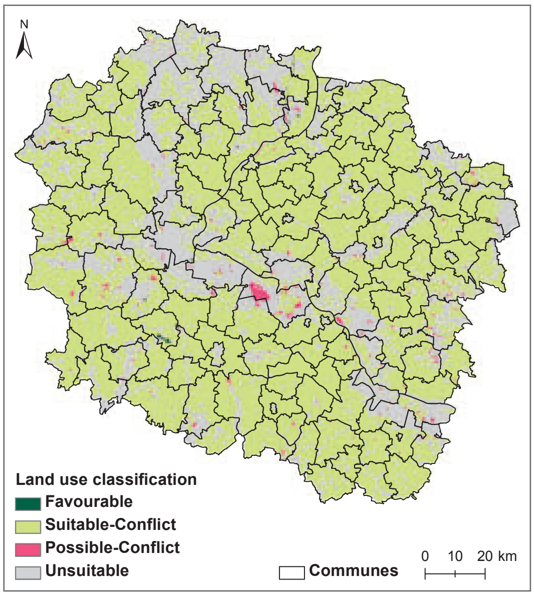
[16] According to ESTIF: 1 million m^2 of installed solar collectors in Poland corresponds to 1 440 TJ useful energy (final) in 2010 (1 m^2 = 0.00144 TJ) (ESTIF 2009)



Map 89: Site Classification for PV Ground Application in the Kujawsko-Pomorskie Region Based on Slope and Aspect Criteria



Map 90: Classification of Land Use Types in the Kujawsko-Pomorskie Region Regarding their Suitability for PV Siting

6.3.2 Technical Potential of Ground-Based Photovoltaic Systems

The assessment procedure described in the previous section involves the classification of land according to its topography, land use functions and ecological importance. As illustrated on Map 89, due to the relatively homogeneous ground elevation profile in the area investigated, 93% of the land was judged to fulfill all suitability criteria for PV siting whereas only 3.5% of the land was judged to fail the suitability criteria (corresponding to condition 0). Due to an insufficient motorway network in the investigated region, the criterion of favorable road conditions was not explored in this case study. Considering the mine, dump and mineral extraction

Table 99: Constraints for PV System Siting (CAS: Complexes of Arable Land Quality)

Land Use Functions	Constraint Level
Agricultural Land	
Soil protected against non-agricultural use (CAS 1, 2, 4, 1z)	High
Agricultural land of moderate quality (CAS 3, 8, 5, 2z)	Moderate
Agricultural land of low quality (CAS 9, 6, 7, 3z)	Low
Nature Protection	
Nature reserves	High
Areas of special protection of birds (Natura 2000)	High
Areas of special protection of habitats (Natura 2000)	High
Ecological corridors	High
Water protection zones	Moderate
Landscape parks	Moderate
Landscape-nature complexes	Moderate
Protected landscape areas	Moderate
Projected landscape parks	Low
Projected protected landscape areas	Low
Protective zone of landscape parks	Low
Projected extension of landscape	Low
Natural Hazard	
Floodplains	High

sites as favorable for installing PV systems, an area of 1115 ha was identified as theoretically suitable (details see Appendix 21). The theoretically suitable agricultural land makes up 71% of the Voivodship's 1.2 Mha area (see Map 90).

In view of potential land use conflicts arising from the land demand for other use like food or energy production or conservation functions, the land was subjected to a classification regarding its eligibility for agricultural and nature conservation functions. Table 99 outlines constraints for the siting of ground-based PV systems related to arable quality land ranking, the classification of ecological sites according to the degree of protection they have been given and the risk of natural hazards.

To identify potentially suitable locations under low and moderate nature protection restrictions, an on-site impact assessment needs to be conducted. With respect to sustainability criteria, arable land characterized by high and moderate crop yield performances should be protected against any construction, although PV development is not excluded if it is not against the local regulatory framework. The sites were evaluated in two steps according to criteria outlined in Table 99 and a final map of PV sites was produced as shown on Map 91.

The digital layers representing the land use derived from KPBPP (2009) - used in the wind energy assessment and the agricultural soil suitability map obtained from the Institute of Soil Science and Plant Cultivation (IUNG-PIB 2009) - were processed using Map Algebra provided by the Spatial Analyst tool. The classification of sites was carried out according to the formula 58:

```
if ((Nature_prot =  high), H,
    if ((Nature_prot =  moderate and
        CAS = high), M-H,
        if ((Nature_prot =  moderate and
            CAS = moderate), M-M,
            if ((Nature_prot =  moderate and
                CAS = low), M-L,
                if ((Nature_prot =  moderate),
                    M-L,
    if ((Nature_prot =  low and
        CAS = high), L-H,                              (58)
        if ((Nature_prot =  low and
            CAS = moderate), L-M,
            if ((Nature_prot =  low and
                CAS = low), L-L,
                if ((Nature_prot =  low), L-L,
    if (CAS = high), NP-H,
        if (CAS = moderate),NP- M,
            if (CAS = low), NP-L,
                other))))))))
```

where Nature_prot is the ranked level of nature conservation, CAS is the Complexes of Arable Land Quality (see Table 99). The site classification is described by H stands for high nature protection restrictions, M-H means moderate nature protection restrictions but a high quality of arable land, M-M means moderate nature protection restrictions and a moderate quality of arable land, M-L means moderate nature protection restrictions and a low quality of arable land, NP-H indicates a non-protected area but a high land quality, NP-M indicates a non-protected area but a medium land quality, etc.

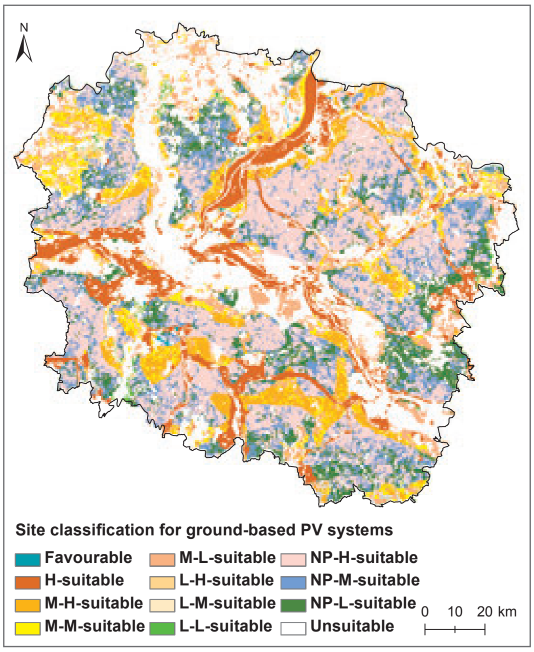
The final site classification for ground-mounted solar parks, performed according to formula 59, includes the land use classification (see Table 96), slope - aspect conditions (results from the formula 46) and the results derived from the first site classification (formula 58) based on both nature protection restrictions and the agricultural suitability factor.

```
if (LUC = F) and SA = 1-4),
    Favorable,
    if ((SS = H and (LUC = S-C or LUC = PC) and  SA = 1-4),
        H-suitable,
        if ((SS = M-H and (LUC = S-C or LUC = PC) and  SA = 1-4),
            MH-suitable,
            if (( SS = M-M  and (LUC = S-C or LUC = PC) and SA = 1-4),
                M-M-suitable,
                if ((SS = M-L  and (LUC = S-C or LUC = PC) and SA = 1-4),
                    M-L-suitable,
            if ((SS = L-H  and (LUC = S-C or LUC = PC) and SA = 1-4),
                L-H-suitable,                                                    (59)
                if ((SS = L-M  and (LUC = S-C or LUC = PC) and SA = 1-4),
                    L-M-suitable,
                    if ((SS = L-L  and (LUC = S-C or LUC = PC) and SA = 1-4),
                        L-L-suitable,
            if ((SS = NP-H  and (LUC = S-C or LUC = PC) and SA = 1-4),
                NP-H-suitable,
                if ((SS = NP-M  and (LUC = S-C or LUC = PC) and SA = 1-4),
                    NP-M-suitable,
                    if ((SS = NP-L  and (LUC = S-C or LUC = PC) and SA = 1-4),
                        NP-L -suitable, Unsuitable ))))))))))
```

where LUC is a land use classification, SA is a slope-aspect condition, SS are sites from the first site classification. The intermediate results are expressed by F stands for sites under favorable conditions, S-C stands for suitable sites but with conflict with arable land, P-C indicates sites with possible-conflict. The final site classification is described by H means high nature and arable land protection, M-H indicates moderate nature protection restrictions but a high quality of arable land, M-M means moderate protection restrictions and a moderate quality of farmland, M-L stands for moderate protection restrictions and a low quality of farmland etc. Sites classified as Favorable indicates favorable locations for ground mounted PV systems found on dump sites or mineral extraction sites, H-suitable are sites within high nature protected areas and on a high quality farmland, MH-suitable indicates location within moderate protected areas but on a high quality of farmland.

Table 100: Site Classification for the Installation of PV Systems Based on the Conservation Restrictions and Land Suitability Criteria

Site Classification	Area [ha]	Share [%]
Favorable	1115	0.06
H-suitable	165445	9.26
M-H-suitable	111217	6.23
M-M-suitable	92972	5.21
M-L-suitable	128912	7.22
L-H-suitable	4081	0.23
L-M-suitable	7156	0.40
L-L-suitable	6649	0.37
NP-H-suitable	381341	21.35
NP-M-suitable	200053	11.20
NP-L-suitable	140453	7.86
Unsuitable	546515	30.60



Map 91: Site Classification for Ground-Mounted PV Applications in the Kujawsko-Pomorskie Region

The area of sites for solar PV parks classified according to formula 59 is outlined in Table 100 and illustrated on Map 91. The area of land favorable for installing PV systems after including the slope and aspect constraints amounts to 1115 ha. Moreover, 140453 ha of suitable land free of any nature protection regulations (NP-L-suitable) are explored. Under the current legal framework, sites located outside the nature protected areas but on moderate and high-quality arable land do not face any legal restrictions toward installing PV systems. Both site classes made up 32% of the region's overall surface.

6.3.3 Technical Potential of Roof-Mounted Photovoltaic Systems

At the national level, the utilization potential of solar energy through thermal collectors was estimated by the Institute for Renewable Energy (ECBREC IEO 2009). The same methodological approach

Table 101: Overview of Building Types Listed in the TBD Database

Type ID	Building Type	Number	Footprint [m^2]	Mean Size [m^2]	Share of Area [%]
BBBD01	Residential Buildings	11139	1373162	123	40
	Multifamily Houses (Mw)	249	95260	391	2.8
	Detached Houses (Mj)	10871	1269994	119	37
	Dormitory	3	1951	650	0.06
	Nursing Home	2	3153	1576	0.09
BBBD02	Industrial Buildings	77	72232	938	2.11
BBBD03	Telecommunication, Transportation Buildings	30	12489	416	0.36
BBBD04	Commercial / Warehouse Buildings	44	7710	175	0.22
BBBD05	Storehouses	113	57422	508	1.7
BBBD06	Office Buildings	84	22826	271	0.67
BBBD07	Social Buildings: Healthcare, Social Care	76	96738	1272	2.8
BBBD08	Public Buildings, Education, Sport, Museums	59	37439	634	1.1
BBBD09	Outbuilding	10413	1581467	151	46
	Green Houses	455			
	Farm Buildings (Gw)	9958	1419 566	142	41.4
	Animal Farms (Gp)	49	34753	709	1
BBBD10	Sacral Buildings	24	9521	396	0.3
BBBD11	Other Buildings Hotels, Camping Houses	1365	158791	116	4.6
	Total	23 781	3484893	146	100

based on the 2002 dwelling census was used by the Office of Spatial Planning of the Kujawsko-Pomorskie Voivodeship (K-PBPPiR 2010) for the study in the Kujawsko-Pomorskie Region. Technical potential was estimated under the assumption of an average solar energy heating demand of 360 MJ/m^2 (ECBREC IEO 2009) and an average dwelling size, so that this potential is expected to reach 646944 MWh in the case study region, while the economic potential (40% of technical potential) is estimated at 258788 MWh (K-PBPPiR 2010). None of the two studies refers to photovoltaic applications due to current support measures.

Since 1989, official statistics have not recorded any information on building stocks and typology in Poland (IWU 2010). The Polish dwelling census of 2001 included buildings with at least one dwelling (GUSB 2002), but does not provide any information on the building topology or footprint. The national annual statistics provide data on the number and area of new apartments constructed but do not contain information on their location and type (IWU 2010).

In order to estimate the roof area, a geo-referenced database on building footprint and statistical data was used. The National Topographic Database

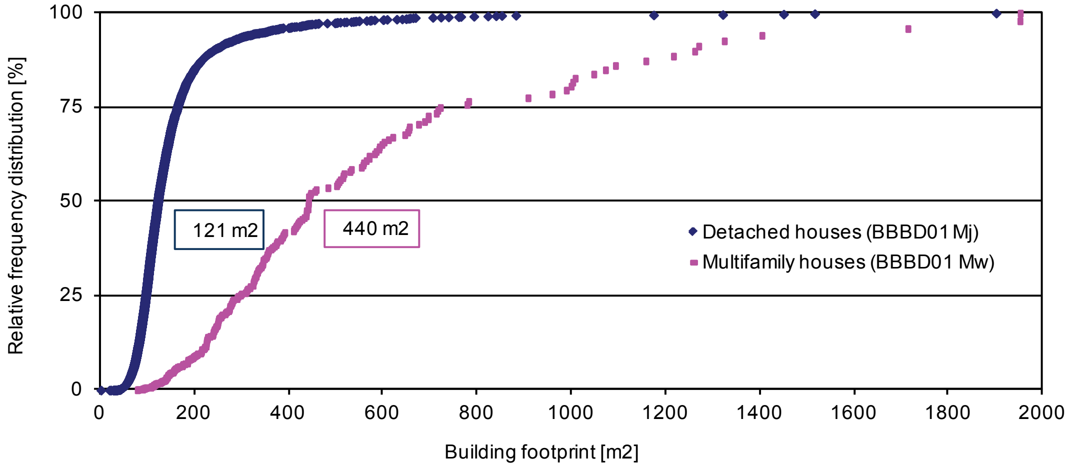


Figure 55: Relative Frequency Distribution and Median of Building Footprint for Detached and Multifamily Houses
Source: Based on Data Derived from GUGiK (2009)

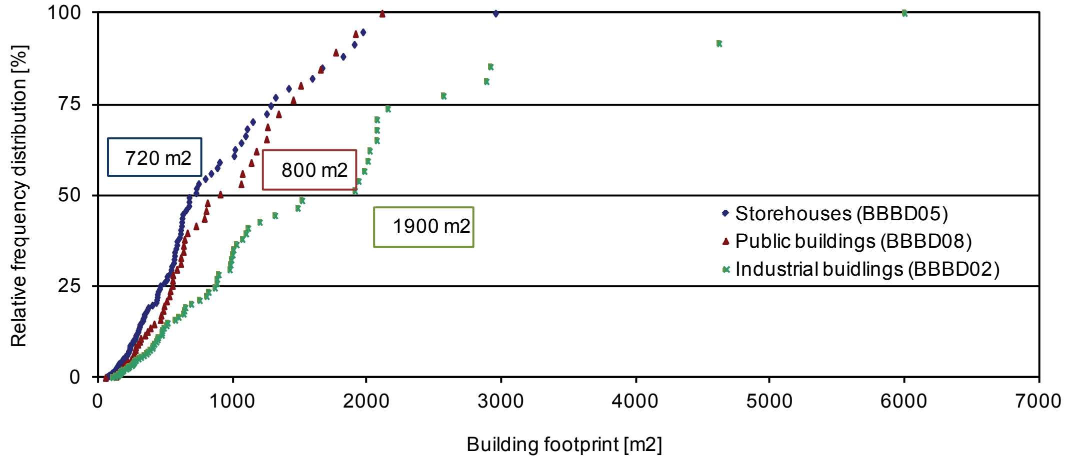


Figure 56: Relative Frequency Distribution and Median of Building Footprint for Store Houses, Public and Industrial Buildings
Source: Based on Data Derived from GUGiK (2009)

(TBD) at a scale of 1:10000, which is a part of the National Spatial Data Infrastructure (GUGiK 2009), contains among other information the vector data of building types. As the national geodatabase (TBD) is under development until 2013, sample data was only available for one county (Aleksandrowskie). The building attributes are presented in Table 101.

Most frequently, the PV arrays and solar thermal collectors are mounted on roofs in the residential sector. Frequency distribution curves were plotted for one family and multifamily houses to derive the median building footprint as shown in Figure 55. Assuming 100 W_p/m^2, the PV module area performance is 6 kW_p for detached houses and 22 kW_p for multifamily houses. On a detached house, the PV system could produce an average 4800 kWh (800 kWh/kW_p), which would cover the electricity needs of a family of four.

In rural areas, the footprint area of farm buildings and animal farms reveals an interesting potential of 175 m^2 and 1070 m^2 respectively. However, with respect to the construction characteristics and the age of those types of buildings, in general only a few percent of the roof surfaces could be dedicated to solar installations. Apart from the residential sector, industrial and public buildings have been more often brought to attention due to their scale. The findings indicate that around 800 m^2 of footprint area is assigned to storehouses and public buildings and 1900 m^2 to industrial buildings (see Figure 56). However, in the county considered, the total surface of those buildings makes up only around 5% of the total footprint area. Due to a lack of statistical data on buildings outside the residential sector, the area cannot be extrapolated to the other counties.

To extrapolate the footprint and then roof surfaces in the residential buildings of multifamily and detached houses, a number of indices were identified with respect to the commune types. For instance, in urban communes (indicated by 1 in Table 102 - Table 104), the fraction of one-family houses is around 93 - 98% in the total footprint area and in rural communes around 99% as outlined in Table 102. However, three urban communes are characterized by a sparsely built-up area, as indicated by indexes for the number of dwellings per building, inhabitants per building, population density and usable floor space per dwelling. For instance, the number of dwellings per building (2.3 - 2.6 in Table 103) is below the respective average figure of 4.2 for all urban communes in the Voivodship. In the 2002 census, 10325 residential buildings were recorded, a number which increased by an average of 9% to 11252 buildings by 2008 (see Table 102). Similarly, the number of inhabitants

Table 102: Residential Buildings in the Aleksandrowki County: Quantity, Footprint and Increase in Number by Commune (Mj - Detached Houses, Mw - Multifamily Houses)

	Number of Buildings		2003 -2008 Increase by	Building Footprint		Share in Cumulative Footprint		Share in Total Number of Buildings	
Communes	Mj	Mw	Mj+Mw	Mj	Mw	Mj	Mw	Mj	Mw
	No.	No.	%	m^2	m^2	%	%	%	%
Aleksandrów Kujawski (1)	1701	84	7	200129	30812	87	13	95	5
Ciechocinek (1)	1489	118	10	198849	50831	80	20	93	7
Nieszawa (1)	312	6	7	46304	2168	95	5	98	3
Aleksandrów Kujawski (2)	2333	13	14	255811	3589	99	1	99	0.6
Koneck (2)	964	1	5	111445	89	100	0	100	0.2
Raciążek (2)	918	1	12	100463	1071	100	0	100	0.1
Waganiec (2)	1037	9	7	112933	3059	99	1	100	0,1
Zakrzewo (2)	828	15	9	96359	3220	98	2	99	0.9
Total	10871	249	9	1269994	95260	-	-	-	-

Source: GUGiK (2009); GUS (2009e)

per building in the three sparsely-populated communes is around 7 compared to the average of 12 for all urban communes in the Voivodship (see Table 104). On the other hand, the population density of 1754 inhabitants in the Aleksandrow-Kujawski commune is higher than the average of 1464 in the county. The fraction of multifamily houses is extrapolated on the basis of dwellings per building by means of a regression function as shown in Figure 57 and Figure 58.

Table 103: Demographic and Housing Characteristics of Communes in the County of Aleksandrowki

	Dwellings per Building	Inh. per Building	Population Density
Communes	No.	No.	Inh/km²
Aleksandrów Kujawski (1)	2.3	6.9	1754
Ciechocinek (1)	2.6	6.4	725
Nieszawa (1)	2.3	6.6	202
Aleksandrów Kujawski (2)	1.2	4.4	86
Koneck (2)	1.2	4.4	57
Raciążek (2)	1.2	4.2	50
Waganiec (2)	1.2	4.2	95
Zakrzewo (2)	1.4	5.0	79

Source: GUGiK (2009); GUS (2009e)

Table 104: Building, Dwelling and Population Density Characteristics of the Communes in the Kujawsko-Pomorskie Voivodship

	Dwellings per Building	Inh. per Building	Population Density
Communes	No.	Inh/Building	Inh/km²
Urban Commune (1)	1.5 - 7.7 (4.2)	4.8 - 21.8 (12)	202 - 2561 (1464)
Rural Commune (2)	1.02 - 1.76 (1.4)	3.9 - 7.2 (5)	19 - 162 (53)
Urban-Rural commune (3)	1.2 - 3.5 (2.1)	4 - 12 (6.9)	32 - 188 (78)
Town in an Urban-Rural Commune (4)	1.3 - 7.1 (2.9)	4.4 - 22.7 (9)	340 - 2136 (1177)
Rural Area in an Urban-Rural Commune (5)	1.1 - 2.5 (1.5)	3.9 - 8.5 (5.6)	6.5 - 72 (39)

Source: GUGiK (2009; GUS (2009e)

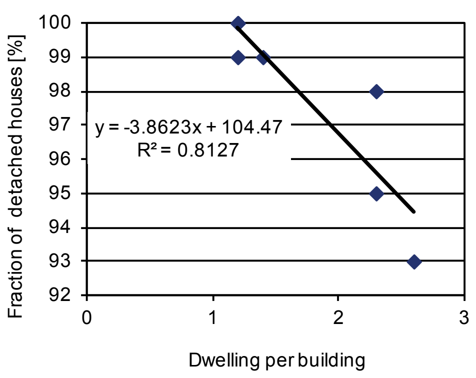


Figure 57: Regression Function Plotted for the Fraction of Detached Houses Against the Dwellings per Building

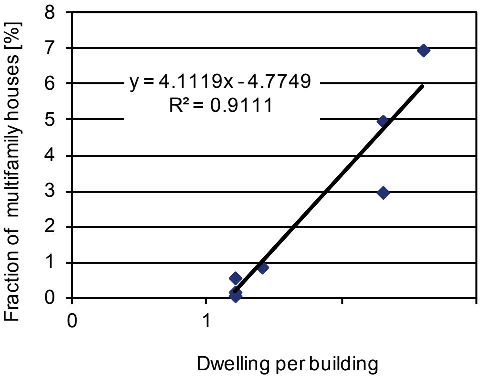


Figure 58: Regression Function Plotted for the Fraction of Multifamily Houses Against the Dwellings per Building

Table 105: Results of The Technical Potential of PV Power Capacity and Electricity Production

	Building Footprints	PV-Potential	Actual PV Electricity Production	Solar Thermal Energy	Potential PV Power	Potential PV Electricity Production
	m^2	MW_p	GWh	m^2	MW_p	GWh
Detached Houses	27559971	688	551	1007381	663	530
Multifamily Houses	6874844	178	137		146	117

Based on the building footprints and the available roof area derived from the assumptions made in chapter 6.2.2, the findings indicate that the potential PV capacity amounts to 688 MW_p on detached houses and 178 MW_p on multifamily houses, which could produce an energy yield of 688 GWh (corresponding to 25% of the total electricity output currently produced in the Voivodship).

As the roof surface may also be dedicated to solar thermal systems, the available area for photovoltaic installations was reduced in this study by the area under thermal installation, assuming 0.5 m^2 per inhabitant in 2020 (ESTIF 2009; NREAP 2010c). As outlined in Table 105, the photovoltaic potential only decreased by 4%, gaining 785 GWh of heat energy[17] from solar thermal systems.

6.3.4 Economic Potential of Rooftop and Ground-Based Photovoltaic Systems

Due to the more than seven times lower investment costs of solar heating systems compared with PV systems, the area dedicated to solar collectors has expanded quite dynamically in recent years in Poland (ECBREC IEO 2009). Furthermore, due to incentive programmes the development of solar heating systems is likely to gain added momentum and is expected to reach a 22 M m^2 cumulated solar collector area by 2020, compared to 130 ths. in 2008, an equivalent of 32000 TJ of energy (ECBREC IEO 2009). Nevertheless, an indicator of 0.6 m^2 per capita cannot be compared with the indicator of 2.0 - 8.0 m^2 per capita recommended by the European Solar Thermal Industry Federation (ESTIF 2009).

For the time being, there are no specific PV programmes to spur the development of solar electricity except for green certificates. Therefore, regarding the development of solar electricity, Poland has been left behind by countries where feed-in tariff systems have been offered (IE 2010). In Poland, apart from tradable green certificates, investment in solar electricity has been encouraged by investment subsidies, preferential loans and tax allowances. Polish investors are eligible for grants worth up to 60% of the investment costs, which can be financed amongst other means through a national programme known as the Green Investment Scheme (GIS) and the Infrastructure and the Environment Operating Programme. However these financial incentives are unable to attract investors.

In this study, electricity costs generated by PV systems were calculated to give an insight into the economic viability of solar power projects. The sales price for PV electricity guaranteed by the Polish Energy Regulatory Office was assumed at 45 € for each MWh and the price of green certificates at 68 €/MWh, resulting in a total a revenue of 113 €/MWh. The operating and maintenance costs including insurance fees were assumed to amount to 1.3% of the PV hardware costs (Lenardic, Petrak et al. 2009). In the case of rooftop photovoltaic systems, at the current average investment cost which varies between 3.0 and 3.5 €/W_p for both options with or without a 60% subsidy, the costs of the generated electricity are neither covered by the market price nor by green certificates. Therefore, an additional incentive instrument is required to drive PV development on roofs. The costs for free-standing applications include the land lease price. The average arable land lease price in the region was recorded at 170 €/ha*y (640 PLN/ha*y) (ANR 2010), which is differentiated from site to site according to the arable land's quality. The estimation of unit costs based on the two land lease price variants of 100 and 400 €/ha*y respectively indicates that this part of the cost has no significant impact when compared

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[17] Under the assumption of 780 kWh/m^2

Table 106: Economic Assessment of Electricity Generated by 10 kW_p Rooftop PV System

	Investment Costs [€/kW_p]			
	3000		3500	
Loan in Percent of Total Investment [%]	100	80	100	80
Return of Debt [%]	4			
Subsidy [%]	60	-	60	-
Electricity Production [kWh/kW_p]	Costs [€ct/kWh]			
800	14.41	29.20	16.81	34.07
850	13.56	27.48	15.83	32.06
Revenues: [€ct/kWh]	11.3			

Table 107: Economic Assessment of Electricity Generated by 10 MW_p Ground-Based PV Systems

	Investment Costs [€/kW_p]											
	1500	2000	2500	1500	2000	2500	1500	2000	2500	1500	2000	2500
Loan in Percent of Total Investment [%]	100			80			100			80		
Return of Debt [%]	4											
Subsidy [%]	60			0			60			0		
Land Lease [€/ha*y]	100						400					
Electricity Production [kWh/kW_p]	Costs [€ct/kWh]											
800	7.43	9.90	12.36	12.95	17.25	21.56	7.54	10.01	12.47	13.06	17.37	21.67
850	6.99	9.31	11.63	12.19	16.24	20.29	7.10	9.42	11.74	12.29	16.34	20.40
900	6.61	8.80	10.99	11.51	15.34	19.16	6.71	8.90	11.09	11.61	15.44	19.26
Revenues: [€ct/kWh]	11.3											

to the total costs of electricity production, which may range from 800 to 900 kWh/kW_p.

At the current investment cost span of 2.0 to 2.5 €/W_p for PV ground associated facilities, the investment requires additional support in the form of subsidies in order to be profitable. The investment price of 1.48 €/W_p is a break-even point for unsubsidized projects, with land lease costs at 100 €/ha*y and 900 hours of solar radiation per year. According to the European Photovoltaic Industry Association (EPIA 2010), a similar cost investment scenario is likely to be feasible even before 2020.

6.4 Solar Energy Potential in the Stuttgart Region

Regarding its contribution toward achieving the German national renewable energy targets of 41 TWh generated by 52 GW_p by 2020, solar energy ranks third after wind and biomass. Between 1990 and 2009, the installed peak power had increased to 9.8 GW_p. Fuelled by a rapid drop in investment costs, only in 2009 installed power reached 3800 MW_p in 2009 (Umweltfinanz 2010). In Germany, almost 50% of the newly installed solar power capacity with a typical output of 10 to 100 kW_p in 2009 was mounted on large roofs of barns, public buildings, schools and factories. Photovoltaic facilities with rated power capacities between 100 kW_p and 1 MW_p installed on large roofs or on the ground made up around 17% of the total capacity installed in 2009 across Germany (EuroObserv‘ER 2010), while large solar parks with outputs over 1 MW_p contributed another 17%. As a result of an amendment to the Renewable Energy Sources Act in 2010, the market share of large-scale megawatt plants in Germany, which had grown sharply since 2008, is expected to decrease again, due to the restriction of PV constructions to brown

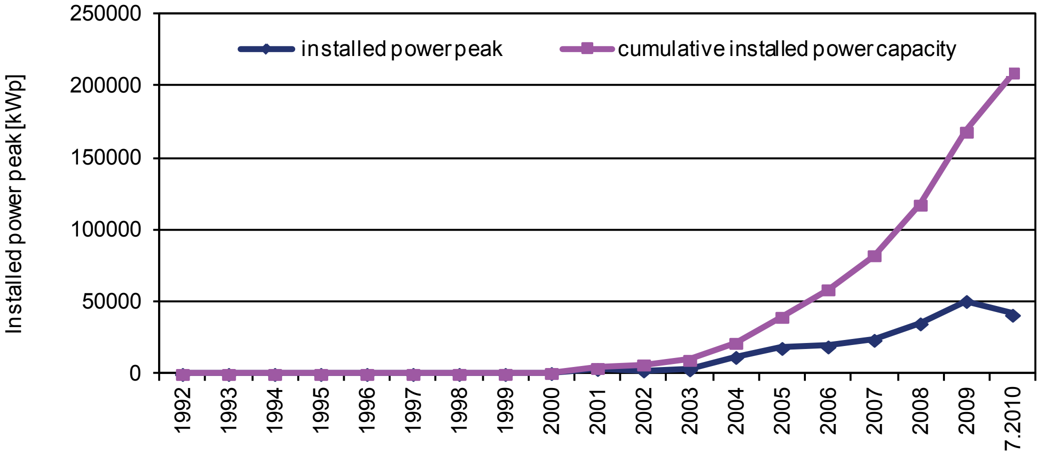

Figure 59: Installed Peak Power in kW_p in the Stuttgart Region up to Mid 2010
Source: Based on Data Derived from EnBW (2010)

field sites, former military ranges, mining areas or alongside highways or rail lines (EEG 2010). The National Renewable Energy Action Plan designates the development of 4500 MW_p of PV systems in 2011, a much higher increase than the one achieved in 2009 under very favorable financial conditions and including land-based applications (NREAP 2010a). In the period from 2012 to 2020, the NREAP scenario assumes an annual growth of 3500 MW_p/y, slightly less than the one registered in 2009 (NREAP 2010a).

In the Stuttgart Region, the accumulated installed peak power had reached 209 MW_p by mid 2010 (EnBW 2010). This growth trend is illustrated in Figure 59. The frequency analysis of the regional datasets indicates that small facilities up to 2 kW_p (1874 installations) make up around 10% of the total installed peak power, facilities between 2 and 5 kW_p (6471 installations) represent 36% of the total installed peak power and facilities between 5 and 20 kW_p (7320 facilities) account for 41% of the total installed peak power. There were 133 PV plants between 100 and 500 kW_p in the Stuttgart region, only three between 500 and 1000 kW_p and one of 1994 MW_p. In total, there were 17961 PV installations in the Stuttgart region; the data does not distinguish between rooftop and land-based applications.

6.4.1 Solar Radiation and Energy Potential

Located in southwest Germany, the Stuttgart region is characterized by a high average solar irradiation of 1100 kWh per square meter of horizontal surface (LUBW 2009) and by a regional sunshine duration span of 1300 - 1900 hours per year (Klimaatlas 2008). The quantity of energy harvested by the PV Crystalline Silicon module using various inclinations is outlined in Table 108. For instance, a south oriented and optimally inclined 1 kW_p module may harvest 833 kWh, in contrast to a flat module with the same capacity, which generates 11% less energy.

6.4.2 Technical Potential of Rooftop PV Systems

Bläsing, Gerth et al. (2000) estimated 1105 ha of usable roof surface for photovoltaic energy facilities in the Stuttgart Region, which could generate 99.5 GWh (358 TJ) of electricity[18]. The study was based on the building micro census data from 1998 and assumes that 25% of the sloping roof area, which represents 95% of the total roof surface and 25% of flat roof surfaces, could be devoted to rooftop PV modules. On the other hand, findings from a study conducted by the Institute of Energy Economics and the Rational Use of Energy (IER, IWS et al. 2000) indicate for the Stuttgart Region the potential of 764 TJ harvested on 20% of the total available roof surface, and a heat potential of 3980 TJ if a solar collector surface of 5 m^2 was installed on 80% of the residential building roofs.

In the present study, vector point data for the Stuttgart Region provided by Infas GEOdaten GmbH (infas 2010) was used to estimate the usable roof surface for solar energy utilization facilities.

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[18] Under the assumption of 900 kWh/kW_p, and PV module area performance of 100 W_p per m^2

Table 108: Illustrative Performance of Grid-Connected PV Installations (Crystalline Silicon) in Stuttgart

Orientation	Units	Inclination					Optimum
South (0°)		0°	20°	35°	60°	90°	33°
Electricity Production from PV System	kWh/kW$_p$	788	868	883	822	608	883
Avg. Global Irradiation	kWh/m^2*y	1070	1190	1210	1130	824	1210
SW/SE (45°)		0°	20°	35°	60°	90°	27°
Electricity Production from PV System	kWh/kW$_p$	788	838	839	766	564	842
Avg. Global Irradiation	kWh/m^2*y	1070	1150	1160	1060	774	1160
West/East (90°)		0°	20°	35°	60°	90°	0°
Electricity Production from PV System	kWh/kW$_p$	788	763	726	622	433	788
Avg. Global Irradiation	kWh/m^2*y	1070	1050	1000	865	611	1070

Source: PVGIS (2006)

The MicroBase house data (German: *MicroBase-Hausdaten*) consists of attributes on building stocks, nine typologies and ten building age classes as detailed in Table 109. However, Infas's data does not register the floor print area. Frequently, solar thermal and PV systems are mounted on roofs of one and two-family houses, which represent more than half of the building stock. Another building type suitable for installing solar thermal and PV systems due to their large roof areas is that of warehouses and factory buildings, which in total represent only 1% of the building stock, but when judged by their roof area, their potential is much higher in comparison to one-family houses. With respect to roof durability, buildings in the Stuttgart region constructed after 1945 represent 77% of the building stock.

The lack of attributes for the above-mentioned building classes regarding their footprint or roof area was supplemented by data from the national residential building typology, which consists of 44 residential building types classified according to construction year and building types (IWU 2003). As the IWU's classification does not match the age and typology classes provided by infas (2010), the average flat and sloping roof areas were assigned to buildings recorded in Infas's data. Given that the area is associated with sloping roofs, particularly for one and two-family houses, it was assumed that 30% of the roof surface could be dedicated to solar technologies. Due to the lack of data, the footprint of industrial buildings was assumed at 1900 m^2 based on the sample characteristic for the Polish case study derived in chapter 6.3.3. The usable roof area was calculated in accordance with the assumptions outlined in Table 110. In addition, a suitability factor of 0.15 was assigned to sloping roofs and of 0.25 to flat roofs (Kaltschmitt 1990). The entire usable roof area is 745 ha estimated for buildings constructed after 1945 and 927 ha for the total building stock. These findings are significantly lower than the value of 1105 ha estimated by Bläsing, Gerth et al. (2000), which results from different data input and assumptions.

The PV systems recorded by the data of (EnBW 2010) are only geocoded on the basis of streets, but without house numbers. Moreover, this database does not differentiate between roof and ground-mounted systems. Therefore, a simplified approach was used to reveal the remaining potential of usable roof surfaces and photovoltaic peak power in the Stuttgart region. The additional constraint imposed on the use of effective areas through competing solar thermal systems may reduce the available effective area by 34% (Quaschning 2000). From the total explored area of 927 ha in the Stuttgart region, 209 ha (209 MW$_p$) are already occupied by PV systems, of which in turn 71 ha have been dedicated to solar thermal systems (34% of 209 ha). From the remaining 647 ha surface, 428 ha would be suitable for solar power units. Based on this approach, the currently installed photovoltaic power could be more than doubled. Besides this, surface potential is also found on building façades, which was however left

Table 109: Number and Share of Buildings in the Stuttgart Region by Typology and Age Classes

Building Typology	Age Classes										
	Before 1900	1900 - 1945	1946 - 1960	1961 - 1970	1971 - 1980	1981 - 1985	1986 - 1995	1996 - 2000	2001 - 2005	2006-2009	Total
	Number of Buildings										
One or Two-Family Houses	16912	60387	61465	62496	38466	18023	16423	16150	16982	6193	313497
Semi-Detached Houses	4077	20230	22120	32922	25836	11825	12378	14861	9709	2450	156408
Apartment Buildings	4610	13506	12169	14380	7236	3546	4299	4378	1207	153	65484
Block of Flats	387	2802	4328	4925	2429	1004	1675	2418	472	46	20486
Multistorey Apartment Buildings	15	46	82	552	287	115	44	53	6	2	1202
Terraced Houses	2	4	7	228	620	164	36	17	13	8	1099
Farmhouses	2288	2862	965	340	86	20	71	63	82	28	6805
Other Buildings	670	3184	1936	4382	3071	1888	2464	1546	1131	383	20655
Warehouses and Factories	133	706	818	1573	1099	380	367	303	210	70	5659
	Share in Total Number of Buildings [%]										
One or Two-Family Houses	5.4	19.3	19.6	19.9	12.3	5.7	5.2	5.2	5.4	2.0	53.0
Semi-Detached Houses	2.6	12.9	14.1	21.0	16.5	7.6	7.9	9.5	6.2	1.6	26.5
Apartment Buildings	7.0	20.6	18.6	22.0	11.1	5.4	6.6	6.7	1.8	0.2	11.1
Block of Flats	1.9	13.7	21.1	24.0	11.9	4.9	8.2	11.8	2.3	0.2	3.5
Multistorey Apartment Buildings	1.2	3.8	6.8	45.9	23.9	9.6	3.7	4.4	0.5	0.2	0.2
Terraced Houses	0.2	0.4	0.6	20.7	56.4	14.9	3.3	1.5	1.2	0.7	0.2
Farmhouses	33.6	42.1	14.2	5.0	1.3	0.3	1.0	0.9	1.2	0.4	1.2
Other Buildings	3.2	15.4	9.4	21.2	14.9	9.1	11.9	7.5	5.5	1.9	3.5
Warehouses and Factories	2.4	12.5	14.5	27.8	19.4	6.7	6.5	5.4	3.7	1.2	1.0

Source: Data Derived from infas (2010)

aside here to keep within the scope of the present study.

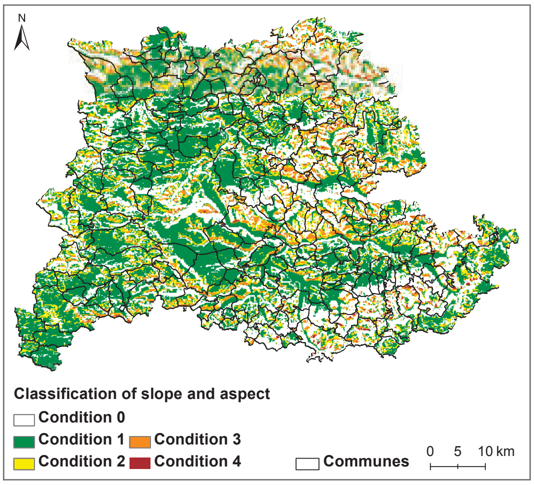
6.4.3 Technical Potential of Ground-Based Photovoltaic Systems in the Stuttgart Region

The assessment of sites regarding their suitability for the installation of land-based photovoltaic applications in the Stuttgart region was carried out over three steps based on the same data sets as the wind energy study (see chapter 5.3.2). Firstly, the land was evaluated in view of the slope and aspects conditions as illustrated on Map 92. Due to adverse terrain conditions, 37% of the available land turned out to be unsuitable (Condition 0). For the second step, in the context of land use trade-off,

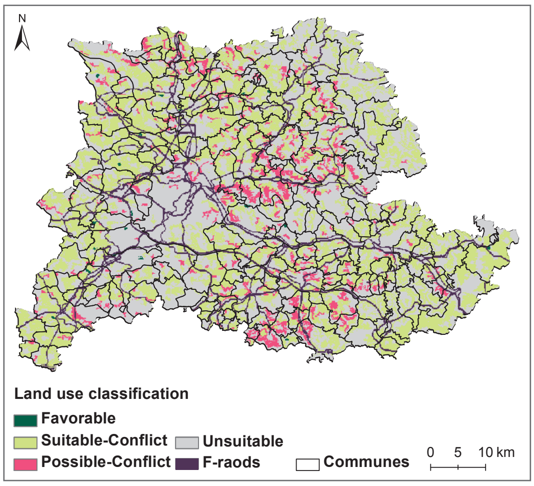
Table 110: Characteristics of Roof Area and Potential for Rooftop PV Systems for Building Stock Constructed after 1945

Type of Buildings	Predominant Roof Type	Average Roof Area	Total Roof Area	Assumptions	Usable Roof Area	Power Peak	Energy
	ha			Share	ha	MW_p	GWh
One or Two-Family Houses	Sloping	139	3283	0.3 - Usable Roof Area 0.95 - Rate of Sloping Roofs 0.05 - Rate of Flat Roofs	153	153	137
Semi-Detached Houses	Sloping	297	3923	0.5 - Usable Roof Area 0.95 - Rate of Sloping Roofs 0.05 - Rate of Flat Roofs	304	304	273
Apartment Buildings	Flat	297	1407	0.5 - Usable Roof Area 0.95 - Rate of Flat Roofs 0.05 - Rate of Sloping Roofs	172	172	155
Blocks of Flats	Flat	298	515		63	63	56
Multistorey Apartment Buildings	Flat	298	34		4	4	3.7
Farmhouses	Flat	139	23	0.5 - Usable Roof Area 0.95 - Rate of Sloping Roofs 0.05 - Rate of Flat Roofs	2	2	1.6
Warehouses and Factories	Flat	1900	916	0.5 - Usable Roof Area 0.5 - Rate of Sloping 0.5 - Rate of Flat Roofs	34	34	31

the area was divided into five classes according to its suitability for PV ground applications, as presented on Map 93. The favorable sites, represented by mineral extraction and dump sites, were identified by means of CLC2006 data (EEA 2009). Data on former military land and brown fields was not available for this project. Another type of favorable land for PV ground applications are sites along highways and railway tracks at a distance of up to 110 m measured from the outside edge of these carriage ways (EEG 2010). A buffer zone of 100 m was processed around motorways and railway lines (see F-roads on Map 93) based on the street vector data (ESRI 2007; NAVTEQ 2009). It must be noted that, owing to the grid of 100 m x 100 m used in the analysis, the explored areas also include the width of the motorways and railways themselves. To preserve ecological goods and agricultural land in the Stuttgart Region, nature conservation areas and farmland were classified with respect to their quality and sensitivity to potential impacts from photovoltaic facilities according to studies by



Map 92: Site Classification for PV Ground Application in the Stuttgart Region Based on Slope and Aspects



Map 93: Classification of Land Use Types in the Stuttgart Region Regarding their Suitability for PV Siting

Table 111: Conditions for Ground-Based PV Systems in the Stuttgart Region

Land Use Functions	Constraint Level
Agricultural Land	
Agricultural Land of High Quality (AZ > 41 and GZ > 41)	High
Agricultural Land of Moderate Quality (AZ = 28 - 40 and GZ = 28 - 40)	Moderate
Agricultural Land of Low Quality (AZ < 28 and GZ < 28)	Low
Nature Protection Areas	
Nature Reserves (NSG)	High
Water Protection Zones (I)	High
Floodplains	High
Biotopes	High
Natura 2000 (FFH, SPA)	Moderate
Landscape Parks	Low
Nature Parks	Low

Günnewig, Püschel et al. (2009) and outlined in Table 111.

On the legal basis, the construction of free-standing PV systems on agricultural land has been prohibited in Germany since September 2010 (EEG 2010). Nonetheless, agricultural soil quality was ranked here according to the existence of high, moderate or low constraints. Classification of sites for PV system development was also carried out for the verges - land strips within 110m of highways or railway lines.

The layers representing nature conservation and agricultural land were grouped into three classes, then rasterized and ranked using the Map Algebra tool according formula 60.

Next, the final site classification for ground mounted solar parks, performed according to formula 61, includes the land use classification, slope-aspect conditions (results from the formula 46) and the results derived from an intermediate site classification (see formula 60) based on both nature protection restrictions and the agricultural land quality.

```
if ((Nature_prot =  high), H,
  if ((Nature_prot =  moderate and
    (AZ or GZ) > 41), M-H,
    if ((Nature_prot =  moderate and
      (AZ or GZ) = 28 - 40), M-M,
      if ((Nature_prot =  moderate and
        (AZ or GZ) < 28), M-L,
        if ((Nature_prot =  moderate)
          M-L,
  if ((Nature_prot =  low and
    (AZ or GZ) > 41), L-H,
    if ((Nature_prot =  low and
      (AZ or GZ) = 28 - 40), L-M,
      if ((Nature_prot =  low and
        (AZ or GZ) < 28), L-L,
        if ((Nature_prot =  low), L-L,
  if ((AZ or GZ) > 41), NP-H,
    if ((AZ or GZ) = 28 - 40), NP- M,
      if ((AZ or GZ) < 28 ), NP-L,
        non_protected ))))))))))
```

(60)

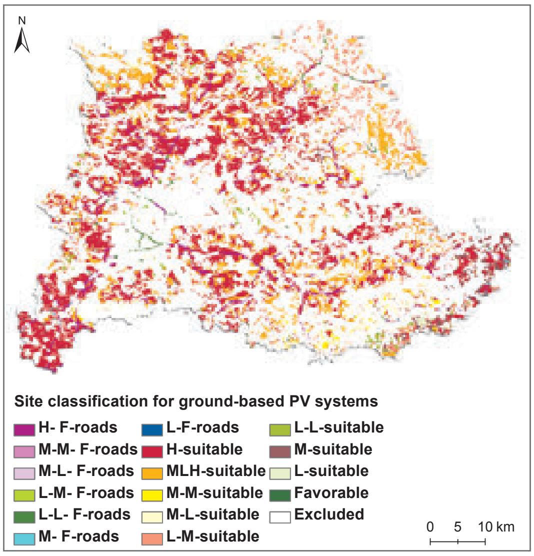
where Nature_prot is the ranked level of nature conservation and AZ or GZ is *Ackerlandzahl* and *Grünlandzahl* (see Table 111).Sites classified as H stands for high nature protection restrictions, M-H means moderate nature protection restrictions, but a high quality of arable land, M-M means moderate nature protection restrictions and a moderate quality of arable land, M-L means moderate nature protection restrictions and a low quality of arable land, NP-H indicates a non-protected area but a high land quality, NP-M and NP-L indicate a non-protected area but a medium or low land quality, etc.

```
if ((SS = H or SS = M-H or SS = L -H or SS =NP-H) and LUC = F-roads and  SA = 1-4),
    H-F-roads,
    if (( SS = M-M  and LUC = F-roads and SA = 1-4),
        M-M-F-roads,
        if ((SS = M-L  and LUC = F-roads and SA = 1-4),
            M-L-F-roads,
            if ((SS = L-M  and LUC = F-roads and SA = 1-4),
                L-M-F-roads,
                if ((SS = L-L  and LUC = F-roads and SA = 1-4),
                    L-L-F-roads,
                    if ((SS = NP-M  and LUC = F-roads and SA = 1-4),
                        NP-M- F-roads,
                        if ((SS = NP-L  and LUC = F-roads and SA = 1-4),
                            NP-L-F-roads,
if (SS = H and (LUC = S-C or LUC = P-C) and SA = 1-4),
    H-suitable,                                                                          (61)
    if ((SS = M-H or SS = L-H or SS =NP-H) and (LUC = S-C or LUC = P-C) and SA = 1-4),
        M-H-suitable,
        if (( SS = M-M  and (LUC = S-C or LUC = P-C) and SA = 1-4),
            M-M-suitable,
            if ((SS = M-L  and (LUC = S-C or LUC = P-C) and SA = 1-4),
                M-L-suitable,
                if ((SS = L-M  and (LUC = S-C or LUC = P-C) and SA = 1-4),
                    L-M-suitable,
                    if ((SS = L-L  and (LUC = S-C or LUC = P-C) and SA = 1-4),
                    L-L-suitable,
                    if ((SS = NP-M  and (LUC = S-C or LUC = P-C) and SA = 1-4),
                        NP-M-suitable,
                        if ((SS = NP-L  and (LUC = S-C or LUC = P-C) and SA = 1-4),
                            NP-L-suitable,
                            if (LUC = F) and SA = 1-4),
                                Favorable, excluded )))))))))))))))))
```

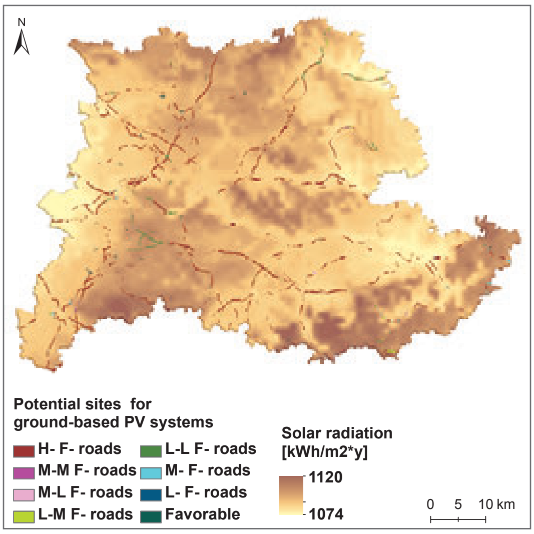
where LUC is a land use classification, SA is a slope-aspect condition, SS are sites from the first site classification. The intermediate results are expressed by F-roads indicates favorable sites alongside roads, S-C stands for suitable sites but with conflict with arable land, P-C indicates possible-conflict, H means high nature and arable land protection, M-H indicates moderate nature protection restrictions but a high quality of arable land, M-M means moderate nature protection restrictions and a moderate quality of farmland, M-L stands for moderate nature protection restrictions and a low quality of farmland etc. The final site classification is described by H-F-roads indicates favorable sites alongside roads, but localized within areas of a high protection because of high quality of agricultural land and nature protection restrictions ranked as high, M-M-F-roads means favorable sites alongside roads under moderate nature protection restrictions and a moderate quality of farmland, M-L-F-roads stands for areas alongside roads identified within areas of moderate nature protection restrictions and a low quality of farmland, L-M-F-roads means location alongside roads identified within low nature protection restrictions and a moderate quality of farmland, NP-M- F-roads indicates favorable sites alongside roads localized outside of nature protection and within areas of a moderate agricultural land quality etc. Sites classified as Favorable indicates favorable locations for ground mounted PV systems found on dump sites or mineral extraction sites, H-suitable are sites within areas of a high nature protection and on a high quality farmland, M-H-suitable, M-M-suitable and M-L-suitable indicate locations within moderate protected areas but on a high, moderate or low quality of farmland etc.

Table 112: Site Classification for Ground Mounted PV Installations

Site Classification	Area [ha]	Share [%]
H- F-roads	8087	2.21
M-M-F-roads	47	0.01
M-L-F-roads	100	0.03
L-M-F-roads	178	0.05
L-L- F-roads	934	0.26
NP-M- F-roads	230	0.06
NP-L-F-roads	6	0.00
H-suitable	62677	17.15
M-H-suitable	28178	7.71
M-M-suitable	2185	0.60
M-L-suitable	1967	0.54
L-M-suitable	7184	1.97
L-L-suitable	2495	0.68
NP-M-suitable	4919	1.35
NP-L-suitable	688	0.19
Favorable	268	0.07
Excluded	245240	67.12



Map 94: Site Classification for Ground-Based PV Systems in the Stuttgart Region



Map 95: Potential Sites for Ground-Based PV Systems and Solar Radiation (Energy Flux) on a Horizontal Surface

The final site classification explored by 16 classes is outlined in Table 112. Two-thirds of the land is unsuitable for PV installations, as it was located under forest, wetlands or settlements (site called Excluded). Under the slope and orientation constraints, the F-roads class makes up around 3% of the total area. The so-called suitable sites competing with food and fodder production and which are ineligible for feed-in tariffs represent 30% of the total area. Map 94 presents the site classification explored for potential development of solar parks and Map 95 illustrates selected favorable sites along carriageways, which require a subsequent individual impact assessment to be carried out at a local level.

The map of the annual solar irradiation on horizontal surfaces obtained from the Baden-Württemberg State Institute for Environment, Measurements and Nature Conservation (LUBW 2009) indicates that the regional differentiation of solar radiation has a lower impact on the energy harvest than the factors of inclination and orientation of PV modules as outlined in Table 108. To get a better picture about the potential of PV installations mounted alongside carriageways outside of highly protected

Table 113: Assumption and Findings of Economic Assessment of Electricity Generated by 20 kW_p PV Systems (Operating and Maintenance Costs incl. Insurance Fees Amounting to 1.3% of Hardware Costs)

	Investment Costs [€/kW_p]			
	3000		3500	
Loan as Percent of Total Investment [%]	100	80	100	80
Return of Debt [%]	4			
Electricity Production [kWh/kW_p]	Costs [€ct/kWh]			
800	31.6	29.87	36.94	34.85
900	28.1	26.5	32.8	30.1
Revenues: [€ct/kWh]	33			

Table 114: Assumptions and Findings of the Assessment of Electricity Generated by 1MW_p Ground Mounted PV System (Operating and Maintenance costs incl. Insurance Fees Amounting to 1.3% of Hardware Costs)

	Investment Costs [€/kW_p]							
	2000	2500	2000	2500	2000	2500	2000	2500
Loan as Percent of Total Investment [%]	100		80		100		80	
Return of Debt [%]	4							
Land Lease [€/ha*y]	250				450			
Electricity Production [kWh/kW_p]	Costs [€ct/kWh]							
800	20.64	26.44	23.6	22.9	20.70	28.7	23	25.80
950	17.40	22.20	19.90	19.33	17.45	24.22	19.40	21.80
Revenues: [€ct/kWh]	25.37 (on Conversion Field) or 24.26 (Other Fields)							

areas, a straightforward calculation[19] indicates a potential 250 MW_p of PV systems, which would harvest 220 GWh of electricity.

6.4.4 Economic Potential of Roof Mounted and Ground-Based Photovoltaic Systems

The energy produced through photovoltaic modules is among the most expensive greenhouse gas abatement options in Germany (Frondel, Ritter et al. 2010). Although, in 2010 the feed-in tariffs were cut due to a roughly 30% investment costs drop for PV systems since 2008, the solar electricity subsidizing costs are still significantly higher than for the wind or biomass electricity.

The assessment performed for exemplary rooftop and ground-mounted PV installations provides an insight into current cost and benefit levels. The profitability of rooftop installations depends on the investment costs and energy yield as shown in Table 113. For instance, a PV system characterized by high investment costs at 3.5 €/W_p is below the profitability threshold regardless of its energy harvest. The energy generation costs for the less expensive investment options are partly covered by FIT payments. However, the return on the investment of 3 €/W_p is around 3 to 7% of IRR depending on the solar energy harvest, which means PV investment remains attractive (Solar Server 2010). Benefits from PV systems have been much more interesting for operators who consume the solar electricity themselves due to the last amendment to the EEG in 2010. For those who installed their system in 2010, personal consumption started at a price of 19.49 cent per kWh (EEG 2010). That said, many electricity suppliers already charge more than this price for electricity and, with the increasing costs of electricity consumption, the option of generating solar energy for one's own consumption is becoming more attractive (Solar Server 2010).

---

[19] Considered area of 1495 ha divided by 2 to extract roads and railway width, PV system area performance at 1MW_p per 3 ha and energy yield of 900 kWh/kW_p

The results of the cost benefit analysis carried out for large free-standing PV facilities (see Table 114) indicate that the photovoltaic business has not lost its initial appeal, but rather facilities constructed at lower investment costs (2000 €/kWp) with high energy conversion efficiency may produce high profits (e.g. a unit revenue of 25.37 €ct/kW$_p$ in comparison to the unit cost 17.4 €ct/kW$_p$).

On the other hand, costs for leasing sites eligible for FIT are lower than those for leasing high quality arable land, though in some cases, onerous site-preparation costs for field conversions make the total investment unprofitable (Günnewig, Püschel et al. 2009).

6.5 Solar Energy Potential in the Region of Provence-Alpes-Côte d'Azur (PACA)

From the national target of 5400 MW$_p$ of energy generated by photovoltaic systems in 2020, a power rate of 720 MW$_p$ (13%) had already been achieved by mid-2010. Over the past two years the deployment of PV systems has accelerated, reaching 1607592 PV systems with a power peak of 92 MW$_p$ (CGDD 2010).

In 2008, the total installed PV capacity in Provence-Alpes-Côte d'Azur had reached a power rate of 2.5 MW$_p$, 30% of which was generated through two central PV installations in Vaucluse (ADEME and AXENNE 2009).

6.5.1 Solar Radiation and Energy Potential

Among other regions, Provence-Alpes-Côte d'Azur located in southern France has ideal solar radiation conditions making the region attractive for the development of solar energy plants. Provided an optimum pitch angle of 36° and south orientation, crystalline silicon PV modules installed in the south of France may yield up to 1280 kWh of electricity per year (see Table 115), which is 30% more than may be obtained by the same module installed in northern France. Therefore, the French support measures introduced a correction coefficient for FIT (up to 20%).

6.5.2 Technical Potential of Rooftop Photovoltaic Systems

Due to its attractive solar yield potential, this energy source is expected to cover a certain share of PACA's energy demand (ADEME and AXENNE 2009). So far, one study has been performed to explore the potential quantity of solar energy harvest in the region. ADEME and AXENNE (2009) estimated PACA's available PV potential on existing and new buildings in time horizons by the years 2015, 2020 and 2030. The analysis was based on statistical data about the type and age of residential buildings (INSEE 2007) as well as on samples of digital data prepared by the French Institut Géographique National (IGN) with the help of BDTOPO software for three districts in Cannes, Plan de Campagne and Carros. The total theoretical potential was restricted by protected areas, historical monuments, unsuitable roof types and shadowing effects.

Table 115: Illustrative Performance of Grid-Connected PV Installations (Crystalline Silicon) Located in Marseille

Orientation	Units	Inclination					Optimum
South (0°)		0°	20°	35°	60°	90°	36°
Electricity Production from PV System	kWh/kW$_p$	1090	1240	1280	1210	890	1280
Avg. Global Irradiation	kWh/m^2*y	1530	1740	1810	1700	1240	1810
SW/SE (45°)		0°	20°	35°	60°	90°	31°
Electricity Production from PV System	kWh/kW$_p$	1090	1190	1200	1110	823	1200
Avg. Global Irradiation	kWh/m^2*y	1530	1670	1700	1570	1150	1700
West/East (90°)		0°	20°	35°	60°	90°	0°
Electricity Production from PV System	kWh/kW$_p$	1090	1060	1010	870	614	1090
Avg. Global Irradiation	kWh/m^2*y	1530	1490	1420	1240	882	1530

Source: PVGIS (2006)

Table 116: Potential Power Peak of Rooftop Photovoltaic Systems in MW_p by 2030

Departments	Single Houses	Multifamily Houses	Industrial Buildings	Commercial Buildings	Sport Related Buildings	Agricultural Related Buildings	Total
Alpes-de-Haute-Provence	85	9	32	17,8	12	46	203
Hautes-Alpes	69	16	25,3	12,5	10	47	179
Alpes-Maritimes	163	80	48	46	28	40	408
Bouches-du-Rhône	371	132	222	129	38	131	1045
Vaucluse	292	64	84	62	28	58	592
PACA	159	33	94	63	18	133	2934

Source: ADEME and AXENNE (2009)

The findings of this analysis suggest that by 2020, the real potential of PV power peak will be 556 MW_p on the rooftops of existing buildings, while on new buildings, 711 MW_p could be installed (totalling 23% of the national target). By 2030, around 3520 GWh of energy could be harvested per year through rooftop PV systems with a power peak of 2934 MW_p as detailed by Table 116. Solar power systems are expected to be installed primarily in the Bouches-du-Rhône department as it has the highest new building development rate compared to other departments (ADEME and AXENNE 2009).

6.5.3 Technical Potential of Ground-Based Photovoltaic Systems

In France, the installation of PV systems on agricultural land is strongly discouraged and hampered by the Town Planning Code (NREAP 2010b). Nonetheless, unlike Germany, stand-alone PV systems on agricultural land are eligible for FIT support schemes in France and may even obtain higher subsidies than in Germany on a conversion land.

The study carried out by ADEME and AXENNE (2009) on the potential of solar energy harvested through ground-mounted systems in France indicates an energy quantity of 5784 GWh/y generated by 4820 MW_p of PV systems by 2030. The site classification was based on fixed coefficients applied to the digital data on land cover and layers representing biodiversity and landscape components. For instance, forestland was also considered in the future land use for PVs. The potential was arrived at as a result of theoretical spatial deployments of two PV systems of 10 MW_p and 50 MW_p at a fixed distance between host sites.

In this study the objective was to classify sites for the potential development of stand-alone PV systems and to explore such locations that mitigate land use conflicts. In the assessment, the same constraints of biodiversity goods and landscape were applied as in the wind energy case study (see chapter 5.4.2). Digital layers obtained from different sources (ESRI 2007; NAVTEQ 2009; Sandre 2009; DIREN 2009a; DIREN 2009b; RTE 2010) were rasterized and processed at a 100 m grid. In the ranking of slope and aspect conditions, around 55% of the total area located particularly in the Alps was excluded from the subsequent analysis (see Map 96). Map 97 shows the land use classified on the basis of the CLC2006 raster data and road data (details in Appendix 21).

In France, there is no data on arable land classification comparable to that of Germany and Poland, thus only the nature and landscape conservation land was ranked in the Map Algebra according to the formula 62.

```
if ((High_prot = Y or Landscape = Y),
    High protection,
    if ((Moderate_prot = Y),
        Moderate protection,                    (62)
        if ((Low_prot = Y),
            Low protection,
            No constraints)))
```

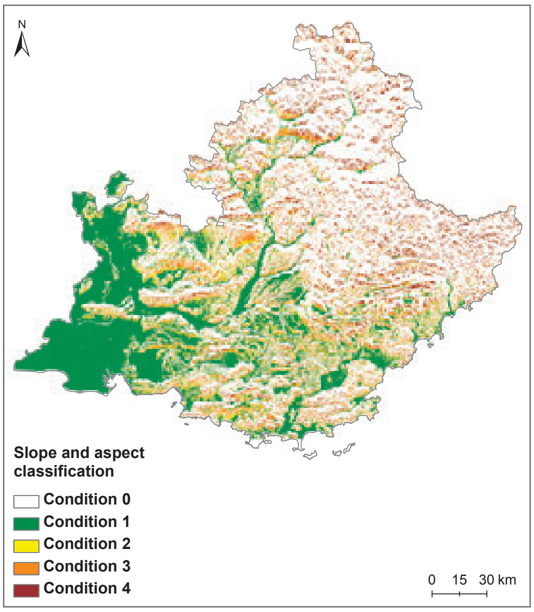
where High_prot, Moderate_prot, Low_prot and Landscape are layers representing classification of land area under nature conservation outlined in Table 94 (see section 5.4.2).

Unlike in the Polish and German case study, favorable land use classes in Provence-Alpes-Côte d‘Azur (apart from mineral extraction sites and dump sites) include bare rocks, sparsely vegetated areas and burnt areas, which are also partially located within areas of nature conservation. Hence, the conditional statement (Eq. 63) was extended in the case of favorable sites by additional conditions in the context of nature and landscape sensitivity to PV impact. Furthermore, the construction of free-standing solar plants alongside motorways is encouraged so as to obtain the synergy effect of an anti-noise barrier. In the final step of the site classification, three grid layers representing land use classifications (LUC), slope-aspects conditions (SA) and nature protection (NP) were classified according to formula 63. The intermediate results are expressed by F-roads that are the favorable sites alongside roads, F stands for favorable, S-C stands for suitable-conflict, P-C means sites with possible-conflict, H are sites under high nature protection restrictions, M are sites under moderate nature protection restrictions, L means low nature protection restrictions and N-P no nature protection restrictions. The final site classification is described by H-F-roads indicates favorable sites alongside roads, but localized within areas of high nature protection restrictions, M-F-roads means favorable sites alongside roads under moderate nature protection restrictions, L-F-roads stands for areas alongside roads identified within area of low nature protection restrictions, N-P-F-roads indicates favorable sites alongside roads localized outside of a protected nature, H-favorable, M-favorable and L-favorable indicate sites for ground mounted PV systems found on dump sites, mineral extraction sites, bare rocks, sparsely vegetated areas and burnt areas localized under a high, moderate or low nature protection restrictions, N-P-favorable stands for favorable sites outside of nature protection restrictions, H-suitable, M-suitable and L-suitable are suitable sites within areas of a high, moderate or low nature protection restrictions, N-P-suitable indicates location outside of protected areas.

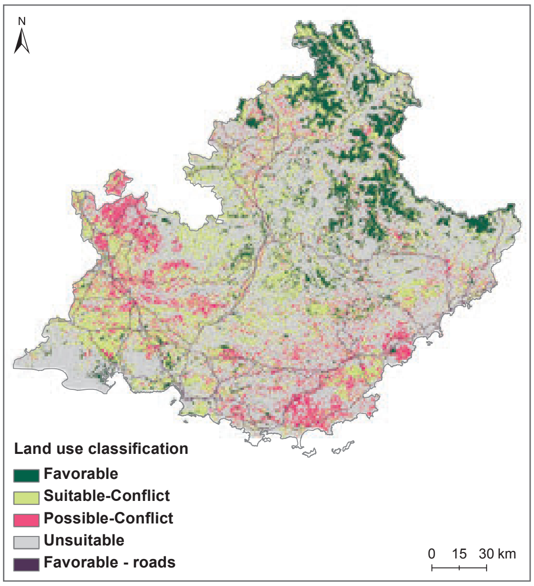
The result of the approach is a grid illustrating 13 different sites on Map 98. Table 117 indicates that two thirds of the total land in Provence-Alpes-Côte d‘Azur is unsuitable for free-standing PV development. The most favorable type of land

```
if (NP = H and LUC = F-roads and SA = 1-4),
    H-F-roads,
    if (( NP = M  and LUC = F-roads and SA = 1-4),
        M-F-roads,
        if ((NP = L  and LUC = F-roads and SA = 1-4),
            L-F-roads,
            if ((NP = N-P  and LUC = F-roads and SA = 1-4),
                N-P-F-roads,
    if (NP = H and  LUC = F and SA = 1-4),
        H-favorable,
        if (NP = M and  LUC = F and SA = 1-4),
            M-favorable,
            if (NP = L and  LUC = F and SA = 1-4),
                L-favorable,
                if (NP = N-P and  LUC = F and SA = 1-4),
                    N-P-favorable,
if (NP = H and (LUC = S-C or LUC = P-C) and SA = 1-4),
    H-suitable,
    if ((NP = M and (LUC = S-C or LUC = P-C) and  SA = 1-4),
        M-suitable,
        if (( NP = L  and (LUC = S-C or LUC = P-C) and SA = 1-4),
            L-suitable,
            if ((NP= N-P  and (LUC = S-C or LUC = PC) and SA = 1-4),
                N-P-suitable, excluded ))))))))))
```

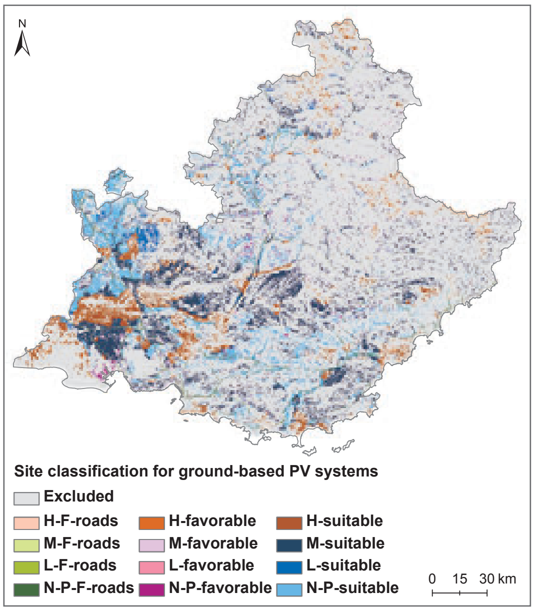
(63)



Map 96: Site Classification for PV Ground Application in the Region of PACA Based on Slope and Aspects



Map 97: Classification of Land Use Types in the Region of PACA Regarding their Suitability for PV Siting



Map 98: Site Classification for Freestanding Solar Power Parks in the PACA Region

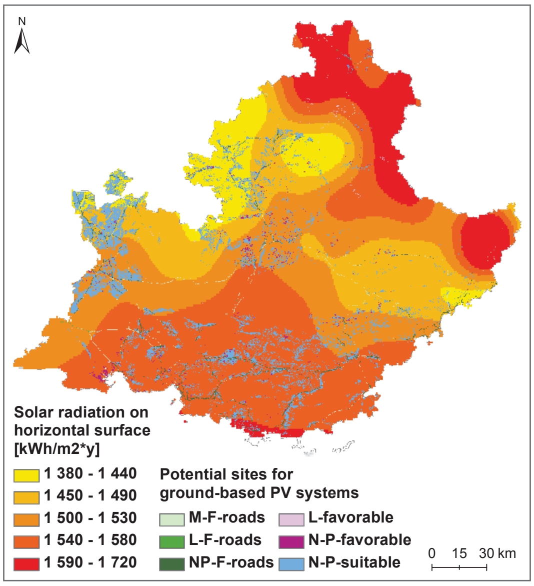
along roads outside nature protected areas (N-P-F-roads) was found on around 23 ths. ha, except the value of this land is overestimated due to the low resolution of the raster grid (100 m). The second most favorable sites (N-P-favorable) on land with a low productivity were found on an area of 18497 ha. The most favorable sites under low nature protection restrictions are related to peripheral zones of the National Park, transition zones of Biosphere Reserves (UNESCO) and water sites sensitive to pollution. These sites can also be considered for the potential development of free-standing PV installations. Eventually, an environmental impact study must assess whether land-based facilities would be permitted within moderately protected areas (under the Directive of Fauna and Flora habitats and RAMSAR). Suitable land outside nature conservation areas should undergo local assessment, taking into account the Town Planning Code with respect to the quality of arable land. Map 99 shows solar radiation on horizontally inclined surfaces obtained from HelioClim (2008) and selected sites with a low risk of land use conflict.

In the PACA region, the solar energy yield varies up to 15% depending on the location. Although this fact should be considered in the economic assessment, it is not sufficient grounds for drawing up solar zones, as the solar harvest efficiency is still higher in PACA than in the central or northern part of the country.

Under the theoretical assumption of an average PV system performance of 1MW_p per 3 ha, the NP-favorable land would accommodate a power rate of 6276 MW_p, which is 4820 MW_p above the power rate estimated by ADEME and AXENNE (2009).

Table 117: Site Classification for Potential Ground-Mounted PV Systems

Site Classification	Area [ha]	Share [%]
H-F-roads	6774	0.21
M-F-roads	10791	0.34
L-F-roads	790	0.02
N-P-F-roads	23894	0.75
H-favorable	20580	0.65
M-favorable	50098	1.58
L-favorable	1682	0.05
N-P-favorable	18497	0.58
H-suitable	109622	3.46
M-suitable	308299	9.72
L-suitable	21819	0.69
N-P-suitable	234906	7.41
Excluded	2363645	74.53



Map 99: Solar Radiation on Horizontally Inclined Surface Potential Sites for Ground-Based PV Applications in the PACA Region

6.5.4 Economic Potential of Rooftop and Ground-Based Photovoltaic Systems

The French government launched an ambitious programme aiming to become a world leader in the development of PV technologies, thus preparing a four-hundredfold increase in the country's electricity yield by 2020 (Gipe 2008). Although France benefits from one of the highest support payments to PV installations in the world (Stenger 2010), the installation level of photovoltaic systems has been lower than that of other leading European countries like Germany or Spain. The reason is that the French policy goal is first and foremost to promote, through FIT instruments, building-integrated photovoltaic systems and rooftop facilities on public buildings rather than land-based solar parks (EuroObserv'ER 2010).

The objective of the present economic assessment was to compare the costs and benefits related to three different PV systems: (i) rooftop photovoltaic applications of less than 3 kW_p, for which 50% of the investment cost is deductible and the VAT sales tax on material and installation costs is reduced from 19.6% to 5.5%; (ii) 20 kW_p rooftop systems on public buildings and (iii) large standalone PV applications. The percentage of costs related to operation and maintenance (incl. insurance), land lease and amortization level was derived from ADEME and AXENNE (2009), however, the assessment is based on newer figures for investment costs taken from the EPIA study (2010).

As seen in Table 118 and Table 119, Provence-Alpes-Côte d'Azur, with a higher energy harvest and FIT (30 to 70%) than Germany, became a lucrative market for photovoltaic development and PV investment. In the case of building-integrated PV systems up to 3 kW_p, unit revenues are more than twice as much as the solar generation costs. Therefore, in France, residential integrated systems smaller than 3 kW_p represent 90% of all PV installations and 45% of the total installed PV capacity (Prinet 2011). Even without subsidies, rooftop integrated installations up to 250 kW_p generate higher profits than ground-based applications.

Table 118: Assumptions and Findings from the Assessment of Electricity Generated by 2 and 20 kW_p Rooftop PV Systems in the PACA Region (incl. Insurance and Taxes Accounting for 1.5% of Hardware Investments)

Power Peak [kW_p]	2		20	
	Investment Costs [€/kW_p]			
	3000	3500	3000	3500
Loan as Percent of Total Investment [%]	44		100	
Return of Debt [%]	4.4		5.5	
Subsidy [%]	54		-	
Electricity Production [kWh/kW_p]	Costs [€ct/kWh]			
1000	17.00	19.30	27.33	24.50
1200	14.82	16.60	23.20	26.40
Revenues: [€ct/kWh]	58 (BIPV Dwelling and Health Care)		50 (BIPV Other Buildings)	
	42 (BIPV Simplified)			

Table 119: Assumptions and Findings from the Assessment of Electricity Generated by 1 MW_p Ground-Mounted PV Systems (incl. Operating, Maintenance and Insurance Costs Accounting for 1.3% of Hardware Costs)

	Investment Costs [€/kW_p]							
	2000	2500	2000	2500	2000	2500	2000	2500
Loan as Percent of Total Investment [%]	100		90		100		90	
Return of Debt [%]	5.5							
Land Lease [€/ha*y]	1000				3000			
Electricity Production [kWh/kW_p]	Costs [€ct/kWh]							
1100	27.3	33.6	26.7	32.8	27.86	34.1	27.23	33.4
1300	23.1	28.5	22.59	27.8	23.6	28.9	23.0	28.2
Revenues: [€ct/kWh]	31.4							

In France, standalone applications make up only 2% of all installed PV systems, but they represent 10% of the total PV power capacity. Under the current payment conditions, large solar parks are more attractive in terms of investment returns than in Germany, but major barriers related to administrative procedures slow down their development (Prinet 2011).

6.6 Summary and Conclusion

The study focuses primarily on ground-based photovoltaic parks, since the installations are land-use inefficient, producing less electricity than wind turbines over a comparable surface area and are incompatible with the most of land use functions. The methods developed make it possible to explore sites where conflict over land use for food and fodder production and other land functions may appear under the current legal and economic framework.

In the Polish region, the study demonstrates that under the present support mechanism system and investment costs, PV facilities still lack the economic power to compete with other RES technologies. Nevertheless, due to falling investment costs, the future development of land-based PV systems in the Kujawsko-Pomorskie Voivodship cannot be excluded as indicated by the economic assessment. Hence, the scenario that standalone PV facilities might compete for a land resource in the Kujawsko-Pomorskie Voivodship cannot be excluded and therefore compensatory measures would be required.

In Germany, the demand pressure on arable land is mitigated by the most recent amendment to the Renewable Energy Law, whereby free-standing PV systems can only be installed on brown fields, former military ranges, mining areas or highway verges.

Despite these spatial constraints, the assessment indicates a level of technical and economic potential in the Stuttgart region which would be interesting for investors.

As in Poland, land-based solar parks in France are eligible for feed-in tariffs and may even obtain higher subsidies than those in Germany. Due to the lack of data on the arable land quality classification, in Provence-Alpes-Côte d'Azur the land use data and land under nature and landscape conservation were rated to determine suitable sites for PV applications.

To avoid making inefficient use of the arable land resource, the study points out the potential sites located alongside motorways and on marginal grounds which are not suitable for agricultural production. The studies' findings should be enhanced by further assessment of social acceptance related to large ground-based solar projects in a regional and local context.

7 Regional Energy-Mix Potential

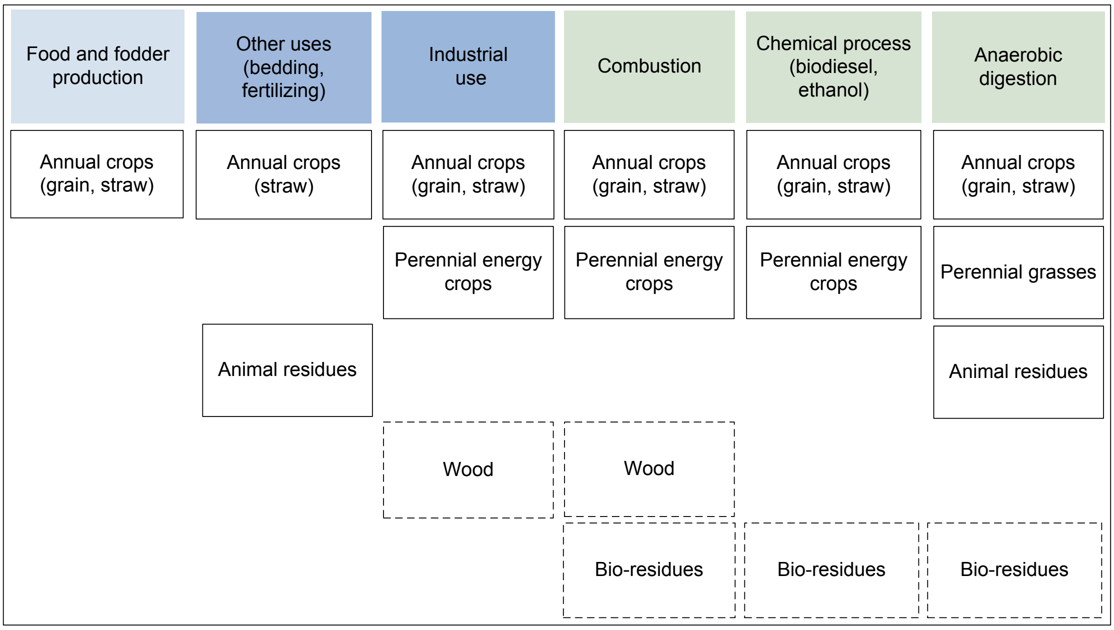
In the section, the study intends to explore investors or land-users' decisions on potential investment options in the three renewable energy sources in different planning context.

7.1 Renewable Energy-Mix and Land-Use Trade-Off

Economic and demographic growth has resulted in increasing demand for land use (Helming and Pérez-Soba 2011). Limited availability of land means that a balanced portfolio of social, economic, and environmental services are needed (Wiggering, Dalchow et al. 2006). Accordingly, different RES options compete with each other for land as well as competing with other uses of land, for example agriculture, leisure and ecological conservation. Compared to conventional fossil fuel-based energy systems, renewable energy sources are more space-intensive and their efficiency of energy production is highly geographically dependent (Seager, Miller et al. 2009; Dijkman and Benders 2010). Wind energy production has higher land use efficiency (energy yield per unit of land used) than biomass and solar energy. Moreover, unlike with energy crop production or solar farms, the land under a wind farm can be used for other purposes, such as agriculture, because wind turbines occupy only a fraction of a farm's surface. However, this type of energy generation may have adverse impacts on ecologically sensitive areas and on the aesthetics of the landscape, thus affecting conservation and recreation (Krewitt and Nitsch 2002).

Unlike wind parks, ground mounted PV systems only have a small negative impact on ecosystems, but they are incompatible with most other uses of the land (Tsoutsos, Frantzeskaki et al. 2005; Günnewig, Koch et al. 2006; Chiabrando, Fabrizio et al. 2009). The most crucial issue associated with solar power parks, highlighted by Tsoutsos, Frantzeskaki et al. (2005), is the reduction of cultivable land. Chiabrando, Fabrizio et al.(2009) suggest that solar farms should only be allowed if a building integrated installation is not economically viability or energy efficient. According to Dijkman and Benders (2010) the competition for arable land could be reduced if large PV parks were located on marginal ground, not suited to agricultural production. This would ensure there is no competition with food and biomass production. However, other competing needs for land use cannot be excluded.

By the same token, biomass energy production may affect land resources in other ways because it requires land for crop cultivation, storage and generation (Russi 2008; Dijkman and Benders 2010). Furthermore, intensive biomass production may



Food and fodder production	Other uses (bedding, fertilizing)	Industrial use	Combustion	Chemical process (biodiesel, ethanol)	Anaerobic digestion
Annual crops (grain, straw)	Annual crops (straw)	Annual crops (grain, straw)	Annual crops (grain, straw)	Annual crops (grain, straw)	Annual crops (grain, straw)
		Perennial energy crops	Perennial energy crops	Perennial energy crops	Perennial grasses
	Animal residues				Animal residues
		Wood	Wood		
			Bio-residues	Bio-residues	Bio-residues

Figure 60: Overview of Utilization Possibilities of Biomass Sources

deplete soil nutrients thus affecting the soil's productivity, and may contribute to the loss of biodiversity (Huston and Marland 2003; Robertson, Dale et al. 2008; Sala, Sax et al. 2009). Biomass production not only conflicts with food and fodder production, but also with other energy crops. For instance, biomass may be used in different technologies resulting in electricity, heat or biofuels (see Figure 60). Annual and perennial crops for energy or commercial material production compete for space with conventional plants. On the other hand, synergy effect may be achieved through the cultivation of conventional cereals whose grain satisfies the food and fodder production, the crops' by-products being used for energy generation, as is the case with straw. Nonetheless, the supply of cereal straws having low bulk and energy density is restricted by economic and logistical factors, among others.

Forest wood was not included in the analysis because forestland does not directly compete for arable land used for biomass production and the construction of wind and solar energy systems. However, the supply and demand balance of forest wood and woody residues (i.e. orchards, green areas) and other combustible wastes has an impact on the demand for short rotation coppices.

7.2 Determinants of Renewable Energy Deployment

All energy-related projects always result in some environmental burden. Most of them are associated with fragmentation of the countryside, visual impact on landscape and interference with flora and fauna (Chiabrando, Fabrizio et al. 2009). The expansion of alternative energy sources is a compulsory EU target so its deployment must balance the multiple uses of land and the interests of stakeholders.

In a liberalized market, land is in hands of private investors and land-users, who look after their own interests. This often leads to competing renewable energy options and conflicting use of land. For this reason, the development of sustainable energy resources needs suitable guidance and management by administrative authorities, in order to balance the actions of private investors with the public interest. At the same time, regulation should not discourage potential investors and RES growth should benefit both environmental and socio-economic systems. Therefore, before designing any incentives or instruments of regulation, the first step must be to explore the investment possibilities of renewable energy sources.

The choice and deployment of RES is a complex issue. Marques and Fuinhas (2010; 2011) made empirical assessments of several socio-economic and political determinants that encourage and/or hamper the deployment of renewable energy. Alongside legal, technical and economic factors, there are social factors that influence the realizable potential of RES (Zoellner, Schweizer-Ries et al. 2008). Acceptance may be expressed in various forms: attitudes, behavior and - most importantly – investments (Wüstenhagen, Wolsink et al. 2007).

The focus of this study is on investors and the potential of investment in wind, biomass and solar energy. The analysis was carried out on the basis of several local factors (see Figure 61) in order to explore investors' or land-users' decisions on the potential deployment of renewable energy.

An investor or a land-user tends to make decisions on investment options on the basis of available information such as land conservation policy, including nature and landscape conservation and the availability of infrastructure (e.g. power lines, roads). Furthermore, land quality is a decisive factor for biomass projects and affects crop production and investment profits. The land quality is also associated with social acceptability when considering projects of large PV parks (Chiabrando, Fabrizio et al. 2009).

Other factors such as energy and crop yield, profitability of energy generation options, and demand for biomass and for renewable energy influence the economic viability of RES projects.

Some information that investors might want is simply not available for example future demand for, and price of, a product. Therefore a high risk investment such as short rotation crops (SRC), perennial grass crops or biogas plants, would need to be offset by higher profits compared to other conventional crops or RES investment options. However, the extent of appropriate compensation for these investment risks, through financial support schemes, is also hard to monetize, given that the land-users' willingness to take risks is subjective.

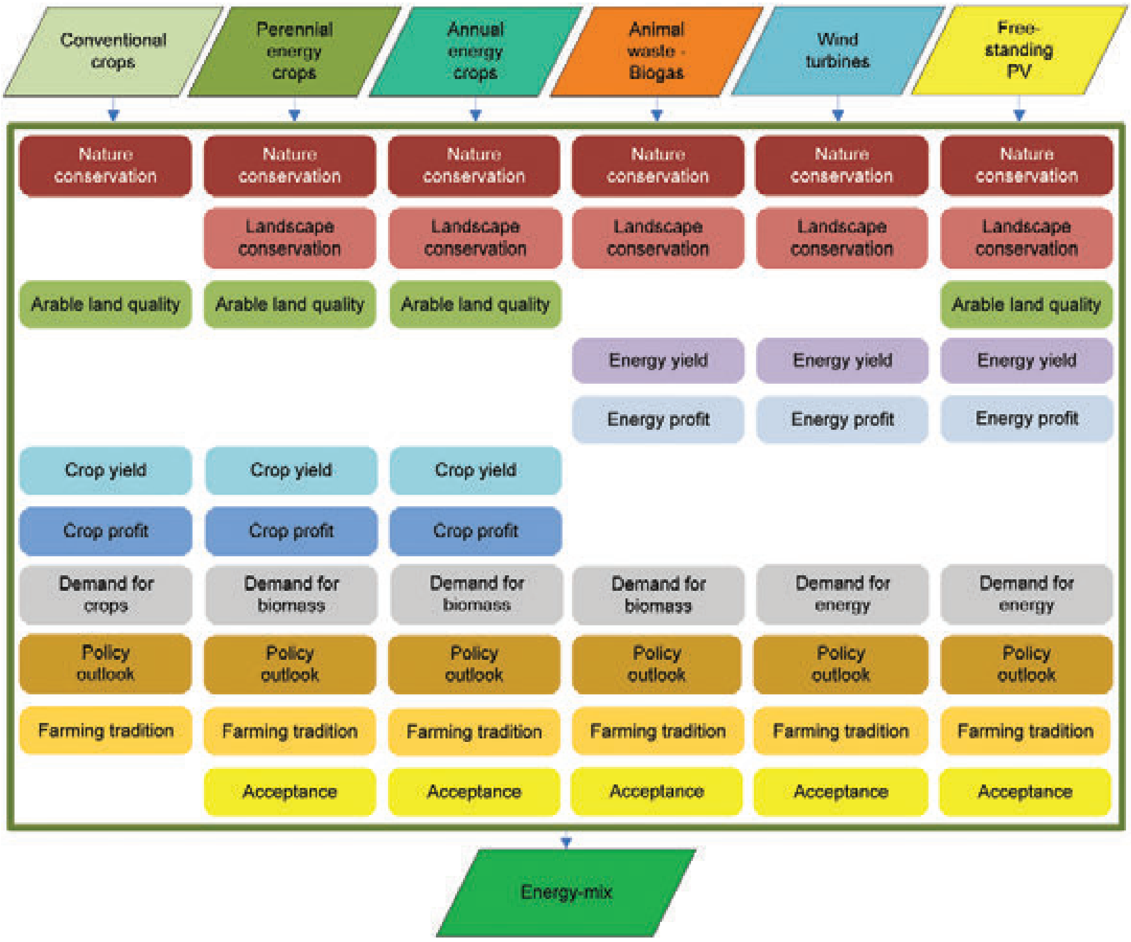


Figure 61: Overview of Factors Influencing the Investor's Decision on Siting the Renewable Energy Production

If investment support schemes are overestimated, it might result in adverse direct, or indirect, socio-economic effects such as a long-term burden on electricity consumers (Frondel, Ritter et al. 2010) or an increase in land lease (Kiessling and Lingenfelser 2011). However, if these support schemes take too narrow a view, they will either fail to enhance RES development or RES expansion will lag behind its targets. Therefore, a flexible set of policy instruments and support measures needs to be tailored to regionally specific conditions (Michalena and Hills 2012). Policy aspects (including energy policy, its instruments and incentive measures) coupled with a minimum of medium-term continuity, can provide sufficient certainty for investors (Marques and Fuinhas 2010; Michalena and Hills 2012).

Several empirical studies have identified a set of factors that shape public attitudes towards renewable energy. The most relevant factors that influence multi-faceted public opinion are policy, environment, economics, the impact on landscape, local perception, and social influence (Gross 2007; Jobert, Laborgne et al. 2007; Van der Horst 2007; Zoellner, Schweizer-Ries et al. 2008). The fundamental issues in the deployment of alternative energy technologies are that the relatively small projects affect not only consumer or investors, but many other actors. Hence, a siting decision and an investment need approval by several involved parties and not only by the investor (Wüstenhagen, Wolsink et al. 2007). Therefore, both social acceptance and the value placed on traditional local farming are relevant drivers in determining the success of RES deployment. People who derive a positive sense of identity from rural landscapes are likely to oppose RES projects (Van der Horst 2007). Public acceptance in a national or regional context is generally high, but decreases as it moves towards the local level (Wüstenhagen, Wolsink et al. 2007). Community acceptance plays a key role in influencing investor decisions. However, a key challenge is to obtain social acceptance of renewable energy development on a local level (Wüstenhagen, Wolsink et al. 2007;

Zoellner, Schweizer-Ries et al. 2008). Jobert et al. (2007) show that local acceptance of stakeholders is influenced by both planning rules and site-specific factors.

For all these reasons, the multi-faceted aspect of RES acceptability requires further local analyses based on empirical surveys.

Against the background, the regional potential of the renwable energy portfolio was analysede in the three case studies.

7.3 Potential of Renewable Energy-Mix in the Kujawsko-Pomorskie Voivodship

The final step of the study is the assessment of the investment' options in renewable energy sources based on already-explored RES potentials and related conflicts for land-use, which may appear in the polish region under the current spatial planning and policy framework.

First, the study investigated the potential for competition for land between crops grown for energy, food or fodder. Prioritizing the exploitation of agricultural waste, the biogas development potential was first evaluated against the purpose of the crops' cultivation (for biogas or other uses). 41 biogas sites were chosen for the development potential analysis on the basis of the relative probability of biogas development due to a high local animal manure density. Under the first assumption of 15% dry matter of biogas feedstock made in chapter 4.2.3.4.2, the agricultural area for growing biogas-dedicated energy crops was assessed in catchment areas of 5 and 10 km radiuses from potential sites for biogas plants. Both radiuses represent a typical transport distance for agricultural co-substrates and allows a potential land use trade-off to be explored. Depending on the biogas quantity in some locations and the availability of agricultural land, the supply of energy crops maight require almost 40% of the agricultural land within a 5 km radius of biogas plants (see Map 100), while within a 10 km distance the demand for biogas co-substrates can be met by considerably lower competitive pressure on conventional agricultural production (see Map 101).

As maize crops represent the basic co-substrates in anaerobic digestion processes in biogas plants, the negative impacts of an intensive mono-cultivation of this crop cannot be neglected. With respect to the risk of increasing ground water pollution and soil erosion, it is not recommended to grow maize crops within water protection areas or within zones featuring water erosion of soil (Majchrzak and Piechota 1998), which cover around 25% of the total cropland surface (see chapter 4.2.2.1). After discounting the area subject to possible water pollution and soil erosion, the share of arable land required for biogas production in total farmland was re-estimated within the two radiuses of 5 and 10 km as shown on Map 102 As the cultivation of perennials or annual crops for biofuels within those zones may exacerbate the pressure on land use, artificial zones around the biogas sites were created, addressing concerns over potential conflicts between land use options.

As the cultivation of invasive alien species IAS [20] (i.e. miscathus, sida, robinia) within nature and landscape conservation areas is restricted under the current legal framework (see chapter 4.2.2.1), the pressure on land is to some extent mitigated within the biogas zones. Map 103 shows for instance that in six zones, more than 60% of the land is protected against IAS. On the other hand, strict regulations do not prevent the land planted with annual crops like rapeseed, sugar beets, cereals and maize to be dedicated to biofuel production, since subsidy payments to energy crops have been abolished and consequently their registration is no longer possible. Aside from this, adverse effects from monoculture or intensive growing should be kept off areas of sensitive biodiversity. To some extent, the direct payment granted for the selection of annual crops solves this problem as it requires sustainable agricultural practices in return (see chapter 4.1.1.5). Therefore, it is recommended to enhance a differentiated crop-mix to mitigate possible soil and water conservation risks in the future (EEA 2007a). On the other hand, through planting perennials on land susceptible to soil erosion, the synergy effect between biomass use, erosion mitigation and biodiversity may be potentiated (Rowe, Street et al. 2009; Feldwisch, Lendvaczky et al. 2010). To maintain the ground water line, sites potentially threatened by water scarcity during the vegetation period were also explored. Consequently, the arable land was evaluated against

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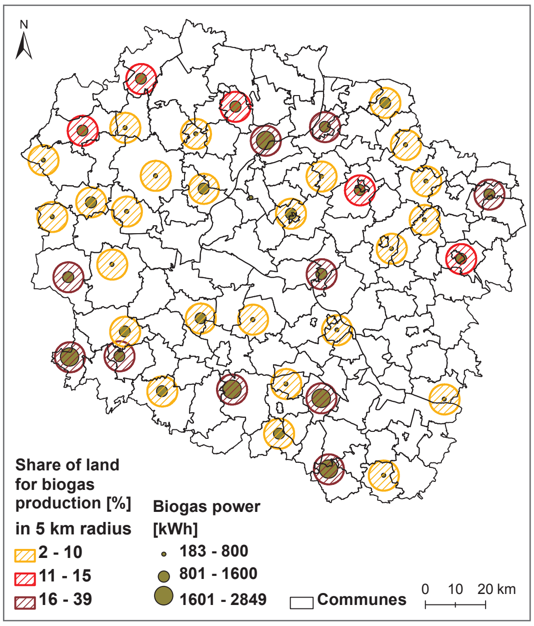
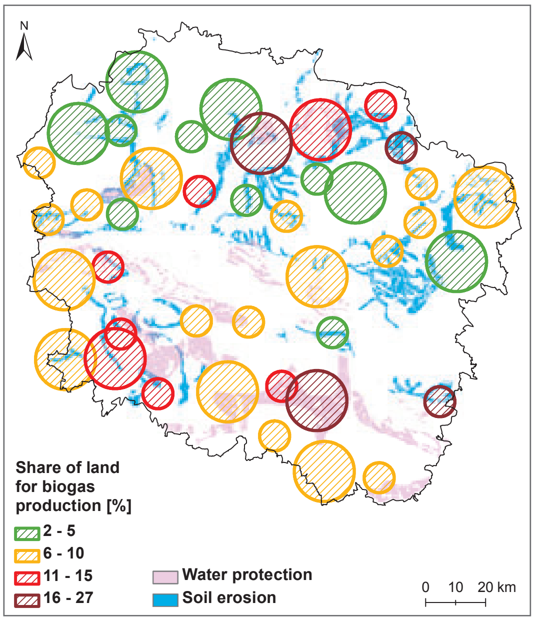
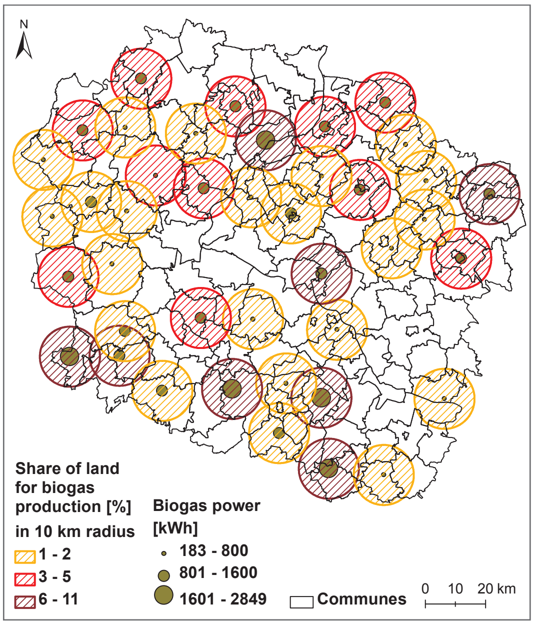
[20] Regarded as a major threat to biological diversity, more info on http://www.iop.krakow.pl/ias/



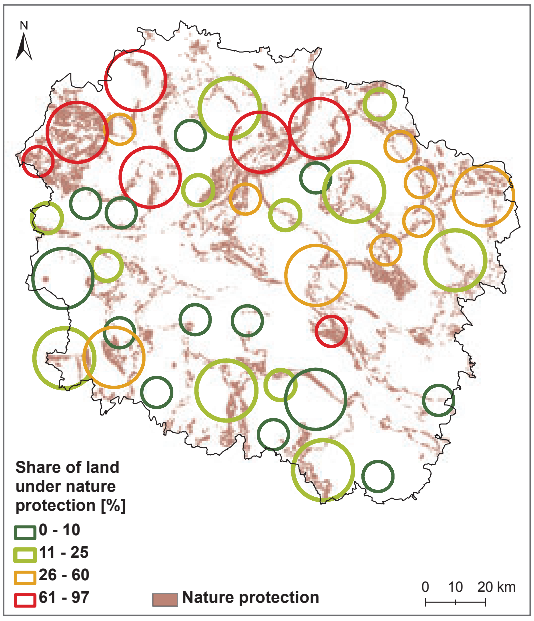
Map 100: Share of Arable Land Dedicated to Biogas Production in Total Agricultural Land within a 5 km Radius of Biogas Plants and Power Capacity



Map 102: Share of Arable Land Required for Biogas Production in Total Farmland within Radiuses of 5 and 10 km From Potential Biogas Plants



Map 101: Share of Arable Land Dedicated to Biogas Production in Total Agricultural Land within a 10 km Radius of Biogas Pants and Power Capacity



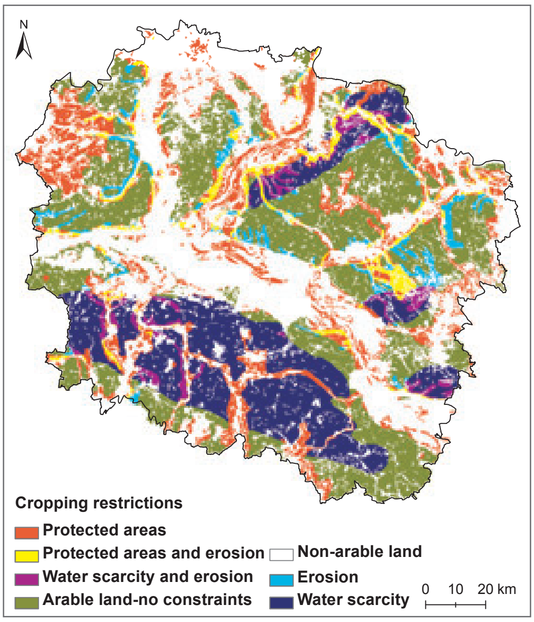
Map 103: Share of Arable Land under Nature Conservation (incl. Water Conservation)

nature conservation requirements as well as against the existing risk of soil erosion and water scarcity in the Map Algebra tool. The conditional statement (64) was used to classify land on the basis of the digital layers representing arable land, protected areas (areas of special protection of birds, areas of special protection of habitats, ecological corridors, water protection zones, landscape parks, protected landscape areas), plus sites under water erosion and seasonal water scarcity.

Map 104 shows arable land evaluated against the nature conservation requirements, erodible sites and potential water scarcity occurring over the vegetation period. Classifications like these allow a better understanding of the regionally scattered constraints and risks related to growing conventional and energy crops as outlined in Table 120.

```
if ((protected_areas = y and erosion = Y),
Protected areas - erosion,
    if((protected_areas = Y),
    Protected areas,
        if((water_scarcity = Y and erosion =Y),
        Water scarcity - erosion,
            if((erosion = Y),                    (64)
            Erosion,
                if((water_scarcity = Y),
                Water scarcity,
                    if((arable_land = Y),
                    Arable land - no constraints,
                    Non - arable land))))))
```

The cultivation of short rotation crops in the Kujawsko-Pomorskie Voivodship could legally be restricted within a 266763 ha area of protected land, which covers 26% of the total arable land available. Moreover, the cultivation of those crops should be avoided on an area of 287089 ha (equaling 28% of the total arable land available in the region) characterized by water scarcity, not only to maintain the ground water level, but also with respect to crop yield performance. As mentioned above, intensive maize cropping should be avoided on areas affected by soil erosion, which cover 87027 ha. An area of 428818 ha (corresponding to 41% of the total arable land available in the region), is free of any of the aforementioned restrictions and thus not protected against the cultivation of short rotation energy crops.



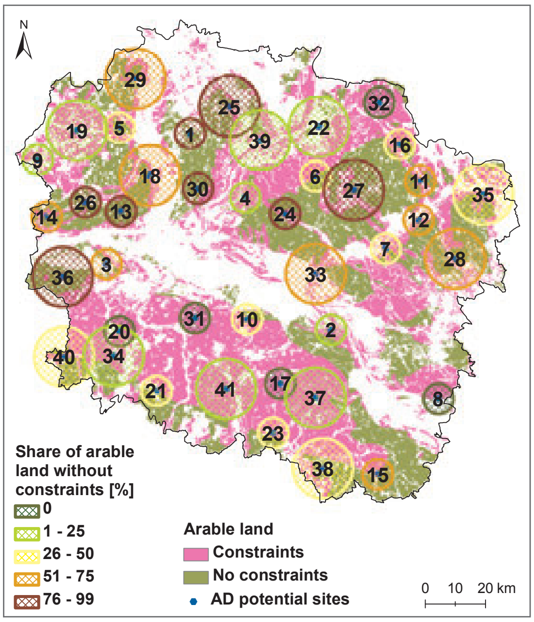
Map 104: Arable Land Situated within Areas Affected by Soil Erosion and Protection Constraints

In the next step, the defined six classes of farmland constraints were explored in 41 biogas zones in order to identify potential constraints for biogas feedstock growing and possible conflicts with other dedicated energy plants (details for each zone are outlined in Appendix 23). As seen on Map 105, five biogas zones cover the arable land, which is restricted by at least one of three constraints. It must be noted that data on nature conservation restrictions was only available for the Kujawsko-Pomorskie Voivodship, so that areas in cross-border zones (No. 8, 9, 30, 38 and 40) were underrepresented due to a lack of data for neighboring regions.

Apart from the demand for cropland, the future development of land-based solar parks due to decreasing investment costs may inflame the land use conflicts in the future. Unless environmental constraints prevent it, the siting of photovoltaic facili-

Table 120: Constraints for the Cultivation of Selected Crops (R - Restricted, A - Avoid, NC - No Constraints, S - Suffer)

	Protected Areas -Erosion	Protected Areas	Water Scarcity-Erosion	Erosion	Water Scarcity	Arable Land - No Constraints
Area [ha]	53916	212847	35699	51328	251390	428818
Share [%]	5.2	20.6	3.5	5.0	24.3	41.5
Willow	R	R	A, S	NC	A, S	NC
Miscanthus	R	R	A, S	NC	A, S	NC
Sida	R	R	A, S	NC	A, S	NC
Maize	A	NC	A, S	A	NC, S	NC
Wheat	NC	NC	NC, S	NC	NC, S	NC
Rye	NC	NC	NC, S	NC	NC, S	NC
Rapeseed	NC	NC	NC, S	NC	NC, S	NC



Map 105: Agricultural Suitability and Constraints within the Potential Sites for Anaerobic Digestion Plants

ties on a high quality arable land is not foreclosed by any legal restrictions. As shown in the economic assessment (see 6.3.4), the size of the land rent has no significant impact on the profitability of land-based PV systems. Economic constraints have so far prevented the replacement of other agricultural and non-agricultural land use functions through solar systems, given that under the current investment costs, generating solar energy can neither compete with the costs of generating wind energy nor with the costs of crop production. Nonetheless, the expected decrease in photovoltaic investment costs and the likely increase in energy prices (EPIA 2010) may relativize these constraints. The PV capacity increase would also be related to the possibility of implementing a support scheme intended primarily to support rooftop PV systems, which have been completely unprofitable so far in comparison with PV applications on the ground due to the economies of scale. Hence, the scenario that PV systems on land can contribute to land use conflicts in the Kujawsko-Pomorskie Voivodship cannot be excluded and therefore compensatory measures would be required.

The solar radiation with a regional difference of 4% in the region is quite evenly distributed, while the wind energy potential harvested in the northern part of the region is about 8% below the potential in the southern part of the region. On the final economic balance sheet, regional differences in solar radiation have only a minor influence on the energy harvest and thus on the revenues (see chapter 6.3.4). In the case of wind energy, the revenue level is high enough above the cost level to not discourage investors (see chapter 5.2.4). On the other hand, while speaking about energy and land use efficiency, the aforementioned discrepancies in the energy yield are a reliable indicator to identify sustainable energy harvest zones.

The conditional statement (see formula 65) performed through the Map Algebra tool allows for a site assessment where potential territorial conflicts may appear between wind and PV ground applications. At sites with moderate and high arable land quality, wind power development is given priority over solar parks. In order to maintain a sustainable energy-mix and if allowed through environmental impact assessment, stand-alone PV systems should primarily be constructed on so called favorable sites outside nature conservation areas characterized by a low farmland quality and low environmental protection requirements. The site classification for wind farm and for solar parks were identified in previous chapters (5.2.2 and 6.3.2) through formula 33 and 59. In this phase, the site classification for both wind farm and solar parks including agricultural land quality was performed by means of formula 65. The spatial assessment results in 13 sites presented on Map 106. Sites classified as Wind-NC indicate a possible unrestricted location for wind development that is also suitable for PV parks. Sites identified as Wind-NC and PV-Favorable are locations suitable for the development of both competing energy sources. There are identified constraints assigned to wind farms, and the locations are also favorable for solar parks. PV-Favorable means sites located on dump sites or mineral extraction sites. PV-NPL indicates sites suitable for the construction of solar parks and located outside ecologically protected areas related to this installation. At these sites, the environmental and/or infrastructural constraints either exclude the construction of wind turbines or have a high or moderate level of ecological protection. PV-LL means sites that have been identified in areas under a low level of ecological protection and are on low quality farmland. Wind-NC and PV-LL indicates sites with the same conditions for solar farms as the previous one, but with no constraints on wind turbine construction. Wind-NC preferred against PV means that locations are within areas of high or medium quality agricultural land, and thus wind farms

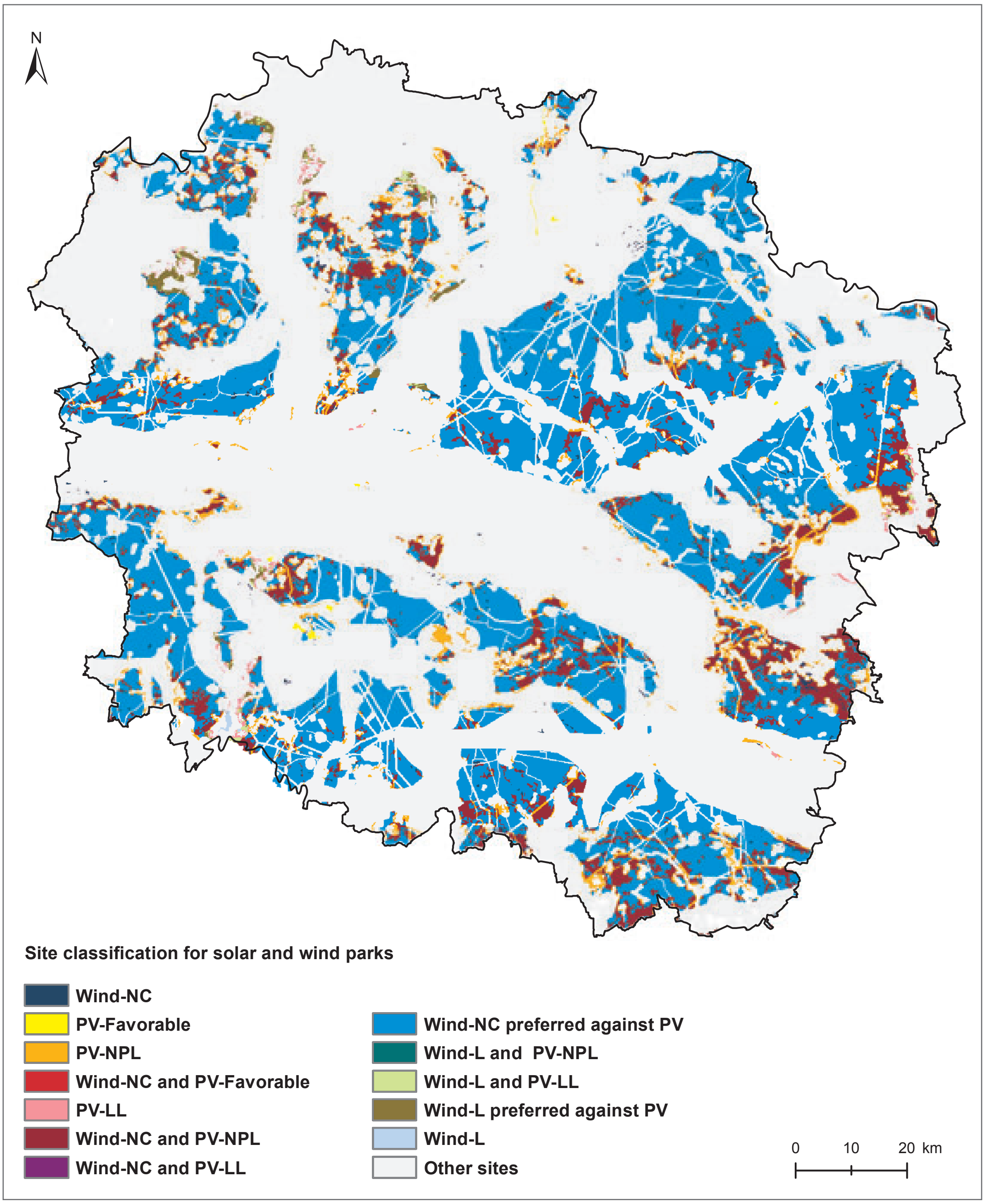
```
if ((Wind_no-constraints =Y and PV_unsuitable =Y),
    Wind-NC,
    if ((Wind_no-constraints = Y and PV_favorable =Y),
        Wind-NC and PV-Favorable,
        if ((PV_favorable =Y),
            PV-Favorable,
            if ((Wind_excluded  or Wind_high_prot or Wind_moderate_prot) and
                (PV_NP-L-suitable =Y )),
                PV-NPL,
                if ((Wind_excluded or Wind_high_prot or Wind_moderate_prot) and
                    (PV-LL-suitable =Y )),
                    PV-LL,
                    if ((Wind_no_constraints =Y and PV_NP-L-suitable =Y ),
                        Wind-NC and PV-NP-L,
                        if ((Wind_no_constraints =Y and PV_L-L-suitable =Y ),
                            Wind-NC and PV-LL,                                  (65)
                            if((Wind_no_constraints =Y and (PV_L-H-suitable =Y or
                                PV_ L-M-suitable = Y or PV_NP-H-suitable =Y or
                                PV_NP-M-suitable =Y )),
                                Wind-NC preferred against PV,
                                if ((Wind_low_prot =Y and PV_NP-L-suitable =Y ),
                                    Wind-L and PV NPL,
                                    if ((Wind_low_prot =Y and PV_L-L-suitable =Y ),
                                        Wind-L and PV-LL,
                                        if((Wind_low_prot =Y  and (PV_L-H-suitable =Y or
                                            PV_L-M-suitable = Y or PV_NP-H-suitable =Y or
                                            PV_NP-M-suitable =Y )),
                                            Wind-L preferred against PV,
                                            if ((Wind_low_prot =Y and PV_unsuitable =Y),
                                                Wind-L, Other sites))))))))))
```

would be favored over large PV parks. Wind-L and PV-NPL are sites identified within areas of low levels of protection with regard to wind farms, but have none of the ecological or infrastructural constraints for PV parks and they have low quality arable land. Wind-L and PV-LL are sites located within areas that have a low level of ecological protection for wind and solar farms and are on low quality farmland. Wind-L preferred against PV means locations within areas of high and medium quality agricultural land, but with a low level of nature conservation. Nonetheless, the erection of wind turbines should be preferred to PV park development. Wind-L are sites under low level of nature conservation and are not suitable for PV systems.

The study identified the land without environmental and infrastructural constraints that is designated for wind park development, and does not conflict with PV systems classified as Wind-NC would cover a surface of 9 178 ha (see Table 121). In addition, a total area of 439 670 ha of farmland of moderate and high quality has been classified as Wind-NC preferred against PV and should not be used for PV ground applications. Sites identified as Wind-NC and PV- NPL, covering 5% of the region's total area, are not high quality land and do not have any environmental constraints on their use. Here there may be possible competition between solar and wind energy development. Sites characterized by a low risk of conflict over the development of PV facilities are labeled PV Favorable. This category applies to dump sites and mineral extraction sites. The label PV-NPL is attributed to areas, outside natural conservation zones that are characterized by low quality arable land. Correspondingly, Figure 6 illustrates the final site classification for wind and solar power development see Map 106.

The surface currently under wind turbines was not included in the assessment due to a lack of spatial data, so that areas within this site classification category were overestimated.

Having obtained a picture of the potential territorial conflicts and constraints associated with the development of RES energy-mix, the next step is to confront the demand for and supply of alternative energy sources in the Kujawsko-Pomorskie region. Table 122 presents a summary of the RES' technical potential obtained in previous sections. The firewood potential is likely to stay at a constant supply level. The wood residues from orchards and green areas as well as cereal residues are used mostly in district and local domestic heating boilers. The remaining potential is rather limited due to high mobilization costs. Consequently, Table 123 and Table 124 detail the area of farmland required for the generation of biomass in order to deliver the region's contribution to the implementation of the 2020 national renewable energy targets (see chapter 2.2). This theoretical approach is aimed at providing a better insight into the potential land pressure risks arising from the energy demand outlined in Table 6. The figures for the amount of power and heat generation outlined in Table 123 rely on the following assumptions: (i) 35% electricity conversion efficiency in CHP; (ii) 45% heat conversion efficiency in CHP; (iii) 90% of heat conversion efficiency in heating boilers; (iv) 12 GJ/t heating value



Map 106: Site Classification for the Development of Solar and Wind Parks in the Kujawsko-Pomorskie Region

Table 121: Site Classification for PV Systems and Wind Parks in the Kujawsko-Pomorskie Voivodship

Sites	Site Classification	Area [ha]	Share [%]
1	Wind-NC	9178	0.51
2	PV-Favorable	1087	0.06
3	PV-NPL	48822	2.73
4	Wind-NC and PV-Favorable	28	0.00
5	PV-LL	4010	0.22
6	Wind-NC and PV-NPL	91608	5.13
7	Wind-NC and PV-LL	14	0.00
8	Wind-NC preferred against PV	439670	24.62
9	Wind-L and PV-NPL	23	0.00
10	Wind-L and PV-L	2625	0.15
11	Wind-L preferred against PV	6149	0.34
12	Wind-L	518	0.03
13	Other sites	1182177	66.19

for agricultural biomass; (v) 14 t/ha yield of short rotation crops; (vi) 100% of agricultural biomass in co-firing power plants and (vii) 60% of agricultural biomass in biomass firing units.

In the case of farmland required for biofuel production as described in Table 124, the following assumptions were made: (i) average cereal yield: 3.8 t/ha; (ii) bioethanol average yield: 7.7 GJ/t; (iii) maize average yield: -4.4 t/ha and (iv) bioethanol average yield: 8.3 GJ/t; (v) sugar beet average yield: 53 t/ha and (vi) ethanol average yield: 2.13 GJ/t.

Depending on different reference factors - installed capacity or agricultural land - used to disaggregate national RES targets, in the electricity sector either 1 or 4% respectively of the regional agricultural land should be dedicated to biomass production that will used for co-firing and combustion, whereas in the heat sector either 7 or 8% of farmland should be reserved for biomass production to be used in heat-only boilers (see Table 123). In Kujawsko-Pomorskie, an area between 9368 ha and 39035 ha is required for the production of bioethanol feedstock, occupying between 1.0 and 4.3% of the region's total agricultural surface depending on the area cultivated with crops not dedicated to the production of feedstock for RES. In view of the high costs for bioethanol production from sugar beets, which is the most efficient option in terms of land consumption, biofuel in the region of Kujawsko-Pomorskie is foremost produced from cereals and maize crops (Grzybek 2008a). The cultivation of feedstock for biodiesel is the most area-consuming national RES target in Poland, requiring almost 9% of the region's total farmland cultivated with rapeseed oil crops (see Table 124). Assuming a maximum land consumption scenario, around 15 - 17% of the region's total agricultural surface should be devoted to the generation of RES for the electricity, heating and transport sectors in order to contribute to Poland's national biomass targets.

As outlined in Table 122, the technical biogas potential is sufficient to meet the regional targets for biogas production, which depend on a reference factor of either 3000 GWh or 5200 GWh of methane equivalent (see Table 6 in chapter 2.2). However, meeting this target will require dedicating between 4.5 and 15% of farmland area for the cultivation of biogas co-substrates, unless they are replaced by other biowaste feedstocks.

The approach described results in a theoretical demand for land surface ranging from 20 to 35% of the overall agricultural land, thus also giving rise to concerns over the maintenance of the food and fodder production which should certainly be addressed. In fact, if 20% of the farmland was devoted to energy crops, the current arable land per capita of 0.48 ha would drop to 0.39 ha/cap. On the other hand, it can be argued that this per capita share is still above the current national rate of 0.36 ha/cap. According to Pisarek, Ganko et al. (2004), a global indicator of 0.24 ha/cap would be "sufficient" to cover the demand for food and fodder production. Nonetheless, considering the possibility of significant divergences in the crop yield and a food supply vulnerability caused by unforeseen natural disasters and cereal price speculation on international

Table 122: Summary of the Potential of Selected RES and Associated Development Constraints in the Region of Kujawsko-Pomorskie

Wood					
Origin:	Quantity [m^3]	Quantity [t]	Energy [GWh]	Constraints	Outlook
Forest, incl.	292778	585556	1627	Already used	Future potential at similar level
Firewood	172803	345606	960		
Slash	119975	239950	667		
Green Areas	-	85000	165	Supply inconstancy in space and time, Logistic constraints	Limited - competition with heating boilers
Orchards	-	4180	8		Limited
Straw					
Cereal's Residues		973865	1894	0.24 Mt currently pelletized, with outlook for 0.4 Mt, and locally used in straw boilers	Limited potential due to logistic constraints
Biogas					
Origin:	Methane [Mm^3]	Energy [GWh]	Area [ha*]	Constraints	Outlook
Manure				Decrease in animal population, Costs of co-substrate, Investment costs, Support system, Acceptability	High Potential
Livestock Units > 100	24	226	-		
Animal Population > 100	44	405	-		
Feedstock-mix					
15% DM (LSU > 100)	98	953	22000		
15% DM (Pop. > 100)	195	2196	46000		
22% DM (Pop. > 100)	566	5601	159000		
Solar					
Sites:	Area [ha]	Power [MW]	Energy [GWh]	Constraints	Outlook
Roof Area	3443	809	647	Investment costs	Likely drop in investment costs and increase of efficiency
Ground-Based:				Investment costs, Acceptability	
Favorable Sites	1115	372	316		
Low Quality Land Outside Protected Areas	140453	46818	39795		
Wind					
Sites with No Constraints	619016	61902	123803	Acceptability	High Potential
Sites under Low Protection	11508	1151	2302		

* Co-substrate yield of 35t/ha

markets, there is a need to keep a flexible reserve of land, which is very difficult to quantify either globally or regionally. The rise in land demand for growing energy crops which is unbalanced both time-wise and spatially may cause a domino effect, i.e. increased land lease prices initiating a rise in crop prices, which would then cause energy prices to go up and thus eventually affect social welfare. To prevent this chain effect, the supply and demand of land for energy crops should be continuously inventoried and if necessary balanced flexibly through an adequate level of support payments allowing such risks to be mitigated. However, prior to drawing up any strategy or designing instruments, the RES development possibilities should be evaluated in the context of investment possibilities and their opportunity costs. As previously mentioned, the implementation of RES targets depends on the investors' benefit options.

The driving force in terms of a direct payment for growing energy crops was abolished in 2010. The economic analysis indicates that the profitability of short rotation crops was also affected by the

Table 123: Transfer of the Polish National Biomass Production Targets onto the Regional Level and Required Farmland for Biomass Production in the Kujawsko-Pomorskie Voivodship

Biomass	Reference Factor	Target to be Reached by 2020	Area	Share in Arable Land
		t/y	ha	%
		For Electricity Production		
Co-Firing	Installed Capacity	11571	827	0.1
	Agricultural Land	46286	3306	0.4
Combustion	Installed Capacity	119571	8541	0.9
	Agricultural Land	478286	34163	3.7
		For Heat Production		
Heat-Only Boilers	Agricultural Land	1019218	72801	8.0
	Population	887706	63408	6.9

Table 124: Transfer of the Polish National Biomass Production Targets onto the Regional Level and Dedication of Farmland for Biofuel Production in the Kujawsko-Pomorskie Voivodship

Biofuels	Target to be Reached by 2020	Energy Crops (Alternatives)	Area	Share in Arable Land
	TJ		ha	%
Bioethanol/ Bio-ETBE	1171	Cereal Grain	39035	4.3
		Maize Silage	21686	2.4
		Sugar Beet	9368	1.0
Biodiesel	2903	Rapeseed	79549	8.7

abolition of establishment payments. Consequently, to make the investment option more profitable than annual energy crops, perennials must be grown on at least a moderate quality of land generating good harvests, indicated by the findings in chapter 4.2.2.2. Nevertheless, the current difference between the gross margins of the considered types of crop is not enough to offset the economic risk over a period of 20 years, although this situation might change very soon due to an anticipated drop in initial investment costs and an increase in prices for lignocellulosic biomass, driven by a growing demand for agricultural biomass under the aforementioned regulation set by the Polish Government's Ordinance of 14 August 2008 (Ministry of Economy 2008). The investor's risk associated with the cultivation of annual energy crops is no different to that for annual conventional crops. Accordingly, the profit margin depends on annual prices either offered on the food market or by producers of biofuels, whose production costs depend on incentives measures (i.e. tax incentives) and crude oil prices. Biofuel production has grown very dynamically over the past decade (GUS 2009g), but the ongoing changes to European and Polish energy policies as well as cuts in support schemes to biofuels (Wąsiewski 2010) may slow this process down somewhat, which will anyhow be balanced out so long as oil prices continue to rise. Given that the competitiveness of biofuel production has so far relied on support mechanisms (e.g. tax incentives, payments to energy crops, certificates etc.), this market is highly dependent on policy decisions, which will in turn affect investors' decisions.

The growing of biogas crops is contingent upon the demand for biogas development, which is also related to a set of quota certificates. Until March 2010, the Polish Government's aid mechanism (the green certificate) had favored the cheapest RES technologies like wind turbines. Subsequently, the diversification of quota-based mechanisms released new investment opportunities predominantly in biogas energy. However, these investment options still bear a great risk associated with the unpredictability of income sources from certificate systems which are not guaranteed over the entire lifetime of biogas plants, but only over a period of 5 to 7 years, which might not be sufficient to encourage ordinary farmers to grow biogas crops. In addition, the set of certificates as such does not provide enough incentives to drive biogas development up to the peak level of feedstock prices. For instance, an increase of

Table 125: Selected Site Factors Influencing Development and Utilization of RES and Conventional Crops Production in the Kujawsko-Pomorskie Region

Factors	Conventional Crops	Annual Energy Crops	Perennial Energy Crops	Crop By-Products	Animal Waste (Biogas)	Wind Turbines	Ground Mounted PV Systems	Rooftop PV Systems
Nature Conservation	Not restricted	Mitigation of high biodiversity	Restricted on legal basis	Restriction related to biomass plants	Restriction related to biogas plants	Restricted(might be allowed after individual environmental impact assessment)		Restricted on historical monuments
Landscape Conservation	Not restricted	Not restricted	Restricted on legal basis					
Arable Land Quality	Impact on the yield	Impact on the yield	Impact on the yield	Impact on the yield	-	-	PV application not restricted	-
Energy Price	-	-	-	-	(Chapter 4.2.4.3.6-4.2.4.3.9)	(Chapter 5.2.4)	(Chapter 6.3.4)	
Energy Costs	-	-	-	-				
Crop Purchase Price	(Chapter 4.2.2.2)				-	-	-	-
Gross Margin					-	-	-	-
Demand for RES and Conventional Crops	Regulated due to policy measures	High Related to the national targets	High Related to the national targets	Very High Related to the national targets	Very High Related to the national targets	Very High Related to the national targets	Low Related to the national targets	Moderate Related to the national targets
Policy Outlook	Single-payment scheme, Complementary Direct Payments	Single-payment scheme, Complementary Direct Payments, indirect through subsidy payments and green certificates to biogas	Complementary Direct Payments to grasses	Indirect support through subsidy payments to CHP	Subsidy payments and green certificates	Subsidy payments and green certificates	Subsidy payments and green certificates	Subsidy payments and green certificates
Farming Tradition	-	Moderate Impact	High Impact	Low Impact	Moderate Impact	High Impact	High Impact	Low Impact
Acceptance	-	-	-	-	-	-	-	-

the maize silage purchasing price from 20 to 30 €/t is expected to raise biogas production costs by on average 10 €/MWh and to constrain the economic viability of projects with a capacity below 300 to 900 kW_e depending on the level of the relevant subsidies (see chapter 4.2.3.4.8). On the other hand, this will encourage biogas investors first to look for local biowaste substrates and to utilize only necessary crop amounts to stabilize the process.

The preliminary technical potential of wind energy explored in the Polish case study is well above the target transferred onto the regional level (see Table 6 in chapter 2.2). Thanks to the quota systems, the wind energy branch offers an interesting economic potential with favorable conditions for investors. Despite this, the actual degree of utilization of this potential will depend on the local-specific criteria (i.e. environmental impact assessment) as well as the willingness of local communities and acceptance of other involved parties to integrate these installations into their energy systems. The wind energy production does not lead to the replacement of land use functions like biomass or ground-mounted PV systems; however, an appropriate harmonization with ecological and socio-economic systems requires the guidance of regional and local authorities, for instance through the preparation of spatial zoning plans.

Concerning the solar electricity targets, under the current conditions the economic factor has turned out to be the main barrier toward implementing the technical potential of rooftop or free-standing photovoltaic systems. Nonetheless, the economic findings suggest that large stand-alone solar units may become economically sustainable and increasingly attractive investment options in the future (see chapter 6.3.4). On the other hand, the synergy effect achieved through the dual use of land for instance settlements and energy production can be realized by means of roof-mounted solar systems.

As empirical studies indicate farming tradition and social and investors' acceptance are influencing factors for RES development. Investors' acceptance is determined particularly by stable political and socio-economic frame conditions (Jäger-Waldau 2005; Michalena and Hills 2012). Hence, the uncertainty and discontinuity of policy and support measures are the main causes of weak development of renewable energy in Poland.

The summary of factors influencing investor decision-making on RES options in the Polish region are outlined in Table 125.

7.4 Potential Renewable Energy-Mix in the Stuttgart Region

In the final step of the study, the potential renewable energy-mix in the Stuttgart region was investigated from investor's perspective so as to identify possible demand for the land resource for energy production, as well as to identify RES-mix allowing the future conflict risk associated with environmental and land use aspects to be minimized.

In the densely populated and highly urbanized region of Stuttgart, the pressure on land use will increase strongly under a growing demand for food and non-food production (Feldwisch, Lendvaczky et al. 2010). The indicator of agricultural land in hectare per capita of 0.05 for the Stuttgart region is very low compared to 0.13 for the federal state of Baden-Württemberg and 0.2 for Germany (StLA 2010). In addition, the agricultural land surface is expected to drop on average by 4% as a result of urban expansion (Feldwisch, Lendvaczky et al. 2010). Due to the extending of biodiversity conservation areas, an already-scarce agricultural production in terms of arable land surface will be further restricted, from 12% currently to 15% by 2020, as well as by the implementation of a sustainability goal i.e. protection before use (German: *Schutz vor Nutzung*), which affects around 6% of agricultural land (NBBW 2004) (see chapter 4.3.2.1). In consequence of the restriction to extensive cultivation of grassland and conventional crops, both crop yield and potential biomass from residues left on field (to prevent soil erosion, for instance) will decrease. Hence there is a high request for harmonizing and coupling together different land use functions (e.g. protection, food production, settlements, recreation etc.), particularly in the Stuttgart region. On the way to increasing regional energy supply independence, the focus should firstly be put on exploiting residues and using synergy effects. Table 126 outlines a summary of the technical potential of RES explored in previous sections of the case study. The woody residues from landscape, orchards and vineyards represent a high and almost unused potential, whose exploitation in biogas plants should theoretically be enhanced by bonus payments. This lignocellulosic material is, however, problematic to use in anaerobic digestion plants due to its slow anaerobic decomposition (Weiland 2010). This cutting material can also be incinerated in CHP units, but supply constraints in time and space considerably affect how feasible it is to be harnessed. The regional pre-assessment shows that in only a few communes did the spatial density of cuttings represent an attractive supplemental option to wood or SRC (see chapter 4.3.4). Despite the high technical potential of cereal harvest residues at 52580 tons (209 GWh), the economic viability of straw utilization through combustion, gasification or pyrolysis processes is limited. Owing to annual crop rotation, the supply of straw is even more diversified than the supply of wood cuttings and largely unpredictable because of changes in the market crop demand and crop prices. Moreover, the humus content of the soil varies with the crops' rotation, affecting the net straw potential after soil fertilization (see chapter 4.3.3.3). With respect to the complexity of logistical constraints connected with lignocellulosic residues, any strategy for their use requires a local assessment and guidance to enhance their sustainable mobilization and utilization.

Although animal livestock production in the Stuttgart region and Baden-Württemberg as a whole amounts to 0.6 and 0.76 LSU per hectare of agricultural land respectively, biogas production in the Stuttgart region is lower than in the federal state of Baden-Württemberg, with a share of around 4% of the total technical potential of manure having so far been utilized in biogas plants (Feldwisch, Lendvaczky et al. 2010). As the economic assessment of using manure in biogas plants suggests promising and high benefits, it is expected that investors will successfully exploit this potential. On the other hand, country-wide experiences have shown up the fatal consequences of a rapid and massive construc-

Table 126: Summary of the RES Potential and Their Development Constraints in the Stuttgart Region

<table>
<tr><td colspan="6">Wood</td></tr>
<tr><td>Origin:</td><td>Quantity [t]</td><td colspan="2">Energy Content [GWh]</td><td>Constraints</td><td>Outlook</td></tr>
<tr><td>Forest</td><td>195175</td><td colspan="2">402</td><td>Used in wood-related manufacture and heating boilers</td><td>Future potential at similar level</td></tr>
<tr><td>Landscape</td><td>22581</td><td colspan="2">50</td><td rowspan="3">Logistical constraints,
Supply inconstancy in space and time,
Decreasing area</td><td rowspan="3">Utilization stimulated through bonus payment</td></tr>
<tr><td>Orchards</td><td>3186</td><td colspan="2">7</td></tr>
<tr><td>Vineyards</td><td>4829</td><td colspan="2">11</td></tr>
<tr><td colspan="6">Straw</td></tr>
<tr><td>Cereal's Residues</td><td>52580</td><td colspan="2">209</td><td>Logistical constraints</td><td>Potential at similar level</td></tr>
<tr><td colspan="6">Biogas</td></tr>
<tr><td>Origin:</td><td>Methane [Mm^3]</td><td>Energy [GWh]</td><td>Area [ha*]</td><td>Constraints</td><td>Outlook</td></tr>
<tr><td>Manure</td><td>11.6</td><td>111</td><td></td><td rowspan="2">Acceptability</td><td rowspan="2">Declining animal population, but liquid manure at similar level</td></tr>
<tr><td>Manure and 40% of Co-Substrates</td><td>51.4</td><td>491</td><td>12622</td></tr>
<tr><td colspan="6">Solar</td></tr>
<tr><td>Sites:</td><td>Area [ha]</td><td>Power [MW]</td><td>Energy [GWh]</td><td>Constraints</td><td>Outlook</td></tr>
<tr><td>Roof Area</td><td>428</td><td>428</td><td>385</td><td>Completion for surface with solar thermal units</td><td>Growing at comparable rate as before 2009</td></tr>
<tr><td>Land-Favorable</td><td>268</td><td>89</td><td>80</td><td rowspan="2">Costs of marginal land preparation,
Acceptability</td><td rowspan="2">Restriction of large scale installation</td></tr>
<tr><td>Along Carriageways</td><td>1170/2</td><td>250</td><td>225</td></tr>
<tr><td colspan="6">Wind</td></tr>
<tr><td>Sites with No Constraints</td><td>8836</td><td>883</td><td>2209</td><td rowspan="2">Vicinity to power lines and local assessment,
Acceptability</td><td rowspan="2">Low potential due to high settlement density and biodiversity area</td></tr>
<tr><td>Sites under Low Protection</td><td>10934</td><td>1093</td><td>2733</td></tr>
</table>

tion of biogas plants, resulting from the 2010 FIT scheme. In fact, this development has also endangered the existence of traditional agricultural holdings (i.e. land lease increases), affected biodiversity due to the expansion of maize monoculture and led to grassland being ploughed, which in turn leads to the intrusion of fauna and flora and carbon release (Gunnar and Habermann 2010; WWF 2011). Although a special permit from nature conservation authorities is required, the ploughing of permanent pasture is not forbidden within the bounds of 10% of the federal state's total agricultural area, a ratio which is provided by the Single Payment Scheme. In Upper Swabia, as a consequence of the increase in maize demand for biogas production, large shares of permanent pasture areas, even including pastures situated within Natura 2000 areas, have been transformed into "maize desert" (Bronner 2011).

In order to enhance the sustainable supply of feedstock and to reduce the pressure on land production for biogas on site, not only the support scheme should be revised but also the authorization instruments. Under the German Building Law, biogas plants up to 500 kW_e are treated as privileged agricultural facilities for which no environmental impact assessment is required. To mitigate further intrusion into ecological and socio-economic systems, the authorization process should be oriented towards the availability of biogas co-feedstock. In addition, the expansion of biogas and other bio energy sources should be further stimulated as to increase fuel and energy yield and efficiency. The economic assessment indicates that without selling the heat, biogas projects may produce benefits (see chapter 4.3.3.1.2).

Unlike the biogas field, German policy has followed a trend regarding photovoltaic investment costs. In this regard, the PV support scheme has recently been adjusted in line with PV costs and technologies (EEG 2010). The cost-benefit analysis shows comparable profitability of roof and ground PV investments, although the surface for large-scale units has been radically limited, which slows down the overall annual increase of the power peak. Due to the multifarious constraints (i.e. land use, nature conservation etc.) outlined in the previous sections, wind and solar energy development is strongly restricted in the Stuttgart region. As with its Polish counterpart, the German region's wind-solar assessment was performed in order for sites to be identified where conflicts may appear between potential wind priority zones set up by the regional authorities and freestanding PV facilities. The spatial assessment was carried out according to formula 66 and results in 11 sites (see Table 127). Sites classified as Wind-NC indicate a potential location without constraints for wind development, but not suitable for solar parks, PV-F-roads points out locations suitable for development of ground-mounted PV units alongside motorways on the low and moderate land quality, and outside of nature protection restrictions, PV-L-F-roads indicates sites explored for PV systems within low nature protection restrictions and alongside motorways on a low or moderate land quality, PV-M-F-roads points out areas explored for solar parks within moderate nature

```
if ((Wind_no_constraints =  Y and  PV_excluded = Y),
  Wind-NC,
    if ((PV_L-F-roads =Y or PV_M-F-roads = Y ),
    PV-F-roads,
      if ((PV_L-L-F-roads= Y or L-M-F-roads = Y),
      PV-L-F-roads,
        if ((PV_M-L-F-roads = Y or PV_M-M-F-roads = Y),
        PV-M-F-roads,
          if ((Wind_no_constraints =  Y and  PV_favorable = Y),
          Wind-NC and PV-Favorable
            if ((PV_favorable = Y),                                    (66)
            PV-Favorable,
              if ((Wind_no_constraints = Y and  PV NP-L-suitable = Y),
              Wind-NC preferred against PV-NP-L,
                if ((Wind_low_prot  = Y and  PV NP-L-suitable = Y),
                Wind-L and PV-NP-L,
                  if (((Wind_no_constraints = Y),
                  Wind-NC preferred against PV,
                    if ((Wind_low_prot = Y),
                    Wind-L preferred against PV, Other sites))))))))))))))
```

protection restrictions and alongside motorways on a low or moderate land quality, Wind-NC and PV-Favorable point out areas suitable for development of both competing energy sources, as no constraints assigned to wind farms were identified, and those locations are favored for solar parks, Wind-NC preferred against PV-NP-L means sites with no constraints assigned to wind farms that should be preferred against solar park development, as these sites are located within areas of low quality of agricultural land and under low level of nature conservation assigned to freestanding PV units, Wind-L and PV-NP-L indicates sites under low level of nature conservation assigned to wind parks and outside of nature conservation assigned to solar parks, and on a low quality of land, Wind-NC preferred against PV means locations with no constraints for wind farms that should be preferred against solar park development, as these sites are located within areas of high or moderate quality of agricultural land and under moderate or high level of nature conservation restrictions, Wind-L preferred against PV means locations within areas of high and medium quality of agricultural land, but under low level of nature conservation restrictions assigned to wind farms

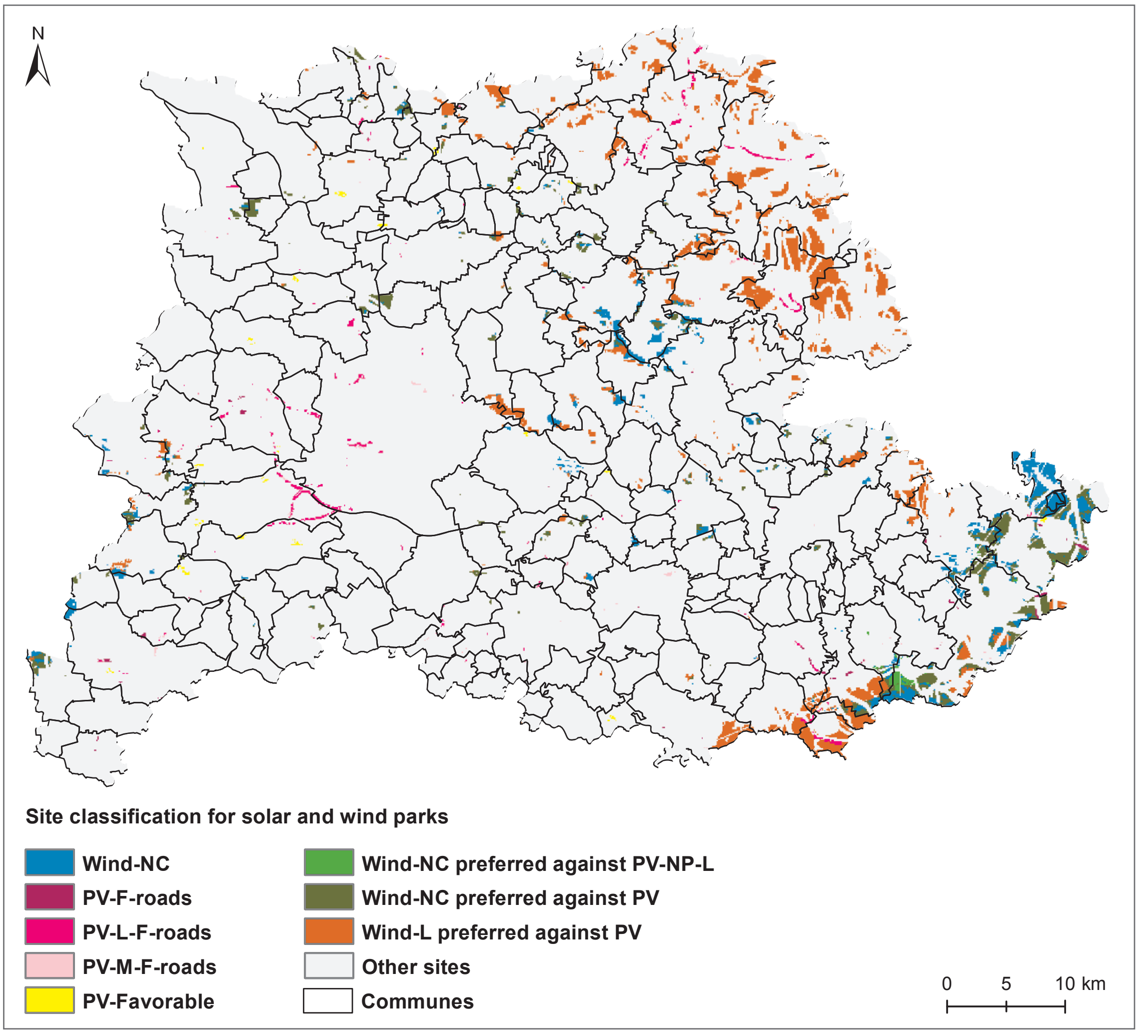
The site classification for both solar and wind park zones is presented on Map 107. Erection of freestanding solar parks is restricted to the verges of motorways and rail lines up to a distance of 110 m within non-protected areas and nature conservation areas under low and moderate protection (sites 2 - 4 in Table 127). Besides this, favorable sites PV-Favorable were assumed on dump sites and mineral extraction sites. Other sites were considered as being ineligible for FIT payments. Hence, the potential wind energy development is given priority at locations where low, moderate and high qualities of arable land on suitable locations was explored. With respect to the restriction that wind turbines must only be erected at a safe distance of 100 m from roads, the strip along motorways is only considered for PV siting. Altogether, the potential area for wind park development (sites 1, 7, 9, 10) comprises 19712 ha - 5% of the region's surface, which is subsequently subjected to site-specific analyses and authorization processes. For land-based PV systems outside nature conservation areas (sites 2-6), the total potential area amounts to 1763 ha - corresponding to 0.5% of the region's surface.

The findings show that both investment options in wind and solar farms are rather exclusive and legally restricted. The land user's choice whether to dedicate the land resource to wind, photovoltaic or biomass energy production is strongly influenced by the German Renewable Energy Law (regulating feed-in tariffs, for example) and regional spatial planning instruments (among them preferential zones for wind energy).

In the case of bioenergy production, although investors benefit from a maximum freedom of decision-making compared to wind and freestanding solar installations, not all options are devoid of investment risks and future revenue insecurity. Unlike biogas crops and biogas production, where high profits are guaranteed over the project's lifespan, compared to annual crops, the investment in short rotation coppices and perennial grasses is associated with a sizable degree of uncertainty caused by unstable market demand and gross margins. As explored in chapters 4.3.2.1, the pedoclimatic conditions in the Stuttgart region favor a high

Table 127: Site Classification for Land-Based Solar Park and Wind Farm Development

Sites	Site Classification	Area [ha]	Share [%]
1	Wind-NC	4253	1.16
2	PV-F-roads	236	0.06
3	PV-L-F-roads	1112	0.30
4	PV-M-F-roads	147	0.04
5	Wind-NC and PV-Favorable	0	0
6	PV-Favorable	268	0.07
7	Wind-NC preferred against PV-NP-L	250	0.07
8	Wind-L and PV-NP-L	0	0
9	Wind-NC preferred against PV	4318	1.18
10	Wind-L preferred against PV	10891	3
11	Other sites	343904	94.12



Map 107: Site Classification for Solar and Wind Park Development in the Stuttgart Region

production performance of conventional crops, perennial grasses and SRC. This strong land production efficiency can be maintained by growing crops which obtain a high yield on sites characterized by moderate conditions (e.g. maize, rye, SRC, perennial grasses). The economic assessment shows that the divergences in gross margin between annual and perennial crops may facilitate the land use performance (see chapter 4.3.2.2). However, the situation may change, as perennials and SRC profits are related to wood price fluctuation and not crops. Above all, miscanthus grass contributes to synergy effects by preventing soil erosion and favoring the maintenance of biodiversity.

As mentioned in chapter 2.5, the transfer of the German scenario for biomass onto the Stuttgart region was performed by Feldwisch, Lendvaczky et al. (2010). The proportional transfer to the agricultural area in the Stuttgart region indicates that around 42% of farmland needed to be devoted to biomass production in order to meet the regional targets set in the electricity, heat and biofuel sectors. Unlike electricity and heat generation, where the total explored animal and agricultural residues were taken into calculation, the assessment of biodiesel and biofuel potential was carried out for the conventional cropland, i.e. wheat, maize, sugar beet and rapeseed oil. Shifting such a large amount of arable land from food to the biofuel production is impossible without endangering food supply independence in this region. If 49346 ha were dedicated to bioenergy production, the factor would drop to 0.027 ha/cap, which would be significantly below the 0.24 ha/cap proposed by Pisarek, Ganko et al. (2004). In practice, though, implementing RES objectives will require more land resources than in theory, because the use of bio-waste sources is limited by logistical and economic factors, as already discussed above.

In the densely populated Stuttgart Region, the transfer of the German national RES objectives proportional to the region's population reveals a required acreage of 213655 ha, which is almost two times more than the total available farmland area of 117781 ha (see Table 129). Transferring national targets onto the regional level like this is not only unacceptable but unfeasible. This shows that a transfer of national targets must be tailored to region's abilities and must be balanced with multifarious factors, not only with the farmland and population rate. The assessment reveals that in the case of the Stuttgart region, a growing energy supply independence would be paid for by a decrease in the food supply reliance, as the greatest potential is related to biomass production and rooftop photovoltaic energy technologies. Under the current legal framework, the regional instruments are unable to influence the land users' choices in the biomass field as with the wind or solar options.

With respect to the political frame condition, a set of public policy incentives towards RES have successfully enhanced the renewable energy development. On the other hand, Frondel, Ritter et al. (2010) critically review the German public sup-

Table 128: Area Required for the Development of Bioenergy from Crops in the Stuttgart Region in the Year 2020: Assignment from Federal Aims Proportional to the Agricultural Land

	Electricity		Heat			Biofuels	
Area [ha]	Liquid	Biogas	Liquid		Biogas	Biodiesel	Bioethanol
Counties	CHP	CHP	CHP*	Heating Boiler	CHP*		
Stuttgart	105	154	105	77	154	162	473
Böblingen	929	1259	929	681	259	1443	4200
Esslingen	820	1080	820	601	1080	1274	3707
Göppingen	1171	1260	1171	858	1260	1819	5293
Ludwigsburg	1340	1778	1340	982	1778	2080	6054
Rems-Murr	1080	1286	1080	791	1286	1676	4879
Total [ha]	5445	6817	5445	3990	6817	8454	24606
	49346						
Share [%]	11	14		8		17	50

*Area included in the electricity generated through CHP plants

Source: Federal Targets After NITSCH (2008) Disaggregated by Feldwisch, Lendvaczky et al. (2010)

Table 129: Area Required for the Development of Bioenergy from Crops in the Stuttgart Region in the Year 2020: Assignment from Federal Aims Proportional to the Population Density

	Electricity		Heat			Biofuels	
Area [ha]	Liquid	Biogas	Liquid		Biogas	Biodiesel	Bioethanol
Counties	CHP	CHP	CHP*	Heating Boiler	CHP*		
Stuttgart	5 070	8 754	8 769	3 692	8 754	7 871	22 906
Böblingen	3 164	5 130	5 270	2 304	5 130	4 913	14 298
Esslingen	4 368	7 224	7 373	3 181	7 224	6 781	19735
Göppingen	2 172	2 993	3 471	1 581	2 993	3 371	9812
Ludwigsburg	4 373	7 032	7 245	3 185	7 032	6 789	19759
Rems-Murr	3 541	5 549	5 892	2 579	5 549	5 498	16000
Total [ha]	22 688	36 682	38 021	16 522	36 681	35 223	102 509
	213655						
Share [%]	11	17		8		16	48

*Area included in the electricity generated through CHP plants

Source: Federal Targets after NITSCH (2008), Disaggregated by Feldwisch, Lendvaczky et al. (2010)

Table 130: Selected Site Factors Influencing Development and Utilization of RES and Conventional Crops Production in the Stuttgart Region

Factors	Conventional Crops	Annual Energy Crops	Perennial Energy Crops	Crop By-Products	Animal Waste (Biogas)	Wind Turbines	Ground-Mounted PV Systems	Rooftop PV Systems
Nature Conservation	Not restricted	Mitigation of biodiversity	Restriction related to recommendation of NBBW (2008)	Restriction related to recommendation of NBBW (2008) and to biomass plants	Restriction related to biogas plants	Restricted on legal basis (might be allowed through individual environmental impact assessment) Restricted on historical monuments		Not restricted
Landscape Conservation	Not restricted	Not restricted	Not restricted					Restricted on historical monuments
Arable Land Quality	Impact on the yield	Impact on the yield	Impact on the yield	Impact on the yield	-	-	Restricted	-
Energy Price	-	-	-	-	Feed-in tariffs	Feed-in tariffs		
Energy Costs	-	-	-	-	(Chapter 4.3.3.1.2)	(Chapter 5.3.4)	(Chapter 6.4.4)	
Crop Purchase Price	(Chapter 4.3.2.2)				-	-	-	-
Gross Margin								
Demand for RES* and Conventional Crops	Regulated due to policy measures	High Related to the national targets	Moderate Related to the national targets	Very High Related to the national targets	Very High Related to the national targets	High Related to the national targets	Low Related to the national targets	High Related to the national targets
Policy Outlook	Single-payment scheme, Complementary Direct Payments	Single-payment scheme, Complementary Direct Payments, Indirect through FIT	Complementary Direct Payments to grasses, No payment to short rotation coppices	Indirect support through FIT for biomass CHP	Support through FIT	Support through FIT	Support through FIT	Support through FIT
Farming Tradition	-	Moderate impact	High impact	Low impact	Moderate impact	High impact	High impact	Low impact
Acceptance	-	-	-	-	-	-	-	-

port for RES, shows that such system imposes high costs to society and show little long-term promise for stimulating the economy, protecting the environment, or increasing energy security. Therefore, the incentive measures need to be amended to ensure a long-term viable and cost-effective deployment of renewable energies.
The factors discussed in this section, which influence an investor's decision-making on land use for RES options in the Stuttgart Region, are summarized in Table 130.

7.5 Potential Renewable Energy-Mix in the PACA Region

In this section, the potential of different alternative energy sources were evaluated to provide a picture of a potential energy-mix that could mitigate conflicts about land use resources as well as risks of intrusion into ecological and socio-economic systems in Provence-Alpes-Côte d'Azur.

Unlike the Stuttgart region, for the most part PACA is not densely urbanized aside from a few cities, but the pressure on land use for biomass sources will strongly affect the food, fodder and industrial crop production mainly due to the region's agro-climatic and geological conditions. The agricultural land indicator in hectares per capita of 0.23 is low compared to 0.48 for France, but the rate of arable land at 0.05 hectares per capita is even more clearly below the national average of 0.3.

Due to the climatic conditions in the PACA region, cultivating crops for energy purposes has turned out to be unprofitable (Chailan, Bourgade et al. 2009). As mentioned above in chapter 4.4.2.2, there are no sugar beet plantations and cereals are exclusively grown for the food market due to high support payments. A small amount of oil seed crops is planted, however, mainly for producing vegetable oils. An assessment of historical land use changes indicates that the current pattern of crop production is likely to change, but as a consequence of the policy changes France is currently undergoing, food and fodder production is not likely to be replaced by biofuel production. The French authorities stated their intention to gradually abolish tax incentives for biofuels by 2012. The reason for this is the high oil prices, which make biofuel production more competitive, and in the face of rising food prices, the expansion of biofuel crops will only make this problem worse.

The development of perennial crops in the region faces several constraints related to plant adaptation to climate conditions or land availability. In southern France, increased perennial grass cropping could even contribute toward aggravating water scarcity problems, as an annual irrigation of 300 mm would be required to obtain a full yield in these agro-climatic conditions, compared to 50 mm of irrigation per year required in the Polish case study region (Dworak, Elbersen et al. 2009). Hence, the trial plantations have failed so far.

Taking into account economies of scale, the biogas potential in Provence-Alpes-Côte d'Azur could mostly be exploited in the three departments of Bouches-du-Rhône, Hautes-Alpes and Alpes-de-Haute-Provence (see chapter 4.4.2.1). However, the manure recovery factor throughout the entire year is very low, as the majority of the animal livestock population consists of sheep and cattle grazed at altitude in the mountains (Chailan, Bourgade et al. 2009). Therefore, the stable and constant supply of biogas fuel can only be ensured by biowaste and energy crops. In the PACA region, the area of permanent pasture, which is almost twice as large as the arable land, could successfully supplement the biogas feedstock without causing any pressure on current land production. The assessment shows that maize silage or other cereals as co-substrates barely qualify as supplements owing to the low quantity produced and the high costs of crops production. On the other hand, the call for increasing FIT payments for biogas production in the German model postulated by the Association of French Agricultural Biogas Producers would cover the acquisition costs of maize silage with a high profit surplus (Klinkert 2010).

In the case of biomass, the major role in increasing bioenergy generation is assigned to wood due to the considerable potential of forest reserves (Peker 2008; Ninon, Guibaud et al. 2009). Considering only wood residues from forests as studied by Levesque, Vallet et al. (2007), the technical potential would be around 333 GWh as outlined in Table 131. In addition, given the dense distribution of orchards and vineyards, by-products from clearing management make their potential for bioenergy generation on a local scale worth considering, as explored in chapter 4.4.3. Nonetheless, the net

Table 131: Summary of RES Potential and the Development Constraints in the PACA Region

Wood				
Origin:	Quantity [t]	Energy [GWh]	Constraints	Outlook
Forests	80000	333	Used in wood-related manufacture and heating boilers	Future potential at higher level
Orchards	85676	190	Logistic constraints, supply inconstancy in space and time,decreasing area	
Vineyards	162960	362		
Straw				
Cereal's Residues	119179	463	Logistic constraints	Potential at lower level
Biogas				
Origin:	Methane $[Mm^3]$	Area [ha*]	Constraints	Outlook
Manure	12		Low FIT to enhance the development, Acceptability	Animal population decline and low manure recovery factor
Manure and 40% Co-Substrates	31	8257 - grassland, 5161 - maize		
Solar				
Sites:	Area [ha]	Energy [GWh]	Constraints	Outlook
Roof Area	-	1520	Focus on new buildings (higher FIT for BIPV)	Rapid growth until revision of FIT mechanism
Favorable Sites	18828	8158	Town Planning Code Acceptability	Lower growth due to authorization barriers
Along Carriageways	Local assessment required			
Wind				
Sites with No Constraints	65867 - 85511	16467 - 22990	Vicinity to power lines, maintenance of landscape beauty, Acceptability	Low potential due to ecological and landscape restrictions
Sites under Low Protection	3064 - 6445	765 - 1587		

explored amount of cuttings (552 GWh) and cereal harvest residues in PACA are subject to the same constraints as those outlined in the previous case study regions.

With respect to the geo-climatic conditions of Provence-Alpes-Côte d'Azur, the findings of this thesis show that high energy production efficiency can be achieved through wind and solar power development and obviously by encouraging the development of hydro power that is beyond the scope of the present study. The French support system promotes a synergy effect related to PV systems which are integrated from the very beginning into the development of building projects, thus reducing material and energy consumption. The very high FIT even for simple BIPV projects up to 250 kWh was introduced to reduce investments in stand-alone solar park projects. However, for land users who either do not encounter conditions enabling rooftop energy technologies to be installed or who face unsuitable agro-climatic conditions, large-scale photovoltaic plants present an attractive income option compared to crop production. In fact, the economic assessment reveals that high energy yields and FIT payments guaranteed over 20 years can make ground-mounted solar parks more profitable than wind energy farms (compare chapters 5.4.4 and 6.5.4). In addition, unlike wind energy installations whose construction is restricted to ZDE sites, the current support policy does not impose any constraints on setting up ground-based photovoltaic facilities on arable land. As the reduction of arable land is crucial issue associated with projects like this would more be hindered during the authorization process and meet the resistance of local communities. The siting assessment for wind and solar parks carried out in the previous sections (see chapters 5.4.2 and 6.5.3) indicate the strong restriction related mostly to environmental constraints on wind

```
if ((Wind_no_constraints =  Y and PV_unsuitable = Y),
    Wind-NC,
    if ((PV_L-F-roads =Y or PV_NP-F-roads = Y),
        PV-F-roads,
        if ((Wind_no_constraints = Y  and PV NP-Favorable =Y),
            Wind-NC and PV-NP-Favorable,
            if ((Wind_no_constraints = Y and PV L-Favorable =Y),
                Wind-NC and PV-L-Favorable,
                if ((Wind_low_prot  = Y  and PV L-Favorable =Y),
                    Wind-L and PV-L-Favorable,
                    if (((PV NP-Favorable = Y, PV L-Favorable =Y),
                        PV-Favorable,
                        if ((Wind_no_constraints = Y and  PV NP-suitable=Y),
                            Wind-NC and PV-NP,
                            if ((Wind_no_constraints = Y and  PV L-suitable=Y),
                                Wind-NC preferred against PV-L,
                                if ((Wind_low_prot  = Y and  PV NP-suitable=Y),
                                    Wind-L and PV-NP,
                                    if ((Wind_low_prot  = Y and  PV L-Suitable=Y),
                                        Wind-L and PV-L,
                                        if (((PV N-P-Suitable = Y),
                                            PV-NP,
                                            if (((PV L-Suitable = Y)
                                                PV-L,
                                                if (((Wind_no_constraints=Y),
                                                    Wind-NC preferred against PV,
                                                    if ((Wind_low_prot = Y),
                                                    Wind-L preferred against PV, Other sites)))))))))))))))
```

(67)

and solar development in Provence-Alpes-Côte d'Azur. The following assessment allows sites to be identified where potential conflicts between wind power zones and potential sites for solar parks may appear. To facilitate the sustainable development of both energy options, future wind power zones should be located on sites unsuitable for solar free-standing plants, as explored in chapter 6.5.3. Moreover, due to a lack of data on arable land quality, the wind zones (Wind-L preferred against PV) were prioritized over PV suitable sites, which indicate potential locations on arable land. The site classification for both wind and solar power development was carried out in the Map Algebra according formula 67. The area of sites is displayed in Table 132. Sites classified as Wind-NC indicates a potential location without constraints for wind development, but the sites are not suitable for solar parks, PV-F-roads points out sites favorable for photovoltaic plants siting alongside motorways outside of nature protection restrictions or within areas under low protection constraints, PV-Favorable indicates favorable sites found on dump sites, mineral extraction sites, bare rocks, sparsely vegetated areas and burnt areas, Wind-NC and PV-NP-Favorable point out areas suitable for development of both competing energy sources, as no constraints assigned to wind farms were identified, and those locations are also favored for solar park siting, Wind-NC and PV-L-Favorable means similar conditions for both sources as previous ones with one exception for solar park siting - the favorable sites are located within areas under a low level of nature conservation restrictions, Wind-L and PV-L-Favorable indicates sites under a low level of nature conservation restrictions assigned to both wind and solar power farms, Wind-NC and PV-NP points out areas suitable for development of both competing energy sources located outside of nature conservation areas, Wind-NC preferred against PV-L means locations with no constraints assigned to wind farms that should be preferred against solar park siting, as these sites are located on arable land under a low level of nature conservation restrictions, Wind-L and PV-L indicates sites located on arable land under low level of nature conservation restrictions assigned to both wind and

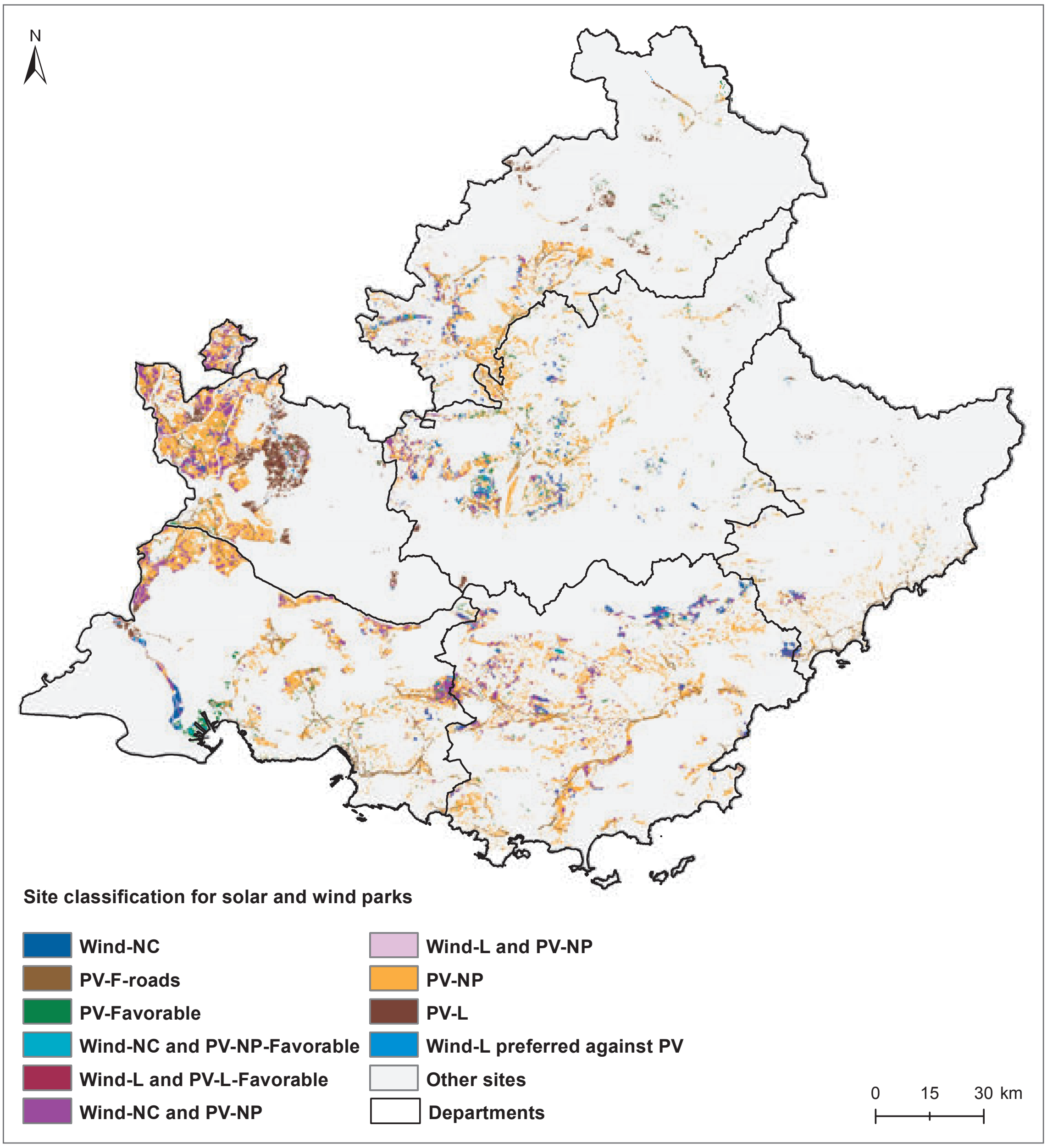
Table 132: Site Classification for PV Ground-Mounted Systems and Wind Park Development

Sites	Site Classification	Area [ha]	Share [%]
1	Wind-NC	19000	0.6
2	PV-F-roads	24684	0.8
3	PV-Favorable	16328	0.5
4	Wind-NC and PV-NP-Favorable	3655	0.1
5	Wind-NC and PV-L-Favorable	0	0
6	Wind-L and PV-L-Favorable	61	0.0
7	Wind-NC and PV-NP	43210	1.4
8	Wind-NC preferred against PV-L	0	0
9	Wind-L and PV-NP	2055	0.1
10	Wind-L and PV-L	0	0
11	PV-NP	191554	6.0
12	PV-L	19760	0.6
13	Wind-NC preferred against PV	0	0
14	Wind-L preferred against PV	948	0.0
15	Other sites	2848950	89.9

solar power farms, PV-NP are sites suitable for PV systems located outside of nature protection areas, PV-L are sites under la ow level of nature conservation restrictions suitable only for PV plant siting, Wind-NC and PV and Wind-L and PV mean sites with no constraints or under low level of nature protection restrictions for wind farm, which should be favored instead of large solar parks.

Sites characterized as possible areas of conflict (Wind-NC and PV-NP-Favorable, Wind-L and PV-L-Favorable, Wind-NC and PV-NP) are related to locations favorable for PV system siting, which were explored on land with a low productivity based on CLC land use classification (see Appendix 21). The sites for PV systems that may mitigate land use conflicts are PV-F-roads and PV-Favorable. However, land users have so far had free choice allowing them to install PV modules on locations explored as suitable outside nature conservation areas and conditionally permissible within areas under low nature protection (PV-L and PV-NP). The area qualified as PV-NP makes up 6% of the region's total surface, but 86% of arable land and 20% of agricultural land.

The study demonstrates various risks related to the expansion of alternative energy sources in the French region and indicates that a sustainable RES-mix development is not fully secure on a legal basis, since the scope of action left for investors allows them to install PV plants on cropland primarily intended for conventional crops. On the other hand, the social acceptability of large ground-based solar farms might be more problematic (Chiabrando, Fabrizio et al. 2009). In France, a social factor can be powerful barrier to erection of solar and wind parks being associated with fragmentation of the countryside and visual impact on landscape (Jobert, Laborgne et al. 2007; Nadaï 2007; Nadaï and Labussière 2009). In addition, the French public is accustomed to having a central energy supply. Therefore, a local renewable energy development can not only base on technocratic scientific and political decision-making. The successful RES deployment requires participation and integration of all involved actors at the different stages of planning, realization and operation (Jobert, Laborgne et al. 2007). The summary of above-mentioned local factors on which land users are expected to make investment choices are presented in Table 133.



Map 108: Site Classification for Solar and Wind Park Development in the PACA Region

Table 133: Selected Site Factors Influencing Development and Utilization of RES and Conventional Crops Production in the PACA Region

Factors	Conventional Crops	Annual Energy Crops	Perennial Energy Cops	Crop By-Products	Animal Waste (Biogas)	Wind Turbines	Ground-Mounted PV Systems	Rooftop PV Systems
Nature Conservation	Not restricted	Mitigation of risk related to areas of high biodiversity	Mitigation of risk related to areas of high biodiversity	Restriction related to biomass plants	Restriction related to biogas plants	Restricted	Restricted	Not restricted
Landscape Conservation	Not restricted	Not restricted	Not restricted	Restriction related to biomass plants	Restriction related to biogas plants	Restricted	Restricted	Restricted on historical monuments
Arable Land Quality	Impact on the yield	Impact on the yield	Impact on the yield	Impact on the yield	-	-	No impact on solar yield, PV application not restricted	-
Energy Price	-				Feed-in tariffs	Feed-in tariffs		
Energy Costs	-					(Chapter 5.4.4)	(Chapter 6.5.4)	
Crop Purchase Price	-				-			
Gross Margin								
Demand for RES and Conventional Crops	Regulated due to policy measures	High Related to the national targets	Moderate Related to the national targets	High Related to the national targets	High Related to the national targets	Very high Related to the national targets	High Related to the national targets	Very High Related to the national targets
Policy Outlook	Single-payment scheme, Complementary Direct Payments	Single-payment scheme, Complementary Direct Payments, Indirect through FIT	Complementary Direct Payments	Indirect support through FIT to biomass CHP	Support through FIT	Support through FIT	Support through FIT	Support through FIT
Farming Tradition	-	Moderate impact	High impact	Low impact	Moderate impact	High impact	High impact	Low impact
Acceptance	-	-	-	-	-	-	-	-

8 Discussion and Recommendations

8.1 Conclusion

An expanded harnessing of renewable energy is inevitable on the way to reducing European countries' unbalanced energy supply reliance, to mitigate greenhouse gas emissions and the depletion of fossil resources. On the other hand, the transition from fossil fuels to renewable energy sources might come at considerable cost, as RES are inefficient in land use and energy production and thus may endanger the food security situation, affecting biodiversity goods and the beauty of the natural landscape. The limited availability of land as a production factor is a restraining element in the production of energy, food or other non-food goods. Accordingly the thesis explores not only the technical and economic potential of alternative energy production, but it contributes to a deeper understanding how different RES utilization options compete for the land resource with each other well as with other needs for land use. The thesis exposes also the role of the policy framework (including spatial and energy planning at a regional level) in balancing out the profit-motivated activities of investors and in dealing with the multi-functionality of land use.

The study's findings demonstrate that Polish investors have enjoyed the greatest freedom in decision-making on land usage across the three countries investigated, which might lead to spatial disorder due to uncontrolled spreading renewable energy production - wind power so far. In view of the favorable wind regime conditions and high biogas production potential in the Kujawsko-Pomorskie region, these two energy sources should be further promoted. Due to a high rate of agricultural land per capita in Kujawsko-Pomorskie compared to the whole country, the cultivation of other energy crops is unlikely to affect food supply independence over the medium-term. The solar energy option results in low efficiency in terms of land use due to a relatively low solar radiation. Eventually, if the high costs of generating solar energy are to be compensated by upcoming amended incentive measures, this might impose high costs on society. The formal quota support scheme has been cost-efficient from a social point of view but renewable energy sources have not achieved the desired and expected development. A successful expansion of RES in Poland requires consistent, effective and at least medium-term continuity of policies that provide certainty for investors.

For the Stuttgart region, the analyses demonstrate that wind and solar energy are on the path to balanced development following the revised German Renewable Energy Law (EEG 2010). However, bio-energy expansion might impose burdens on socio-economic and environmental systems, as has already happened in some regions due to the high financial incentives and an inadequate biogas-plant authorization framework provided by the respective laws. Although animal manure represents an attractive potential for the Stuttgart region, its sustainable exploitation must be managed in space and time to mitigate any increase of land rent prices, negative effects on the region's biodiversity and replacement of food production. Cultivating alternative energy crops would be paid for by a decrease in the food supply reliance. Thus, the focus in the Stuttgart region should be placed on harvesting solar energy through building-integrated systems and on conversion fields. These investment locations have already been enhanced by the amendment to German Renewable Energy Law (EEG 2010).

In Provence-Alpes-Côte d'Azur, the RES-mix is related to its favorable wind regime and solar radiation. The administrative barriers that have slowed down wind energy utilization can be mitigated through the establishment of preferential wind power zones. The sustainable development of solar energy is certainly facilitated by FIT mechanisms and authorization processes. However, since large shares of land in this region are characterized by low productivity, those preferential sites should be included into the Regional climate, air and energy plans to strengthen land use efficiency as well as synergy effects.

Three case studies show that the alternative energy-mix is highly site-dependent, based upon factors such as geographical latitude, the current pattern of land occupation, climate, soil quality, precipitation, wind regime and local administration policies. Therefore the transformation of national objectives onto regional and local levels requires a careful analysis, as demonstrated in the thesis. The work reveals that the development of a sustainable RES-mix in these three regions is not guaranteed under the current framework of legal instruments and support mechanisms established at the respective national levels.

8.2 Limitations of the Methodological Approach

The aim of the thesis was to provide instruments that would facilitate a preliminary assessment of the risks and rewards related to RES development at a regional level. A set of approaches was developed to support the regional planning process in a transparent way and to provide a better understanding of a region's specific wind, solar and biomass energy-mix, with particular regard to trade-offs concerning the land user's investment options. Furthermore, these tools can also be applied at the communal level to support local planning processes.

The secondary aim was to establish a uniform approach that would be based on equivalent data types (national and local statistics, digital layers) and thus potential outcomes could be compared at the European regional level. This objective has been not met due to the lack of comparable mapping schemes and the diverging quality and quantity of statistical and digital datasets in different EU member states. Owing to the confidentiality constraints in France and Germany, the assessment could not be carried out at a communal level. Moreover, in France and Poland, only out-of-date agricultural censuses were available for this work, so that the results for these two countries are insufficient to provide a consistent outlook on the respective land use patterns, energy crop production and animal population. Therefore the regional up-to-date statistics were constantly compared to local statistics to give an insight into the ongoing changes and errors in the estimation. Both countries are to publish new census data at the end of 2011.

Furthermore, CORINE Land Cover data (CLC 2006) was used in the three case studies because it provides a uniform mapping scheme of 44 classes of land cover. Nevertheless, this data is not free from errors associated with the uncertainty of heterogeneous classes due to its low resolution (1:100000) and the errors produced while digitizing the low-resolution satellite images. On the other hand, the CORINE project provides a substitute for the expensive Digital Landscape Model (ATKIS), which covers Germany at a scale of 1:10000, and the BD CARTO® database available for France at a scale of 1:50000.

Consistent digital data on soil characteristics and maps representing arable land quality was not available for any of the three study regions. The digital layers used in the Polish and German case studies to assess suitable sites for growing crops provide comparable classes on arable land quality, but in France such a data layer is unobtainable.

In addition, there is no exhaustive, official database for the location and power capacity of every RES installation that could serve as a reference for subsequent potential assessments. In Poland such data is not provided at a communal level, only at a county level. In Germany, the electric utility companies are obliged to publish information on RES energy producers. However, the locations of many installations are hard to geocode, as addresses outlined in the database are either related to energy operators or the location of RES installations. Moreover, not just datasets but also constraints derived from legal documents and support schemes affect the design and implementation of the techno-economic analyses. Under these conditions, a uniform approach cannot be developed.

The three case studies illustrate the impact associated with datasets on the quality and quantity of analysis. The results lead to differing perceptions on RES potential. For instance, the biogas assessment in Poland shows that a wide range of analyses can be carried out on the basis of data on animal population at the level of cities and villages. The highest potential uncertainty is caused by assumptions made at the county level in the Stuttgart region.

8.3 Limitations of the Study and Recommendations for Further Work

Regarding the scope of the study, the thesis focused on the main alternative energy sources, which are expected to contribute greatly to the energy supply. Their production and utilization is mutually exclusive and coupled with the land use resource.

The less-promising biomass resources, such as wood by-products from building materials and chemically treated wood from industrial by-products (e.g. from the furniture industry), were beyond the scope of this study. With respect to economies of scale, the potential of these biomass origins is rather limited. On the other hand, the potential of woody and waste residues from the wood and food processing industry as well as from material manufacturing were not taken into account due to a lack of data in the national statistics. Nonetheless, with respect to synergy effects, the sustainability of biomass exploitation requires bio-waste resources to be used first, before replacing the land intended for food production by energy crop production.

Hydro energy and geothermic energy sources were left out of the study because their investigation requires a local assessment being directly associated with an intrusion into nature. Moreover, neither of these alternative sources have such a direct effect on land use conflicts as the other RES considered in the thesis.

A number of key findings have been outlined in this report. However, a number of fields require further detailed work. Aspects that deserve more attention and require deeper analysis are, firstly, the potential of bio-waste resources that can be fed with manure to produce biogas, and secondly, building-associated solar installations.

Apart from the technocratic determinates, the social acceptance is a part of renewable energy implementation. The thesis looks at this process as investor's decision only, but the realizable RES potential is determined by social acceptance of any kind. This includes market acceptance, which is partly acceptance of investors, but acceptance by all relevant actors as well. The multi-faceted aspect of RES acceptability that becomes a key issue in the decision-making process requires a careful study.

It must thus be borne in mind that the methods and findings presented in the thesis can contribute to the policy and decision-making process, but these results alone do not suffice to take a decision on the appropriate RES-mix. The eventual decision emerges from a social discourse coloured by varying degrees of acceptance of alternative energy sources.

Appendixes

Appendix 1: Exemplary Polish Funding Sources Offered for RES Development in 2010

Programme	Action/ priority	Purpose	Investment Aid and Conditions
Infrastructure and Environment Operating Programme	Action 9.1 High efficiency energy generation	Construction and reconstruction of CHP that meet the requirements for high-efficiency cogeneration set out in directive 2004/8/WE	- min. value of 10 million PLN - max value of 30 million PLN - subsidy from 30% up to 70% of eligible costs
	Action 9.4 Generation of energy from renewable sources	- Projects for the construction or capacity increase of small hydro power stations up to 10 MW and units producing electrical energy from biomass or biogas	- min. value of 10 million PLN, - subsidy from 30% up to 70% of eligible costs but in total max value of 40 million PLN
		- Projects for the construction or capacity increase of units producing electrical energy using wind energy or solar and geothermal heat	- min value of 20 million PLN, - subsidy up to 70% of eligible costs but max value of 40 million PLN
National Fund for Environmental Protection and Water Management	National System of Green Investment	Projects for the construction units producing electricity from wind, biomass, solar and geothermal energy	- min. value of 10 million PLN, - subsidy up to 30 % of eligible costs - preferential loan on 45% of project values - 15 years of financing period
	Program for projects of the renewable energy and high efficiency of cogeneration		- loan of 75% of eligible costs of the project - min value of 10 million PLN - partial cancellation of the loan up to 50%, depending on the profitability of the project
Voivodship Environmental Protection and Water Management Funds		Generation of energy derived from renewable sources (e.g. biomass, solar, geothermal, wind energy)	- min value of 1 million PLN - max value of 10 million PLN - preferential loan of 75% of eligible costs with interest rate of 3%
Rural Development Programme	Action: Basic services for rural economy and population	Generation or distribution of energy derived from renewable sources (e.g. biomass, solar, geothermal, wind energy)	
Regional Operating Programme	Priority 2 Preservation and rational utilization of environment Measure 2.4. Environmentally friendly energy infrastructure	Construction, expansion, modification of units generated electricity and thermal energy based on hydro, biomass, biogas and geothermal energy and solar	subsidy up to 50% of eligible costs
Bank of Environmental Protection			loan of 80% of eligible costs of the project

Appendix 2: Feed-in Tariffs and Bonuses for Electricity Production from Biomass and Biogas in Germany in 2010

Base feed-in-tariffs	€ct/kWh
Installations <= 150 kWel	11.55
Installations > 150 kWel and <= 500 kWel	9.09
Installations > 500 kWel and <= 5 MWel	8.17
Installations > 5 MWel and <= 20 MWel (only if cogeneration)	7.71
Installations > 20 MWel	No feed-in tariff
Increase of the feed-in tariffs for electricity from biogas installations subject to licensing in accordance with the Federal Immission Control Act, if the formaldehyde limits are complied with	+ 1.00
Bonuses	€ct/kWh
Technology bonus (>= 5 MWel)	
Innovative technology (e.g. fuel cell, Stirling motor, gas turbine, steam motor)	2.00
Biomethane production <= 350 m3/h	2.00
Biomethane production >350 m3/h and <= 700 Nm3/h	1.00
CHP bonus	
Only for electricity fed into the grid (<= 20 MWel)	3.00
Bonus for electricity from renewable sources (NaWaRo bonus)	
Installations <= 150 kWel	
Biomass without biogas	6.00
Biogas	7.00
Bioenergy with at least 30% manure used as feedstock	+ 4.00
Bioenergy with a majority of the feedstock coming from landscape management	+ 2.00
Installations > 150 kWel and <= 500 kWel	
Solid biomass	6.00
Liquid biomass (only for installations commissioned after the 01/01/2009)	0.00
Gaseous biomass (except biogas)	6.00
Biogas	7.00
Bioenergy with at least 30% manure used as feedstock	+ 1.00
Bioenergy with a majority of the feedstock coming from landscape management	+ 2.00
Installations > 500 kWel and <= 5 MWel	
Solid biomass	4.00
Liquid biomass (only for installations commissioned after the 01/01/2009)	0.00
Gaseous biomass	4.00
Wood combustion	2.50
Combustion of wood from short rotation coppice and landscape management	4.00
Degression on feed-in-tariffs and bonuses	%/year
From 01/01/2010	1.0
Duration	20 years

Source: EEG (2010)

Appendix 3: Summary of Feed-in Tariffs for Selected RES in France in 2010

Biomass	Combustion of Solid Biomass	4.5 €ct/kWh$_{el}$
	Optional Bonus	Between 8 and 13 €ct/kWh granted according to the power rating
Biogas	Cogeneration Rate	
	<=150 kW$_{el}$	9.8 €ct/kWh$_{el}$
	> 150 kWel <= 2 MW$_{el}$	9.8 to 8.2 €ct/kWh$_{el}$ (Linear interpolation)
	> 2 MW$_{el}$	8.2 €ct/kWh$_{el}$
	Methanisation bonus	2 €ct/kWh$_{el}$
	Total Overall Efficiency	(Valorization) in terms of heat and electricity that is sold and/or used
	Smaller Than 40%	No bonus
	Between 40% and 75%	0 - 3.3 €ct/kWh$_{el}$ (linear interpolation)
	Above 75%	3.3 €ct/kWh$_{el}$
Wind Onshore	During 10 Years	8.2 €ct/kWh$_{el}$
	During 5 Years	2.8 - 8.2 c€/kWh depending on the location‘s productivity
Wind Offshore	During 10 Years	13 €ct/kWh$_{el}$
	During 10 Years	3 - 13 €ct/kWh$_{el}$ depending on the location‘s productivity
Solar	Inland	
	BIPV on Recently Constructed* Residential Buildings, Schools, Health Facilities and Dwellings	58 €ct/kWhel (from 52 €ct)
	BIPV (on Other Recently Constructed Buildings)	50 €ct/kWhel (from 45 €ct)
	Simplified BIPV Integrated Into Constructions	42 €ct/kWhel (from 52 €ct)
	Ground-Mounted PV >250 kW (south)**	31.4 €ct/kWh$_{el}$ (from 32 €ct)
	Ground-Mounted PV >250 kW (north)	37.7 €ct/kWh$_{el}$ (32 €ct)

*“recently constructed” - in France current FiT legislation is applied to photovoltaic systems built in recent two years

**Ground-mounted photovoltaic projects larger than 250 kW are benchmarked at 31.4 €ct/kWh, and adjusted according to a regional multiplier that ranges from 1.0 to 1.2. This means that the tariff for ground-mounted projects reaches 37.68 €ct/kWh in the least-sunny areas of France.

Source: Order (2010a)

Appendix 4: Chemical Characteristic of Selected Biomass Feedstock

	Dry matter	Bulk density	Heating value
Feedstock	%	t_{fm}/m^3	MJ/kg_{fm}
Maize silage	35	0.35	-0.8
Liquid manure	6-11	1.2	18
Manure	20	0.84	
Straw	86	0.094	14.5
Straw square bale	86	0.15	14.5
Straw round bale	86	0.12	14.5
Wood chips fresh	65	0.4	7.4
Wood chips fresh	50	0.3	10.4
Industrial wood	75	-	12.8
Bio-residues	30	-	2.6

Source: Kappler (2008)

Appendix 5: Estimated Potential of the Energy Generated from Substrate-Mix, Total Annual Transport Costs of Manure from Animal Holdings (with at Least 100 LSU) to Selected Potential Sites for Biogas Plants in the Kujawsko-Pomorskie Region

Site	LSU	Liquid manure	Transport costs	Agricultural feedstock	Total methane	Total el. power	Electricity	Heat	Bio-methane
		m^3	k €	t_{fm} /y	ths m^3	kWe	MWh_e/y	MWh_{th}/y	MWh_e/y
1	2328	9374	10	3192	440	183	1465	2159	4271
2	3528	11428	19	4374	574	237	1959	2782	5563
3	2461	13395	15	3955	583	241	1995	2826	5657
4	2527	20355	28	5161	822	338	2907	3906	7971
5	4081	20807	17	6324	920	378	3290	4337	8920
6	7467	16978	15	8057	970	398	3490	4557	9413
7	8602	18064	30	9032	1067	438	3876	4974	10354
8	8663	20786	12	9528	1163	477	4257	5375	11277
9	9312	21654	22	10127	1226	503	4515	5641	11896
10	7367	27529	26	9745	1321	541	4901	6031	12817
11	9093	25867	39	10676	1357	556	5046	6176	13163
12	10182	24352	24	11186	1364	558	5074	6203	13229
13	4956	33574	38	9065	1397	572	5211	6338	13553
14	4877	35863	35	9391	1470	602	5511	6630	14262
15	11164	30038	15	12821	1608	658	6081	7170	15598
16	11716	34751	59	13993	1797	734	6870	7889	17426
17	6483	44611	80	11973	1851	757	6624	8092	17956
18	13951	33782	53	15396	1883	769	6748	8866	18262
19	13042	41417	64	16032	2092	855	7578	9768	20293
20	11375	45024	62	15467	2125	868	7710	9910	20615
21	12798	43082	41	16139	2135	872	7751	9953	20713
22	16742	37792	41	18018	2166	885	7875	10085	21015
23	15166	41402	76	17517	2205	900	8027	10247	21384
24	11488	47677	86	15988	2221	907	8092	10315	21542
25	16682	41972	66	18673	2304	941	8428	10667	22353
26	12092	50460	80	16874	2347	958	8599	10845	22765
27	16230	48577	87	19457	2503	1022	9231	11495	24283
28	17797	48531	60	20546	2585	1055	9564	11831	25076
29	16433	51448	83	20078	2611	1066	9669	11937	25328
30	17968	53009	79	21412	2745	1120	10218	12483	26631
31	18889	52200	97	21922	2767	1129	10307	12571	26842
32	17610	58781	92	22124	2921	1192	10940	13188	28337
33	26767	59418	113	28640	3430	1402	13055	15161	33270
34	25519	66688	77	28978	3609	1475	13806	15837	35007
35	26671	69137	113	30192	3753	1534	14413	16372	36403
36	25325	74220	122	30098	3853	1575	14836	16741	37374
37	34175	88033	107	38595	4790	1956	18099	21384	46464
38	36537	88152	127	40268	4920	2008	18639	21885	47721
39	43821	99172	52	47203	5679	2317	21826	24749	55088
40	43800	99999	75	47327	5706	2328	21939	24848	55348
41	40615	142949	265	52255	6987	2849	27412	29387	67773
Total	646300	1892345	2604	767801	98270	40155	367835	441611	495672

Appendix 6: Biogas Potential and Energy Production from Cattle and Pig Manure. Considered Animal Farm Hosing with at Least 100 Animal Population in the Kujawsko-Pomorskie Region

		Cattle farms	Cattle	Pig farms	Pigs	Methane	Gross energy	Electrical power	Electricity	Heat
Commune	County	No.	No.	No.	No.	m^3/y	MWh	kW	MWh	MWh
Aleksandrow Kujawski	aleksandrowski	0	0	10	1704	39	354	16	127	152
Aleksandrwo Kujawski	aleksandrowski	0	0	0	0	0	0	0	0	0
Badkowo	aleksandrowski	1	105	34	9791	241	2211	100	796	951
Barcin	zninski	6	874	16	2632	222	2036	92	733	875
Bartniczka	brodnicki	2	241	60	15460	395	3620	163	1303	1557
Baruchowo	wloclawski	0	0	3	438	10	91	4	33	39
Biale Blota	bydgoski	0	0	1	110	2	23	1	8	10
Bobrowniki	lipnowski	0	0	3	1915	43	398	18	143	171
Bobrowo	brodnicki	5	708	67	14456	459	4208	189	1515	1809
Boniewo	wloclawski	0	0	4	1032	23	214	10	77	92
Brodnica	brodnicki	0	0	2	310	7	64	3	23	28
Brodnica	brodnicki	3	1339	50	13128	546	5007	225	1803	2153
Brzesc Kujawski	wloclawski	1	126	12	2089	71	648	29	233	279
Brzozie	brodnicki	2	284	49	14902	390	3578	161	1288	1538
Brzuze	rypinski	6	786	27	6512	294	2691	121	969	1157
Bukowiec	swiecki	2	526	66	15203	442	4052	182	1459	1743
Bydgoszcz	m. Bydgoszcz	1	189	4	7225	199	1822	82	656	783
Byton	radziejewski	1	195	3	515	48	439	20	158	189
Cekcyn	tucholski	0	0	7	1511	34	314	14	113	135
Chelmno	chelminski	0	0	1	132	3	27	1	10	12
Chelmno	chelminski	3	522	22	7176	259	2379	107	857	1023
Chelmza	torunski	0	0	0	0	0	0	0	0	0
Chelmza	torunski	4	1336	60	15949	609	5588	251	2012	2403
Chocen	wloclawski	1	179	6	2713	95	868	39	313	373
Chodecz	wloclawski	1	509	9	9855	318	2913	131	1049	1253
Chrostkowo	lipnowski	2	218	9	2174	90	823	37	296	354
Ciechocin	golubsko-dobrzynski	5	559	45	9080	309	2838	128	1022	1220
Ciechocinek	aleksandrowski	0	0	0	0	0	0	0	0	0
Czernikowo	torunski	3	371	20	3461	147	1351	61	486	581
Dabrowa	mogilenski	1	108	49	9103	226	2074	93	747	892
Dabrowa Biskupia	inowroclawskie	2	1151	15	32435	948	8695	391	3130	3739
Debowa Laka	wabrzezno	3	486	47	16878	472	4332	195	1560	1863
Dobrcz	bydgoski	5	1080	54	18526	620	5686	256	2047	2445
Dobre	radziejewski	2	247	12	2807	109	1004	45	361	432

Commune	County	Cattle farms No.	Cattle No.	Pig farms No.	Pigs No.	Methane m^3/y	Gross energy MWh	Electrical power kW	Electricity MWh	Heat MWh
Dobrzyn n. Wisla	lipnowski	0	0	5	8878	201	1843	83	663	792
Drgacz	swiecki	1	266	3	354	57	527	24	190	227
Drzycicn	swiecki	3	394	49	15488	424	3887	175	1399	1671
Fabianki	wloclawski	0	0	4	686	16	142	6	51	61
Gasowa	zninski	2	280	45	21309	534	4901	221	1764	2107
Gniewkowo	inowroclawskie	5	1327	30	12549	531	4867	219	1752	2093
Golub Dobrzyn	golubsko-dobrzynski	0	0	3	503	11	104	5	38	45
Golub Dobrzyn	golubsko-dobrzynski	1	119	62	17003	407	3732	168	1344	1605
Gorzno	brodnicki	3	345	37	22358	570	5229	235	1883	2249
Gostycyn	tucholski	3	1192	44	9650	440	4035	182	1453	1735
Grudziadz	grudziacki	0	0	11	8399	190	1744	78	628	750
Gruta	grudziacki	2	778	38	10749	388	3557	160	1281	1530
Inowrcolaw	inowroclawskie	0	0	3	463	10	96	4	35	41
Inowroclaw	inowroclawskie	4	661	18	6803	277	2539	114	914	1092
Izbica Kujawska	wloclawski	5	910	24	5990	305	2794	126	1006	1202
Jablonowo Pomorskie	brodnicki	5	782	47	15137	488	4475	201	1611	1924
Janikowo	inowroclawskie	2	302	14	2877	121	1112	50	400	478
Janowiec Wielkopolski	zninski	2	643	102	56059	1389	12733	573	4584	5475
Jeziora Wielkie	mogilenski	2	222	19	4559	144	1325	60	477	570
Jezowo	swiecki	3	454	24	15782	442	4050	182	1458	1741
Kamien Krajenski	sepolinski	1	328	35	7351	227	2085	94	751	897
Kcynia	nakielski	10	2616	48	31357	1196	10968	494	3948	4716
Kesowo	tucholski	6	1289	31	15349	587	5383	242	1938	2315
Kijewo Krolewskie	chelminski	3	473	17	2676	148	1362	61	490	586
Kikol	lipnowski	4	498	16	2542	150	1376	62	496	592
Koneck	aleksandrowski	1	125	10	2479	79	728	33	262	313
Koronowo	bydgoski	4	677	122	35824	937	8591	387	3093	3694
Kowal	wloclawski	0	0	0	0	0	0	0	0	0
Kowal	wloclawski	0	0	4	541	12	112	5	40	48
Kowalewo Pomorskie	golubsko-dobrzynski	5	600	70	16065	475	4358	196	1569	1874
Kruszwica	inowroclawskie	13	5949	42	18527	1525	13985	629	5035	6014
Ksiazki	wabrzezno	3	400	22	8514	267	2449	110	882	1053
Labiszyn	zninski	4	1173	25	5751	348	3193	144	1149	1373
Lasin	grudziacki	2	572	57	16052	470	4307	194	1551	1852

		Cattle farms	Cattle	Pig farms	Pigs	Methane	Gross energy	Electrical power	Electricity	Heat
Commune	County	No.	No.	No.	No.	m^3/y	MWh	kW	MWh	MWh
Lipno	lipnowski	0	0	0	0	0	0	0	0	0
Lipno	lipnowski	1	105	15	3280	94	860	39	310	370
Lisewo	chelminski	0	0	32	9726	220	2019	91	727	868
Lniano	swiecki	1	104	38	7521	190	1739	78	626	748
Lubanie	wloclawski	1	100	10	2413	73	671	30	242	289
Lubianka	torunski	3	1155	33	11057	465	4264	192	1535	1833
Lubicz	torunski	1	324	32	12910	352	3232	145	1164	1390
Lubien Kujawski	wloclawski	2	258	21	5398	170	1560	70	562	671
Lubiewo	tucholski	0	0	29	5748	130	1193	54	430	513
Lubraniec	wloclawski	1	131	32	6352	168	1542	69	555	663
Lysomice	torunski	0	0	18	4393	99	912	41	328	392
m. Grudziadz	grudziacki	0	0	5	10634	241	2208	99	795	949
Mogilno	mogilenski	9	2065	130	36259	1205	11046	497	3977	4750
Mrocza	nakielski	4	1190	31	14004	538	4935	222	1777	2122
Naklo nad Notecia	nakielski	7	2083	23	5176	504	4625	208	1665	1989
Nieszawa	aleksandrowski	0	0	1	209	5	43	2	16	19
Nowa Wies Wielka	bydgoski	0	0	2	428	10	89	4	32	38
Nowe	swiecki	3	514	12	3342	171	1570	71	565	675
Obrowo	torunski	5	549	42	12455	384	3521	158	1268	1514
Osie	swiecki	0	0	22	4811	109	999	45	360	429
Osieciny	radziejewski	6	1876	20	31526	1062	9742	438	3507	4189
Osiek	brodnicki	1	115	32	8970	224	2058	93	741	885
Osielsko	bydgoski	0	0	2	1018	23	211	10	76	91
Pakosc	inowroclawskie	3	628	5	2546	174	1599	72	576	687
Papwo Biskupie	chelminski	0	0	30	7148	162	1484	67	534	638
Piotrkow Kujawski	radziejewski	9	1432	8	9499	481	4412	199	1588	1897
Pluznica	wabrzezno	5	950	41	13343	479	4389	198	1580	1887
Pruszcz	swiecki	2	326	137	34429	840	7703	347	2773	3312
Raciazek	aleksandrowski	1	102	7	1204	46	424	19	153	0
Radomin	golubsko-dobrzynski	4	430	50	14821	415	3810	171	1371	1638
Radziejow	radziejewski	0	0	0	0	0	0	0	0	0
Radziejow	radziejewski	2	309	12	1667	95	873	39	314	375
Radzyn Chelminski	grudziacki	3	316	25	6436	204	1875	84	675	806
Rogowo	rypinski	1	102	10	4619	124	1133	51	408	487
Rogowo	zninski	3	1025	56	23964	733	6722	302	2420	2890
Rogozno	grudziacki	1	104	23	12667	306	2807	126	1010	1207

Commune	County	Cattle farms No.	Cattle No.	Pig farms No.	Pigs No.	Methane m^3/y	Gross energy MWh	Electrical power kW	Electricity MWh	Heat MWh
Rojewo	inowroclawskie	3	426	15	5443	202	1856	84	668	798
Rypin	rypinski	0	0	7	5045	114	1047	47	377	450
Rypin	rypinski	6	1145	38	13727	524	4801	216	1728	2064
Sadki	nakielski	7	3014	20	3789	646	5923	267	2132	2547
Sepolno Krajenskie	sepolinski	8	1316	60	17909	650	5961	268	2146	2563
Sicienko	bydgoski	5	1612	48	10574	539	4942	222	1779	2125
Skepe	lipnowski	1	128	1	154	27	250	11	90	108
Skrwilno	rypinski	3	383	11	3027	140	1281	58	461	551
Sliwice	tucholski	1	105	1	130	22	206	9	74	89
Solec Kujawski	bydgoski	0	0	4	1071	24	222	10	80	96
Sosno	sepolinski	4	551	44	10738	345	3168	143	1141	1362
Stolno	chelminski	1	145	23	4480	128	1177	53	424	506
Strzelno	mogilenski	3	635	24	10844	364	3333	150	1200	1433
Swiece nad Osa	grudziacki	4	1274	31	15177	580	5322	239	1916	2288
Swiecie	swiecki	0	0	57	49796	1127	10337	465	3721	4445
Swiedziebnia	brodnicki	3	346	17	4293	161	1481	67	533	637
Swiekatowo	swiecki	3	453	37	9387	297	2721	122	979	1170
Szubin	nakielski	9	1773	42	9371	542	4967	224	1788	2136
Tluchowo	lipnowski	1	110	5	1108	46	417	19	150	180
Topolka	radziejewski	2	320	14	36793	892	8183	368	2946	3519
Torun	m. Torun	0	0	2	15665	355	3252	146	1171	1398
Tuchola	tucholski	2	643	26	10391	355	3253	146	1171	1399
Unislaw	chelminski	2	369	8	2132	117	1071	48	386	461
Wabrzezno	wabrzezno	0	0	2	560	13	116	5	42	50
Wabrzezno	wabrzezno	3	509	64	21242	575	5277	237	1900	2269
Waganiec	aleksandrowski	1	281	7	2989	120	1099	49	396	473
Wapielsk	rypinski	2	300	32	12308	334	3066	138	1104	1319
Warlubie	swiecki	0	0	29	5993	136	1244	56	448	535
Wiecborg	sepolinski	3	463	71	22273	590	5413	244	1949	2327
Wielgie	lipnowski	2	366	6	1282	97	890	40	320	383
Wielka Nieszawka	torunski	0	0	0	0	0	0	0	0	0
Wloclawek	wloclawski	1	337	5	980	85	778	35	280	334
Wloclawek	m. Wloclawek	0	0	0	0	0	0	0	0	0
Zakrzewo	aleksandrowski	5	980	14	3672	265	2432	109	876	1046
Zbiczno	brodnicki	2	220	21	5101	156	1434	65	516	617
Zbojno	golubsko-dobrzynski	0	0	16	5699	129	1183	53	426	509
Zlawies Wielka	torunski	2	511	30	6068	232	2131	96	767	916
Zlotniki Kujawskie	inowroclawskie	2	500	24	13513	399	3657	165	1317	1573

Commune	County	Cattle farms No.	Cattle No.	Pig farms No.	Pigs No.	Methane m^3/y	Gross energy MWh	Electrical power kW	Electricity MWh	Heat MWh
Znin	zninski	10	2686	111	30450	1189	10899	490	3924	4687
Total		343	74124	3807	1342467	44167	405013	18226	145805	173973

Appendix 7: Biogas Potential and Energy Production from Co-Substrates Mix of 15% DM (Animal Manure and Energy Crops). Considered Animal Holdings with at least 100 Animal Population in the Kujawsko-Pomorskie Region

		Co-substrate (15% DM)	Total methane	Gross energy production	Total electrical power	Total electricity	Total heat	Area required for energy crops	Share in arable land
Commune	County	t /y	Mm^3	MWh	kW	MWh	MWh	ha	%
Aleksandrow Kujawski	aleksandrowski	1789	207	2248	101	809	967	51	0.6
Aleksandrwo Kujawski	aleksandrowski	0	0	0	0	0	0	0	0.0
Badkowo	aleksandrowski	10564	1233	13521	608	4867	5814	302	4.1
Barcin	zninski	5123	703	8484	382	3054	3648	146	1.8
Bartniczka	brodnicki	16884	1980	21780	980	7841	9365	482	9.4
Baruchowo	wloclawski	460	53	578	26	208	249	13	0.3
Biale Blota	bydgoski	116	13	145	7	52	62	3	0.2
Bobrowniki	lipnowski	2011	232	2527	114	910	1086	57	2.0
Bobrowo	brodnicki	17090	2064	23133	1041	8328	9947	488	4.5
Boniewo	wloclawski	1084	125	1362	61	490	586	31	0.5
Brodnica	brodnicki	326	38	409	18	147	176	9	1.4
Brodnica	brodnicki	17400	2180	24999	1125	9000	10750	497	6.4
Brzesc Kujawski	wloclawski	2534	309	3479	157	1252	1496	72	0.7
Brzozie	brodnicki	16414	1932	21291	958	7665	9155	469	7.9
Brzuze	rypinski	8960	1135	13099	589	4716	5633	256	4.0
Bukowiec	swiecki	17383	2074	23075	1038	8307	9922	497	6.4
Bydgoszcz	m. Bydgoszcz	8097	959	10617	478	3822	4565	231	9.2
Byton	radziejewski	1067	148	1798	81	647	773	30	0.5
Cekcyn	tucholski	1587	183	1994	90	718	857	45	1.1
Chelmno	chelminski	139	16	174	8	63	75	4	0.8
Chelmno	chelminski	8944	1099	12461	561	4486	5358	256	4.7
Chelmza	torunski	0	0	0	0	0	0	0	0.0
Chelmza	torunski	20354	2521	28704	1292	10333	12343	582	3.8
Chocen	wloclawski	3332	408	4606	207	1658	1981	95	1.2
Chodecz	wloclawski	11722	1419	15921	716	5732	6846	335	3.7
Chrostkowo	lipnowski	2871	359	4118	185	1483	1771	82	1.5
Ciechocin	golubsko-dobrzynski	11043	1347	15186	683	5467	6530	316	6.2
Ciechocinek	aleksandrowski	0	0	0	0	0	0	0	0.0
Czernikowo	torunski	4636	583	6694	301	2410	2878	132	1.9
Dabrowa	mogilenski	9850	1151	12630	568	4547	5431	281	3.6
Dabrowa Biskupia	inowroclawskie	37164	4438	49395	2223	17782	21240	1062	11.3
Dabrowa Chelminska	bydgoski	2671	362	4330	195	1559	1862	76	2.0
Debowa Laka	wabrzezno	19034	2260	25056	1128	9020	10774	544	8.2
Dobrcz	bydgoski	22368	2721	30636	1379	11029	13174	639	6.6
Dobre	radziejewski	3614	449	5120	230	1843	2202	103	1.8
Dobrzyn nad Wisla	lipnowski	9322	1076	11714	527	4217	5037	266	3.1
Drgacz	swiecki	1090	160	1992	90	717	857	31	0.7
Drzycicn	swiecki	17326	2051	22694	1021	8170	9759	495	8.3
Fabianki	wloclawski	720	83	905	41	326	389	21	0.5

		Co-substrate (15% DM)	Total methane	Gross energy production	Total electrical power	Total electricity	Total heat	Area required for energy crops	Share in arable land
Commune	County	t/y	Mm³	MWh	kW	MWh	MWh	ha	%
Gasowa	zninski	23130	2707	29721	1337	10700	12780	661	8.5
Gniewkowo	inowroclawskie	16759	2105	24166	1087	8700	10391	479	4.6
Golub Dobrzyn	golubsko-dobrzynski	528	61	664	30	239	285	15	5.4
Golub Dobrzyn	golubsko-dobrzynski	18174	2114	23117	1040	8322	9940	519	4.9
Gorzno	brodnicki	24407	2862	31478	1417	11332	13536	697	16.0
Gostycyn	tucholski	13351	1694	19567	881	7044	8414	381	4.9
Grudziadz	grudziacki	8819	1018	11082	499	3989	4765	252	3.2
Gruta	grudziacki	13387	1645	18643	839	6712	8017	382	4.2
Inowrcolaw	inowroclawskie	486	56	611	27	220	263	14	1.1
Inowroclaw	inowroclawskie	8928	1115	12766	574	4596	5489	255	2.0
Izbica Kujawska	wloclawski	8747	1126	13121	590	4724	5642	250	2.6
Jablonowo Pomorskie	brodnicki	18005	2179	24456	1101	8804	10516	514	5.5
Janikowo	inowroclawskie	3836	482	5528	249	1990	2377	110	1.5
Janowiec Wielkopolski	zninski	60598	7080	77653	3494	27955	33391	1731	17.4
Jeziora Wielkie	mogilenski	5386	650	7288	328	2624	3134	154	2.1
Jezowo	swiecki	17797	2113	23426	1054	8433	10073	508	10.8
Kamien Krajenski	sepolinski	8604	1035	11580	521	4169	4979	246	2.3
Kcynia	nakielski	39988	4951	56373	2537	20294	24240	1143	7.0
Kesowo	tucholski	19597	2427	27643	1244	9951	11886	560	7.8
Kijewo Krolewskie	chelminski	4087	532	6243	281	2247	2684	117	1.9
Kikol	lipnowski	4014	527	6209	279	2235	2670	115	1.5
Koneck	aleksandrowski	2940	355	3988	179	1436	1715	84	1.6
Koronowo	bydgoski	39443	4641	51149	2302	18414	21994	1127	5.4
Kowal	wloclawski	0	0	0	0	0	0	0	0.0
Kowal	wloclawski	568	66	714	32	257	307	16	0.2
Kowalewo Pomorskie	golubsko-dobrzynski	18488	2211	24637	1109	8869	10594	528	4.8
Kruszwica	inowroclawskie	35516	4860	58555	2635	21080	25179	1015	5.5
Ksiazki	wabrzezno	10020	1208	13527	609	4870	5817	286	4.4
Labiszyn	zninski	9206	1213	14314	644	5153	6155	263	3.8
Lasin	grudziacki	18399	2198	24459	1101	8805	10517	526	5.0
Lipno	lipnowski	0	0	0	0	0	0	0	0.0
Lipno	lipnowski	3728	444	4930	222	1775	2120	107	0.9
Lisewo	chelminski	10212	1179	12833	577	4620	5518	292	4.1
Lniano	swiecki	8178	958	10520	473	3787	4523	234	5.2
Lubanie	wloclawski	2804	337	3757	169	1353	1616	80	1.8
Lubianka	torunski	14728	1848	21211	955	7636	9121	421	5.9

		Co-substrate (15% DM)	Total methane	Gross energy production	Total electrical power	Total electricity	Total heat	Area required for energy crops	Share in arable land
Commune	County	t /y	Mm^3	MWh	kW	MWh	MWh	ha	%
Lubicz	torunski	14430	1708	18892	850	6801	8123	412	6.7
Lubien Kujawski	wloclawski	6365	768	8602	387	3097	3699	182	1.6
Lubiewo	tucholski	6035	697	7584	341	2730	3261	172	2.6
Lubraniec	wloclawski	7023	828	9132	411	3288	3927	201	1.7
Lysomice	torunski	4613	533	5796	261	2087	2492	132	1.6
m. Grudziadz	grudziacki	11166	1289	14031	631	5051	6033	319	21.6
mogilno	mogilenski	43647	5304	59681	2686	21485	25663	1247	6.3
Mrocza	nakielski	17917	2221	25300	1139	9108	10879	512	5.0
Naklo nad Notecia	nakielski	11059	1543	18773	845	6758	8072	316	3.6
Nieszawa	aleksandrowski	219	25	276	12	99	119	6	1.1
Nowa Wies Wielka	bydgoski	449	52	565	25	203	243	13	0.7
Nowe	swiecki	4897	631	7357	331	2648	3163	140	2.8
Obrowo	torunski	14560	1751	19581	881	7049	8420	416	5.3
Osie	swiecki	5052	583	6348	286	2285	2730	144	4.3
Osieciny	radziejewski	38168	4647	52353	2356	18847	22512	1091	10.4
Osiek	brodnicki	9729	1138	12495	562	4498	5373	278	5.0
Osielsko	bydgoski	1069	123	1343	60	484	578	31	1.1
Pakosc	inowroclawskie	4369	585	6960	313	2506	2993	125	2.2
Papwo Biskupie	chelminski	7505	867	9431	424	3395	4055	214	3.4
Piotrkow Kujawski	radziejewski	13840	1781	20744	933	7468	8920	395	3.7
Pluznica	wabrzezno	16575	2035	23052	1037	8299	9912	474	4.9
Pruszcz	swiecki	37031	4318	47296	2128	17026	20337	1058	9.5
Raciazek	aleksandrowski	1540	191	2173	98	782	935	44	1.8
Radomin	golubsko-dobrzynski	16723	1986	22021	991	7927	9469	478	7.3
Radziejow	radziejewski	0	0	0	0	0	0	0	0.0
Radziejow	radziejewski	2585	338	3971	179	1430	1708	74	0.9
Radzyn Chelminski	grudziacki	7611	919	10304	464	3709	4431	217	2.9
Rogowo	rypinski	5125	605	6679	301	2405	2872	146	2.4
Rogowo	zninski	27930	3356	37496	1687	13499	16123	798	8.0
Rogozno	grudziacki	13581	1582	17310	779	6231	7443	388	5.9
Rojewo	inowroclawskie	6865	847	9624	433	3465	4138	196	2.9
Rypin	rypinski	5297	612	6657	300	2396	2862	151	28.3
Rypin	rypinski	17505	2168	24677	1110	8884	10611	500	5.3
Sadki	nakielski	12116	1784	22281	1003	8021	9581	346	3.9
Sepolno Krajenskie	sepolinski	22358	2750	31175	1403	11223	13405	639	5.5
Sicienko	bydgoski	15455	1990	23195	1044	8350	9974	442	4.0
Skepe	lipnowski	507	75	937	42	337	403	14	0.2
Skrwilno	rypinski	4212	535	6190	279	2228	2662	120	2.3

		Co-substrate (15% DM)	Total methane	Gross energy production	Total electrical power	Total electricity	Total heat	Area required for energy crops	Share in arable land
Commune	County	t /y	Mm^3	MWh	kW	MWh	MWh	ha	%
Sliwice	tucholski	420	62	774	35	278	333	12	0.4
Solec Kujawski	bydgoski	1125	130	1413	64	509	608	32	2.0
Sosno	sepolinski	12763	1544	17327	780	6238	7451	365	3.4
Stolno	chelminski	5096	607	6742	303	2427	2899	146	2.0
Strzelno	mogilenski	13101	1594	17949	808	6462	7718	374	3.3
Swiece nad Osa	grudziacki	19376	2400	27330	1230	9839	11752	554	7.8
Swiecie	swiecki	52286	6038	65702	2957	23653	28252	1494	17.9
Swiedziebnia	brodnicki	5442	673	7648	344	2753	3289	155	2.5
Swiekatowo	swiecki	11079	1337	14983	674	5394	6443	317	7.1
Szubin	nakielski	14627	1915	22530	1014	8111	9688	418	3.0
Tluchowo	lipnowski	1460	183	2093	94	753	900	42	0.6
Topolka	radziejewski	39497	4602	50381	2267	18137	21664	1128	15.5
Torun	m. Torun	16448	1899	20669	930	7441	8888	470	26.1
Tuchola	tucholski	12647	1542	17397	783	6263	7481	361	4.2
Unislaw	chelminski	3235	421	4929	222	1774	2119	92	2.0
Wabrzezno	wabrzezno	588	68	739	33	266	318	17	4.6
Wabrzezno	wabrzezno	23678	2799	30946	1393	11140	13307	677	5.2
Waganiec	aleksandrowski	3897	486	5555	250	2000	2389	111	2.5
Wapielsk	rypinski	13733	1624	17960	808	6465	7723	392	6.7
Warlubie	swiecki	6293	727	7907	356	2847	3400	180	3.2
Wiecborg	sepolinski	24637	2904	32042	1442	11535	13778	704	6.0
Wielgie	lipnowski	2334	316	3790	171	1364	1630	67	0.8
Wielka Nieszawka	torunski	0	0	0	0	0	0	0	0.0
Wloclawek	wloclawski	1939	267	3225	145	1161	1387	55	1.1
Wloclawek	m. Wloclawek	0	0	0	0	0	0	0	0.0
Zakrzewo	aleksandrowski	6502	876	10464	471	3767	4500	186	3.0
Zbiczno	brodnicki	5950	715	7992	360	2877	3436	170	3.5
Zbojno	golubsko-dobrzynski	5984	691	7519	338	2707	3233	171	2.6
Zlawies Wielka	torunski	7751	960	10936	492	3937	4703	221	2.5
Zlotniki Kujawskie	inowroclawskie	15539	1858	20696	931	7451	8899	444	4.7
Znin	zninski	39225	4872	55578	2501	20008	23898	1121	5.8
Total		1609725	195342	2196301	98834	790668	944410	45992	4.4

Appendix 8: Biogas Potential and Energy Production from Co-Substrates Mix of 22-23% DM (Animal Manure and Energy Crops). Considered Animal Holdings with at least 100 Animal Population in the Kujawsko-Pomorskie Region

		Co-sub-trate (22% DM)	Total methane	Gross energy	Total electrical power	Total electricity	Total heat	Area required for energy crops	Share in arable land
Commune	County	t /y	Mm^3	MWh	kW	MWh	MWh	ha	%
Aleksandrow Kujawski	aleksandrowski	5368	543	5330	240	1919	2292	153	1.9
Aleksandrwo Kujawski	aleksandrowski	0	0	0	0	0	0	0	0.0
Badkowo	aleksandrowski	32732	3315	32611	1467	11740	14023	935	12.6
Barcin	zninski	24023	2478	24760	1114	8914	10647	686	8.4
Bartniczka	brodnicki	53037	5376	52915	2381	19049	22753	1515	29.5
Baruchowo	wloclawski	1380	139	1370	62	493	589	39	0.9
Biale Blota	bydgoski	347	35	344	15	124	148	10	0.5
Bobrowniki	lipnowski	6032	610	5990	270	2156	2576	172	6.1
Bobrowo	brodnicki	58280	5932	58606	2637	21098	25200	1665	15.3
Boniewo	wloclawski	3251	329	3228	145	1162	1388	93	1.6
Brodnica	brodnicki	977	99	970	44	349	417	28	4.3
Brodnica	brodnicki	65455	6693	66384	2987	23898	28545	1870	24.1
Brzesc Kujawski	wloclawski	8848	902	8917	401	3210	3834	253	2.5
Brzozie	brodnicki	52053	5279	51983	2339	18714	22353	1487	25.0
Brzuze	rypinski	34661	3549	35232	1585	12684	15150	990	15.4
Bukowiec	swiecki	57357	5829	57500	2588	20700	24725	1639	21.0
Bydgoszcz	m. Bydgoszcz	26161	2656	26173	1178	9422	11254	747	29.9
Byton	radziejewski	5132	530	5298	238	1907	2278	147	2.5
Cekcyn	tucholski	4760	481	4726	213	1701	2032	136	3.4
Chelmno	chelminski	416	42	413	19	149	178	12	2.3
Chelmno	chelminski	32000	3265	32317	1454	11634	13896	914	17.0
Chelmza	torunski	0	0	0	0	0	0	0	0.0
Chelmza	torunski	74287	7586	75151	3382	27054	32315	2122	13.9
Chocen	wloclawski	11768	1200	11871	534	4274	5105	336	4.3
Chodecz	wloclawski	40205	4094	40451	1820	14562	17394	1149	12.6
Chrostkowo	lipnowski	10772	1101	10922	492	3932	4697	308	5.7
Ciechocin	golubsko-dobrzynski	38664	3941	38972	1754	14030	16758	1105	21.6
Ciechocinek	aleksandrowski	0	0	0	0	0	0	0	0.0
Czernikowo	torunski	17580	1798	17841	803	6423	7672	502	7.3
Dabrowa	mogilenski	30618	3102	30516	1373	10986	13122	875	11.3
Dabrowa Biskupia	inowroclawskie	122888	12489	123220	5545	44359	52984	3511	37.2
Dabrowa Chelminska	bydgoski	12131	1250	12477	561	4492	5365	347	9.1
Debowa Laka	wabrzezno	61914	6287	61983	2789	22314	26653	1769	26.7
Dobrcz	bydgoski	77797	7926	78371	3527	28213	33699	2223	23.0
Dobre	radziejewski	13288	1357	13451	605	4842	5784	380	6.5
Dobrzyn nad Wisla	lipnowski	27966	2827	27770	1250	9997	11941	799	9.3
Drgacz	swiecki	5903	612	6137	276	2209	2639	169	4.0

Commune	County	Co-substrate (15% DM) t /y	Total methane Mm^3	Gross energy production MWh	Total electrical power kW	Total electricity MWh	Total heat MWh	Area required for energy crops ha	Share in arable land %
Drzycicn	swiecki	55879	5672	55896	2515	20122	24035	1597	26.7
Fabianki	wloclawski	2161	218	2146	97	772	923	62	1.5
Gasowa	zninski	72163	7312	71948	3238	25901	30938	2062	26.6
Gniewkowo	inowroclawskie	63415	6486	64346	2896	23165	27669	1812	17.4
Golub Dobrzyn	golubsko-dobrzynski	1584	160	1573	71	566	677	45	16.1
Golub Dobrzyn	golubsko-dobrzynski	55701	5638	55434	2495	19956	23837	1591	15.1
Gorzno	brodnicki	76638	7768	76458	3441	27525	32877	2190	50.4
Gostycyn	tucholski	51854	5310	52725	2373	18981	22672	1482	19.1
Grudziadz	grudziacki	26457	2675	26271	1182	9458	11297	756	9.7
Gruta	grudziacki	47863	4883	48334	2175	17400	20784	1368	14.9
Inowrcolaw	inowroclawskie	1458	147	1448	65	521	623	42	3.2
Inowroclaw	inowroclawskie	33327	3407	33779	1520	12160	14525	952	7.3
Izbica Kujawska	wloclawski	35249	3615	35944	1617	12940	15456	1007	10.4
Jablonowo Pomorskie	brodnicki	61758	6288	62135	2796	22369	26718	1765	18.8
Janikowo	inowroclawskie	14499	1483	14710	662	5296	6325	414	5.8
Janowiec Wielkopolski	zninski	188160	19059	187507	8438	67503	80628	5376	53.9
Jeziora Wielkie	mogilenski	18357	1868	18458	831	6645	7937	524	7.2
Jezowo	swiecki	57885	5878	57950	2608	20862	24918	1654	35.3
Kamien Krajenski	sepolinski	29060	2956	29196	1314	10510	12554	830	7.9
Kcynia	nakielski	145863	14895	147551	6640	53118	63447	4168	25.4
Kesowo	tucholski	71551	7307	72385	3257	26059	31126	2044	28.5
Kijewo Krolewskie	chelminski	16943	1740	17315	779	6233	7445	484	8.1
Kikol	lipnowski	16971	1744	17368	782	6253	7468	485	6.5
Koneck	aleksandrowski	10059	1024	10118	455	3642	4351	287	5.3
Koronowo	bydgoski	125032	12679	124857	5619	44948	53688	3572	17.2
Kowal	wloclawski	0	0	0	0	0	0	0	0.0
Kowal	wloclawski	1704	172	1692	76	609	728	49	0.7
Kowalewo Pomorskie	golubsko-dobrzynski	61405	6242	61596	2772	22175	26486	1754	16.0
Kruszwica	inowroclawskie	165442	17062	170446	7670	61361	73292	4727	25.6
Ksiazki	wabrzezno	34019	3462	34195	1539	12310	14704	972	15.0
Labiszyn	zninski	39230	4032	40170	1808	14461	17273	1121	16.1
Lasin	grudziacki	60860	6185	61026	2746	21969	26241	1739	16.7
Lipno	lipnowski	0	0	0	0	0	0	0	0.0
Lipno	lipnowski	12222	1242	12245	551	4408	5265	349	3.0

Commune	County	Co-substrate (15% DM)	Total methane	Gross energy production	Total electrical power	Total electricity	Total heat	Area required for energy crops	Share in arable land
		t /y	Mm^3	MWh	kW	MWh	MWh	ha	%
Lisewo	chelminski	30637	3097	30422	1369	10952	13082	875	12.2
Lniano	swiecki	25563	2590	25492	1147	9177	10961	730	16.4
Lubanie	wloclawski	9401	956	9439	425	3398	4059	269	6.0
Lubianka	torunski	55620	5688	56426	2539	20314	24263	1589	22.1
Lubicz	torunski	46499	4719	46508	2093	16743	19999	1329	21.6
Lubien Kujawski	wloclawski	21648	2203	21763	979	7835	9358	619	5.3
Lubiewo	tucholski	18106	1831	17979	809	6473	7731	517	7.8
Lubraniec	wloclawski	22367	2269	22346	1006	8044	9609	639	5.3
Lysomice	torunski	13838	1399	13741	618	4947	5909	395	4.7
m. Grudziadz	grudziacki	33497	3387	33262	1497	11974	14303	957	64.9
Mogilno	mogilenski	151386	15422	152464	6861	54887	65560	4325	21.9
Mrocza	nakielski	65533	6693	66306	2984	23870	28512	1872	18.5
Naklo nad Notecia	nakielski	53798	5557	55580	2501	20009	23899	1537	17.8
Nieszawa	aleksandrowski	658	67	654	29	235	281	19	3.3
Nowa Wies Wielka	bydgoski	1348	136	1339	60	482	576	39	2.0
Nowe	swiecki	19779	2029	20173	908	7262	8674	565	11.4
Obrowo	torunski	49115	4997	49340	2220	17762	21216	1403	17.9
Osie	swiecki	15155	1532	15048	677	5417	6471	433	12.9
Osieciny	radziejewski	133075	13560	134086	6034	48271	57657	3802	36.3
Osiek	brodnicki	30326	3072	30232	1360	10884	13000	866	15.7
Osielsko	bydgoski	3207	324	3184	143	1146	1369	92	3.4
Pakosc	inowroclawskie	19324	1989	19839	893	7142	8531	552	9.7
Papwo Biskupie	chelminski	22516	2276	22358	1006	8049	9614	643	10.3
Piotrkow Kujawski	radziejewski	55698	5712	56791	2556	20445	24420	1591	15.0
Pluznica	wabrzezno	59130	6032	59700	2687	21492	25671	1689	17.4
Pruszcz	swiecki	114319	11576	113856	5124	40988	48958	3266	29.3
Raciazek	aleksandrowski	5629	575	5695	256	2050	2449	161	6.7
Radomin	golubsko-dobrzynski	54426	5527	54490	2452	19616	23431	1555	23.6
Radziejow	radziejewski	0	0	0	0	0	0	0	0.0
Radziejow	radziejewski	10813	1111	11057	498	3981	4755	309	3.7
Radzyn Chelminski	grudziacki	25961	2643	26107	1175	9398	11226	742	10.1
Rogowo	rypinski	16386	1662	16377	737	5896	7042	468	7.7
Rogowo	zninski	93937	9555	94340	4245	33962	40566	2684	26.8
Rogozno	grudziacki	41773	4229	41588	1871	14972	17883	1194	18.2
Rojewo	inowroclawskie	24813	2533	25081	1129	9029	10785	709	10.5
Rypin	rypinski	15892	1607	15780	710	5681	6786	454	84.9
Rypin	rypinski	63850	6520	64589	2907	23252	27773	1824	19.2
Sadki	nakielski	66187	6862	68846	3098	24785	29604	1891	21.3

Commune	County	Co-substrate (15% DM)	Total methane	Gross energy production	Total electrical power	Total electricity	Total heat	Area required for energy crops	Share in arable land
		t /y	Mm^3	MWh	kW	MWh	MWh	ha	%
Sepolno Krajenskie	sepolinski	80101	8173	80903	3641	29125	34789	2289	19.7
Sicienko	bydgoski	62324	6392	63558	2860	22881	27330	1781	16.2
Skepe	lipnowski	2789	289	2902	131	1045	1248	80	1.3
Skrwilno	rypinski	16429	1683	16711	752	6016	7186	469	9.0
Sliwice	tucholski	2300	238	2392	108	861	1029	66	2.3
Solec Kujawski	bydgoski	3374	341	3350	151	1206	1441	96	6.1
Sosno	sepolinski	43743	4454	44007	1980	15843	18923	1250	11.6
Stolno	chelminski	16722	1699	16755	754	6032	7205	478	6.5
Strzelno	mogilenski	45589	4645	45927	2067	16534	19749	1303	11.4
Swiece nad Osa	grudziacki	70740	7224	71564	3220	25763	30772	2021	28.3
Swiecie	swiecki	156857	15858	155758	7009	56073	66976	4482	53.8
Swiedziebnia	brodnicki	19751	2016	19971	899	7190	8588	564	9.1
Swiekatowo	swiecki	37723	3839	37928	1707	13654	16309	1078	24.3
Szubin	nakielski	61433	6311	62839	2828	22622	27021	1755	12.5
Tluchowo	lipnowski	5470	559	5546	250	1997	2385	156	2.3
Topolka	radziejewski	121658	12318	121137	5451	43609	52089	3476	47.7
Torun	m. Torun	49345	4989	48999	2205	17640	21070	1410	78.2
Tuchola	tucholski	44306	4516	44661	2010	16078	19204	1266	14.6
Unislaw	chelminski	13358	1371	13647	614	4913	5868	382	8.1
Wabrzezno	wabrzezno	1764	178	1752	79	631	753	50	13.9
Wabrzezno	wabrzezno	76074	7720	76069	3423	27385	32709	2174	16.8
Waganiec	aleksandrowski	14473	1479	14663	660	5279	6305	414	9.5
Wapielsk	rypinski	44170	4483	44171	1988	15902	18994	1262	21.4
Warlubie	swiecki	18878	1909	18746	844	6748	8061	539	9.7
Wiecborg	sepolinski	78494	7962	78424	3529	28232	33722	2243	19.1
Wielgie	lipnowski	10626	1095	10931	492	3935	4700	304	3.7
Wielka Nieszawka	torunski	0	0	0	0	0	0	0	0.0
Wloclawek	wloclawski	9153	944	9438	425	3398	4058	262	5.0
Wloclawek	m. Wloclawek	0	0	0	0	0	0	0	0.0
Zakrzewo	aleksandrowski	29207	3008	30018	1351	10806	12908	834	13.4
Zbiczno	brodnicki	20028	2037	20116	905	7242	8650	572	11.9
Zbojno	golubsko-dobrzynski	17952	1815	17826	802	6417	7665	513	7.8
Zlawies Wielka	torunski	28312	2891	28643	1289	10312	12317	809	9.1
Zlotniki Kujawskie	inowroclawskie	51566	5242	51723	2328	18620	22241	1473	15.5
Znin	zninski	144266	14737	146037	6572	52573	62796	4122	21.4
Total		5563003	566609	5600816	252037	2.016294	2.408351	158943	14.8

Appendix 9: Farmland in ha under Crops for Different Energy Fuels Production in the Stuttgart Region

Years	2004	2005	2006	2007
	Biogas			
Böblingen		2	17	49
Esslingen	32	46	38	63
Göppingen	99	141	358	415
Ludwigsburg			250	759
Rems-Murr-Kreis			9	119
Stuttgart	18	5	18	28
Sum	149	194	689	1433
	Biodiesel			
Böblingen	758	517	526	544
Esslingen	290	145	147	143
Göppingen	779	368	337	335
Ludwigsburg	619	539	509	440
Rems-Murr-Kreis	319	220	240	249
Stuttgart	22	21	15	22
Sum	2787	1810	1774	1733
	Bioethanol			
Böblingen		25	53	48
Esslingen		30	84	79
Göppingen		18	46	42
Ludwigsburg		223	361	411
Rems-Murr-Kreis		16	81	98
Stuttgart		9	27	29
Sum		321	652	706
	Oil crops			
Böblingen				
Esslingen				
Göppingen				
Ludwigsburg	4.9			24.8
Rems-Murr-Kreis				
Stuttgart				
Sum	4.9			24.8
	Solid biomass			
Böblingen	0.8	2.6	2.6	2.6
Esslingen		7.6		
Göppingen			2.9	
Ludwigsburg				
Rems-Murr				1.6
Stuttgart				
Sum	0.8	10.2	5.5	4.2
	Renewable raw materials			
Böblingen		1.5		
Esslingen	8			
Göppingen			3	
Ludwigsburg	2.7	2.8	9.9	11.2
Rems-Murr			2.9	0.4
Stuttgart			2	
Sum	10.7	4.3	17.7	11.6

Years	2004	2005	2006	2007
	Other			
Böblingen				
Esslingen				
Göppingen	30.2	4.2		
Ludwigsburg				2.4
Rems-Murr			6.7	
Stuttgart				
Sum	30.2	4.2	6.7	2.4
Total Cropland	2983	2344	3145	3915

Source: Feldwisch, Lendvaczky et al. (2010)

Appendix 10: Agro-Climate Requirement for Planting Selected Crops and Site Classification in the Kujawsko-Pomorskie Voivodship

Crop	CAS	Annual precipitation [mm]	Annual temperature [°C]	Slope [%]	Height above the sea level [m]	Site classification
Willow	1, 2, 4	> 550	> 6	< 18	<700	> HY
	1, 2, 4	< 550	> 6	< 18		AY
	3, 5, 8	> 550	> 6	< 18		>AY
	-	> 550	-	< 18		<AY
	-	< 550	-	< 18		LY

Crop	CAS	Annual precipitation [mm]	Annual temperature [°C]	Slope [%]	Height above the sea level [m]	Site classification
Miscanthus	1, 2, 4	>700	> 7	< 12	< 700	>HY
	1, 2, 4	> 500, < 700	> 7	< 12		HY
	1, 2, 4	< 500	> 7	< 12		< AY
	3, 5, 8	>700	> 7	< 12		>AY
	3, 5, 8	> 500, < 700	> 7	< 12		<AY
	-	>500		< 12		>LY
	-	<500	-	< 18		LY

Crop	CAS	May-Sept precipitation [mm]	Annual temperature [°C]	Slope [%]	Height above the sea level [m]	Site classification
Maize	1, 2, 4	>500	> 7	< 12	< 700	HY
	1, 2, 4	>250, < 500	> 7	< 12		< HY
	1, 2, 4	< 250	> 7	< 12		< AY
	3, 5, 8	> 500	>7	< 12		> AY
	3, 5, 8	> 250, < 500	> 7	< 12		< AY
	-	> 250	> 7	< 12		>LY
	-	>250	-	-		LY

Crop	CAS	Annual precipitation [mm]	Annual temperature [°C]	Slope [%]	Height above the sea level [m]	Site classification
Sida hermaphrodita	1, 2, 4	> 550	> 6	< 18	< 700	> HY
	1, 2, 4	< 550	> 6	< 18		AY
	3, 5, 8	> 550	> 6	< 18		>AY
	-	> 550	> 6	< 18		< AY
	-	< 550	-	< 18		LY

Crop	CAS	Annual precipitation [mm]	Annual temperature [°C]	Slope (%)	Height above the sea level [m]	Site classification
Rapeseed	1, 2	> 600	> 6	< 18	<700	HY
	1, 2	> 450, < 600	> 6	< 18		< HY
	1, 2	< 450	> 6	< 18		< AY
	3, 4 ,5, 8	> 600	> 6	< 18		> AY
	3, 4, 5, 8	> 450, < 600	> 6	< 18		< AY
	-	> 450	-	< 18		> LY
	-	< 450	-	< 18		< LY

Crop	CAS	Annual precipitation [mm]	Annual temperature [°C]	Slope [%]	Height above the sea level [m]	Site classification
Wheat	1, 2	> 550	>6	< 18	<1000	> HY
	1, 2	< 550	>6	< 18		< HY
	3, 4, 5, 8	> 550	>6	< 18		> AY
	3, 4, 5, 8	< 550	>6	< 18		< AY
	6, 7, 9	> 550	>6	< 18		> LY
	-	-	>6	< 18		LY

Crop	CAS	Annual precipitation [mm]	Annual temperature [°C]	Slope [%]	Height above the sea level [m]	Site classification
Rye	1.2	-	-	< 18	<1000	> HY
	3, 4, 5, 8	> 350	> 6	< 18		HY
	3,4, 5, 8	< 350	> 6	< 18		< HY
	6, 7, 9	> 350	> 6	< 18		AY
	6, 7, 9	< 350	> 6	< 18		<AY
	-	-	-	< 18		LY

Appendix 11: Agro-Climate Requirement for Planting Selected Crops and Site Classification in the Stuttgart Region.

Crop	Ackerland-zahl (DE)	Soil moisture capacity	Annual precipitation [mm]	Annual temperature [°C]	Slope [%]	Height above the sea level [m]	Site classification for Willow and Poplar
Willow Poplar	> 40	Fresh, moderate fresh, moderate wet	> 500	> 6	< 18	<700	1. > HY (> 40)
	> 40	Moderate fresh, change fresh, fresh to wet, change wet	> 500	> 6	< 18		2. HY (> 40)
	> 40	Moderate fresh to fresh, moderate	> 500	> 6	< 18		2. HY (> 40)
	> 40	Moderate dry to fresh	> 500	> 6	< 18		3. < HY (>40)
	<= 40, >28	Fresh, moderate fresh, moderate wet	> 500	> 6	< 18		4. > HY (28-40)
	<= 40, >28	Moderate fresh, change fresh, fresh to wet, change wet to wet	> 500	> 6	< 18		5. HY (28-40)
	<= 40, >28	Moderate fresh to fresh, moderate change wet to wet	> 500	> 6	< 18		5. HY (28-40)
	<= 40, >28	Moderate dry to fresh	> 500	> 6	< 18		6. AY (28-40)
	<= 40, >28	-	> 550	> 6	< 18		7. < AY (28-40)
	< 40	Dry to Moderate dry, Moderate dry,	> 550	> 6	< 18		8. > LY
	< 40	Moderate fresh, wet moderate change fresh, wet, fresh to wet, change wet	-	-	< 18		9. LY
	-	wet, change wet	-	-	< 18		11. LY (wet)
	-	-	-	-	-	-	Other

Crop	Ackerzahl (DE)	Soil texture	May-Sep precipitation [mm]	Annual tempera-ture [°C]	Slope [%]	Height above the sea level [m]	Site classification
Maize	>60	Sandy loam, loamy sand, clay loam, silty clay	> 500	> 8	< 12	< 700	> HY
	>60		> 250, < 500	> 8	< 12		HY
	<= 60, >40		> 500	> 8	< 12		< HY
	<= 60, >40		> 250, < 500	> 8	< 12		AY
	>40		<250		< 12		< AY
	<= 40, >28		> 500	> 8	< 12		> AY
	<= 40, >28		> 250, < 500	> 7	< 12		> LY
	<= 40, >28		< 250	> 7	< 12		LY
	-	-	> 250	-	< 12		> LY
	-	-	< 250	-	< 12		< LY
	-	-	-	-	-		Erosion risks

Crop	Ackerland-zahl (DE)	Soil texture	Annual pre-cipitation [mm]	Annual tempera-ture [°C]	Slope [%]	Height above the sea level [m]	Site classification
Miscanthus	>60	Sandy loam, loamy sand, clay loam, silty clay	>700	> 7	< 18	< 700	> HY (> 60)
	>60		> 500, < 700	> 7	< 18		HY (> 60)
	<= 60, >40		>700	> 7	< 18		> HY (40-60)
	<= 60, >40		> 500, < 700	> 7	< 18		< HY (40-60)
	>40		< 500	> 7	< 18		< AY(> 40)
	<= 40, >28		>700	> 7	< 18		> AY (28-40)
	<= 40, >28		> 500, < 700	> 7	< 18		AY (28-40)
	-		>500	-	< 18		< AY
	-	-	<500	-	< 18		LY

Crop	Ackerland-zahl (DE)	Soil texture	Annual pre-cipitation [mm]	Annual tempera-ture [°C]	Slope [%]	Height above the sea level	Site classification
Rapeseed	>60	Sandy loam, clay loam, loamy clay	> 600	> 6	< 18	<1000	> HY
	>60		> 450, < 600	> 6	< 18		< HY
	<= 60, >40		>600	> 6	< 18		> AY
	<= 60, >40		> 450, < 600	> 6	< 18		< AY
	<= 40, >28		> 450	> 6	< 18		> LY
	-		> 450	> 6	< 18		> LY
	-	-	< 450	-	-		< LY

Crop	Ackerland-zahl (DE)	Soil texture	Annual pre-cipitation [mm]	Annual tempera-ture [°C]	Slope [%]	Height above the sea level [m]	Site classification
Wheat	>60	Clay loam, loamy clay	> 550	> 6	< 18	<1000	> HY
	>60		< 550	> 6	< 18		< HY
	<= 60, > 40		> 550	> 6	< 18		> AY
	<= 60, > 40		< 550	> 6	< 18		< AY
	<= 40, > 28		> 550	> 6	< 18		>LY
	>28		< 550	-	<18		
	-	-	>550	-	<18		

Crop	Ackerland-zahl (DE)	Soil texture	Annual pre-cipitation [mm]	Annual tempera-ture [°C]	Slope [%]	Height above the sea level	Site classification
Rye	<= 40, >28	Sand, sandy loamy sand	> 350	> 6	< 18	<700	> AY
	<= 40, >28		< 350	> 6	< 18		AY
	<28		> 350	> 6	< 18		< AY
	< 28	-	> 350	> 6	< 18		>LY
	>< 40-105	-	<350	-	< 18		< LY

Appendix 12: Factors for Estimating Large Stock Units

Animal population:	LSU/Animal
Cattle	
Cows and beef over 2 years old	1.2
Female cattle 1-2 years	0.6
Male cattle 1-2 years	0.7
Female cattle 0.5-1 year	0.4
Male cattle 0.5-1 year	0.5
Female cattle up 6 months	0.19
Male cattle up 6 months	0.3
Pigs	
Porker (up 110 kg)	0.13
Porker (up 115 kg)	0.14
Porker (up 120 kg)	0.15
Poultry	
Laying hen	0.0034
Pullet (up 18 weeks)	0.0014
Chicken (up 35 days)	0.0015
Sheep	
Sheep over 1 year	0.1
Sheep up 1 year	0.05
Horses	
Horses over 3 years	1.1
Horses up 3 years	0.7
Ponys	0.7

Source: StaLa (2007)

Appendix 13: Roughness Length Based on the CLC Data

Roughness length	CLC classes
1.200	Continuous urban fabric
0.750	Broad-leaved forest
	Coniferous forest
	Mixed forest
0.600	Green urban areas
	Transitional woodland-shrub
	Burnt areas
0.500	Discontinuous urban fabric
	Industrial or commercial units
	Port areas
	Construction sites
	Sport and leisure facilities
0.300	Complex cultivation patterns
	Land principally occupied by agriculture with significant areas of natural vegetation
	Agro-forestry areas
0.100	Vineyards
	Fruit trees and berry plantations
	Olive groves
	Annual crops associated with permanent crops
0.070	Road and rail networks and associated land
0.050	Non-irrigated arable land
	Permanently irrigated land
	Rice fields
	Inland marshes
	Salt marshes
0.030	Pastures
	Natural grasslands
	Moors and heath land
0.005	Airports
	Mineral extraction sites
	Dump sites
	Bare rocks
	Sparsely vegetated areas
0.001	Glaciers and perpetual snow
	Peat bogs
	Salines
	Intertidal flats
0	Beaches. dunes, sands
	Water courses
	Water bodies
	Coastal lagoons
	Estuaries
	Sea and ocean

Appendix 14: Constraints for Wind Turbine Siting in the Region Kujawsko-Pomorskie

	Distance	Dataset source
Settlements		
Residential area	500	111 class (EEA 2009)
Single dwellings	500	112 class (EEA 2009)
Industry and commercial development zone	250	121 class (EEA 2009)
Leisure time and green areas		
Leisure and recreation areas	450	142 class (EEA 2009)
Green land and graveyard. camping	450	141 class (EEA 2009; Geofabrik 2010)
Infrastructure facility		
Planned motorways	150	(ESRI 2007; KPBPP 2009)
Roads	100	(ESRI 2007; KPBPP 2009)
Railway lines	100	(ESRI 2007; KPBPP 2009)
Air ports	3000	124 class (EEA 2009; KPBPP 2009)
Power network	200	(KPBPP 2009)
Mine and dump areas	100	131. 132. 133 classes (EEA 2009)
Cultural assets		
Castle, cultural relict	1000	(Geofabrik 2010)
Wetlands		
Streams	250	(ESRI 2007; KPBPP 2009)
Inland water	200	(ESRI 2007; KPBPP 2009)
Flood area	200	(ESRI 2007; KPBPP 2009)
Nature protection		
Nature reserves	500	(KPBPP 2009)
Projected nature reserves	500	(KPBPP 2009)
Landscape parks	200	(KPBPP 2009)
Projected landscape parks	200	(KPBPP 2009)
Protected landscape areas	200	(KPBPP 2009)
Projected protected landscape areas	200	(KPBPP 2009)
Buffer of landscape parks	200	(KPBPP 2009)
Nature 2000	500	(KPBPP 2009)
Areas of special protection of birds	1000	(KPBPP 2009)
Areas of special protection of habitats	500	(KPBPP 2009)
Ecological areas	500	(KPBPP 2009)
Nature monuments	100	(KPBPP 2009)
Landscape-nature complexes	200	(KPBPP 2009)
Ecological corridors	500	(KPBPP 2009)
Habitat of migrating birds	5000	(KPBPP 2009)
Forest and semi natural areas		
Forest	200	(EEA 2009; KPBPP 2009)
Protected forest	500	(KPBPP 2009)
Orchards	50	(EEA 2009)

Appendix 15: Appendix 15 Constraints for Wind Turbine Siting in the Stuttgart Region

	Distance	Individual examination	Dataset source
Settlements			
Residential area	500		(EEA 2009; infas 2010)
Industry and commercial development zone	250		(EEA 2009)
Leisure time and green areas			
Leisure and recreation areas	500		142 class (EEA 2009)
Green land and graveyard, camping	500		141 class (EEA 2009; Geofabrik 2010)
Infrastructure facility			
Motorways, Roads	100		(ESRI 2007; NAVTEQ 2009)
Railway lines	100		(ESRI 2007; NAVTEQ 2009)
Air ports	2000		124 class (EEA 2009; KPBPP 2009)
Mine and dump areas	100		131. 132. 133 classes (EEA 2009)
Cultural assets			
Castle, cultural relict	500	x	(Geofabrik 2010)
Monuments	100	x	(Geofabrik 2010)
Nature protection			
Existing and planned nature protection areas	200		(LUBW 2009)
Particularly protected biotopes (§ 32 NatSchG BW und §30a WaldG BW) Waldbiotope. Wetflächen und Heideflächen)	30	x	(LUBW 2009)
Nature monuments	100	x	(LUBW 2009)
Areas of special protection of birds - Natura 2000	1000	x	(LUBW 2009)
Areas of special protection of habitats - Natura 2000	1000	x	(LUBW 2009)
Landscapes			
Landscape conservation area (LGS)		x	(LUBW 2009)
Landscape with sensible components		x	(LUBW 2009)
Water protection			
Water protection - zone I	200	x	(LUBW 2009)
Water protection - zone II	200	x	(LUBW 2009)
Protected water (Gewässer 1 Ordnung)	200		(LUBW 2009)
Forest and semi natural areas			
Forest	200		(EEA 2009)
Orchards	100		(EEA 2009)
Wetlands			
Streams, Inland water	100		(WaBoA 2007)
Flood area	100		(LUBW 2009)

Appendix 16: Constraints for Wind Turbine Siting in the PACA Region

	Distance	Individual examination	Dataset source
Settlements			
Residential area	500 m		(EEA 2009)
Industry and commercial development zone	500 m		(EEA 2009)
Leisure time and green areas			
Leisure and recreation areas	500 m		(EEA 2009)
Green land and camping	500 m		(EEA 2009; Geofabrik 2010)
Infrastructure facility			
Roads	30m + total high of turbine and blades (150 m)		(ESRI 2007; NAVTEQ 2009)
Railway lines			(ESRI 2007; NAVTEQ 2009)
Air ports	2 km	x	(EEA 2009)
Power network	200 m	x	Réseau de Transport d'Electricité (RTE)
Mine and dump areas	200 m	x	131, 132, 133 classes (EEA 2009)
Cultural assets			
Castle, cultural relict: Classified sites (sites classés) defined under the Act of May 2, 1930 amended by Law of December 28, 1967	1-5 km	x	(DIREN 2009b)
The „listed sites”are defined under the Act of May 2, 1930 amended by Law of December 28, 1967 for the protection of sites of artistic, historic, scientific, legendary or picturesque	1-5 km		(DIREN 2009b)
ZPPAUP*	1-5 km	x	
Natural habitats, fauna and flora			
Areas of special protection of birds (ZPS, ZICO) - Natura 2000		x	(DIREN 2009b)
Areas of special protection of habitats (pSIC) - Natura 2000		x	(DIREN 2009b)
ZNIEF		x	(DIREN 2009b)
National and regional nature reserve	1 km		(DIREN 2009b)
Protected forest			(DIREN 2009b)
Prefectoral biotope protection (APB)	1 km		(DIREN 2009b)
Sensitive natural area	1 km	x	(DIREN 2009b)
Biological reserves	200 m		(DIREN 2009b)
Biosphere reserves		x	(DIREN 2009b)
RAMSAR		x	(DIREN 2009b)
Water protection (SAGE)		x	(DIREN 2009b)
Landscapes			
The Grands Sites de France network (OGS)	5 km	x	(DIREN 2009b)
Landscape with sensible components	5 km	x	(DIREN 2009b)
Forest and semi natural areas			
Forest	100 m		(EEA 2009)
Orchards and vineyards	100 m		(EEA 2009)
Wetlands			

	Distance	Individual examination	Dataset source
Streams	100 m		(EEA 2009)
Inland water	100 m		(EEA 2009)
Floodplain areas (AZI)	100 m	x	(DIREN 2009b)

*Zone de Protection du Patrimoine Architectural, Urbain et Paysager

Appendix 17: Zones of Protection for Architectural, Urban and Landscape Patrimony in the PACA Region (French: ZPPAUP Zones de Protection du Patrimoine Architectural)

Departments	Commune
Alpes-de-Haute-Provence	Manosque
	Annot
	Quinson
	Hautes-Alpes
	Embrun
	Serres
	Saint-Véran
	Lagrand
	Remollon
	Tallard - Chateauvieux
	Saint André-de-Rosans
Alpes-Maritimes	Le Bar-sur-Loup
Bouches-du-Rhône	Peyrolles
	Vauvenargues
	Jouques
	Marseille-Belsunce
	Marseille-Le Panier
	Aix -en-Provence - Entremont Saint Donat
	Marseille-République
	Cornillon-Confoux
	Rognes village
	Trans-en-Provence
Var	Porquerolles
	Lorgues
	Hyères-les-Palmiers
	Toulon
	Fréjus
	La Seyne Tamaris Sablettes
Vaucluse	Sorgues: Chateau de Brantes
	Pernes-les-Fontaines
	Carpentras

Appendix 18: Potential Wind Sites Area and Protection Level by Communes in the Stuttgart Region

ID	Commune	Reference yield < 60%	Excluded	High protection	Moderate protection	Low protection	No constraints
111000	Stuttgart	8923200	200636800	67600	0	743600	0
115001	Aidlingen	8314800	15074800	1622400	67600	743600	946400
115002	Altdorf	9734400	7030400	0	0	0	67600
115003	Boeblingen	6557200	32380400	0	0	0	202800
115004	Bondorf	4258800	13520000	0	0	0	0
115010	Deckenpfronn	5002400	5746000	67600	0	0	608400
115013	Ehningen	3650400	13790400	0	0	0	67600
115015	Gőrtringen	6557200	12438400	0	0	0	405600
115016	Gőufelden	4664400	15277600	0	0	0	0
115021	Herrenberg	21158800	44345600	0	67600	0	405600
115022	Hildrizhausen	6286800	6422000	0	0	0	0
115024	Holzgerlingen	2028000	11627200	0	0	0	0
115028	Leonberg	10478000	38261600	0	0	0	0
115029	Magstadt	4867200	14736800	0	0	0	0
115034	Moetzingen	1554800	6557200	0	0	0	0
115037	Nufringen	2095600	8314800	0	0	0	0
115041	Renningen	9464000	20212400	135200	338000	202800	540800
115042	Rutesheim	6016400	10207600	0	0	0	0
115044	Schoenaich	4056000	10275200	0	0	0	0
115045	Sindelfingen	11018800	39275600	67600	0	0	135200
115046	Steinenbronn	3109600	6827600	0	0	0	0
115048	Waldenbuch	11086400	11424400	0	0	0	0
115050	Weil der Stadt	10342800	30014400	608400	67600	811200	1081600
115051	Weil im Schoenbuch	9937200	15818400	0	0	0	270400
115052	Weissach	7165600	14939600	0	0	0	0
115053	Jettingen	6422000	11965200	67600	0	202800	2028000
115054	Grafenau	3109600	8247200	270400	0	270400	1216800
116004	Altbach	0	3109600	0	0	0	0
116005	Altdorf	0	3312400	0	0	0	0
116006	Altenriet	338000	3109600	0	0	0	0
116007	Baltmannsweiler	7368400	10816000	0	67600	270400	0
116008	Bempflingen	1284400	5205200	0	0	0	0
116011	Beuren	2771600	7503600	338000	1149200	67600	0
116012	Tosingen an der Teck	2366000	8382400	2906800	2839200	135200	67600
116014	Deizisau	0	4867200	0	135200	0	338000
116015	Denkendorf	3718000	9261200	0	0	202800	67600
116016	Dettingen unter Teck	5070000	8179600	405600	1216800	0	0
116018	Erkenbrechtsweiler	338000	4732000	135200	1690000	0	0
116019	Esslingen am Neckar	2704000	43399200	135200	0	202800	473200
116020	Frickenhausen	1081600	9869600	0	135200	0	67600
116022	Grobettlingen	405600	4191200	0	0	0	0
116027	Hochdorf	540800	6760000	0	0	0	0
116029	Holzmaden	135200	2704000	0	0	0	0
116033	Kirchheim unter Teck	6084000	34138000	405600	608400	0	0
116035	Koengen	2230800	9396400	67600	0	135200	540800
116036	Kohlberg	202800	4394000	0	0	0	0
116037	Lichtenwald	3650400	7300800	0	0	135200	0
116041	Neckartailfingen	811200	7571200	0	0	0	0
116042	Neckartenzlingen	1487200	7503600	0	0	0	0

ID	Commune	Reference yield < 60%	Excluded	High protection	Moderate protection	Low protection	No constraints
116043	Neidlingen	2366000	6895200	1149200	2433600	0	0
116046	Neuffen	3244800	10680800	1419600	1825200	0	0
116047	Neuhausen auf den Fildern	1892800	10342800	0	0	67600	0
116048	Notzingen	1081600	6557200	0	0	0	67600
116049	Nrtingen	6151600	39343200	0	338000	0	67600
116050	Oberboihingen	202800	5881200	0	0	0	0
116053	Ohmden	878800	4664400	0	67600	0	0
116054	Owen	1352000	5881200	811200	1892800	0	0
116056	Plochingen	1149200	9396400	0	0	0	0
116058	Reichenbach an der Fils	338000	7300800	0	0	0	135200
116063	Schlaitdorf	743600	6354400	0	0	0	0
116068	Unterensingen	3109600	4799600	0	0	0	0
116070	Weilheim an der Teck	3177200	15548000	2433600	5137600	0	67600
116071	Wendlingen am Neckar	202800	11492000	0	67600	0	270400
116072	Wernau (Neckar)	202800	10275200	0	0	0	405600
116073	Wolfschlugen	1622400	5610800	0	0	0	0
116076	Aichwald	2298400	11492000	0	0	608400	0
116077	Filderstadt	5340400	32110000	0	0	0	405600
116078	Leinfelden-Echterdingen	4867200	23660000	0	0	0	0
116079	Lenningen	4123600	23119200	3650400	8044400	2974400	67600
116080	Ostfildern	405600	22037600	0	0	0	270400
116081	Aichtal	9464000	14331200	0	0	0	67600
117001	Adelberg	3312400	5813600	0	0	0	473200
117002	Aichelberg	0	4123600	67600	135200	0	0
117003	Albershausen	270400	6084000	0	0	0	0
117006	Bad Ditzenbach	1960400	10816000	608400	6557200	3650400	1757600
117007	Bad Üeberkingen	2298400	17238000	1419600	3312400	0	67600
117009	Birenbach	0	2366000	0	0	0	67600
117010	Boehmenkirch	2839200	28932800	1690000	3312400	0	14196000
117011	Boertlingen	2095600	5881200	0	0	0	405600
117012	Boll	1690000	8652800	270400	338000	0	0
117014	Deggingen	2366000	12506000	2028000	3447600	405600	1960400
117015	Donzdorf	3718000	26093600	2028000	2163200	1622400	4596800
117016	Drackenstein	338000	3109600	0	0	2028000	473200
117017	Drnau	1014000	3988400	135200	202800	0	0
117018	Ebersbach an der Fils	4664400	20685600	0	0	67600	878800
117019	Eislingen/ Fils	3177200	13182000	0	0	67600	0
117020	Eschenbach	1014000	3515200	0	202800	0	0
117023	Gammelshausen	67600	2839200	0	270400	0	0
117024	Geislingen an der Steige	6354400	41574000	4732000	1487200	2974400	17981600
117025	Gingen an der Fils	2230800	6895200	67600	473200	0	202800
117026	Goeppingen	8923200	49415600	338000	135200	608400	473200
117028	Gruibingen	1419600	10951200	4461600	6151600	0	0
117029	Hattenhofen	946400	6962800	0	0	0	0
117030	Heiningen	2298400	9261200	67600	676000	0	135200
117031	Hohenstadt	811200	5813600	67600	0	5340400	0
117033	Kuchen	202800	7233200	0	1352000	0	135200

ID	Commune	Reference yield < 60%	Excluded	High protection	Moderate protection	Low protection	No constraints
117035	Mühlhausen im Töle	202800	4461600	202800	338000	946400	202800
117037	Ottenbach	1757600	7165600	0	67600	2704000	0
117038	Rechberghausen	67600	5881200	0	0	0	135200
117042	Salach	946400	6624800	0	135200	608400	67600
117043	Schlat	2568800	5678400	135200	1352000	0	0
117044	Schlierbach	2163200	8450000	0	0	0	202800
117049	Süen	3244800	8450000	0	676000	0	0
117051	Uhingen	7030400	17305600	0	202800	202800	270400
117053	Wöschenbeuren	3109600	8314800	0	0	1352000	540800
117055	Wangen	1622400	7571200	0	0	0	270400
117058	Wiesensteig	3988400	11289200	67600	4934800	2636400	0
117060	Zell unter Aichelberg	405600	5746000	0	0	0	0
117061	Lauterstein	2501200	10816000	1149200	338000	67600	8517600
118001	Affalterbach	2433600	7436000	0	0	0	135200
118003	Asperg	0	5881200	0	0	0	0
118006	Benningen am Neckar	0	4596800	0	0	0	0
118007	Besigheim	2163200	14398800	0	0	202800	0
118010	Boennigheim	6827600	12708800	0	0	135200	270400
118011	Ditzingen	6151600	23930400	0	0	0	0
118012	Eberdingen	10613200	15277600	0	0	0	0
118014	Erdmannhausen	1690000	6354400	0	0	202800	202800
118015	Erligheim	1216800	4934800	0	0	0	0
118016	Freudental	405600	2095600	67600	338000	0	0
118018	Gemmrigheim	473200	6760000	0	0	0	946400
118019	Gerlingen	3920800	13317200	0	0	0	0
118021	Groübottwar	7706400	15345200	0	0	1825200	135200
118027	Hemmingen	2298400	10140000	0	0	0	0
118028	Hessigheim	338000	3920800	0	0	0	676000
118040	Kirchheim am Neckar	743600	7368400	0	0	338000	676000
118046	Kornwestheim	0	13452400	0	0	0	1149200
118047	Loechgau	2704000	8450000	0	0	67600	0
118048	Ludwigsburg	2704000	39951600	0	0	270400	338000
118049	Marbach am Neckar	4732000	13858000	0	0	0	67600
118050	Markgroeningen	6354400	22240400	0	0	0	0
118051	Moeglingen	1081600	8247200	0	0	0	676000
118053	Mundelsheim	1622400	7503600	0	0	1216800	202800
118054	Murr	1216800	6557200	0	0	0	0
118059	Oberriexingen	1757600	5002400	0	0	0	1081600
118060	Oberstenfeld	7098000	13182000	67600	0	1081600	0
118063	Pleidelsheim	1216800	9193600	0	0	0	0
118067	Schwieberdingen	2028000	12844000	0	0	0	67600
118068	Sersheim	3650400	7841600	0	0	0	0
118070	Steinheim an der Murr	4732000	17711200	0	0	135200	608400
118071	Tamm	608400	8112000	0	0	0	0
118073	Vaihingen an der Enz	18454800	53268800	0	608400	0	946400
118074	Walheim	676000	5137600	0	0	67600	135200
118076	Sachsenheim	23322000	32583200	67600	1757600	67600	202800
118077	Ingersheim	743600	10748400	0	0	0	270400
118078	Freiberg am Neckar	270400	12776400	0	0	0	67600
118079	Bietigheim-Tosingen	6151600	24809200	0	0	0	67600

ID	Commune	Reference yield < 60%	Excluded	High protection	Moderate protection	Low protection	No constraints
118080	Korntal-Mnchingen	2636400	17914000	0	0	0	67600
118081	Remseck am Neckar	811200	21564400	0	0	67600	0
119001	Alfdorf	27580800	28797600	135200	0	12168000	0
119003	Allmersbach im Tal	946400	6895200	67600	0	135200	67600
119004	Alth³tte	3920800	11762400	135200	135200	2028000	135200
119006	Auenwald	4394000	13858000	0	202800	946400	67600
119008	Backnang	4732000	34340800	0	0	811200	135200
119018	Burgstetten	1487200	8247200	0	0	0	405600
119020	Fellbach	2366000	22578400	338000	67600	1690000	473200
119024	Groaerlach	10207600	12776400	135200	0	4326400	0
119037	Kaisersbach	14466400	8247200	135200	0	5813600	0
119038	Kirchberg an der Murr	1622400	10951200	67600	0	67600	473200
119041	Korb	608400	7300800	0	0	811200	202800
119042	Leutenbach	608400	12979200	0	0	135200	1284400
119044	Murrhardt	28527200	32380400	743600	67600	9058400	0
119053	Oppenweiler	7706400	11221600	0	0	1081600	0
119055	Plderhausen	13182000	12032800	0	67600	608400	0
119061	Rudersberg	11762400	23322000	67600	0	3380000	1014000
119067	Schorndorf	12708800	41303600	67600	1419600	338000	743600
119068	Schwaikheim	676000	8382400	0	0	0	0
119069	Spiegelberg	10748400	13587600	270400	270400	3244800	0
119075	Sulzbach an der Murr	19604000	18319600	135200	405600	1757600	0
119076	Urbach	8652800	11492000	67600	67600	338000	0
119079	Waiblingen	4056000	37315200	0	0	676000	540800
119083	Weissach im Tal	608400	11086400	0	473200	1892800	0
119084	Welzheim	8923200	17305600	270400	0	11018800	0
119085	Winnenden	3853200	21158800	67600	0	878800	1892800
119086	Winterbach	5948800	9802000	338000	202800	135200	405600
119087	Aspach	8314800	23457200	67600	0	2771600	338000
119089	Berglen	8247200	13384800	67600	0	878800	3244800
119090	Remshalden	811200	12303200	67600	0	1081600	1352000
119091	Weinstadt	4934800	24268400	135200	0	1554800	878800
119093	Kernen im Remstal	2028000	11289200	135200	0	811200	473200

Appendix 19: Area of Potential Sites for Wind Zones Development with Full Load Hours (Based on Minimum Wind Speed Data) Explored as without Constraints and Low Protection in the PACA Region

			Full load hours			
Id	Cantons	Area [ha]	Min	Max	Range	Mean
0404	BARCELONNETTE	3	672	672	0	672
0513	MONETIER-LES-BAINS (LE)	25	672	866	195	796
0514	ORCIERES	4	672	866	195	769
0432	MANOSQUE-SUD-EST	33	866	866	0	866
0497	DIGNE-LES-BAINS	1	866	866	0	866
0508	EMBRUN	4	866	866	0	866
0512	LARAGNE-MONTEGLIN	141	866	866	0	866
0518	SAINT-BONNET-EN-CHAMPSAUR	33	866	866	0	866
0607	CONTES	1	866	866	0	866
0608	COURSEGOULES	35	866	866	0	866
0520	SAINT-FIRMIN	32	672	1320	649	891
0612	LEVENS	31	672	1320	649	1021
0407	ALLOS-COLMARS	55	866	1320	454	990
0408	DIGNE-LES-BAINS-EST	34	866	1320	454	960
0410	FORCALQUIER	1695	866	1320	454	999
0412	LAUZET-UBAYE (LE)	26	866	1320	454	901
0414	MEES (LES)	1078	866	1320	454	1005
0415	MEZEL	985	866	1320	454	992
0420	REILLANNE	58	866	1320	454	1195
0426	SEYNE	37	866	1320	454	989
0505	BATIE-NEUVE (LA)	204	866	1320	454	891
0507	CHORGES	21	866	1320	454	1104
0509	GAP-CAMPAGNE	486	866	1320	454	1189
0523	TALLARD	251	866	1320	454	1036
0599	GAP	37	866	1320	454	903
0602	BAR-SUR-LOUP (LE)	21	866	1320	454	1191
0636	MANDELIEU-CANNES-OUEST	264	866	1320	454	1129
1301	AIX-EN-PROVENCE-NORD-EST	18	866	1320	454	1068
1302	AIX-EN-PROVENCE-SUD-OUEST	5	866	1320	454	1230
8307	COLLOBRIERES	21	866	1320	454	909
8308	COMPS-SUR-ARTUBY	18	866	1320	454	1068
8313	FREJUS	14	866	1320	454	931
8314	GRIMAUD	125	866	1320	454	986
8316	LORGUES	272	866	1320	454	988
8319	RIANS	1231	866	1320	454	1035
8322	SAINT-TROPEZ	64	866	1320	454	1249
8326	TAVERNES	301	866	1320	454	960
8410	CARPENTRAS-SUD	400	866	1320	454	1075
8415	MORMOIRON	1062	866	1320	454	1038
8418	PERNES-LES-FONTAINES	65	866	1320	454	957
8419	PERTUIS	190	866	1320	454	893
0610	GRASSE-SUD	9	1320	1320	0	1320
1308	CIOTAT (LA)	12	1320	1320	0	1320
8397	HYERES	1	1320	1320	0	1320
8401	APT	1	1320	1320	0	1320
8411	CAVAILLON	105	1320	1320	0	1320
8420	SAULT	1	1320	1320	0	1320
0409	ENTREVAUX	95	672	1969	1298	974

			Full load hours			
Id	Cantons	Area [ha]	Min	Max	Range	Mean
0422	SAINT-ANDRE-LES-ALPES	180	672	1969	1298	1428
0427	SISTERON	372	672	1969	1298	1094
0431	DIGNE-LES-BAINS-OUEST	865	672	1969	1298	988
0516	RIBIERS	182	672	1969	1298	965
0517	ROSANS	1108	672	1969	1298	1112
0522	SERRES	2045	672	1969	1298	1129
0524	VEYNES	377	672	1969	1298	1207
0402	ANNOT	217	866	1969	1103	1210
0405	BARREME	326	866	1969	1103	1315
0406	CASTELLANE	45	866	1969	1103	1284
0411	JAVIE (LA)	20	866	1969	1103	1294
0416	MOTTE-DU-CAIRE (LA)	178	866	1969	1103	1277
0419	PEYRUIS	452	866	1969	1103	980
0423	SAINT-ETIENNE-LES-ORGUES	1052	866	1969	1103	1166
0428	TURRIERS	266	866	1969	1103	1279
0430	VOLONNE	317	866	1969	1103	1029
0515	ORPIERRE	299	866	1969	1103	1172
0609	ESCARENE (L‘)	36	866	1969	1103	1308
0611	GUILLAUMES	48	866	1969	1103	1319
0620	ROQUESTERON	4	866	1969	1103	1694
0622	SAINT-ETIENNE-DE-TINEE	64	866	1969	1103	1268
0625	SAINT-VALLIER-DE-THIEY	527	866	1969	1103	1658
0694	GRASSE	180	866	1969	1103	1521
1327	PEYROLLES-EN-PROVENCE	1382	866	1969	1103	1206
1329	ROQUEVAIRE	130	866	1969	1103	1781
1334	TRETS	2618	866	1969	1103	1292
1335	ALLAUCH	24	866	1969	1103	1318
8301	AUPS	479	866	1969	1103	1417
8302	BARJOLS	2332	866	1969	1103	1114
8304	BESSE-SUR-ISSOLE	784	866	1969	1103	1072
8306	CALLAS	2216	866	1969	1103	1257
8309	COTIGNAC	976	866	1969	1103	938
8311	DRAGUIGNAN	584	866	1969	1103	1033
8317	LUC (LE)	68	866	1969	1103	1063
8323	SALERNES	425	866	1969	1103	1030
8325	SOLLIES-PONT	140	866	1969	1103	1396
8336	CRAU (LA)	127	866	1969	1103	1315
8337	MUY (LE)	352	866	1969	1103	1304
8404	BEAUMES-DE-VENISE	560	866	1969	1103	1385
8413	ISLE-SUR-LA-SORGUE (L‘)	314	866	1969	1103	1349
8414	MALAUCENE	410	866	1969	1103	1414
1306	BERRE-L‘ETANG	178	1320	1969	649	1958
1307	CHATEAURENARD	947	1320	1969	649	1872
1309	EYGUIERES	305	1320	1969	649	1942
1310	GARDANNE	31	1320	1969	649	1383
1312	LAMBESC	812	1320	1969	649	1361
1326	ORGON	619	1320	1969	649	1950
1332	SALON-DE-PROVENCE	51	1320	1969	649	1931
1348	CHATEAUNEUF-COTE-BLEUE	6	1320	1969	649	1861
1351	PELISSANNE	187	1320	1969	649	1570
1352	PENNES-MIRABEAU (LES)	56	1320	1969	649	1413

			Full load hours			
Id	Cantons	Area [ha]	Min	Max	Range	Mean
8320	ROQUEBRUSSANNE (LA)	155	1320	1969	649	1350
8423	AVIGNON-EST	25	1320	1969	649	1372
0652	MENTON-OUEST	3	1969	1969	0	1969
1303	ARLES-EST	11	1969	1969	0	1969
1311	ISTRES-NORD	25	1969	1969	0	1969
1331	SAINT-REMY-DE-PROVENCE	308	1969	1969	0	1969
1350	MARTIGUES-OUEST	5	1969	1969	0	1969
1395	ISTRES	65	1969	1969	0	1969
8497	AVIGNON	12	1969	1969	0	1969
0418	NOYERS-SUR-JABRON	609	672	2943	2271	1238
0403	BANON	2639	866	2943	2077	1734
0503	ASPRES-SUR-BUECH	450	866	2943	2077	1419
0621	SAINT-AUBAN	136	866	2943	2077	1406
8305	BRIGNOLES	1506	866	2943	2077	1412
8310	CUERS	799	866	2943	2077	1376
8312	FAYENCE	2921	866	2943	2077	1337
8321	SAINT-MAXIMIN-LA-SAINTE-BAUME	2416	866	2943	2077	1425
8406	BOLLENE	3201	866	2943	2077	1891
8409	CARPENTRAS-NORD	991	866	2943	2077	1390
8421	VAISON-LA-ROMAINE	1969	866	2943	2077	1425
8422	VALREAS	3106	866	2943	2077	1404
1333	TARASCON	2030	1320	2943	1622	1962
1396	MARTIGUES	42	1320	2943	1622	1977
8303	BEAUSSET (LE)	305	1320	2943	1622	1761
8405	BEDARRIDES	1328	1320	2943	1622	1776
8416	ORANGE-EST	1159	1320	2943	1622	1792
8417	ORANGE-OUEST	1511	1320	2943	1622	1992
8499	ORANGE	669	1320	2943	1622	1992
1328	PORT-SAINT-LOUIS-DU-RHONE	1349	1969	2943	973	2069
1349	ISTRES-SUD	373	1969	2943	973	2024
1398	ARLES	2798	1969	2943	973	1972
8318	OLLIOULES	4	1969	2943	973	2213

Appendix 20: Area of Potential Sites for Wind Zones Development with Full Load Hours (Based on Maximum Wind Speed Data) Explored as Without Constraints and Low Protection in the PACA Region

			Full load hours			
Id	Cantons	Area [ha]	Min	Max	Range	Mean
0514	ORCIERES	465	672	1320	1233	681
0402	ANNOT	316	672	2943	2271	1494
0403	BANON	2825	672	4364	3692	2488
0404	BARCELONNETTE	430	672	1320	649	728
0405	BARREME	530	672	2943	2271	1593
0406	CASTELLANE	70	672	2943	2271	1518
0407	ALLOS-COLMARS	262	672	1969	1298	930
0408	DIGNE-LES-BAINS-EST	194	672	1969	1298	998
0409	ENTREVAUX	333	672	2943	2271	958
0411	JAVIE (LA)	166	672	2943	2271	870
0412	LAUZET-UBAYE (LE)	158	672	1969	1298	921
0414	MEES (LES)	3322	672	1969	1298	1160
0415	MEZEL	1951	672	1969	1298	1198
0416	MOTTE-DU-CAIRE (LA)	1230	672	2943	2271	898
0418	NOYERS-SUR-JABRON	1012	672	4364	3692	1393
0420	REILLANNE	150	672	1969	1298	1210
0422	SAINT-ANDRE-LES-ALPES	274	672	2943	2271	1706
0426	SEYNE	346	672	1969	1298	795
0427	SISTERON	1058	672	2943	2271	1119
0428	TURRIERS	812	672	2943	2271	1170
0430	VOLONNE	589	672	2943	2271	1339
0431	DIGNE-LES-BAINS-OUEST	2635	672	2943	2271	1072
0497	DIGNE-LES-BAINS	182	672	1320	649	735
0502	ARGENTIERE-LA-BESSEE (L‘)	186	672	1320	649	754
0503	ASPRES-SUR-BUECH	482	672	4364	3692	2050
0504	BARCILLONNETTE	261	672	866	195	685
0505	BATIE-NEUVE (LA)	505	672	1969	1298	1117
0506	BRIANCON-NORD	6	672	672	0	672
0507	CHORGES	138	672	1969	1298	873
0508	EMBRUN	203	672	1320	649	727
0509	GAP-CAMPAGNE	499	672	1969	1298	1762
0511	GUILLESTRE	77	672	1320	649	701
0512	LARAGNE-MONTEGLIN	2111	672	1320	649	814
0513	MONETIER-LES-BAINS (LE)	81	672	1320	649	838
0515	ORPIERRE	686	672	2943	2271	1262
0516	RIBIERS	952	672	2943	2271	959
0517	ROSANS	1685	672	2943	2271	1391
0518	SAINT-BONNET-EN-CHAMPSAUR	217	672	1320	649	831
0520	SAINT-FIRMIN	101	672	1969	1298	1013
0521	SAVINES-LE-LAC	103	672	1320	649	929
0522	SERRES	2652	672	2943	2271	1487
0523	TALLARD	666	672	1969	1298	1077
0524	VEYNES	589	672	2943	2271	1482
0525	BRIANCON-SUD	160	672	866	195	676
0599	GAP	179	672	1969	1298	1011
0607	CONTES	20	672	1320	649	798
0609	ESCARENE (L‘)	42	672	2943	2271	1812
0611	GUILLAUMES	49	672	2943	2271	1943

			Full load hours			
Id	Cantons	Area [ha]	Min	Max	Range	Mean
0612	LEVENS	37	672	1969	1298	1422
0620	ROQUESTERON	6	672	2943	2271	1948
0621	SAINT-AUBAN	173	672	4364	3692	1822
0625	SAINT-VALLIER-DE-THIEY	555	672	2943	2271	2392
0626	SOSPEL	4	672	672	0	672
0629	VILLARS-SUR-VAR	1	672	672	0	672
8304	BESSE-SUR-ISSOLE	917	672	2943	2271	1558
8306	CALLAS	2440	672	2943	2271	1800
8308	COMPS-SUR-ARTUBY	26	672	1969	1298	1373
8309	COTIGNAC	1184	672	2943	2271	1382
8311	DRAGUIGNAN	1041	672	2943	2271	1360
8312	FAYENCE	3179	672	4364	3692	1932
8313	FREJUS	70	672	1969	1298	932
8316	LORGUES	390	672	1969	1298	1361
8323	SALERNES	546	672	2943	2271	1456
8337	MUY (LE)	389	672	2943	2271	1866
8401	APT	3	672	1969	1298	1169
8404	BEAUMES-DE-VENISE	655	672	2943	2271	1898
8409	CARPENTRAS-NORD	1196	672	4364	3692	1895
8410	CARPENTRAS-SUD	961	672	1969	1298	1276
8414	MALAUCENE	603	672	2943	2271	1781
8415	MORMOIRON	1807	672	1969	1298	1289
8418	PERNES-LES-FONTAINES	160	672	1969	1298	1230
8421	VAISON-LA-ROMAINE	1990	672	4364	3692	2120
0410	FORCALQUIER	1908	866	1969	1103	1470
0419	PEYRUIS	496	866	2943	2077	1451
0423	SAINT-ETIENNE-LES-ORGUES	1399	866	2943	2077	1605
0432	MANOSQUE-SUD-EST	80	866	1320	454	1286
0608	COURSEGOULES	48	866	1320	454	1283
0618	PUGET-THENIERS	1	866	866	0	866
0622	SAINT-ETIENNE-DE-TINEE	81	866	2943	2077	1732
8301	AUPS	520	866	2943	2077	2048
8302	BARJOLS	2540	866	2943	2077	1644
8305	BRIGNOLES	1538	866	4364	3498	2091
8310	CUERS	834	866	4364	3498	2020
8317	LUC (LE)	113	866	2943	2077	1413
8319	RIANS	1453	866	1969	1103	1523
8326	TAVERNES	521	866	1969	1103	1366
8498	CARPENTRAS	3	866	1320	454	1018
0602	BAR-SUR-LOUP (LE)	21	1320	1969	649	1784
0636	MANDELIEU-CANNES-OUEST	273	1320	1969	649	1684
0694	GRASSE	180	1320	2943	1622	2270
1301	AIX-EN-PROVENCE-NORD-EST	18	1320	1969	649	1609
1302	AIX-EN-PROVENCE-SUD-OUEST	6	1320	1969	649	1753
1327	PEYROLLES-EN-PROVENCE	1423	1320	2943	1622	1792
1329	ROQUEVAIRE	130	1320	2943	1622	2661
1334	TRETS	2653	1320	2943	1622	1924
1335	ALLAUCH	24	1320	2943	1622	1969
1354		81	1320	2943	1622	1861
8307	COLLOBRIERES	30	1320	1969	649	1364
8314	GRIMAUD	131	1320	1969	649	1484

			Full load hours			
Id	Cantons	Area [ha]	Min	Max	Range	Mean
8320	ROQUEBRUSSANNE (LA)	160	1320	2943	1622	1992
8321	SAINT-MAXIMIN-LA-SAINTE-BAUME	2416	1320	4364	3043	2127
8322	SAINT-TROPEZ	64	1320	1969	649	1868
8325	SOLLIES-PONT	141	1320	2943	1622	2078
8336	CRAU (LA)	131	1320	2943	1622	1945
8406	BOLLENE	3209	1320	4364	3043	2820
8413	ISLE-SUR-LA-SORGUE (L')	314	1320	2943	1622	2014
8419	PERTUIS	199	1320	1969	649	1356
8422	VALREAS	3111	1320	4364	3043	2094
0610	GRASSE-SUD	9	1969	1969	0	1969
1306	BERRE-L'ETANG	178	1969	2943	973	2926
1307	CHATEAURENARD	947	1969	2943	973	2797
1308	CIOTAT (LA)	12	1969	1969	0	1969
1309	EYGUIERES	305	1969	2943	973	2901
1310	GARDANNE	31	1969	2943	973	2064
1312	LAMBESC	812	1969	2943	973	2030
1326	ORGON	619	1969	2943	973	2914
1332	SALON-DE-PROVENCE	51	1969	2943	973	2885
1333	TARASCON	2030	1969	4364	2395	2932
1348	CHATEAUNEUF-COTE-BLEUE	6	1969	2943	973	2781
1351	PELISSANNE	187	1969	2943	973	2344
1352	PENNES-MIRABEAU (LES)	56	1969	2943	973	2108
1396	MARTIGUES	42	1969	4364	2395	2953
8303	BEAUSSET (LE)	305	1969	4364	2395	2629
8397	HYERES	1	1969	1969	0	1969
8405	BEDARRIDES	1328	1969	4364	2395	2651
8411	CAVAILLON	105	1969	1969	0	1969
8416	ORANGE-EST	1159	1969	4364	2395	2676
8417	ORANGE-OUEST	1511	1969	4364	2395	2976
8420	SAULT	1	1969	1969	0	1969
8423	AVIGNON-EST	25	1969	2943	973	2047
8499	ORANGE	669	1969	4364	2395	2975
0652	MENTON-OUEST	3	2943	2943	0	2943
1303	ARLES-EST	11	2943	2943	0	2943
1311	ISTRES-NORD	25	2943	2943	0	2943
1328	PORT-SAINT-LOUIS-DU-RHONE	1349	2943	4364	1421	3088
1331	SAINT-REMY-DE-PROVENCE	308	2943	2943	0	2943
1349	ISTRES-SUD	373	2943	4364	1421	3023
1350	MARTIGUES-OUEST	5	2943	2943	0	2943
1395	ISTRES	65	2943	2943	0	2943
1398	ARLES	2798	2943	4364	1421	2946
8318	OLLIOULES	4	2943	4364	1421	3298
8497	AVIGNON	12	2943	2943	0	2943

Appendix 21: Land Use Classification for Installing PV Systems in Poland, Germany and France Based on CLC 2006

LABEL3	CLC CODE	Poland	France	Germany
Continuous urban fabric	111	unsuitable	unsuitable	unsuitable
Discontinuous urban fabric	112	unsuitable	unsuitable	unsuitable
Diffused construction (fr. Bati duffus)	113*	-	unsuitable	-
Industrial or commercial units	121	unsuitable	unsuitable	unsuitable
Road and rail networks and associated land	122	unsuitable	unsuitable	unsuitable
Port areas	123	unsuitable	unsuitable	unsuitable
Airports	124	unsuitable	unsuitable	unsuitable
Mineral extraction sites	131	favorable	favorable	favorable
Dump sites	132	favorable	favorable	favorable
Construction sites	133	unsuitable	unsuitable	unsuitable
Green urban areas	141	unsuitable	unsuitable	unsuitable
Sport and leisure facilities	142	unsuitable	unsuitable	unsuitable
Non-irrigated arable land	211	suitable-conflict	suitable-conflict	suitable-conflict
Permanently irrigated land	212	-	suitable-conflict	-
Rice fields	213	-	conflict-possible	-
Continious area of land parcels	214*	-	conflict-possible	-
Vineyards	221	-	conflict-possible	conflict-possible
Fruit trees and berry plantations	222	conflict-possible	conflict-possible	conflict-possible
Olive groves	223	-	conflict-possible	-
Lavendis	224*	-	suitable-conflict	-
Pastures	231	suitable-conflict	suitable-conflict	suitable-conflict
Annual crops associated with permanent crops	241	suitable-conflict	suitable-conflict	suitable-conflict
Complex cultivation patterns	242	suitable-conflict	suitable-conflict	suitable-conflict
Land principally occupied by agriculture, with significant areas of natural vegetation	243	suitable-conflict	suitable-conflict	suitable-conflict
Agro-forestry areas	244	conflict-possible	conflict-possible	conflict-possible
Broad-leaved forest	311	unsuitable	unsuitable	unsuitable
Coniferous forest	312	unsuitable	unsuitable	unsuitable
Mixed forest	313	unsuitable	unsuitable	unsuitable
Natural grasslands	321	suitable-conflict	suitable-conflict	suitable-conflict
Moors and heathland	322	-	unsuitable	unsuitable
Sclerophyllous vegetation	323	suitable-conflict	suitable-conflict	suitable-conflict
Transitional woodland-shrub	324	conflict-possible	conflict-possible	conflict-possible
Beaches, dunes, sands	331	unsuitable	unsuitable	unsuitable
Bare rocks	332	-	favorable	-
Sparsely vegetated areas	333	-	favorable	-
Burnt areas	334	-	favorable	-
Glaciers and perpetual snow	335	unsuitable	unsuitable	unsuitable

LABEL3	CLC CODE	Poland	France	Germany
Wetlands	400*	-	unsuitable	-
Inland marshes	411	-	unsuitable	-
Peat bogs	412	-	unsuitable	-
Salt marshes	421	-	unsuitable	-
Salines	422	-	unsuitable	-
Intertidal flats	423	unsuitable	unsuitable	-
Water courses	511	unsuitable	unsuitable	unsuitable
Water bodies	512	unsuitable	unsuitable	unsuitable
Coastal lagoons	521	-	unsuitable	unsuitable
Estuaries	522	-	unsuitable	unsuitable
Sea and ocean	523	-	unsuitable	unsuitable

Appendix 22: Site Conditions for Ground-Mounted PV Installations in the Stuttgart Region

	Distance	Individual examination	Dataset
Motorways	150		(ESRI 2007; NAVTEQ 2009)
Roads	150		(ESRI 2007; NAVTEQ 2009)
Railway lines	150		(ESRI 2007; NAVTEQ 2009)
Land previously used for economic, transport, housing or military purposes		x	No data
Agricultural land of poor performance		x	(WaBoA 2007)
Cultural assets	outside		
Castle. Cultural relict	500	x	(Geofabrik 2010)
Monuments	100	x	(Geofabrik 2010)
Particularly protected biotopes (§ 32 NatSchG BW und §30a WaldG BW) Waldbiotope. Wetflächen und Heideflächen)		(x)	(LUBW 2009)
Nature monuments		x	(LUBW 2009)
Areas of special protection of birds - Natura 2000 (SPA)		(x)	(LUBW 2009)
Areas of special protection of habitats - Natura 2000 FFH			(LUBW 2009)
NGS			(LUBW 2009)
Biotope § 32 BbgNatSchG		(x)	
Water protection in zone I		x	(LUBW 2009)
Moderate protected areas			
Landscape conservation area (LGS)		x	(LUBW 2009)
Landscape with sensible components		x	(LUBW 2009)
Nature park		x	(LUBW 2009)
Water protection in zone II and III	200	x	(LUBW 2009)
Streams	50		(WaBoA 2007)
Inland water	50		(WaBoA 2007)
Flood area			(LUBW 2009)
Forest			(LUBW 2009)
Wind parks		x	

Appendix 23: Potential Growing Area and of Energy Crops under Different Constraints Explored within the Biogas Power Plants Zones in the Kujawsko-Pomorskie Region

Biogas power plant sites	Protected areas-Erosion	Protected areas	Share of protected	Water scarcity-Erosion	Erosion	Share erosion	Water Scarcity	Share of water scarcity	Arable land no constraints	Share of no constraints	Total land in zones
	ha	ha	%	ha	ha	%	ha	%	ha	%	ha
1	0	23	0.6	0	0	0.0	0	0.0	3547	99.4	3570
2	1351	2683	77.3	0	27	0.5	0	0.0	1155	22.1	5216
3	219	143	12.3	0	802	27.2	0	0.0	1783	60.5	2947
4	959	2125	50.5	248	138	6.3	2143	39.2	488	8.0	6101
5	1135	1440	40.4	0	1327	20.8	0	0.0	2473	38.8	6375
6	1	133	2.1	197	0	3.0	3556	57.9	2590	40.0	6477
7	1325	1447	55.4	0	858	17.2	0	0.0	1370	27.4	5000
8	250	0	7.1	1292	1	36.7	1976	92.9	0	0.0	3519
9	0	3239	99.6	0	0	0.0	0	0.0	13	0.4	3252
10	0	484	9.0	0	0	0.0	3409	63.2	1501	27.8	5394
11	422	1490	30.0	0	347	5.4	0	0.0	4112	64.5	6371
12	748	835	38.5	0	125	3.0	0	0.0	2401	58.4	4109
13	317	222	7.5	0	46	0.6	0	0.0	6624	91.9	7209
14	229	498	12.2	0	1641	27.6	0	0.0	3570	60.1	5938
15	0	0	0.0	0	0	0.0	2005	30.3	4623	69.7	6628
16	1348	485	27.1	0	2339	34.6	0	0.0	2594	38.3	6766
17	0	846	15.1	0	0	0.0	4766	84.9	0	0.0	5612
18	1896	2667	29.2	0	2379	15.2	0	0.0	8671	55.5	15613
19	1244	17316	97.7	0	14	0.1	0	0.0	431	2.3	19005
20	59	123	7.5	453	0	18.7	1784	92.5	0	0.0	2419
21	0	0	0.0	675	0	11.9	2219	50.8	2800	49.2	5694
22	3047	5183	58.7	2046	25	14.8	1773	27.2	1942	13.9	14016
23	0	145	2.3	0	0	0.0	4164	66.6	1939	31.0	6248
24	657	216	13.1	0	771	11.6	0	0.0	5008	75.3	6652
25	119	2156	16.9	0	857	6.4	0	0.0	10332	76.7	13464
26	4	250	4.6	0	286	5.2	0	0.0	4946	90.2	5486
27	0	4936	21.8	0	0	0.0	0	0.0	17683	78.2	22619
28	133	3070	14.5	0	3775	17.1	0	0.0	15146	68.5	22124
29	1147	1738	20.3	0	1843	12.9	0	0.0	9504	66.8	14232
30	869	390	18.8	0	144	2.2	0	0.0	5290	79.0	6693
31	0	685	9.8	64	0	0.9	6253	90.2	0	0.0	7002
32	337	952	18.9	800	0	11.7	4733	81.1	0	0.0	6822
33	552	3383	32.7	0	296	2.5	0	0.0	7809	64.9	12040
34	1110	5919	32.8	807	0	3.8	9193	46.7	4400	20.5	21429
35	1455	5355	40.4	0	2179	12.9	0	0.0	7858	46.6	16847
36	1	1106	6.6	140	224	2.2	2235	14.2	13071	77.9	16777
37	0	2162	7.7	0	0	0.0	24748	88.3	1129	4.0	28039
38	0	4649	23.6	0	0	0.0	6662	33.8	8387	42.6	19698
39	2384	7364	71.0	0	1256	9.1	0	0.0	2724	19.8	13728
40	714	1550	17.2	432	373	6.1	3638	30.8	6491	49.2	13198
41	0	5796	23.1	9	0	0.0	18705	74.7	528	2.1	25038
Total	24032	93204	27.6	7163	22073	6.9	103962	26.1	174933	41.1	425367

Appendix 24: Description of the Corine Land Cover Class (CLC 2006)

CLC classes	CLC	Description
Continuous urban fabric	111	Most of the land is covered by structures and the transport network building, roads and artificially surfaced areas cover more than 80% of the total surface, including: · urban center types and dense ancient suburbs where buildings form a continuous and homogeneous fabric; · public services or local governments and commercial/industrial activities with their connected areas inside continuous urban fabric when their surface is less than 25 ha; · interstices of mineral areas; · parking lots, concrete or asphalt surfaces; · transport network; · small squares, pedestrian zones, yards; · urban greenery (parks and grass areas) amounting to 20% of the polygon area; · unvegetated and vegetated cemeteries less than 25 ha located inside continuous urban fabric
Discontinuous urban fabric	112	Most of the land is covered by structures building, roads and artificially surfaced areas associated with vegetated areas and bare soil, which occupy discontinuous but significant surfaces, including: · private housing estates, residential suburbs made of individual houses with private gardens and/or small squares; · scattered blocks of residential flats, hamlets, small villages where numerous unmineralised interstitial spaces (gardens, lawns) can be distinguished; · large blocks of flats where green spaces, parking areas and adventure playgrounds cover significant surface area; · transport network; · sport area smaller than 25 ha included within discontinuous urban fabric; · buildings with educational, health care and production functions and market places smaller than 25 ha included within this class; · unvegetated and vegetated cemeteries smaller than 25 ha included within discontinuous urban fabric; · public utilities/communities surfaced areas less than 25 ha; · holiday cottage houses are included in 112 if infrastructures like houses, road network are visible in the satellite image; they must also be connected to built-up areas;
Diffused construction (fr Bati duffus)	113*	This class established by CRIGE for the French CLC classification. More information on website http://wwwcrige-pacaorg/frontblocks/donnees/select_LOT_DONNEESasp

Industrial or commercial units	121	Artificially surfaced areas (with concrete, asphalt, tarmacadam, or stabilized, e.g. beaten earth) without vegetation occupy most of the area, which also contains buildings and/ or vegetation, including: · research and development establishments; · security and law and order services (fire stations, penal establishments); · company benefit schemes (old people's home, convalescent homes, orphanages, etc); · stud farms, agricultural facilities (co-operatives, state farm centers, livestock farms, living and exploitation buildings); · exposition sites, fair sites; · nuclear power plants, military barracks, testing pistes, test fields, biological waste water treatment plants, water houses, transformers; · large shopping and exposition centers; · hospitals, spas,; · universities, schools; · parking lots; · abandoned industrial sites and by-products of industrial activities where buildings are still present; · water retention dam and hydroelectric dam in total >25 ha; · telecommunication networks (relay stations for TV, telescopes, radar stations
Road and rail networks and associated land	122	Motorways, railways, including associated installations (stations, platforms, embankments) of minimum width of 100 m
Port areas	123	Infrastructure of port areas, including quays, dockyards and marinas
Airports	124	Airport installations: runways, buildings and associated land
Mineral extraction sites	131	Areas with open-pit extraction of industrial minerals (sandpits, quarries) or other minerals (opencast mines). Includes flooded gravel pits, except for river-bed extraction
Dump sites	132	Landfill or mine dump sites, industrial or public
Construction sites	133	Spaces under construction development, soil or bedrock excavations, earthworks
Green urban areas	141	Areas with vegetation within urban fabric Includes parks and cemeteries with vegetation
Sport and leisure facilities	142	Camping grounds, sports grounds, leisure parks, golf courses, racecourses, etc. Includes formal parks not surrounded by urban zones
Non-irrigated arable land	211	Cultivated areas regularly ploughed and generally under a rotation system. Cereals, legumes, fodder crops, root crops and fallow land Includes flower and tree (nurseries) cultivation and vegetables, whether open field, under plastic or glass (includes market gardening). Includes aromatic, medicinal and culinary plants. Excludes permanent pastures and meadows (also on disused arable land)
Permanently irrigated land	212	Crops irrigated permanently and periodically, using a permanent infrastructure (irrigation channels, drainage network) Most of these crops could not be cultivated without an artificial water supply Does not include sporadically irrigated land
Rice fields	213	Land developed for rice cultivation, surfaces regularly flooded
Continuous area of land parcels	214*	This class established by CRIGE for the French CLC classification. More information on website http://wwwcrige-pacaorg/frontblocks/donnees/select_LOT_DONNEESasp
Vineyards	221	Areas planted with vines
Fruit trees and berry plantations	222	Parcels planted with fruit trees or shrubs: single or mixed fruit species, fruit trees associated with permanently grassed surfaces Includes chestnut and walnut groves

Olive groves	223	Areas planted with olive trees, including mixed occurrence of olive trees and vines on the same parcel
Lavenders	224*	This class established by CRIGE for the French CLC classification. More information on website http://wwwcrige-pacaorg/frontblocks/donnees/select_LOT_DONNEESasp
Pastures	231	Dense, predominantly grass cover, of floral composition, not under a rotation system, mainly used for grazing
Annual crops associated with permanent crops	241	Non-permanent crops (arable lands or pasture) associated with permanent crops on the same parcel
Complex cultivation patterns	242	Small parcels of diverse annual crops, pasture and/or permanent crops
Land principally occupied by agriculture. with significant areas of natural vegetation	243	Areas principally occupied by agriculture, interspersed with significant natural areas
Agro-forestry areas	244	Annual crops or grazing land under the wooded cover of forestry species
Broad-leaved forest	311	Vegetation formation composed principally of trees, including shrub and bush under stories, where broad-leafed species predominate (Presence of conifers 0 - 10%)
Coniferous forest	312	Vegetation formation composed principally of trees, including shrub and bush understories, where coniferous species predominate (Presence of conifers 91 - 100%)
Mixed forest	313	Vegetation formation composed principally of trees, including shrub and bush understories, where broad-leafed and coniferous species co-dominate
Natural grasslands	321	Low productivity grassland. Often situated in areas of rough uneven ground. Frequently includes rocky areas, briars, and heathland
Moors and heathland	322	Vegetation with low and closed cover, dominated by bushes, shrubs and herbaceous plants (heath, briars, broom, gorse, laburnum, etc.)
Sclerophyllous vegetation	323	Bushy sclerophyllous vegetation: a dense vegetation association composed of numerous shrubs associated with siliceous soils in the Mediterranean environment
Transitional woodland-shrub	324	Bushy or herbaceous vegetation with scattered trees. Can represent either woodland degradation or forest regeneration/colonization
Beaches. Dunes, sands	331	Beaches, dunes and expanses of sand or pebbles in coastal or continental, including beds of stream channels with torrential regime
Bare rocks	332	Scree, cliffs, rocks and outcrops
Sparsely vegetated areas	333	Includes steppes, tundra and badlands. Scattered high-attitude vegetation
Burnt areas	334	Areas affected by recent fires, still mainly black
Glaciers and perpetual snow	335	Land covered by glaciers or permanent snowfields
Inland marshes	411	Low-lying land usually flooded in winter, and more or less saturated by water all year round

Peat bogs	412	Peatland consisting mainly of decomposed moss and vegetable matter May or may not be exploited
Salt marshes	421	Vegetated low-lying areas, above the high-tide line, susceptible to flooding by sea water. Often in the process of filling in, gradually being colonized by halophilic plants
Salines	422	Salt-pans, active or in process Sections of salt marsh exploited for the production of salt by evaporation. They are clearly distinguishable from the rest of the marsh by their segmentation and embankment systems
Intertidal flats	423	Generally unvegetated expanses of mud, sand or rock lying between high and low water-marks
Water courses	511	Natural or artificial water-courses serving as water drainage channels. Includes canals. Minimum width to include: 100 m
Water bodies	512	Natural or artificial stretches of water
Coastal lagoons	521	Unvegetated stretches of salt or brackish waters separated from the sea by a tongue of land or other similar topography. These water bodies can be connected with the sea at limited points, either permanently or for parts of the year only
Estuaries	522	The mouth of a river within which the tide ebbs and flows
Sea and ocean	523	Zone seaward of the lowest tide limit

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Abstract

Renewable energy sources (RES) can undoubtedly contribute to protecting the environment, conserving fossil fuels, diversification of the fuel supply, as well as enhance regional and rural development opportunities. However, every energy production process affects the environment and involves the use of land resources. The risks linked to intensified RES use should be adequately taken into consideration in any planning process, as ill-conceived energy policies may adversely impact land and local ecosystems, and lead to increases in public spending (EEA 2006; OECD 2008).

As the expansion of alternative energy sources is a compulsory political target of the EU, their development must harmonize the preservation of natural elements and balance multiple land use functions, which is of primary importance in those European countries characterized by a low factor of land per inhabitant compared to other continents.

The development of a regional RES-mix which is to the largest possible extent sustainable requires both guidance and cooperation at different administrative levels, as well as stimulation through different measures. At the same time, the top-down regulations should not discourage potential investors, but encourage growth in the field of RES which in turn should positively impact environmental and socio-economic systems.

Therefore, before designing any instruments for the regulation of both RES and land-use, the most essential step is to explore investment possibilities in different contexts.

The primary objective of this work was to develop a transparent framework that may help to explore a regional RES portfolio and to highlight emerging problems associated with RES deployment.

Above all, the aim of the present study was to develop a uniform approach based on equivalent data sources (e.g. statistics, digital layers), resulting in comparable outcomes at the European regional level. With respect to alternative energy sources, the biomass, wind and solar energy sources were taken into consideration.

This approach was applied to three European regions: the Kujawsko-Pomorskie Voivodship in Poland, the Stuttgart Region in Germany, the Region of Provence-Alpes-Côte d'Azur in France. Given the differences between these three regions as to the variables and datasets relevant for this study, it was not possible to analyze them by a uniform approach.

Supported by a geographic information system (GIS), the study allows for locating and quantifying the potentials of biomass, wind and solar as well as for exploring some of the potential planning issues associated with their development.

Different GIS-based approaches were developed to assess the conventional and energy crops' respective cultivation potential under pedoclimatic requirements confronted with regional conditions. Attention was also given to agricultural waste and woody residues from forests, vineyards and orchards. The technical and economic biogas generation potential was assessed under various scenarios of biogas feedstock-mix in the context of the quantity of land required for biogas crop production. The objective of the assessment was to evaluate potential replacement processes of current crop cultivation patterns, which could be feasible on a legal and economic basis.

In the case of wind energy, the objective was to identify conditions for the expansion of wind power through a methodology that includes both regional specific characteristics and regulation constraints.

Ground associated photovoltaic units are not compatible with agricultural land use functions, so that their uncontrolled development may increase the pressure on land use. Therefore, the objective of this study was to develop an approach that would make it possible to evaluate the technical and economic potential of ground-based PV systems under the political framework conditions in the three study regions including policy incentives, spatial planning instruments and spatial confinement under land-use prioritization.

In the final stage, the verbal-argument analysis was carried out based on local factors in order to explore the land-users' decisions on potential locations for renewable energy usage. The potential variations in RES use from the investors' perspective were contrasted against an energy-mix which would balance

the trade-off between contradictory land-use and environmental objectives.

The study finds that sustainable energy development ought not to be left to an unregulated market, but requires suitable guidance and management by the administrative authorities, so as to manage the conflict over land resources and to balance the actions of private investors with the public interest. The developed approach makes it possible to explore not only the technical and economic potential of alternative energy production, but it contributes to a deeper understanding of how different RES production options compete with each other for land resources and with other uses of land. However, the results are not enough on which to base a decision on the appropriate RES portfolio. The eventual decision emerges form social discourse colored by varying degree of acceptance of alternative energy sources. This transparent approach would thus help to build the public acceptance of an optimal renewable energy-mix that balance the interests of stakeholder.

Zusammenfassung

Erneuerbare Energien können positiv zur Schonung der fossilen Energieträger sowie zum Umweltschutz, zur Energieversorgungssicherheit und zur Entwicklung des ländlichen Raumes beitragen. Jeder Prozess der Energieerzeugung hat jedoch erhebliche Auswirkungen auf die Umwelt und erhöht den Bedarf an der Ressource Land. Deshalb müssen die Risiken, die mit intensivierter Nutzung von regenerativen Energien verbunden sind, untersucht werden, da sonst die Energiepolitik negative Auswirkungen auf die Landnutzung, auf lokale Ökosysteme und sowie auf sozioökonomische Systeme haben kann (EEA 2006; OECD 2008).

Da der Ausbau von regenerativen Energiequellen eine verbindliche politische Vorgabe der EU ist, muss die Nutzung im Einklang mit der Bewahrung der Umwelt und den vielfältigen Landnutzungsfunktionen erfolgen. Dies ist vor allem in den europäischen Ländern mit einer geringen landwirtschaftlichen Fläche pro Einwohner von zentraler Bedeutung.

Die Bestimmung eines geeigneten regionalen Mix an regenerativen Energien bedarf einer sektorübergreifenden Kooperation auf verschiedenen Verwaltungsebenen in der Phase der Planung und bei der Durchführung von Maßnahmen. Gleichzeitig sollten die von den Verwaltungen vorgegebenen Normen und Regularien potentielle Investoren nicht abschrecken, sondern Anreize setzen, um den Ausbau von regenerativen Energien und die damit verbundenen positiven Auswirkungen auf die Umwelt und sozioökonomische Systeme zu fördern.

Bevor man entsprechende Strategien und Fördermaßnahmen entwickelt, ist es daher notwendig, die absehbaren Wirkungen von regenerativen Energien in verschiedenen Kontexten zu analysieren.

In diesem Zusammenhang liegt das Hauptaugenmerk der vorliegenden Arbeit auf der Erstellung eines nachvollziehbaren regionalplanerischen Unterstützungsinstruments, um ein besseres Verständnis für regionalspezifische Wirkungen eines alternativen Energie-Mix, bezogen auf die Flächenfunktionen und mögliche sozioökonomische Zielkonflikte, zu ermitteln. Zusätzlich dazu war ein Teilziel die Entwicklung einheitlicher Methoden, basierend auf gleichwertigen Datenquellen (z.B. statistischen Daten und Geodaten), die zu vergleichbaren Ergebnissen auf regionaler Ebene z.B. für die europäischen Staaten führen. Bezüglich des Energieträgers wurden die Biomasse, die Photovoltaik und die Windenergie ausgewählt.

Das Verfahren wurde für drei EU-Regionen angewandt: die Kujawsko-Pomorskie Woiwodschaft in Polen, die Region Stuttgart in Deutschland und die Provence-Alpes-Côte d'Azur Region in Frankreich. Durch die unterschiedlichen Datenquellen und -formate in den drei Region wurden verschiedene Variablen identifiziert, die einem solchen Ansatz zugrunde zu legen sind. Die Entwicklung eines einheitlichen Ansatzes war wegen uneinheitlicher Datengrundlagen allerdings nicht umsetzbar, so dass datenabhängige regionalspezifische Verfahren anzuwenden sind.

Die Methodologie besteht aus einem schrittweisen Vorgehen zur Potentialermittlung erneuerbarer Energien, das eine nachvollziehbare Untersuchung der technischen und ökonomischen Potentiale und Nutzungsmöglichkeiten von Biomasse-, Wind- und Solarenergie ermöglicht. Die Analysen wurden mit Hilfe des geographischen Informationssystems (GIS), das für die Quantifizierung der Potentiale unter raumbezogenen Aspekten ideal geeignet ist, durchgeführt.

Das GIS-gestützte Verfahren wurde entwickelt, um die Potentiale von konventionellen Anbaupflanzen und nachwachsenden Rohstoffen (NaWaRo) unter spezifischen bodenkundlichen und klimatischen Bedingungen zu untersuchen. Daneben wurde der Fokus auf die landwirtschaftlichen Abfälle und holzartige Reststoffe aus Wäldern, Wein- und Obstgärten gelegt. Das technische und ökonomische Biogaspotential wurde unter verschieden Biogasrohstoffeinsätzen und im Zusammenhang mit dem benötigen Flächenpotenzial für einen Anbau von nachwachsenden Rohstoffen analysiert. Hierbei war es das Ziel, die potenziellen Verdrängungsprozesse des derzeitigen ernährungsorientierten Pflanzenanbaues durch NaWaRo unter den gesetzlichen und wirtschaftlichen Rahmenbedingungen herauszuarbeiten.

Im Fall der Windenergie war es das Ziel, die Bedingungen für den Ausbau der Windkraft zu identifizieren und eine Methode zu entwickeln, die die regionalen Besonderheiten und raumbezogenen Beschränkungen berücksichtigt.

Bei der Betrachtung der Nutzung von Solarenergie sind aufgrund von Skaleneffekten eher die großflächigen Photovoltaik (PV)-Anlagen auf Freiflächen von zunehmendem Interesse. Jedoch sind die PV-Freiflächenanlagen mit keiner landwirtschaftlichen Landnutzungsfunktion kompatibel, so dass ihr unkontrollierter Ausbau zu Landnutzungskonflikten führen kann. Bezogen auf diesem Hintergrund lag der Fokus auf der Entwicklung eines Ansatzes zur Analyse des technischen und wirtschaftlichen Solarenergiepotenzials unter Berücksichtigung der politischen Rahmenbedingungen, der raumplanerischen Planungsziele und der räumlichen Beschränkungen unter Landnutzungsprioritätensetzung in den drei Regionen.

Im letzten Schritt wurde anhand der Standortfaktoren eine verbal-argumentative Analyse der Entscheidungen von Landnutzer über die potentiellen Standorte für die Nutzung regenerativer Energien durchgeführt. Die potentiellen Varianten der Nutzung erneuerbarer Energien aus der Sicht der Investoren wurden einem Energie-Mix, der die Landnutzungskonflikte und -ansprüche optimieren soll, gegenübergestellt.

Die Ergebnisse der Studie lassen darauf schließen, dass eine nachhaltige Entwicklung der erneuerbaren Energien nicht dem unregulierten Markt überlassen werden kann, sondern ein Mitwirken der öffentlichen Träger erfordert, um die Konflikte vor allem um die Landressourcen zu regulieren und Maßnahmen von Investoren untereinander und mit den öffentlichen Interessen abzuwägen. Deshalb besteht eine Möglichkeit mit der entwickelten Methodik, die Konflikte zwischen den Akteuren um die Landressourcen frühzeitig zu erkennen und vorausschätzen. Mit dem nachvollziehbaren planerischen Vorgehen kann man auch die gesellschaftliche Akzeptanz eines optimalen regionalen Energie-Mix erhöhen.

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Renewable energy sources (RES) can undoubtedly contribute to environmental protection, conservation of fossil fuels, and diversification of the fuel supply. However, every energy production process affects the environment and involves the use of land resources. Therefore, the risks linked to intensified RES usage should be adequately taken into consideration, as ill-conceived energy policies may adversely impact land and local ecosystems and lead to growing public and social expenditures. The objective of this work was to develop a transparent framework that provides for a better understanding of the regional-specific RES-mix related to land use functions and socio-economic trade-offs. Supported by a geographic information system (GIS), the study allows for locating and quantifying the potential of wind, biomass and solar energy as well as for exploring some of the territorial conflicts associated with their potential development. The approaches developed were applied to three European regions: the Kujawsko-Pomorskie Voivodship in Poland, the Stuttgart Region in Germany, and the Region of Provence-Alpes-Côte d'Azur in France.

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