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Municipalities as change agents? Reconsidering roles and policies in local energy sector-coupling

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ABSTRACT

Municipalities play an important role in the energy transition process by implementing and advancing policy measures for climate protection at the local level. However, available options and technologies for the integration and defossilization of electricity, heating, industry and mobility are diverse and complex. Considering the interplay of societal action, technical options, individual values, decision-making processes, and available policy measures to defossilize the energy system, the municipality takes on a critical role in coordination and creating transparency. Addressing these challenges in the theoretical light of the Multi-Level Perspective (MLP) and the Policy Mix Approach (PMA), the authors develop a classification system of policy instruments and measures for municipal action in fostering sector coupling activities. The main argument is that municipalities dispose of considerable scope of action with several roles they can play in order to orchestra the transition. The study relies empirically on desk research as well as workshops with local actors in three municipalities in the field of sector coupling in Germany. The aim was to identify multidimensional potentials for municipal action in order to develop effective and efficient policy packages by developing a classification system. The results contribute to a structured basis for the discourse on energy transition in municipalities and are a central building block for a horizontal and vertical coordination in the development of a sector coupling strategy.

1. Introduction

A significant reduction in energy demand, the expansion of renewable energies and increased sector coupling are key prerequisites for the success of the energy transition and thus for reaching the climate targets set out in the Paris Climate Agreement. Municipalities are key players in this challenging transformation of the energy system towards a climate-friendly and sustainable energy system. There are basically two reasons for this: first, municipalities and in particular cities are areas of high energy consumption. Heating, traffic, trade, industry and craft are centered in local, more densely populated municipal areas [1–3]. Second, given the local character of heat, for instance, municipalities are crucial change agents for the heat decarbonization, and the energy transition in general [4].

We understand municipalities in a wider sense as having agency via municipal administration, municipal policy-making, and municipal owned corporations — thus the scope of action refers to executive, regulative and economic power. Municipalities are strongly connected and networked with many relevant local stakeholders, their citizens, business and industry, and hence have the opportunity to create, shape and implement the intended change. Accordingly, a crucial question is about the options for action and the factual power to shape local policies for change. Within this paper we argue that local municipalities dispose of considerable scope of action due to their executive, regulative and economic power in order to support the transformation. The argument is based on a twofold perspective: first, the agency of municipalities goes beyond its mere executive implementation power as a solely state subordinated vicarious agent if one considers the different roles municipalities can and do play. Second, the strength of municipal transformation agency is based on a great variety of different policy measures which ideally sum up to a coherent policy package of continuous pinpricks understood as a niche management strategy [5–7].

We will illustrate the argument using a case study of local energy sector coupling. Energy sector coupling intends to strongly connect and couple the energy sectors (i.e., industry, transport, building, and electricity) by means of direct or indirect electrification with the aim to reduce carbon dioxide (CO_2) emissions. However, available options and technologies for sector integration and coupling activities are diverse

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and complex [8]. Besides complex technology solutions, there are socio-economic challenges for their implementation, such as barriers to behavioral change, regulatory and economic constraints, conflicts of use (roof photovoltaics vs. greening, geothermal vs. drinking water), complex funding structures, and a diverse set of actors involved [9,10]. Thus, reaching a full energy transition at local level is challenging but remarkable progress is possible provided full scope of municipal agency is used — the argument we aim to demonstrate.

The research connects to two theoretical approaches that are particularly suitable for the analysis: (1) the *Multi-Level Perspective* (*MLP*), originally developed by Frank Geels [11], and (2) the *Policy Mix Approach* (*PMA*) [12,13]. The MLP approach focuses on the role of decentralized innovations and challenges regarding their development and diffusion as a niche strategy towards an existing regime. That gives insights on how several complementary policy actions may develop their transformative power as continuous decentralized pinpricks for change in order to challenge the prevailing regime. The PMA is suitable as it analyzes policy action that can support progress on municipal sector coupling through an integrated approach, using policy packages in a bundle to overcome the relevant constraints at local level [14–16]. Empirically, we carried out desk research for a sector coupling policy inventory, and stakeholder workshops for inventory evaluation. The empirical findings were analyzed in the light of the two theoretical approaches to identify the main challenges regarding sector coupling activities in municipalities. In a second step, we developed a classification system for policy measures to systemize, classify and cluster our findings. The classification system was developed on the basis of the policy inventory.

The paper is organized as follows: Section 2 provides background information by pointing out the key issues of municipal sector coupling, and summarizing the theoretical approaches of Multi-Level Perspective (MLP), and the Policy Mix Approach (PMA). Section 3 sets out the research approach, as well as the data and the methods used. In Section 4, the main results are presented with first outlining municipal challenges, second presenting the classification system, third illustrating several classified policy measures, and last introducing clustering options. Finally, Section 5 discusses the main findings and draws some short conclusions.

2. Background

2.1. Municipal energy sector coupling

The concept of sector coupling has recently gained importance and is discussed intensively [17,18]. Sector coupling encompasses socio-technical options to decarbonize applications in the end-use energy sectors (households, transport, industries, commerce/trade/services) through the "substitution of fossil energy sources with electricity generated predominantly from renewable sources or with other renewable energy sources and sustainable forms of energy use in new cross-sector applications or through increased use of known cross-sector applications" [19]. This integrated, holistic view on sector coupling promises synergies and new impetus for the transformation of the energy system for greater climate compatibility and sustainability. Key objectives of sector coupling are a) the reduction of greenhouse gas emissions through the substitution of fossil energy sources, and b) the provision of flexibility options and system services. So far, however, there is no uniform definition and use of the term in politics, science and industry. In a narrower understanding, only the conversion of (surplus) electricity generated from renewable energies into gases or liquids is included in the definition [19]. In a broader understanding, almost all aspects of the interconnection of energy-relevant sectors are included [19,20]. In addition to the technical perspective, sector coupling is emphasized as a socio-technical challenge in transformation processes [21–23].

2.2. The Multi-Level Perspective (MLP) approach

The Multi-Level Perspective (MLP) by Geels [11] is a prominent framework for understanding and analyzing transformative change in large socio-technical environment. It assumes that changes within established regimes result from innovations emerging from niches [24]. Change, in the context of MLP, describes the replacement of one socio-technical regime by another in response to interactions between different system levels [25,26]. MLP distinguishes three main levels of analysis: the regime, the niche, and the landscape. The 'socio-technical regime' describes the dominant set of rules that different social groups adhere to and that provide guidance to the different actors within the regime. The regime also defines internal technological pathways, which reinforce the socio-technical regime [11]. Consequently, the regime is reluctant to change, acting as a retention mechanism for radical innovations. The regime can encompass various dimensions, e.g., technology, user practices and application domains, symbolic meanings of technology, infrastructure, industry structure, policy and techno-scientific knowledge. The 'niche' is where radical innovations that aim at challenging the socio-technical regime emerge from. It provides early-stage innovations a protected space to develop independently from regular market mechanisms [24,27]. Within the niche, innovations can evolve and gradually stabilize into dominant designs until finally diffusing into the socio-technical regime and become mainstream [27]. 'Landscape' metaphorically describes all exogenous factors that are difficult to influence and change only slowly over time [25]. They define the structural context in which the regime and the niche are embedded [11,25]. 'Landscape' developments comprise a heterogenous set of factors that can influence the regime and the niche by encouraging innovations and triggering change or by consolidating the existing regime. The MLP framework is typically applied to analyze socio-technical transformations at the national level, e.g. [28]. However, there are a few recent studies that consider more localized regime-level units of analysis by focusing on the municipal level [29].

The key aspect of the MLP for our study is the fact that target-oriented transformation (as it is the case with energy transition towards climate neutrality) originates from socio-technical niche innovations which need to find their way in overtaking the regime to stabilize. From that end, two aspects are of major relevance for our study. First, comprehensive transformation change – such as the energy transition – needs to rely not on just one (radical) niche innovation, but must comprise a serious bunch of reinforcing measures and innovations to be successful. Second, from an agency perspective both regime stabilizers and niche innovation supporters are most probably present in municipal institutions and decision-making bodies.

2.3. The Policy Mix Approach (PMA)

Efficient and effective policy mixes and bundles are one way to overcome target-oriented transformation challenges and materialize change. In other words: no decision–no transition. Thus, the Policy Mix Approach is a suitable and widely applied framework among scholars. Recent research has shown that combined interventions and measures are required to achieve different targets, to mitigate mutually unintended effects and enhance benefits [30–33]. It is therefore a question of tailor-made policy packages that are able to implement targeted transformation paths and that are continuously adapted to changes in the political, societal and economic environment. The policy instruments usually address various policy fields and targets. In the debate, several typologies of individual policy instruments exist. They have been categorized as the following: technology push or demand-pull policies [34]; the triad of economic, regulatory and informational instruments [12]; also labelled as carrots, sticks and sermons [35]; or as contributing to the creation of new or the destruction of old regimes [36,37]. Besides, the policy mix literature has deduced core dimensions (i.e., coherence, consistency, congruence, credibility and comprehensiveness) which are most relevant for an effective policy mix [38–42]. To our knowledge the policy mix literature has not focused intensively on the discussion and negotiation processes taking place in the implementation at the municipal level [43,44].

The PMA approach is appropriate for our research since it addresses the issue of orchestrating target-oriented transformation through supporting policies. Strategic niche management as a policy strategy is based on adequate policy packages that encourage and stimulate socio-technical change from niches to mainstream. Without supporting policies, promising change innovations can hardly prevail. For our research, we rely on PMA as the starting point for elaborating on municipal challenges for sector coupling initiatives, and the analysis of existing sector coupling measures and policies.

2.4. Leading research questions and novelty of the research approach

What is lacking so far, is a discussion on sector coupling with regards to agency on municipal level which is the main focus of the paper. In our understanding, municipal sector coupling locates the concept of sector coupling at the level of municipalities. Sector coupling comprises socio-technical options for decarbonizing applications in the final energy sectors (households, transport, industry, commerce/trade/services) through the use of predominantly renewably produced electricity via direct and indirect electrification. In a broader understanding, the use of so-called other renewable energy sources refers to both no wind and no photovoltaic technologies and that is, for instance geothermal energy, biomass and sustainable energy generation from waste, wastewater or waste heat which may play a crucial role for the heat transition on municipal level. Sector coupling options are intended firstly, from a climate protection perspective, to minimize greenhouse gas emissions by substituting fossil energy sources and; secondly, from an energy system perspective, to increase flexibility and system efficiency for better integration of fluctuating renewables. The "municipal" level can manage sector coupling from different angles of agency that is their executive, legislative, and economic power in interaction with local stakeholders and the specific local framework conditions. The municipality can take on different roles to fulfil the rationales, i.e., consumer and role model, planner and regulator, supplier and provider as well as advisor and promoter [21,22]. Municipalities as change agents can be actively involved in one or more roles.

Against the background of the above-outlined state-of-the-art of sector coupling, MLP, and PMA, we define the following research questions:

- What are specific challenges and the scope for action of municipalities in the field of sector coupling?
- Which concrete measures for sector coupling action are available?
- How to systemize, classify, and cluster these measures for coherent policies?

In doing so, our research approach differs from previous research in the following aspects: First, to our knowledge, there has been no systematic and comprehensive examination of policy instruments at municipal level addressing the sector integration in the energy system. Existing studies rather consider the topic of sector coupling at the overall energy system level and do not specifically address the roles of municipalities, e. g. [45–47]. Second, in the area of the Multi-Level Perspective approach there is a lack of analyzing promising niche innovation strategies and policies encouraged and set by municipal agency. The agency matter of municipalities also addresses the question of the potentially contradictory role of municipalities as being both change agents and resistance agents. Third, the policy mix literature does not comprehensively address the issue of local policy-making and implementation, nor is it coherent in clustering and packaging of policies. We hence conclude that the analysis of the scope for design and provision of coherently bundled policy measures serving as niche management strategy is insufficient.

3. Methods

We used an explorative and qualitative research design due to a lack of systematically conducted empirical research analyzing the development of policies and results in the field of municipal sector coupling. An explorative design is reasonable if an object is under-researched and only basic knowledge of causes and effects is available [48–51]. The same applies to the use of a qualitative approach because hypothesis-testing methods require systematic knowledge to sharpen a set of clear hypotheses.

Based on extensive desk research and a workshop series, we developed a classification system for municipal policy measures that aims at steering sector coupling activities. Applying a transdisciplinary approach, we included three German municipalities in the research carrying out a workshop series, i.e., the cities of Walldorf, Freilassing, and Berlin. In comparison, we integrated a small-town municipality with the particularity of two global business players (Walldorf), a small town with rather an industrial production focused socio-economic structure (Freilassing), and the uniqueness of the metropolis of Berlin.

The *city of Walldorf* is located in southwestern Germany in the south of the Rhine-Neckar district in Baden-Württemberg. With approximately 16,000 inhabitants, Walldorf belongs to the small-town category. The economic structure of Walldorf is characterized by two large employers, so that Walldorf has about as many jobs as inhabitants. The city's largest employer is the internationally active software company SAP (13,000 employees locally), and Heidelberger Druckmaschinen AG producing large-scale printing devices (5600 employees locally). With Stadtwerke Walldorf, Walldorf has an independent municipal utility company that supplies the community with electricity, heat, gas and water as a local supplier.

The *city of Freilassing* is located in the Upper Bavarian district of Berchtesgadener Land. With approximately 17,000 inhabitants and an area of 14.82 km^2, Freilassing also falls into the category of a small town. As a location for industry and commerce, Freilassing is considered the economically strongest municipality in the district. This is favored by the good infrastructure as well as the geographic location of the city, including the neighboring economic area of Salzburg. Freilassing has 1900 commercial enterprises and 330,000 m^2 of commercial and industrial space. The urban development concept adopted in 2012 was expanded in 2016 and includes the areas of urban planning, economic development, transport, energy and climate protection as well as landscape and ecology.

Finally, *Berlin* as a major city with 3.85 million inhabitants in northeastern Germany disposes of an ambitious energy concept. In many areas, Berlin is already well positioned; for example, with a length of more than 1900 km, Berlin has one of the largest district heating networks in Europe. In addition, despite economic and population growth, energy consumption and CO_2 emissions declined in every year from 2016 to 2020.

The set of methods we applied was based on a four-step procedure.

In a first step, relevant challenges for municipal sector coupling as summarized in Section 4 have been derived by carrying out six stakeholder and expert workshops between 2021 and 2022. The workshop series consisted of two workshops in each of the three municipalities and gathered 10–15 participants coming from institutions such as the municipal administration, municipal utilities, local companies and other associations. The results were then evaluated by authores with the two theories MLP and PMA.

In a second step, a comprehensive literature-based desk research analysis was carried out. A total of 35 relevant studies and publications published between 2011 and 2020 were identified using the following search keywords: municipal sector coupling, climate protection concept, "Mobilitätswende", "Stromwende", "Wärmewende", E-Mobility, Power-to-Heat, industrial sector coupling, Power-to-X and "kommunale

Sektorkopplung" (English: municipal sector coupling). The sample includes climate protection concepts as well as studies from the field of socio-technical and techno-economic energy research.

In a third step, the classification system was inductively derived and then tested and adapted in the course of user tests with municipal representatives to systemize, classify and cluster the findings. In this context, the term "measure" is used for an individual action that can be undertaken by a municipality. Measures can either be political, administrative or entrepreneurial in nature. Furthermore, two dimensions have been distinguished: a) a municipality enables other actors to implement sector coupling measures and b) a municipality implements sector coupling measures itself. The classification system was finalized on a comprehensive empirical analysis using different types of municipalities as exemplary prototypes in the field of sector coupling in Germany.

In the fourth step, we demonstrate the practical application of the catalog of measures when compiling a policy package by illustrating an exemplary measures portfolio for the heat sector.

4. Results

Based on comprehensive desk research and a workshop series with the three participating municipalities, we gathered knowledge on municipal challenges for encouraging sector coupling activities, and set up an inventory of one hundred policy measures in the field of energy system sector coupling at the local and regional level (the full list is displayed in the appendix). On the basis of the inventory we developed a multidimensional policy measure classification system. The classification system integrates several characteristics deduced from the literature (e.g. MLP, PMA) and workshops which helped to systemize the broad scope of identified energy transition-related policies and interventions. The classification system illustrates two important indications: first, from a scientific point of view, it reveals the broad potential of municipalities to shape and implement energy transition policies which sum up to a policy package of continuous pinpricks. Second, from a policy-makers perspective, the classification inventory helps local decision-makers to choose and shape tailor-sized policy packages adapted to specific needs of their municipality.

In the following we will depict the main results with an overview on major sector coupling challenges and the work on the policy measure classification system. We first present the socio-technical action frame where sector coupling challenges are placed. Then, we present the full set of categories and characteristics used in the classification system. Thereafter, we classify the policy measures inventory according to this system. Finally, we demonstrate the full range of a comprehensive policy package with an energy sector reference to heat and mobility transition.

4.1. Identify sector coupling challenges: the socio-technical action frame

Municipalities as change agents for sector coupling towards integrated energy systems based on renewable energies face considerable challenges that include economic, social, political, technical, financial, systemic and communicative aspects. The main challenges identified are depicted in Table 1.

As a result, sector coupling activities face a great variety of policy problems. Legal hurdles refer to a lack of legal authority and the bureaucratic structures. Thus, the executive and administrative role as subordinated to the state comes into play. Sector coupling is an in-between and interdepartmental policy topic where environmental, construction, climate, traffic and transportation and other authorities, as well as municipal energy, gas and water suppliers, and the municipal housing sector are addressed. Acceptance with the introduction of new technologies including cost burdens are often crucial issues. In addition, energy technologies and infrastructures often require long-term planning and implementation processes, have trade-off issues with use and land competition, and show use case specific challenges such as

Table 1
Challenges in introducing the concept of municipal sector coupling.

No.	Challenge	Manifestation & explanation
1	Legal hurdles	Lack of legal authority in the municipality & bureaucratic structures
2	Complexity in interdepartmental coordination processes in municipalities	Due to its complexity as a cross-cutting issue, sector coupling requires active action by the municipality through coordination and agreement across all departments as well as dialogue and inclusion in the implementation of other stakeholders and local civil society. Interaction of different actors is time-consuming and sometimes fraught with conflict
3	Lack of public acceptance & challenges in communicating sector coupling activities	Lack of acceptance of renewable energy technologies or other infrastructure interventions in the community, social compatibility of a resulting renewable energy system (e.g. high electricity price in winter due to demand for heating and low PV-production), challenges to communicate municipal sector coupling activities as they not all directly relate to problems in the municipality itself, but to higher levels/global problems (climate change)
4	Complexity of the technical options and challenges in energy supply	Substitution of fossil energy sources with renewable ones is extremely challenging in terms of quantity; lock-in effects and long investment cycles, e.g., in the area of gas infrastructure or heating networks; various priority fields of action: some actors describe heat for buildings as priority, other focus on transport or industry depending on local problem structure
5	Lack of proper infrastructure for applied technologies	Renewable energy supply may require appropriate infrastructure which needs to be adapted or newly installed (e.g., power grid extension, long-distance and local heating network).
6	Costs & resources	Excessive investment costs, funding as a frequently requested measure, lack of resources and funding, long amortization periods, lack of resources (workforce, data, materials)
7	Difficult and lengthy planning and implementation of community-wide measures	Heterogenous technical requirements: e.g., different heating needs depending on building efficiency or production processes and technological dependencies (roof renovation before PV can be installed, energetic renovation of efficient use of heat pumps); expansion and strengthening of power networks and expansion of renewable electricity, long-term planning cycles e.g., for heating networks
8	Competition for land and use	Ground-mounted PV, wind turbines, agriculture, industrial area, residential area; groundwater vs geothermal energy, rooftop PV vs green roofs, and differing potentials of renewable energy
9	Various use case specific challenges	For instance, budgetary law problems regarding contracting; regulatory challenges for using waste heat; bureaucratic burden, regulation of municipal companies

Source: Own elaboration based on workshops with municipalities and desk research [21,22,52,53].

budgetary, regulatory, and bureaucratic problems.

4.2. Systemize the diversity: categories and characteristics

The multidimensional policy measure classification system was deduced from a policy measure inventory gathering one hundred sector coupling measures and interventions on municipal level. It classifies each measure by eight main categories with a different number of characteristics each. Fig. 1 shows the overall composition of the set of categories surrounding sector coupling measures and interventions.

The *role of municipality* is a key category for local energy transition policies. There is still no clear picture whether local and regional actors and policy-makers considerably contribute to energy transition on local level. Some scholars argue that regional actors often face limited opportunities for creating change due to the lack of regulatory power, limited administrative capacity, and dependence on linkages with higher policy arenas to be able to scale up [44,54–56]. However, we argue that local actors play a critical role considering that municipalities with their diverse fields of political, administrative and economic activities can play several roles in pushing the energy transition. The Climate Alliance [21] identified four roles for municipalities in the field of climate protection which can also be transferred into the context of sector coupling. Municipalities act as consumers and role models, planners and regulators, suppliers and providers, as well as advisors and promoters. These roles can be taken by municipal administration, politics, and enterprises. Considering the multi-faceted actor perspective, complementary energy transition activities at the local level provide an opportunity for change through various complementary measures and interventions by different municipal actors. Thereby, the classification of measures according to these roles can support the diversification of policy bundles and facilitate the communication with third parties (see Table 1, challenge 3).

The category *sector and field of action* relates to the common areas of energy consumption. It differentiates the four main sectors 'mobility', 'heating, 'industry' and 'electricity'. A key objective of sector coupling is to integrate these sectors mainly through direct and indirect electrification initiatives. The main target sectors in Germany are mobility, which is currently dominated by fossil fuels, and the heat sector in which oil and natural gas are the main energy sources. These fields of action are familiar to the decision-makers in the current regime. So, the category supports the transition of the regime by linking the common mindset to

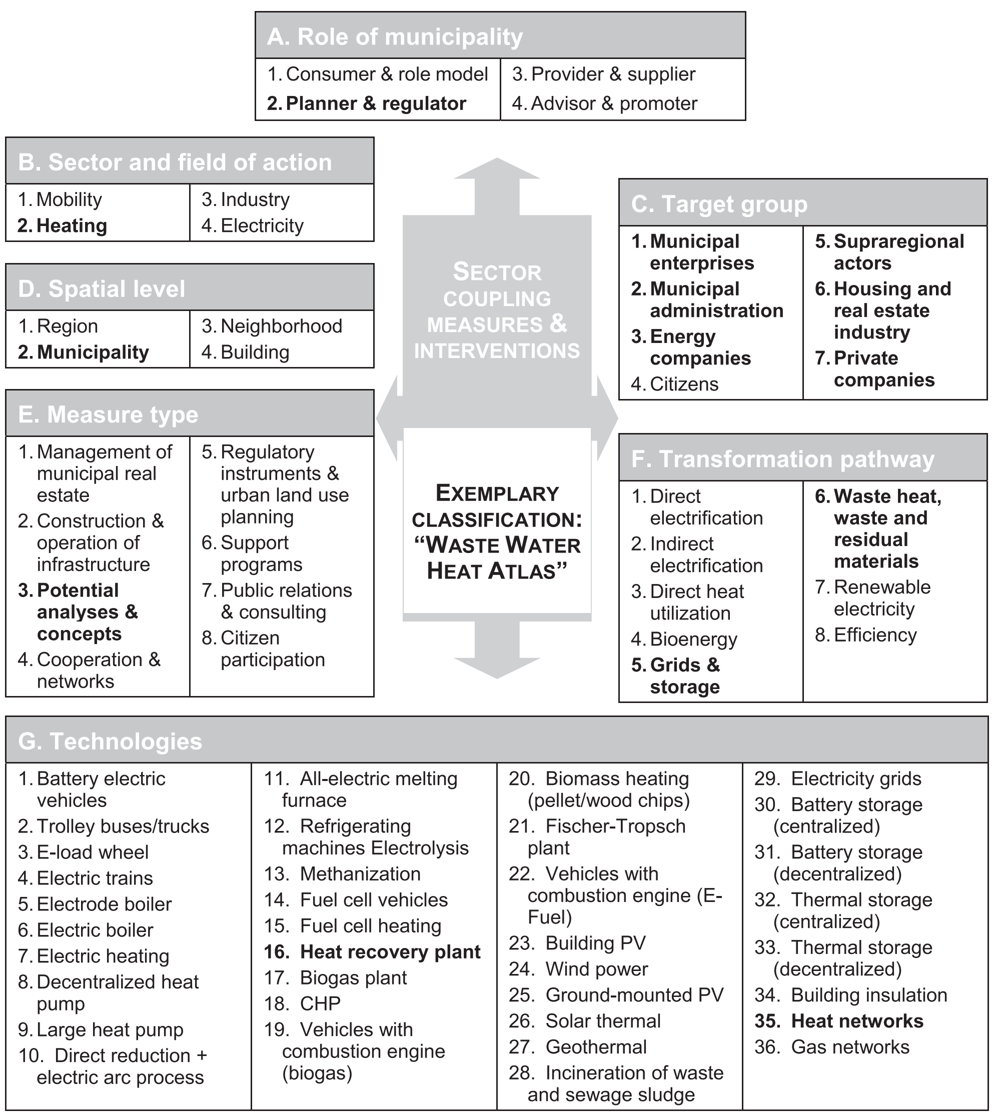


Fig. 1. The sector coupling classification system — with the measure 'waste water heat atlas' exemplarily classified (illustrated in bold variables). Source: own elaboration.

the niche's innovative solution approaches (see Table 1, challenge 4).

The *target group* categorizes main addressees of action implementation. It differentiates municipal decision-makers both in administration and local public enterprises. Local public utilities are key actors within the energy system. The economic spectrum of municipal enterprises is mostly limited to tasks of general interest. The fields of action include supply and disposal tasks (municipal utilities and waste disposal companies), mobility and infrastructure (local transport and transport companies) and social facilities (hospitals, nursing homes), and housing associations. Further target groups comprise the private business sector with energy companies, the housing and real estate industry, private companies, and, on a household level, private citizens, and supra-regional actors. In particular the challenges 2, 3 and 6 (see Table 1) are addressed by this category by clarifying the main addressee for the measure. Moreover, target group specification facilitates spreading the efforts induced by a policy mix among several actors.

The *spatial level* considers the spatial reference of energy coupling measures. It differentiates region, municipality, neighborhood and buildings. Depending on the energy sector focus, the spatial level differs. The heat sector, for instance, is building- and neighborhood-centered both on private household and industry level. The mobility sector, by contrast, has larger spatial effects with reference to mobility patterns of passenger and freight transport. This category responds to the challenges 4, 6 and 7 (see Table 1).

Several *measure types* cluster the inventory of specific sector coupling activities. In total eight measure types were identified. Management of municipal real estate properties and construction and operation of infrastructure relate to provision and maintenance of public goods and services. Elaboration of potential analysis and concepts refers to planning processes of public sector projects and schemes while regulatory instruments and specifically urban land use planning and support programs cover the field of local policy-making. Encouraging cooperation and network building, providing public relation and consultancy services, and fostering citizen participation relates to the area of indirect steering approaches. This classification helps to manage complexity (see Table 1, challenges 2 and 4).

Transformation pathways towards sector coupling relates to the main coupling strategies of energy sector integration. The category comprises direct and indirect electrification, the use of renewable electricity and other options of renewables such as direct and indirect heat utilization (long distance heating, geothermal heat, waste heat), and activities in the area of energy grids and storage, and efficiency. The category addresses whether certain kinds of technologies should be forced or not. By increasing the transparency of this question, it can support the coherence of a policy package (see Table 1, challenges 8 and 9).

The last category specifies *technologies of sector coupling* which are used to implement sector coupling measures. It is not surprising that a vast amount of different single technologies was found in the sector coupling inventory. The set of technologies refers to alternative drives (e.g., electric bikes, vehicles and trains, fuel cells), provision of renewable energies (e.g., wind and solar, heat recovery and biogas plants, e-fuels, solar thermal and geothermal), electric heating systems (e.g., boilers, heat pumps), processing technologies (e.g., electrolysis, methanization, Fischer-Tropsch), grid and infrastructure (e.g., heat, gas and electricity network), and storage capacities (e.g., battery and thermal storage). Like the transformation pathways the category demonstrates the technological focus of measures. Moreover, it addresses challenge 5 (see Table 1) since different technologies need different resources.

4.3. Classify the diversity: the scope of the policy measure inventory

The inventory of sector coupling measures revealed an astonishing width and depth of local and regional options to encourage the niches sector coupling technologies or to displace the current energy regime. For the purpose of illustration, we classified eight policy measures according to our classification system in Table 2. The table shows that local energy transition policies need to be viewed from a multidimensional perspective that goes beyond the mere administrative power of a municipality as the lowest level of state authority. A short description of four practical implementations of sector coupling measures from Table 2 will outline this argument.

The municipality of Barßel in Lower-Saxony contracted external expertise for *energy consulting for public properties*. Co-funded by federal state resources, the consulting contract delivered recommendations for renovating several public buildings (i.e., sport center, schools, town hall). Based on the energy refurbishment concept, the administrative committee decided at the end of November 2017 to refurbish the aging sports hall to the standard of a "KfW Efficiency Building 70". This included renewal of the entire building shell including the floor slab, replacing the old ventilation system with an efficient one with heat recovery, optimization of the leaky windows and the inefficient heat supply, and installment of a photovoltaic system on the roof to supply electricity. Energy costs were calculated to be reduced from 24,000 euros to 11,500 euros/year. The financing of the investment was supported by the KfW subsidy "IKK-Energieeffizient Bauen und Sanieren" ("IKK-Energy-efficient Construction and Renovation"). To conclude, the energy consultancy emphasized the municipality's role as consumer and role model (category A; variable 1, according to Table 2 abbreviated from here on: A: 1), and addressed as an integrated approach all energy sectors and fields of action (B: 1–4) with a wide range of technologies covered (G: ns). As target groups, both municipal enterprises and administration itself were addressed (C: 1, 2). The exemplary measure focusses on potential analysis and concepts as planning instruments (E: 3) to set a good example with its public properties.

In 2013, the city of Dresden passed its *integrated energy and climate protection concept* which foresees a per capita reduction of 5.8 tons $CO_{2\text{-eq}}$ in the areas of electricity, heat and mobility. The plan has been updated in 2021. The dominant approach of the plan/document is the emphasis on the primary role of the municipality as planner and regulator (A: 2) within the energy sectors (B: 1–4). All target groups are addressed (C: all) while the measure type refers to potential analysis and concept (E: 3). Due to its holistic approach, all pathway types and a wide range of specific technologies are considered (F: all; E: ns). The aim is to update the catalog of measures, establish a comprehensive participation process to involve Dresden's diverse stakeholders, develop various implementation paths to achieve the target by 2030 and the target of climate neutrality well before 2050, and to set up a monitoring and controlling process. Fields of action are classified into energy-efficient urban development in existing and new buildings, efficient provision of renewable energies for electricity and heat use, promoting climate-friendly behavior in everyday life, material cycles and contributions of CO_2 sinks, planning and changing Dresden sustainably, and developing transport in a climate-friendly way.

Another example is *public utility concession takeover from private energy enterprises*. Supported by Städtische Werke AG (the municipal energy supplier in Kassel), several municipalities in the Kassel city area have founded municipal utilities and taken over concessions of private energy supply networks for electricity, gas, and district heating. Together with a number of municipalities bordering Kassel urban area, the Städtische Werke AG set up municipal utilities to bid for the concessions of the local energy supply networks. The plan was that these municipal utilities would also manage these in the second step, before growing into a fully-fledged energy supplier later on. There are several local benefits with this strategy of what was called re-municipalization: the surpluses generated by the power grid benefit the municipal coffers and could be used for municipal investments. The citizens benefit from inexpensive products, increasing municipal added value and the preservation of jobs. Here, the provider's and supplier's role of municipalities (A: 3) is emphasized with a focus on heat and electricity (B: 1, 4). Target groups are mainly municipal enterprises and administration (C: 1, 2) while the measure type refers to construction and operation of

Table 2
Illustration of eight exemplary measures.

Example of eight measures from the full inventory	A: Role of municipality	B: Sector & field of action	C: Target group	D: Spatial level	E: Measure type	F: Transformation pathway	G: Technologies
• *Energy consulting for public properties	1	1, 2, 3, 4	1, 2	1, 2, 3, 4	3	ns	ns
• Procurement of alternative drive public vehicles	1	1	1, 2	2	1	1, 2, 4	1, 2, 14, 19, 22
• *Integrated energy and climate protection concept	2	1, 2, 3, 4	all	2	3	all	ns
• **Waste water heat atlas	2	2	1, 2, 3, 5, 6, 7	2	3	5	16, 35
• *Public concession takeover from energy enterprises	3	2, 4	1, 2	2	2	5	29, 35, 36
• Integrated P2G system in residential complex	3	2	1, 3, 4, 6, 7	4	2	2	12, 13, 18
• *Mobility consulting for citizens	4	1	4, 7	2	7	1, 2, 4, 8	1, 3, 14, 19, 22
• Energy consulting for citizens	4	2	4, 7	2	7	1, 8	5, 6, 7, 8, 9, 15, 16, 18, 20, 33, 34, 35

Explanation: numeration of variables within categories according to Fig. 1; all = addresses all variables; ns = not specifiable; * = measure described in text; ** = exemplary measure classification displayed in Fig. 1.
Source: Own elaboration.

energy infrastructure (E: 2). The main technologies addressed are thus the grids for power, heat and gas (G: 29, 35, 36) which belongs to the transformation pathway covering grids and storage (F: 5).

A fourth measure example is *mobility consulting for citizens*. The city of Tübingen offers regular consultations on sustainable mobility and other energy topics (e.g., energy efficient house renovation, e-bike testing, switch to green electricity). The offer is free of charge, takes place in individual on-site or phone consultations, and is part of the climate protection campaign "Tübingen macht blau" (English: "Tübingen turns blue"). Consulting is offered by several experts of the city of Tübingen such as the local municipal utility, the agency for climate protection, staff from environmental and climate protection units, or the non-governmental organization *Viva con Agua*. Here, the municipality takes on the role as advisor and promoter (A: 4) in the field of mobility (B: 2) targeting both citizens and private companies (C: 4, 7). The measure type is labelled public relations and consulting (E: 7) which addresses the transformation pathways direct and indirect electrification, bioenergy, and efficiency in the field of passenger and cargo traffic (F: 1, 2, 4, 8). Thus, several technologies in the area of mobility are relevant such as electric and fuel cell vehicles, E-load wheels and potentially combustion engine vehicles using biofuels and e-fuels (G: 1, 3, 14, 19, 22).

Taking a closer look at the four measures, the complementary and multidimensional approach becomes clearer. Energy consulting for public properties addresses municipal climate responsibility to adequately renovate its own buildings to fulfil state-of-the-art energy climate standards. Local real estate and building authorities within the municipal administration are key actors for change. The planning tool of integrated energy and climate protection concept goes beyond single properties and develops cross-sector strategies from a superior municipal perspective. Here, key actors are several authority departments and public enterprises working closely together. Public utility concession takeover, in contrary, is a business strategy of public utility companies to provide services in the general interest. Free of charge mobility and energy consulting for citizens, finally emphasizes the role of promoting and advising citizens with several experts being key agents with providing their expertise. These aspects all fall under the theme of municipal sector coupling and illustrate its inherent diversity in different dimensions. The categories chosen can help to structure these dimensions and thus contribute to the systematization of municipal sector coupling.

4.4. Cluster the diversity: distinct measure portfolios for the heat and mobility sector

The classified measures inventory provides a basis for addressing energy transition needs at the local and regional level. It opens a perspective for shaping coherent policy packages on local municipality level from very different options for action. The added-value of policy package is its presumed amplified impact compared to mere single action. In that sense, the policy package serves as continuous pinpricks as a niche management strategy as required by the MLP approach. From the local level, the dominant carbon-intense energy system, thus, is to be challenged through this policy of pinprick approach.

We will illustrate the policy package potential provided by the inventory on the basis of a mobility and a heat measures portfolio. The transition of both towards environmental and climate friendliness remains a major challenge in Germany. The supply of heat in households, commerce, trade, services (tertiary sector) and industry (including process heat in industry) accounts for more than half of the final energy consumption. However, renewable energy sources play a minor role in the provision of energy for heating purposes. In Germany the heat sector accounts for approximately 18 % of total CO_2 emissions. Compared to 1990, considerable progress in heat has reduced CO_2 emissions by about 40 %. Literature states that few policy instruments play a crucial role for a successful heat transition, namely [57]: high renovation rate and requirements for new construction; electrification through heat pumps; renewable heat (i.e., solar thermal, geothermal and biomass); heat networks (incl. waste heat), option of "green gases"; digitalization and flexibilization, and CO_2 pricing.

The exemplary measures portfolio for the *heat sector* as compiled from the classified inventory connects well with some of these key policies.

Fig. 2 outlines the heat measures portfolio as compiled from the classified inventory. First, the portfolio of measures was compiled by means of the variable "heat" within the category "sector & field of action". As a result, 24 single measures addressing the heat transition were found. Second, the portfolio is clustered by the corresponding role of municipality.

The portfolio addresses and specifies some of the key policies mentioned and covers the multidimensional spectrum of the policy measure classification system (see Table 3).

High renovation rate and requirements for new construction is, for instance, supported by renovation consultation and renovation campaigns as a service provider while minimum energy standards for new public buildings display the consumer role of the public body. The

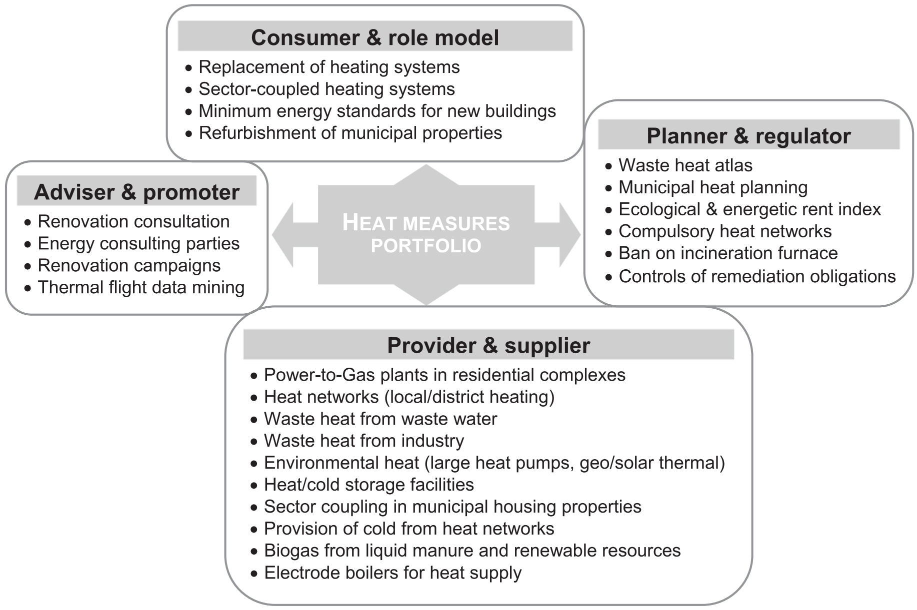
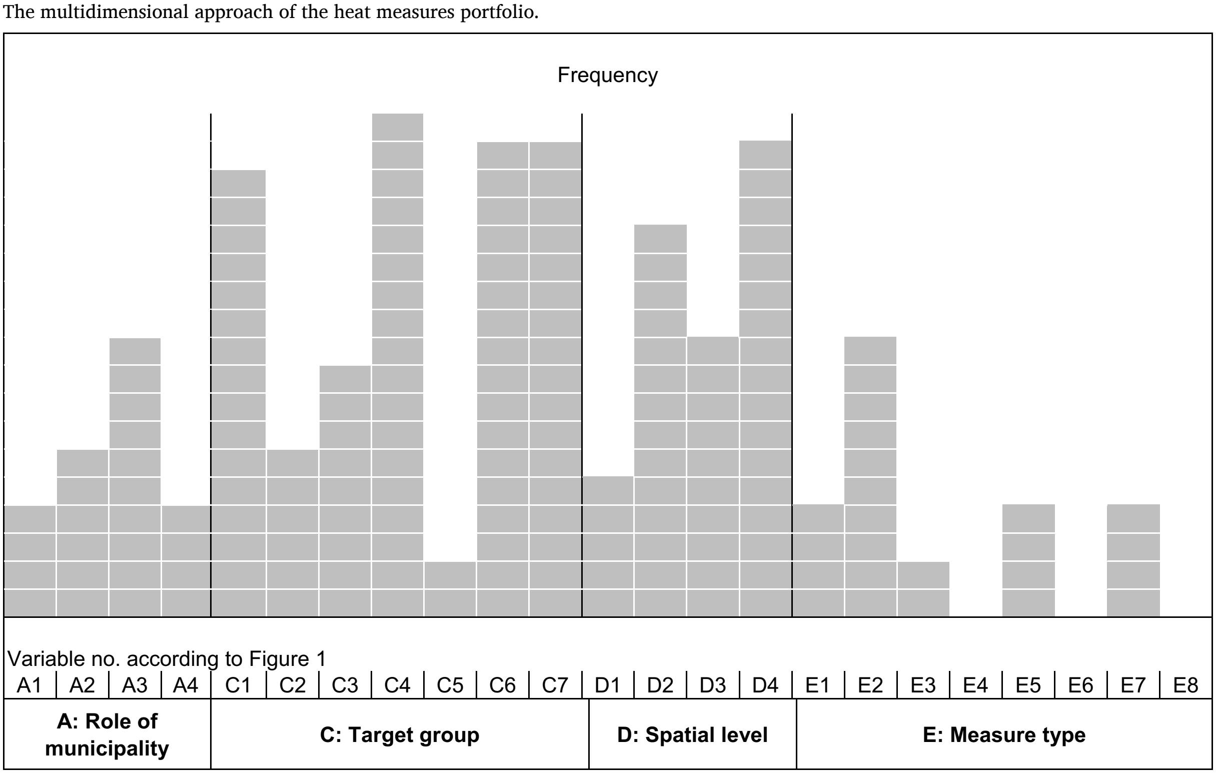


Fig. 2. Heat measures portfolio for local municipalities.
Source: own elaboration.

Table 3
The multidimensional approach of the heat measures portfolio.



Explanation: multiple choices possible.
Source: Own elaboration.

change towards renewable heat provision and "green" gases is addressed by several measures of local public companies as energy provider and supplier. This comprises, for instance, Power-to-Gas plants in residential complexes, waste heat (from waste water or industry) and environmental heat or biogas. Also, the heat infrastructure as heat networks and storage facilities is covered. However, the portfolio clearly goes beyond the set of policy instruments mentioned above. Within the planner's and regulator's role, the waste heat atlas, ecological and energetic rent index, municipal heat planning, and the compulsory use of heat networks are extending the set of instruments considerably.

Table 3 reveals the multi dimensionality of measures municipalities can implement regarding heat. For the heat measures portfolio, it displays the frequency of every characteristic of the four categories shown. The obtained heat measure portfolio considers all four roles of the municipality (A1–4) with an emphasis on providing and supplying heat (A3) based on renewables and sector coupling heat technologies such as heat networks fed with, for instance, heat from waste water, industry, heat pumps or geo- and solar thermal.

Furthermore, it aims at several target groups (C) equally, that is citizens (C4), the housing and real estate industry (C6), private companies (C7) and municipal enterprises (C1). At the spatial level, the proposed measures largely address single buildings (D4), area neighbourhoods (D2) and the municipality (D3) while fewer measures are targeting the regional level (D1). Furthermore, Table 3 reveals an imbalance with regard to the measure type (E). Construction and operation of heat infrastructure (E2) is the main focus of the measures in the heat portfolio. Several measures then address the management of municipal real estate (E1), support programs (E6), and public relation and consulting initiatives (E7).

A second illustrative measure portfolio example refers to the mobility sector. Fig. 3 shows the measurement package addressing municipal mobility action as gathered in the inventory of the one hundred policy measure list. In total, 17 single policy measures were found among municipal sector coupling addressing the mobility and transport sector with emphasis on infrastructure, transport mode, and behavioral mobility decisions. Again, it reveals that all four roles of municipalities identified are well covered with single policy measures. The consumer and role model addresses transport mode and infrastructure. First, incentives within the public procurement system shall stimulate conversion of the municipal vehicle fleet towards alternative drives. Second, public properties when fundamentally renovated or newly built shall be installed with charging facilities for electric mobility vehicles. The adviser and promoter role of municipalities considers subsidizing and consulting policies. It advocates and stimulates both private purchase decision towards alternative drive vehicles, and installation of private charging stations via a subsidy program. Similarly, a funding program has been set up to promote cargo bikes with electric motors. Finally, a free of charge citizen consulting program offers advice on sustainable mobility and transport options. The planer and regulator role of municipalities refers to integral planning of municipality-wide mobility concepts, and the carrot policy of free or discounted parking spaces for electric vehicles. The provider and supplier role shows the most comprehensive list of measures addressing the municipalities' agency towards the use of alternative fuels, support and/or operate sustainable transport mode services (e-bike, e-carsharing), change the public fleet with both passenger and freight vehicles towards electric drives, and install and operate sustainable electric mobility infrastructure (e.g. photovoltaic systems on parking lots, fast-charging parks for cars and ships).

Again, the measure portfolio for mobility and transport reveals a great variety of measures addressing the complex challenge of urban transport transition. The portfolio focuses on the provision of renewable energy supply, refers to corresponding infrastructures and transport mode technologies, aims at nudging individual and private sustainable transport decision-making, and reaches out to several target groups.

5. Discussion

The results contribute to a structured basis for the discourse on energy transition in municipalities and are a central building block for a horizontal and vertical coordination in the development of a sector coupling strategy. At the same time, the analysis allows conclusions to be drawn for an expansion of the theory on MLP as well as the PMA to include factors influencing municipal coordination.

Municipalities and their locally rooted institutions are key players in the implementation of the energy transition with increased sector coupling and are predestined to deal with different groups and their various interests, to take them seriously and to lead them onto a common future path of climate neutrality. Thus, local agency deserves deeper analysis. Our research identified eight major challenges for the large-scale deployment of sector coupling technologies at the municipal level as illustrated above (see Table 1). Taking the MLP framework to analyze the development and establishment of sector coupling innovations, we locate the challenges in order to identify possible entry points for policy measures (Fig. 1). In this context, sector coupling technologies are considered to be innovations emerging from coevolutionary processes alongside the dominant socio-technical regime, aiming to challenge the status quo hitherto dominated by centralized, fossil-fuel powered systems. Municipalities provide a decentralized and protected experimental space for sector coupling innovations, where

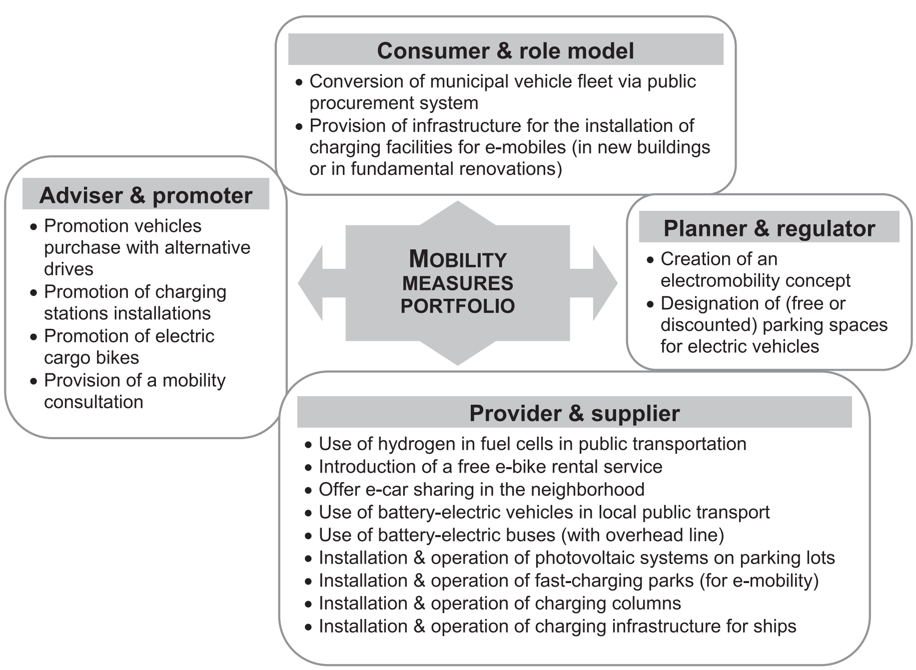


Fig. 3. Mobility measures portfolio for local municipalities.
Source: Own elaboration.

they can be tested and implemented until they finally diffuse into the existing regime.

As shown in Fig. 4, important legal, technological, economic and social barriers to the implementation of municipal sector coupling exist at various levels. To overcome several of these challenges, this research developed a comprehensive set of measures that can be applied at the municipal level and individually selected to promote and facilitate the spread of sector coupling technologies. The selection of the categories in the classification system of the measures, which is presented in Section 4, is based both on the analysis of the obstacles in the multi-level system (see orange numbers in Fig. 4 which refer to numbering of barriers in Table 1) and the Policy Mix Approach, in which the authors apply the typology used there (regulatory, economic and informational instruments) to classify the measures. At the same time, this analysis attempts to supplement variables for policy mix research on the municipal level using the example of sector coupling, e.g., including the role model for municipalities.

Addressing these challenges in the theoretical light of the Multi-Level Perspective (MLP) and the Policy Mix Approach (PMA), the authors developed a classification system of policy instruments and measures for municipal action to foster sector coupling activities. This section summarizes the main findings of our study and reflects the methodological and content-related limitations of the study.

Firstly, the study revealed the importance of an integrated analysis of political options at municipal level in the area of sector coupling. The workshop participants in all three municipalities have called for an accelerated expansion of sector coupling. They emphasized the need for innovative and integrated ways of thinking, but also pointed out that municipal discourse is simplified by talking about concrete measures instead of abstract visions or scenarios. The authors respond to these three demands by developing a collection of measures for municipal sector coupling. This is intended to accelerate the expansion of sector coupling by providing an overview of already tested measures. In addition, the classification system combines different areas of sector coupling so that they can be collectively thought of. The collection of concrete measures linked with example projects also leads the discussion on site from the abstract to the practical implementation level. Since the classification system developed is supposed to structure the collection of measures for the practical application and be connectable to scientific models, it can serve as a linkage between theory and practice of municipal sector coupling. Thematically, Figs. 1–4, together with the entire inventory in the annex summarize our findings. With regard to the limitations of the approach, it can be stated that a consideration of trade-offs between the measures is not yet sufficiently reflected in the approach and would have to be supplemented. In addition, other impact dimensions of the measures are relevant, such as costs and resource requirements, and efficacy and efficiency which, however, vary depending on regional conditions. They must hence be considered on a case-by-case basis.

Secondly, the study supplements variables for policy mix research on the municipal level using the example of sector coupling. The analysis shows that the role of municipality is a key category for local energy transition policies., i.e., the municipality as consumer and role model, planner and regulator, supplier and provider, consultant and promoter. In addition, we argue that local actors play an important role stressing the fact that municipalities with their diverse fields of political, administrative and economic power have several possibilities, e.g. via infrastructure decisions, citizens participation, or regulation activities regarding space, for paving the way towards the energy transition. Accordingly, the classification system supports a municipal strategy of various decentralized permanent alternative pinpricks challenging the current fossil fuel-based system and networking for a new prototypical

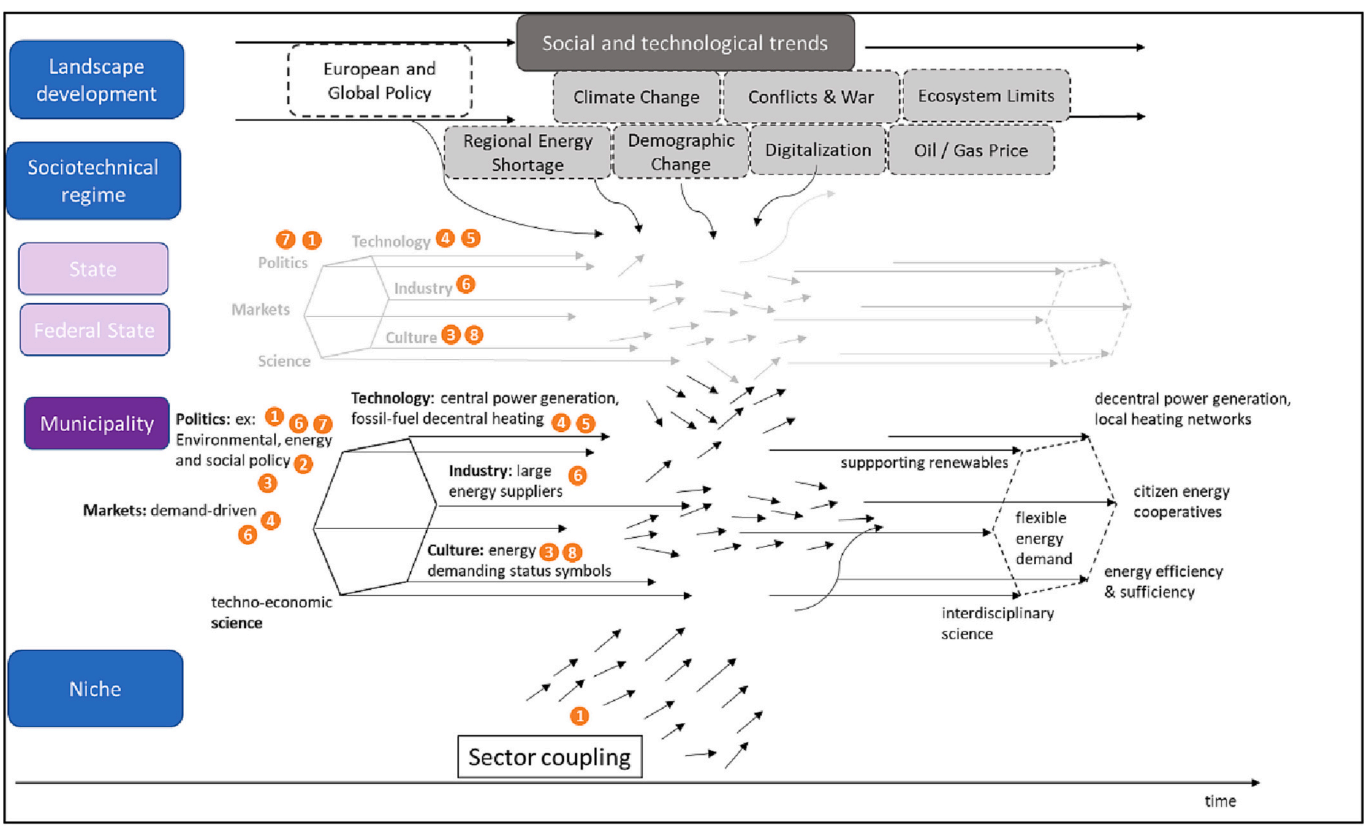


Fig. 4. The concept of municipal sector coupling and associated challenges in the light of the Multi-Level Perspective approach.
Explanation: orange numbering = challenges as indicated by numbers in Table 1.
Source: own elaboration based on [11].

system. Thus, in our view municipalities have a considerable agency for stimulating change.

Thirdly, our findings allow to derive coherent bundles of policies serving as niche management strategy in the field of sector coupling. The MLP analysis of municipal sector coupling has shown that the power of action of the municipalities at the local level is strongly influenced by socio-political decisions at a higher level (e.g., the expansion of networks or Power-to-X technologies, which not all municipality can operate themselves). However, there is considerable shaping power with, for instance, the involvement of local stakeholders for the municipalities as change agents and resistance mediators. The classification system supports municipalities in analyzing the possible options and can also serve as a starting point for a dialogue with citizens and other stakeholders. With regard to the limits of the approach, it can be stated that it contains one hundred core measures for municipal sector coupling. Depending on the case, further ancillary measures must be added when putting together policy packages [31].

6. Conclusions

Re-considering the role of municipalities as change agents and driving force for the energy transition has been the main focus of this research. Transition and transformation research do so far not stress an outstanding leadership and agency role of municipalities towards the energy transition and climate change [58,59]. We aimed at analyzing the potential agency of municipalities in the field of sector-coupling. Based on a measure sector coupling inventory, we found, however, there is evidence for considerable multi-role agency of municipalities if one expands the understanding of caverning capacities. Municipalities dispose of several direct and indirect agency options if one refers to their executive, regulative, and economic power as institutionalized in municipal administration, municipal policy-making, and municipal owned corporation. From that end, municipalities have considerable change agency power provided they play out their roles using a coordinated and complementary policy package and portfolio design. The one hundred measure inventory and its systematization, classification and clustering reveal there is much potential for municipalities to act as change agents and driving forces for the energy transition.

Further research should address the following two aspects: Firstly, a first user test of the classification system in the form of interviews was carried out in the course of the study. From the authors' point of view, a broader empirical test based on numerous municipal examples is necessary to expand the classification system and its measures. Secondly, the classification system is very suitable as an aid for exploring possible options for policy planning. From the authors' point of view, a scientific and practical ex-ante impact assessment of the measures in the second step is a good starting point, especially with regard to citizen participation processes.

Declaration of competing interest

The authors declare no conflict of interest. The funders had no role in the design of the study, collection, analyses, interpretation of data, writing of the manuscript, or the decision to publish the results.

Data availability

Data will be made available on request.

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The sole responsibility for this paper lies with the authors.

Appendix A. List of exemplary projects and policy measures

No.	Name of the measure	Exemplary projects and policy measures
1	Conclusion of an energy supply contracting	Residential quarter Mariendorf, Berlin
2	Conclusion of an energy saving contracting	Residential quarter Mariendorf, Berlin
3	Replacement of heating systems	City hall Fürth, city hall Prinzerdorf
4	Provision of infrastructure for the installation of charging facilities for e-mobiles (in new buildings or in fundamental renovations)	Installation of vehicle charging columns at the new town hall in Aldingen
5	Participation in cooperatives/energy communities	Citizen energy community, Weissacher Tal
6	Operation of renewable energy generation plants for self-supply	Energy association Freilassing
7	Carrying out an energy-related potential analysis	Potential analysis renewable energies for the community Ebhausen
8	Implementation of an energy-related inventory	Potential analysis renewable energies for the community Ebhausen
9	Introduction of an office for climate protection/energy management	Municipal guideline
10	Introduction of a municipal energy management system (KEM)	Municipal energy management in Rottweil
11	Use of sector-coupling heating systems	Multipurpose hall in Altenplos
12	Creation and monitoring of energy and greenhouse gas balances	Energy and greenhouse gas balance for the Rhein-Neckar district
13	Establishment of minimum energy standards for the construction of new municipal buildings that go beyond legal requirements (e.g. energy-plus buildings)	Specifications of the energy guideline for new buildings and renovation projects in Stuttgart
14	Financial participation in (sector coupling) projects of third parties	Participation of the municipality Ingenried in WKA in Bidingen
15	Continuous analysis of funding potentials	Checking for EU-funding opportunities in Regensburg
16	Membership in/establishment of a (regional) energy agency	Energy agency Rhein-Sieg
17	Examination of the use of near-surface geothermal energy in new construction and renovation measures	Nußdorf in the district of Traunstein examines geothermal energy possibilities
18	Renovation of municipal properties	Residential quarter Mariendorf, Berlin
19	Participation in statewide, national and international competitions	Federal competition for bioenergy municipalities
20	Participation in national and international networks, initiatives	Energy cities
21	Participation and/or initiation of/in local energy efficiency network	Climate pact Flensburg e.V.
22	Conversion of gas supply contracts to biogas	Biogas feed-in plant in Gordemitz
23	Conversion of the municipal vehicle fleet via the procurement system	Vehicle fleet for Berlin municipal cleaning
24	Conversion of buildings to central control technology	*No municipal example found*

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No.	Name of the measure	Exemplary projects and policy measures
25	Leasing of (roof) areas of municipal properties for photovoltaic systems	Roof PV Mühlhausen
26	Perception of consulting or coaching	Energy consulting for the municipality of Barßel in Lower Saxony
27	Compulsory connection and use of heat networks	Compulsory connection and use (district heating statutes), city of Butzenbach
28	Designation of (free or discounted) parking spaces for electric vehicles	Privileging of electric cars, Stuttgart
29	Designation and consideration of CO_2 emissions in municipal decisions (e.g. investments, awards)	Evaluation of draft resolutions, climate emergency Karlsruhe
30	Designation of areas for the production of renewable energies	Designation of areas suitable for wind energy by the municipality of Breydin
31	Definition and anchoring of concrete objectives in municipal mission statement/strategy	Mission statement on climate neutrality until 2035 in Darmstadt
32	Introduction of an ecological/energetic rent index	Energetic condition of residential buildings in the rent index, Berlin
33	Introduction of a ban on incineration (restriction of the use of air-polluting substances § 9 para. 1 no. 23 BauGB)	Incineration ban in new development areas, Walldorf
34	Creation of a municipal heat planning	Municipal heat planning, Heidelberg
35	Creation of a waste heat atlas	Wastewater heat atlas, Berlin
36	Creation of an electromobility concept	Municipal electromobility concept of the municipality of Kirchzarten
37	Creation of an integrated urban development concept (ISEK)	Integrated urban development concept (“ISEK”), Freilassing
38	Preparation of municipal energy and climate protection concepts	Integrated Energy and Climate Protection Concept, Dresden
39	Establishment of minimum energy standards in urban development contracts	Urban development contracts, Würzburg
40	Climate-neutral quarter planning	“Am Bergle” Schlier
41	Solar obligation in development plans and in property purchase contracts	Solar obligation in development plans, Waiblingen
42	Strengthening of controls of remediation obligations and punishment of offenses	*No municipal example found*
43	Offer e-car sharing in the neighborhood	E-car pooling in the Lincoln housing estate in Darmstadt
44	Establishment and operation of heating networks (local/district heating)	Development and expansion of heating networks, city of Weilheim i.OB
45	Operation of Power-to-Gas plants in residential complexes	Power-to-Gas plant in Augsburg residential complex
46	Installation of intelligent meters (smart meters)	*No municipal example found*
47	Introduction of a free e-bike rental service	Heinerbike Darmstadt, free e-bike rental service
48	Use of battery-electric buses (with overhead line)	Municipal transport company, Esslingen
49	Use of battery-electric vehicles in local public transport	Local transportation plan, Speyer
50	Use of hydrogen in fuel cells in public transportation	Hydrogen buses, Aachen
51	Energetic utilization of biogenic residues	Biowaste fermentation plant in Bernburg
52	Generation and use of biogas from manure and renewable resources	District heating generation based on biogas in Darmstadt
53	Installation and operation of photovoltaic systems on parking lots	*No municipal example found*
54	Installation and operation of renewable energy systems for power generation as suppliers	Expansion of photovoltaics, Kulmbach
55	Installation and operation of electric (or electrode) boilers for heat supply	Intelligent combined heat and power (iCHP) plant with electrode boilers, Bad Reichenhall
56	Installation and operation of charging infrastructure for ships	Charging infrastructure for an electric ferry in Kiel
57	Installation and operation of charging columns	Expansion of charging column infrastructure, Berlin
58	Installation and operation of Power-to-Gas plants (electrolyser) for hydrogen production	Electrolyser, Ingolstadt and Karlshuld
59	Installation and operation of fast-charging parks (for e-mobility)	Fast-charging park, Freiburg
60	Integration of sector coupling options at municipal housing associations	Power-to-Gas plant in Augsburg residential complex
61	Provision of cooling from heat networks	Cooling from district heating, Karlsruhe municipal utility company
62	Utilization of waste heat from waste water	Heat recovery from wastewater, Hamburg
63	Use of waste heat from industry	Waste heat recovery from chemical plant, Rheinfelden
64	Use of environmental heat (large-scale heat pumps, geothermal energy, solar thermal energy)	iCHP plant with river heat pump, Lemgo
65	Utilization of heat/cold storage facilities	Energy and future storage, Heidelberg
66	Acquisition of concessions (electricity, gas, district heating)	Municipal and community utilities, Kassel area
67	Leasing of PV plants	PV lease model, Schweinfurt municipal utility company
68	Offer of a mobility consultation	Mobility consulting, Tübingen
69	Offer of refurbishment consultation	Energy consulting, Walldorf
70	Offer of energy checking for citizens incl. energetic first consultation	“Karlsruhe Energy Quarters” initiative, Karlsruhe
71	Offer of thematic excursions	Excursion guide, Lahr
72	Establishment of climate protection funds to finance sector coupling measures	Climate Innovation Fund, Stuttgart
73	Advice on energy generation plants	On-site consulting on photovoltaics, Heidelberg
74	Provision of a solar register or calculator for citizens	Solar register, Aachen
75	Provision of information via web applications, flyers, brochures, etc.	Smartphone app named Smart.Grid
76	Directly approach individual actors	District heating from refinery, Karlsruhe
77	Implementation of a renovation campaign	Renovation campaign, Lahr
78	Implementation of a solar campaign	Solar campaign “Öcher Solar Offensive”, Aachen
79	Implementation of an ideas competition	Climate protection ideas competition, Frankfurt
80	Carrying out thermal flights for energy advice	Thermal flight, Darmstadt
81	Establishment of an energy show house	Renovation showcase, Karlsruhe
82	Creation of a communication concept and a communication strategy	Communication and publicity concept, Leinigerland municipality
83	Promotion of the purchase of vehicles with alternative drives	Environmentally friendly mobile subsidy program, Heidelberg
84	Promotion of the installation of RE systems	Support program for photovoltaic systems on roofs and facades, Heidelberg
85	Promotion of the installation of charging stations	Environmentally friendly mobile subsidy program, Heidelberg
86	Promotion of the use of sector coupling technologies in the renovation of old buildings	Climate bonus Karlsruhe
87	Promotion of cargo bikes with electric motors	Funding program for cargo bikes, Karlsruhe
88	Promotion of micro combined heat and power plants	Promotion of CHP units by energy suppliers, Darmstadt
89	Initiation and offer of energy consulting parties	Energy consulting parties in the district of Nordfriesland

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No.	Name of the measure	Exemplary projects and policy measures
90	Initiation of climate talks or energy regulars' tables	Climate regulars'table, Offenburg
91	Initiation of adult education courses on the topic of sector coupling	"Future-oriented energy for all": educational series at Hessian adult education centers
92	Cooperation with craft guilds or chambers of crafts	Climate Alliance, Gelsenkirchen-Herten
93	Creation of financial participation opportunities	Intercommunal energy cooperative, NEW - Neue Energien West eG
94	Creation of participation opportunities in planning processes	Urban development advisory board, Freilassing
95	Training of multipliers	Adult education center course "Climate change on our doorstep! What can I do?", Stuttgart
96	Sensitization and involvement of pupils	Climate checker, Kempten
97	Making successes visible	Energy monitor, Freilassing
98	Awarding of a prize for exemplary sector coupling projects to local companies	Climate Protection Award, Bühl
99	Networking of regional players	Energy efficiency network, Karlsruhe
100	Networking of industrial companies	Feasibility study: hydrogen-based iron ore direct reduction at the Wilhelmshaven site

Source: own elaboration.

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