Principles and Tools for Designing Strategies for Sustainable Urban Development: A "Process-based" and "Action-oriented" Approach at Neighbourhood Level

zur Erlangung des akademischen Grades eines

Doktors der Ingenieurwissenschaften
(Dr.-Ing.)

von der Fakultät für Wirtschaftswissenschaften
des Karlsruher Instituts für Technologie (KIT)

genehmigte

Dissertation

von

Maria Balouktsi, M.Sc.

aus Karlsruhe

Tag der mündlichen Prüfung: 09. August 2018
Referent: Prof. Dr.-Ing. habil.Thomas Lützkendorf
Koreferent: Prof. Dr. rer. pol. David Lorenz

Abstract

Cities constitute essential parts of the solution to many of the current sustainable development challenges. They have a major role to play in sustainable development both as crucial "engines" of socio-economic growth and significant "originators" of environmental loads. The special significance of cities for sustainable development is also reflected in the Sustainable Development Goal (SDG) 11 "*Make cities and human settlements inclusive, safe, resilient and sustainable*" of the 2030 Agenda for Sustainable Development.

To organize and to support a sustainable urban development is, however, a particularly complex task to accomplish for any local authority or stakeholder group. The reasons for this complexity are related to the amplitude of the sustainability concept, to the variety and changing nature of the factors to be taken into account, as well as to the challenge for balancing the needs and interests of different stakeholder groups involved in – or affected by – urban interventions. The neighbourhood, as a more manageable urban unit than the city, and as a promising level to test out new ideas and ways of achieving sustainable urban development, has increasingly been acknowledged by research, policy and industry.

The thesis therefore investigates new approaches to support sustainable urban development at the neighbourhood scale, with a specific focus on the neighbourhoods in Europe. Existing literature indicates that prevailing approaches are traditionally prescriptive and outcomes-based and fail to acknowledge the process nature of sustainable urban development. Furthermore, their contribution commonly starts and ends with the measurement of indicators and the provision of assessment results in the form of static "snap-shots" without those being reflected in specific possibilities for action in the local area. This hardly solves the problem of the (further) development of existing neighbourhoods. Decoding these results into context-

specific strategies and actions, as well as ways of managing these actions, remains a challenge and an area not much researched yet.

To remediate these weaknesses and gaps, the thesis proposes a comprehensive and integrated conceptual "process-based" and "action-oriented" overall framework which combines three approaches:

(1) a step-by-step structured workflow model that decomposes the process of SUD into manageable tasks and incorporates all necessary quality requirements that should accompany a transition to sustainability; the purpose is to support the preparation phase of sustainable urban development process

(2) a methodology for identifying problem areas, their respective trade-offs, as well as selecting, organising and describing indicators in an action-oriented fashion; the purpose is to provide a new proposal for linking indicators to possibilities for action so that their use does not only focus on assessing but also guiding development;

(3) a methodology for prioritising and selecting concrete strategies and actions for neighbourhoods. The usefulness of the latter is illustrated by the means of a hypothetical case, and with the help of a web-based tool built by the author specifically for the multi-criteria decision analysis (MCDA) method ELECTRE III.

The originality of this research lies in that such a comprehensive framework, bringing all the above-mentioned elements together into one coherent solution, has not been available until now. The value of the research is that the proposed overall framework can be a helpful decision support tool for any neighbourhood in Europe which is developing a sustainable development plan.

Contents

Table of Figures

Table of Tables

Table of Abbreviations

AC	Action Team
AoP	Areas of Protection
BaU	Business as Usual
CT	Core Team
DM	Decision Maker
DPSIR	Driver-Pressure-State-Impact-Response
ELECTRE	ELimination Et Choix Traduisant la REalité (ELimination and Choice Expressing REality)
EU	European Union
GHG	Greenhouse Gas
ISO	International Organization for Standardization
MCDA	Multi-Criteria Decision Analysis
MDG	Millennium Development Goal
NSAS	Neighbourhood Sustainability Assessment System
PSR	Pressure-State-Response
QC	Quality Criterion
QR	Quality Requirement
SDG	Sustainable Development Goal
SNDP	Strategic Neighbourhood Development Plan
SUD	Sustainable Urban Development
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
WCCD	World Council on City Data

Preface

The present work was created between 2015 and 2018 during my work as a research associate at the Institute of Sustainable Management of Housing and Real Estate (ÖÖW) of the Karlsruhe Institute of Technology (KIT).

By the completion of the present thesis, I feel particularly happy to be given the chance to thank the people who have provided me with their support. This whole undertaking has filled me with important experience that has matured me as a researcher as well as a person and I feel the need to acknowledge the people standing by my side during this whole phase.

First and foremost, among them, I would like to thank my supervisor, Prof. Dr.-Ing. habil. Thomas Lützkendorf, for his invaluable guidance, his role as a mentor, his scientific as well as ethical support and for his confidence in me which constantly motivated me throughout our collaboration. Additionally, I would like to thank Prof. Dr. rer. pol. David Lorenz for agreeing to act as second examiner.

I would also like to thank my partner Eckart for his unfailing support and encouragement. Finally, I would like to give my very special thanks to my family, my parents Anastasios and Katerina and my siblings Ioannis and Despoina, for their continuous love, encouragement and support all these years.

Maria Balouktsi

Karlsruhe, July 2018

1 Introduction

This thesis proposes a new integrated conceptual framework to provide comprehensive and consistent guidance to decision making during the planning phase of a neighbourhood-scale sustainable urban development in the European context, that, until now, has not been available. Therefore, this chapter first provides an introduction to the problem and related trends as initial steps on the solution path (Sections 1.1 and 1.2). Second, it indicates the shortcomings or gaps in current practices that necessitate this research (Section 1.3) and formulates the research questions (Section 1.4). Third, it defines the scope of the research and the specific methodological approach followed (Sections 1.5 and 1.6). Finally, it presents the structure of the present thesis (Section 1.7).

1.1 Urbanisation: Current Situation, Topics and Trends

Urbanisation is a megatrend that will significantly shape future urban living. In particular, the year 2008 marked a new milestone in human history. For the first time in recorded history more than half of the world's population lives in urban areas. According to the World Bank data (World Bank Open Data, n.d.), this percentage has now risen to more than 54%, and if present trends continue, it is projected that almost three-quarters of the world population will live in cities by 2040 (UN Habitat, 2011). This trend goes hand-in-hand with built-up area expansion and, as the World Bank's data reveals (World Bank Open Data, n.d.), reinforces already existing complex and intersecting urban challenges, such as energy consumption and greenhouse gas (GHG) emissions. Remarkably, even though cities occupy less than 2% of world's land surface (UN-Habitat, 2011), their impact is immense: their residents consume more than two-thirds of the world's energy and are responsible for up to 70% of GHG emissions (UN-Habitat, 2011).

Although more than 90% of the increase in urbanisation is expected to take place in countries of the developing world (UN-Habitat, 2011), this does not mean that Europe should not be concerned; so-called “developed” and “developing” nations share the same global environment and interest to preserve it for current and future generations. Nor does it mean that Europe does not have a significant role to play in limiting the environmental impacts of its cities. The nature of the challenge to be faced is simply different. Whereas in developing countries the main challenge is to accommodate spatial and economic growth without increasing the environmental burdens (e.g. GHG emissions) arising from it, in Europe the focus should be to transform existing cities to be more sustainable, resilient and liveable.

Yet this is no easy task. There are many challenges inherent to manage the sustainable transformation of urban environments. Cities are complex networks of many interacting components, namely infrastructures (e.g. mobility and communications networks, water and energy cycle), functions (such as living, working, health and education) and society itself made up of citizens (individuals, households, organizations and businesses) and government. One challenge is to balance the wide-ranging interests of the large number of independent stakeholders that have an influence in the overall functioning of the urban areas, and to act as a cohesive whole. Indeed, local authorities directly manage only a minority of the key services a city provides and can only successfully exercise their strategic management role through partnerships with all the other stakeholders in the city.

Equally challenging is to take a holistic and integrated view on sustainable urban development (SUD), while addressing the unique set of characteristics and geographic context of each urban area, which together provide a specific set of local challenges and opportunities for local leaders to consider. Finally, cities are also faced with the complexity of translating the diverse and common issues into concrete strategies and actions. The question therefore arises of how to simultaneously address all these complexities inherent in managing urban environments to achieve a SUD – an imperative solution for cities in response to an increasingly urbanised world.

1.2 The Importance and Role of Cities

In this new context or "urban age", as many now characterise the twenty-first century, the quest for SUD takes centre stage in both political and scientific arenas (Joss et al., 2015). Recent political agreements defining the future of sustainable development imply that no matter how ambitious the global goals for sustainable development are, without the consideration of urban areas (i.e. cities and their constituent parts) they are predestined to fail (Koch & Ahmad, 2018). On the policy level, without doubt, the most important initiative and best opportunity for transforming the world to a sustainable state is the recent UN initiative, known as the 2030 Agenda for Sustainable Development (UN General Assembly, 2015) and adopted in 2015. In the context of this Agenda, "sustainable cities and human settlements" (Goal 11) is one of its 17 Global Sustainable Development Goals (SDGs) and it paves the way for fully transformative urban commitments and principles.

Cities are also important players for the achievement of other SDGs. The goals themselves are broken down into 169 targets that largely draw on previous international agreements and detail issues and topics that all the countries committed to the agenda need to address. Estimates on the basis of the wording of these targets reveal that as much as 65% of the SDG targets are at risk without the involvement of local governments and urban leaders (Cities Alliance, 2015, p.19). This acknowledges the pivotal role of cities for the global sustainable development agenda and gives a new momentum to the pursuit of SUD at local levels.

The view of cities as driving forces for limiting global environmental impacts and as solution-providers for global sustainability problems is also evident in other significant political agreements and discussions. In addition to the establishment of a universal agenda for sustainable development, 2015 also brought another promising development in the form of an international agreement, where again, cities are put in the spotlight: the commonly known as "Paris Agreement" was adopted at the 21st Session of the Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC) to address the threat of climate change and explicitly highlights the important role of local government in this global effort to limit the global temperature rise (UNFCCC, 2015). Beyond the agreement itself, this is also highlighted in a series of academic outputs (e.g. Gouldson et al., 2016; van der Ven et al., 2017). Finally, it is no coincidence that the New Urban Agenda adopted at the UN's Conference on Housing and Sustainable Urban Development (Habitat III) in Quito in October 2016 (Habitat III, 2016), takes full consideration of the two milestone achievements of 2015.

All these international agreements explicitly stating the role of cities for their success are illustrative of the increasingly prominent position SUD is now taking on the policy stage – and indeed, this is already echoed by related policy commitments on the part of municipal governments across countries and global regions (e.g. the Global Covenant of Mayors for Climate & Energy (Gesing, 2017)). The concept of SUD is however not new: the starting point was a popular but ambiguous definition of sustainable development, which was proposed by the Brundtland Report of 1987 (entitled Our Common Future) for the first time (WCED, 1987). According to this report sustainable development is "*the development that meets the needs of the present without compromising the ability of future generations to meet their needs*" (p. 43). After that, two contrasting perspectives or concepts of sustainability (i.e. sustainable development) started occurring in literature, differing on the basis of whether natural capital can be substituted by human-made capital (Li & Li, 2017): "weak sustainability", which allows for substitutability (trade-offs between natural and human-made capital) and "strong sustainability", which assumes limits to substitutability.

Following either of these two perspectives, numerous definitions of SUD or urban sustainability have been suggested (Cooper, 2017; Li & Li, 2017), as attempts to translate these concepts into a more specific field of application – the urban environment. However, a concise and robust definition of SUD has been lacking to date (Cooper, 2017). Remarkably, the unresolved problem of definition and methodology did not stop attempts to put SUD into practice (Cooper, 2017). Thus, beyond policy-level initiatives, as Joss et al. (2015) characteristically states "*there is nevertheless clear evidence of an exponential rise in urban sustainability initiatives of one kind or another since the early*

2000s". These practical initiatives are diverse, ranging from entire cities or neighbourhoods built from scratch to neighbourhood transformation or retrofitting projects (Joss et al., 2015). They also vary with respect to whether the initiation comes from the top-down or as a result of grassroots movements.

Part of this transition from theory to practical experimentation also constitutes the recent proliferation of sustainability assessment systems for cities and neighbourhoods, with each one of them representing a different attempt to translate urban sustainability into a set of indicators and/or processes designed to be applicable across diverse contexts (Sharifi & Murayama, 2013; Komeily & Srinivasan, 2015). All these assessment systems emerged in the light of the need to measure, and sometimes award or certify attainment of or progress towards sustainability outcomes. Although their contribution to advance SUD is undoubtedly significant, they have attracted a lot of criticism over the last decade for their techno-centric approaches to SUD, their rigidity, and emphasis on certification (sometimes also called "accreditation" or "labelling") as the "final goal" (Saiu, 2017).

Indeed, when accreditation relies on static approaches (i.e. focusing on an absolute performance assessment at a specific point in time), this may lead to a stigmatisation of an existing neighbourhood in case of a poor performance. The fear of stigmatisation and the disadvantages the latter often brings (e.g. discouragement of potential investors from engaging in the urban transformation processes) leads many local authorities to abstain from applying such systems in their neighbourhoods and cities (Lützkendorf & Balouktsi, 2017). Additionally, the black-box approach followed by many of these systems that oversimplifies the city or the neighbourhood into a bundle of predictable and controllable factors and processes is often considered as a main failure factor for such initiatives (Saiu, 2017).

Given the significant differences across cities, and even neighbourhoods within the same city, the question of standardization also arises. Not surprisingly, the widespread interest in urban sustainability and its assessment led to the first, and relatively recent attempt of providing a common framework of indicators under the international standard ISO 37120 "*Sustainable development of communities - Indicators for city services and quality of life"*

(ISO, 2014). Broadly, standardisation entails several potential benefits. Standards create a common language among stakeholders and this provides the possibility of shared learning with respect to both the contents and practices of SUD. In this way, local practices can become, aside from more broadly accessible to external stakeholders, also transferable and replicable to other contexts. However, following the previous line of arguments that inflexibility and oversight of locality are generally undesirable features, as well as that direct comparisons entails dangers for existing cities and neighbourhoods, what exactly should and can be standardised remains debated (Joss & Rydin, 2018).

Finally, the recent arrival of a multitude of urban sustainability assessment systems, as well as of standardisation in this direction, opens up an additional set of relevant questions that concern the practice interface (Joss et al., 2015). The task of such systems commonly starts and ends with the measurement of indicators and the provision of assessment results. Decoding these results into context-specific strategies and actions, as well as ways of managing these actions, remains a challenge and an area not much researched yet. Taken into account the complexity and heterogeneity of the real urban settings to which these systems are applied (or aimed at being applied), it should not be assumed that precise actions and their implementation can be directly imagined or derived from looking into the frameworks themselves.

1.3 Shortcomings in Current Practices

Based on the discussion provided above on the overall problem of urbanisation and the recent trends and topics with regard to SUD, it can be concluded that a certain movement towards seeking solutions with regard to the design, assessment and implementation of SUD already exists since more than a decade. But lately this topic is not only gaining increased momentum, but also a sense of urgency. Postponing action or endangering success is currently not a viable option. For this reason, it is necessary to overcome existing shortcomings and barriers in current planning practices for SUD. The various criticisms directed at prevailing practices include the following:

- ineffective approaches to deal with the complexity of urban transformation projects;
- techno-centric approaches failing to achieve a comprehensive integration of environmental, social and economic aspects;
- market-led approaches focusing on certification or labelling as the "final goal" to the detriment of long-term orientation of planning;
- rigid and inflexible approaches to cope with local particularities and needs;
- insufficient approaches with regard to promoting real community participation and democratic processes;
- non-strategic approaches solely focusing on how to define and measure sustainability for just purely comparative or certification reasons, rather than "action-oriented" approaches that link the use of indicators with actual possibilities for actions.

The acknowledgement of these failures of current SUD practices calls for an exploration for and adoption of new approaches. This requires that the right questions are first asked. This is what is attempted in the following section.

1.4 Research Questions

Anything new requires some level of testing and learning before full adoption. The same applies to new approaches to SUD in cities. Perhaps the most appropriate way to allow a gradual transition to more innovative approaches to SUD is to first promote and examine their success at the neighbourhood scale, as it represents the most fundamental unit of urban development (Xia et al., 2015), and the minimum scale to take account of the social, economic and institutional aspects of sustainability (Berardi, 2013; Sharifi & Murayama, 2014). Given the shortcomings of current SUD practices and the urgency for cities to prepare for the prospects of the future, the following first overarching question emerges:

"How can the current practice of sustainable urban development on a neighbourhood level be improved to overcome the weaknesses of certification-oriented concepts?"

To answer this question, sub-questions are needed to gain a better understanding of how to overcome each above-mentioned *weakness* of certification-centric approaches. The first major flaw of current approaches is their tendency to oversimplify the complexity of urban transformation projects into a system of indicators. However, SUD is a highly complex and continuously evolving process and it must be explored as such, instead of viewing it as a fixed target. Every process though, no matter how complex it is, it can be decomposed in a number of distinct and interconnected steps. Looking at a process as a stepwise workflow simplifies its analysis, but without oversimplifying the process itself viewing it as a single task. Yet, every individual process step requires the inclusion of different relevant actor groups to be systematically coordinated and has its own requirements, which must be met to achieve best practice. This also applies to SUD. There is a call for finding a way to design the SUD process in a way that promotes real community participation and democratic processes and copes with local particularities and needs.

This discussion leads to the following three sub-questions that were simultaneously explored:

(1) *What specific quality requirements can ensure a high-quality SUD process (e.g. a more effective, co-creative and "open" process)?*

(2) *How can the SUD process be organised into distinct and interconnected steps?*

(3) *How can stakeholder involvement be addressed at each step of the SUD process?*

Along with viewing the SUD process as a workflow, it can also be described as a combination of top-down and bottom-up processes. Although a general description of a good practice can be provided for bottom-up processes, these cannot be easily (and maybe they should not be) generalised to their very core, since they are always dependent on the context of the individual cases. On the other hand, general frameworks describing key top-down processes can be constructed and be relevant across multiple contexts within one region (Europe in the case of this research), since they are grounded on pre-existing knowledge. Building on the critique that current approaches have a predominantly techno-centric character failing to consider environmental, social and economic aspects in an integrative manner, it is also of value to examine specific top-down processes related to the assessment task of the process. A precondition of any assessment process is that goals, themes and indicators relevant and important for the European context, but also actionable on a neighbourhood level are in place.

This discussion leads to the following two interrelated sub-questions:

(4) *What specific goals, themes and indicators relevant to European context need to be considered for assessing and monitoring SUD on a neighbourhood level?*

(5) *How indicators can be linked with actual possibilities for actions?*

The acknowledgement of a lack of non-strategic approaches failing to link the use of indicators with actual possibilities for actions demands to go beyond a limited focus on the assessment task. This is attempted in sub-question (5) as a starting point. However, this also requires an examination of the process of identifying, assessing and selecting concrete SUD strategies and actions. The present researcher starts with the assumption that, although strategies and actions themselves are context-specific, a generic procedure grounded on a generic set of evaluation criteria can be constructed to guide decision makers throughout the critical process of selecting strategies and actions. This process or step is referred to as “critical”, because it forms the basis for resource allocation decisions. This is a complex challenge that can potentially met through an evaluation approach that involves Multi-Criteria Decision Analysis

(MCDA) to deal with the various and often conflicting criteria and stakeholder preferences typically characterising complex decision problems. The advantages and usefulness of MCDA methodology to deal with such complicated processes has been extensively outlined in literature (Gerber, 2013; Shukla et al., 2016).

This debate gives rise to the following two sub-questions:

(6) *How can specific SUD strategies be identified, evaluated and selected?*

(7) *How can multi-criteria decision analysis be used as a decision support tool in this context?*

1.5 Scope of the Research Topic

The broad research topic of this thesis is SUD at neighbourhood scale in the European context. The rationale behind the selection of "neighbourhood" as a spatial scale to investigate SUD on the basis of the defined research questions is justified below:

(1) Neighbourhoods are increasingly recognised as a more manageable unit of analysis compared to cities with respect to investigating the possibilities of achieving SUD in a certain urban setting.

(2) Neighbourhood is considered a crucial spatial scale to test new and innovative approaches and solutions to identify successes and failures, before moving to a full implementation at the city scale.

(3) In the same way a city should not be seen as a unit in isolation but in connection to others cities in a global urban system striving for sustainable development, a city cannot be considered sustainable if its constituent parts are unsustainable.

(4) It is easier to encourage and enable sustainable lifestyles of the residents of a neighbourhood than a city, because the successes of SUD become tangibles aspects of their daily life

(5) The delivery of urban transformation relies less on centralised institutions and can be generated from bottom-up, that is, by the action of the community.

However, in the context of this research, “neighbourhood” is not purely viewed from a territorial perspective. It is primarily seen as a space where a specific population is residing or working and which space provides specific services and infrastructures that improve the daily life of this living and working population. This population though has specific consumption patterns that can affect both the local and global environment. In other words, the environmental impacts caused by the activities of each resident or business owner occurring inside the territory of the neighbourhood expand beyond the boundaries of this local area. They are therefore tied to a specific environmental footprint. Accounting for these impacts constitutes the so-called “consumption-based” view of the neighbourhood’s activities and it is the one considered in the context of this thesis.

Geographically, the focus is on Europe but this does not mean that the ideas presented in this research are not applicable to other regions. To put it differently, this thesis’s geographic focus serves as a limit to the scope of its findings but not necessarily to its potential contribution. However, an analysis of important SUD problems relating to the provision of basic services in neighbourhoods such as people living in slums or inadequate access to sanitation are missing from this thesis. Such problems are hardly met in European areas, but they are pressing challenges in the developing world. For some issues this often applies the opposite way around. Some themes treated in the thesis such as barrier-free design to accommodate the needs of an increasing ageing population in Europe, despite being significant everywhere, their level of urgency varies depending on the demographic trends observed in each region. The selection of a geographic region was therefore necessary.

Finally, the conceptualisation of SUD in this research follows the four-pillar model, or also known as the "prism of sustainability" (Valentin & Spangenberg, 2000), that incorporates the economic, environmental, social, and institutional dimensions of sustainability (the contents of each dimension are fully explained in Spangenberg, (2004)). Going beyond the traditional concept of sustainability that is concerned with handling relationships between social systems and the environment in a fair and economically feasible way, and without causing irreparable damage to the environment, was necessary for the following simple reason: without an urban governance that is based on strong institutional foundations such as process leadership, procedural equity, empowerment and collaboration, the other three pillars of sustainability cannot be effectively pursued. The institutional pillar or dimension creates the preconditions for creating powerful mechanisms to manage trade-offs among stakeholder groups or institutions with conflicting views, motivations and priorities.

1.6 Methodological Approach

Guided by the research questions, this thesis proposes a conceptual "process-based" and "action-oriented" overall framework which aims to support SUD planning and decision-making on a neighbourhood level. This overall framework is comprised of three individual and interconnected frameworks that attempt to answer the three groups of sub-questions respectively as provided above.

The *process framework*, as it is called in the context of this thesis, establishes a step-by step workflow to describe the SUD process, and it therefore follows a "workflow thinking". The strategy of decomposing the complex process of SUD into its constituent parts can provide a comprehensive understanding of the process, which facilitates: (1) the identification of involvement possibilities and influence with respect to relevant actor groups for each process step; (2) the fundamental goals and challenges inherent in each step so that to propose appropriate guidance.

The second part of the overall framework, is called the *assessment framework* and it shifts (and more specifically narrows down) the focus of the thesis from the overall SUD process to a specific task – the task of assessing and monitoring the progress towards SUD – a fundamental task of every SUD process. The assessment framework describes a formal way around which the sets of goals, themes and indicators are organised.

Finally, the third part of the overall framework, called the *action prioritisation framework*, provides a structured procedure for identifying, assessing and selecting concrete SUD strategies and actions. This framework integrates MCDA as a valuable tool to support this procedure.

Broadly, the research consists of two parts which make use of different methodological approaches: the development of the conceptual three-part overall framework (the *process framework*, the *assessment framework* and the *action prioritisation framework*) and the illustration of the application of the last part of this framework with a hypothetical case study. More specific methodologies will be further outlined throughout the chapters of this thesis.

The Development of the Overall Conceptual Framework

To develop the conceptual three-part overall framework, first, relevant literature, publications and studies were reviewed to get in-depth information and a clear understanding on the current political and practice-based context with respect to the field of urban sustainability and SUD.

With regard to available neighbourhood sustainability assessment practices, a comprehensive investigation of previous comparative researches in this emerging field was initially undertaken to: (1) identify and catalogue the internationally most visible neighbourhood-scale sustainability assessment systems (NSASs); (2) identify the main points of critique to their approaches as discussed by other researchers. To evaluate the logical soundness of the arguments presented in literature and to reveal potential unidentified shortcomings, the assessment manuals themselves of several NSASs (where free access was possible) were examined.

Not surprisingly, in many cases, it was found that information included in previous papers is somewhat out-of-date. This is reasonable, given that many of these systems are continuously updated and new versions are usually published every three to five years to address changing knowledge and priorities. The same applies to the previous research of the present researcher in this field, as can be seen in Balouktsi et al. (2013). It may also be the case that the overview shown in the context of this thesis does not reflect the latest versions of some of the systems; the survey was completed by the first half of 2017. Along with the identification of deficiencies and shortcomings, this extensive literature and document analysis also led the present researcher to develop a typology of NSASs on the basis of their primary underlying functions, being (1) performance assessment, (2) certification and (3) planning. This constituted the starting point of their critical analysis.

Although neighbourhood was selected as a level of analysis and action and Europe as the geographical focus, to identify the global trends expected to influence the current SUD practices at the neighbourhood level, the literature review covered a much broader scope: it also investigated central initiatives in the global political agenda to progress towards sustainable development, such as the 2030 Agenda for Sustainable Development (UN General Assembly, 2015) and international standardization activities in the field of urban sustainability (e.g. the standard ISO/FDIS 37120 (ISO, 2017)).

Furthermore, results from the research project “Urban Transition Lab 131” (R131) (Quartier Zukunft, 2017) were included in the work. This is a project focused on the sustainable development of the district “Oststadt” of the city of Karlsruhe. Together with project partners from the Institute for Technology Assessment and Systems Analysis (ITAS) of the Karlsruhe Institute of Technology (KIT), the fundamentals for the development, systematization and selection of topics and indicators related to SUD were discussed in a series of project workshops and meetings over the period of two years (2015-2017). An originally planned guideline document for a process-based sustainability assessment of neighbourhoods is still under development with project partners. The present author’s main contributions in the context of this thesis that also went into this project are:

- analysis and classification of sustainability assessment systems for cities and districts;
- a systematic framework under which to organise topics and indicators;
- structured workflows to organise the process of SUD.

A preliminary state of the above-mentioned results can also be found in peer-reviewed conference papers that were produced in the meantime to reflect partial results of the project (i.e. Lützkendorf et al., 2016; Balouktsi et al., 2017; Lützkendorf & Balouktsi, 2017). The feedback from the fruitful discussions with the audience during the presentations of these papers also stimulated an expanded understanding of the challenges and possibilities of achieving SUD on a neighbourhood level beyond the experience gained in the project group.

Finally, the development of the third part of the conceptual framework was exclusively based on a literature search. Notwithstanding the drawback of an absence of interviews or real case studies, the material presented is still worthwhile, as a vast number of primary and secondary sources were available for analysis. Yet, to gain a more in-depth understanding in particular of the capabilities of MCDA to support the selection process of SUD strategies and actions, the present author developed a hypothetical case study to which the MCDA framework was applied (described below).

Illustration of the Action Prioritisation Framework by Means of Hypothetical Case Study

To illustrate the action prioritisation framework by means of a hypothetical case study requires: (1) the selection of an appropriate MCDA method, and (2) the creation of a hypothetical, but logical input data set. The hypothetical situation selected for consideration was the choice between different actions for the realisation of a nearly climate neutral neighbourhood as an ambitious target within the context of the overall sustainable development process. This topic was mainly selected for two reasons: First, although this is a newly emerging decision situation for European cities and neighbourhoods, it is becoming increasingly important, even a necessity, after COP21 in Paris. Second, the recent mushrooming of both academic and practice-based literature on this subject matter and the emergence of databases of climate mitigation actions (e.g. the ClimateTechWiki database (n.d.)) creates a fertile ground to arrive at a sensible hypothetical data set.

Consequently, the second requirement was simply fulfilled by researching the existing body of literature dealing with generic analyses and evaluations of climate mitigation actions against diverse criteria to derive a generic performance table for a list of selected climate mitigation actions. With regard to the first requirement, the first step was to conduct a literature review to identify the various multi-criteria methods and their characteristics with the purpose to select a widely-applied and comprehensive MCDA method that provides the possibility of non-compensation, and therefore caters for a strong sustainability concept. ELECTRE III was identified as an appropriate method for the purposes of this research. The second step was to identify a software tool to automate the execution of ELECTRE III with the following fundamental desirable features: free for use, with a user-friendly interface and adequate possibilities of data and results visualisation. Considering the limited options available with regard to existing ELECTRE III tools, the present researcher decided to develop an own interactive and user-friendly web tool for the purposes of the hypothetical case.

The development of the web tool, called *ELECTRE III_R*, was made possible through the exploitation of the R-packages Shiny (Chang et al., 2017) and Shinydashboard (Chang & Borges Ribeiro, 2017) – which runs on top of Shiny – to create the frontend. The R-Shiny package was chosen for two reasons. First, it offers the possibility to build and maintain web applications with a user-friendly and interactive graphical user interface by purely coding in R. Therefore, no knowledge of Javascript/CSS/HTML is necessary. Second, the functions and tools it contains also greatly decrease the amount of R coding necessary.

For the processing of the method itself in R, related R functions found in literature (Prombo, 2014) were combined with own R scripts for the parts of the method that could not be catered for through existing functions. Finally, the results obtained from the web-tool were validated in two ways: (1) by running the input data sets of two specific case studies from literature to cross-check the results generated by the tool with the output result of the case studies; (2) by first building an ELECTRE III workflow using the Diviz software platform (Meyer & Bigaret, 2012), then inputting the same input data set in both tools to run the method, and finally comparing the results generated.

1.7 Structure of the Thesis

Having clarified the background, the research questions, the scope and the methodological approach of the thesis in the previous sections of the introduction (Chapter 1), this section describes the content of the remaining five chapters.

Chapter 2, *Setting the Scene: Trends, Challenges and Opportunities*, lays the foundation for the present thesis. It delves into the topics and trends that are currently driving or are expected to drive sustainable urban development practices through an in-depth critical examination of the existing literature and work. These topics and trends are referred to as "*elements*". A description of the chapter's contents and line of argument is given in the first section (2.1). Four self-contained sections follow to allow readers to focus independently on each particular "element". Each of these self-contained sections end with a brief discussion of the main points of importance. Section 2.2 is dedicated to the topic of SDGs, as the most recent concerted global effort towards sustainable development, and critically examines the relevance of SDG targets to the topic of neighbourhood development in Europe.

Section 2.3 reviews the academic research on neighbourhood sustainability assessment along the assessment manuals of selected NSASs. The purpose is to identify shortcomings and limitations in existing sustainability assessment practices focusing in particular on their suitability for application to the improvement of existing neighbourhoods. Moving from assessment to action, Section 2.4 discusses the potential of MCDA approaches in providing a framework for evaluating, prioritizing and selecting SUD actions in the context of a participatory SUD framework. In section 2.5, the status of international standardization activities on urban level are presented. International standards affect both governments and industries and provide an indication of the direction the future regulation is heading. The final section (2.6) gives a summary of the chapter and closes with short discussion about the need for placing all these otherwise independent (but interrelated) developments into an integrated concept. This discussion forms the rationale for developing the conceptual overall framework presented in the next section.

Chapter 3, *A New Process-based and Action-oriented Overall Framework*, is the core of the thesis. It introduces the conceptual three-part overall framework. First, a short description of how neighbourhood is understood as an object of assessment and scale of intervention in the context of this research is provided (section 3.1). Section 3.2 looks at the *process framework* – i.e. the first part of the conceptual framework that is exclusively dedicated to unveil the process of SUD focusing on the preparation/pre-implementation phase – starting with the establishment of generic quality requirements for the SUD process. These requirements are incorporated into the *workflow* that represents the SUD process later in this section.

Section 3.3 introduces the *assessment framework*, which focuses on guiding a specific task inherent in every SUD process: the development, selection and systematisation of indicators to assist the assessment and monitoring of progress. The *assessment framework* can therefore be seen as a "zooming in" on particular aspects of the process complicated enough to require their own framework. Section 3.4 presents the third part of the overall conceptual framework, the *action prioritisation framework*, which also concentrates on a distinct part of the SUD planning process: the evaluation, prioritisation and selection of SUD strategies and actions. As in the previous chapter, each of the sections describing one part of the conceptual framework end with a brief discussion of the main points of importance. The final section (3.5) gives a summary of the chapter and connects the experiences gained through the development of the three interdependent sub-frameworks.

Chapter 4, *Development of a Web-based Decision Support Tool with ELECTRE III for a Customised Ranking of Actions*, establishes the we-based software tool developed to handle the computational aspects of ELECTRE III and make the overall MCDA process more illustrative, transparent, and comprehensible. The reasoning behind the choice of ELECTRE III method is laid out in the first section (4.1). Section 4.2 briefly explains the ELECTRE III method, providing all the steps of the methodology and formulas associated with each step. Section 4.3 presents the main features and visualisation possibilities of the web application by a means of a simple case study taken from literature. This section also explains the validation procedure followed to ensure that it provides correct results. Finally, Section 4.4 summarises the results of the endeavour to develop an own tool for the purposes of the next chapter.

Chapter 5, *Climate Action Planning in the Light of COP21: A Hypothetical Case Study*, applies the findings from the two previous chapters to a hypothetical case study. Section 5.1 discusses the overall importance of the current topic of climate neutrality, which is the underlying topic of the hypothetical decision situation (that is, decision on climate mitigation actions to achieve the status of nearly climate neutral), while Section 5.2 focuses on the actual demonstration of the findings of the previous two chapters. The final section (5.3) provides a summary of the chapter.

Chapter 6, *Summary and Conclusions*, first reintroduces the research relevance (Section 6.1), and then discusses the contributions, conclusions and limitations of the work in three individual sections (6.2-4). Finally, an outlook with recommendations for future research are provided (Section 6.5).

A schematic overview of the different chapters, sections, and their connections is provided below (Figure 1.1).

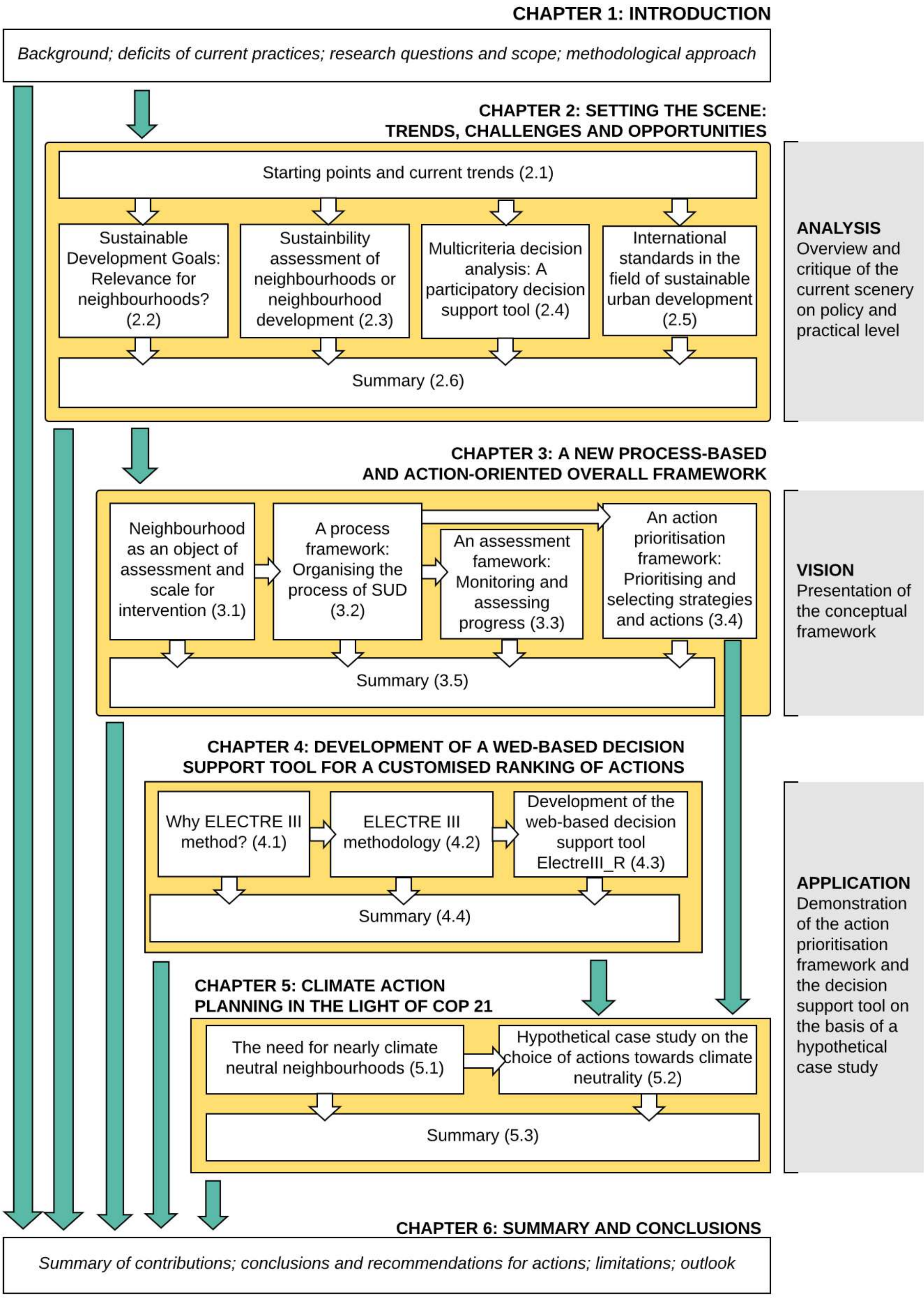


Figure 1.1. Schematic overview of the structure of the thesis into chapters and sections (Source: Present author)

2 Setting the Scene: Trends, Challenges and Opportunities

This chapter reviews the existing literature to explore the trends that influence, or are expected to influence, the current SUD practices at the neighbourhood level. The purpose is two-fold: (1) to investigate which of the current advancements, either in the policy setting or research methods, currently disconnected from, but (potentially) related to, urban sustainability as a general topic can help current improvement practices in neighbourhoods as new elements in the equation (Sections 2.1 and 2.3); (2) to have a critical look at current approaches to identify their most common shortcomings and deficiencies, the consequences for the existing neighbourhoods and what are the possible solutions to overcome them (Sections 2.2 and 2.4). Finally, a summary is provided (Section 2.5).

2.1 Starting Points and Current Trends

The current world is characterised by an increasing recognition by policy makers and urban practitioners that global sustainable development needs to be addressed at the urban and sub-urban level; in other words, the city and neighbourhood level. This has resulted in many different research, practice-based and political agendas to run in parallel. Often, individual questions are discussed such as the selection of indicators to assess the progress towards SUD, the development of related strategies or the involving of relevant local actors in the SUD processes, but without arranging them into an overall context. There is – from the point of view of the present researcher – a need to bring the different "elements" (e.g. frameworks, processes and stakeholders) together in a new "configuration". These elements are shortly introduced below (also depicted in Figure 2.1):

Sustainable Development Goals (SDGs)

2015 marked a significant milestone in the global quest for sustainable development. The adoption of the 17 global SDGs (UN General Assembly, 2015) signals the need for urgent transformative action to enable significant progress towards sustainable development over the next decade (i.e. up to 2030). Judging from the content of the goals, it is apparent that many of them will have to be addressed locally. Indeed, Goal 11 places cities at the centre of attention and acknowledges their powerful role in contributing to a sustainable world; but it is not the only goal relevant to urban areas. There is agreement on the need to "localise" the SDGs and require implementation at the city level (see Section 2.2). Yet the "how" is blurry and requires further discussion. SDG 11 builds on traditions such as the Local Agenda 21 (Coenen, 2009) and the Leipzig Charter on Sustainable European Cities (Eltges & Hamann, 2010). This "element" describes the SUD goals and relates them to other goals of sustainable development.

Neighbourhood as a "Manageable" Urban Unit in Driving Global Sustainability

Assessing and delivering urban sustainability, or sustainable urban development in the case of existing urban areas, can be a complex task with numerous stakeholders (individuals and organisations) and competing issues involved. For this reason, many practitioners view neighbourhood scale as the "sweet spot" between the building and the city in achieving sustainable development goals. Particularly, there is growing empirical evidence and recognition that:

(1) Cities are "organically" developed and formed from the bottom-up through the millions of self-organizing socio-economic transactions at the building and neighbourhood scales (in addition to top-down "master plans") (Batty, 2008).

(2) There is good potential for more meaningful community engagement at the neighbourhood scale than at the city and building scales. The neighbourhood scale allows more active and informed engagement and sense of ownership (compared with city scale) and more diverse interests to engage in decisions shaping socio-cultural and environmental considerations (compared with the building scale) (Waldron et al., 2013).

(3) In some cases, neighbourhoods can be viewed as a space for "innovation and experimentation", where infrastructure systems that are untested can be piloted before being applied citywide (e.g. storm water management) (Fitzgerald et al., 2014).

All these arguments establish the role of the neighbourhood as critical for the designing of strategies for SUD in cities, and in turn, global sustainable development. This is also what led to the growing emergence of assessment frameworks for neighbourhood sustainability (next element). So far, there is no uniform and generally accepted definition and interpretation of the term "neighbourhood". Depending on the context, a different definition can be formulated. "Context" incorporates not only physical dimensions (i.e.

characteristics) – meaning the built (e.g. block shape and street design) and natural environment (e.g. geography and climate) – but also non-physical dimensions – meaning socio-economic (e.g. human activities and behaviour) and institutional factors (e.g. regulations, policies and land ownership).

The definition adopted by the present thesis is discussed later (Section 3.1). This "element" defines the object of assessment and forms the basis for the determination of system boundaries.

Indicator-based Frameworks for Neighbourhood Sustainability Assessment

There is still limited knowledge and consensus on how to measure and assess sustainability or sustainable development of urban areas (Komeily & Srinivasan, 2015). Nevertheless, there is a proliferation of attempts to assess urban sustainability through the development and use of urban sustainability assessment frameworks (sometimes also called "systems" or "tools"). Many of them focus on the neighbourhood level as a softer transition from building (micro-scale) to urban scale (meso- and macro-scale). These are here referred to as Neighbourhood Sustainability Assessment Systems (NSASs) and have become a dominant instrument for guiding the efforts of improving the urban environment (Elgert, 2018). These systems are typically indicator-based.

Indicators are popularly used in sustainability assessments due to their easiness in representing certain properties of human–environmental systems, as well as effectiveness in communication with decision-makers and other stakeholders (Li & Li, 2017). Indicators are described by ISO 21929-2 (ISO, 2010) as: "*figures and measures that enable information on a complex phenomenon like environmental impact to be simplified into a form that is relatively easy to use and understand.*" The same standard further specifies that the three main functions of indicators are quantification, simplification and communication.

Whereas positive impact of NSASs on progressing towards a more sustainable built environment and mainstreaming green innovation in neighbourhoods cannot be doubted, there are various issues with regard to their nature and suitability for the sustainable development of existing neighbourhoods to be addressed or considered (see Section 2.3). Their technical nature and view of urban sustainability that prioritize measurable aspects (Boyle & Michell, 2017) than human-centred aspects such as participation processes – along with their certification-driven approach than a benefits-led approach in the implementation of strategies – raises the question of how appropriate or useful they are to guide the upgrading of existing neighbourhoods.

These "elements" represent the assessment systems and indicators. They must be adapted to the object of assessment and be related to the objectives pursued.

Tools for Action Assessment, Prioritisation and Selection

The implementation of SUD is a difficult and multifaceted task. This is due to the fact that conflicting and incommensurable aspects such as environmental, economic and social issues, as well as conflicting stakeholder interests should be dealt with simultaneously when actions have finally to be put in place. Multi-Criteria Decision Analysis (MCDA) methods are well-known to cope with these difficulties, and although already used for decades in several fields, an increasing interest in their application for selecting actions with regard to improving urban sustainability began making its appearance over the last decade (e.g. Kain & Söderberg, 2008). MCDA methods offer an alternative to the monetary valuation of environmental and social aspects when faced with the selection of SUD actions (for a deeper analysis, see Section 2.4). These "elements" represent the methods and tools.

Although all the above-mentioned elements now constitute different streams of knowledge and work, they are related and reinforcing – see Figure 2.1. The question though arises: How the different elements can be integrated into a common and coherent framework? Before investigating this question, an in-depth background analysis of each individual element is necessary and provided below.

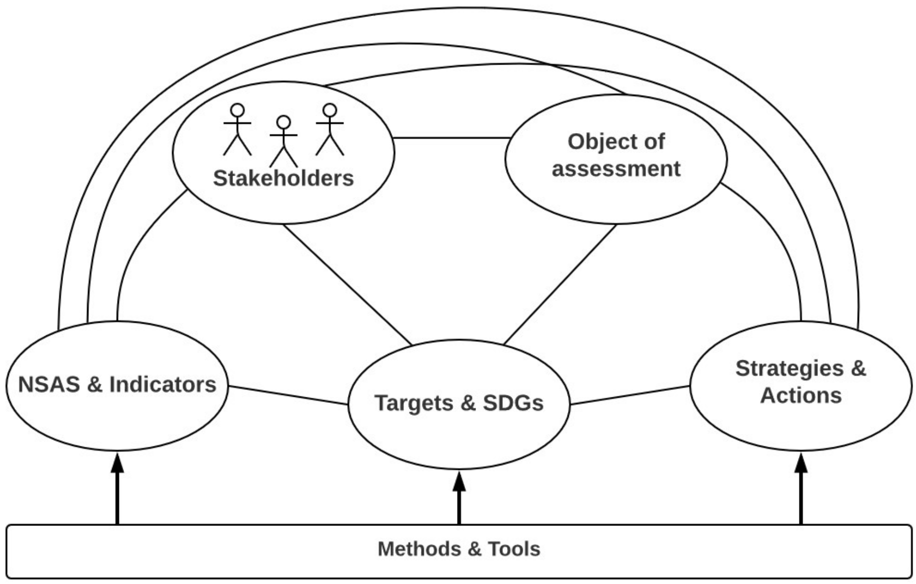


Figure 2.1. The different elements making up the current scene (Source: Present author)

2.2 Sustainable Development Goals (SDGs): Relevance for Neighbourhoods?

In September of 2015 the United Nations (UN) officially introduced 17 Sustainable Development Goals (SDGs) and 169 targets in order to be able to provide guidance at global, national, regional and local level towards a more sustainable world (UN General Assembly, 2015). The 17 ambitious goals (Figure 2.2) cover all four dimensions of sustainable development (environmental, economic, social and institutional – see also section 2.3) and were agreed upon by more than 190 countries who negotiated the agenda. Their development builds on experiences made from the UN Millennium Development Goals (UN, 2015) – eight goals that were adopted in 2000 with the aspiration to be achieved in 2015. The SDGs, however, unlike their predecessors, are universal and do not only address developing-world challenges. They include many topics of direct relevance for developed countries, and consequently European countries.

While UN considered the MDGs campaign a great success, specifically calling it in the final report on MDGs the "*most successful anti-poverty movement in history*" (UN, 2015, p. 3), scepticism about the validity of such a claim is also apparent. Several researchers challenge this claim (Hickel, 2016; Pingali, 2016) by demonstrating the ambiguity of the metrics that have been used by UN to measure success on poverty eradication. Additionally, regardless of the metrics used, eventually not all MDGs were finally met (examples are MDG 4 and MDG 5, where child mortality rate and global maternal mortality ratio were reduced by about half and not two-thirds as planned). For this reason, it is hoped that SDGs will learn not only from the successes, but also failures of MDGs.

Since the release and adoption of the 17 SDGs and their 169 targets, many developments have taken place, the most recent one being the adoption of *"the global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development"* on 6 July 2017 (UN General Assembly, 2017). The global indicator framework was developed by the Inter-Agency and Expert Group on Sustainable Development Goal

Indicators (IAEG-SDGs) in order to be able to follow up progress towards reaching the SDGs. Its development was therefore led by countries themselves through the membership of their national statistics offices in IAEG-SDG group. The indicator set includes a list of 232 generally agreed indicators distributed across the different SDGs and their targets (UNSD, 2018a). However, nine of them function as multi-purpose indicators monitoring more than one target, and in some cases more than one goal.

Figure 2.2. An overview of the 17 SDGs (Source: Adapted from UN General Assembly (2015)).

Among the criteria for selecting indicators, data availability was not considered, which led IAEG-SDG to classify indicators into three categories, the so called "tiers", based on the soundness of the methodology and the availability of data (UNSD, 2018b). "*Tier I indicators*" have an internationally established methodology and regularly produced data by a critical mass of countries, and are therefore considered as ready-to-use; "*Tier II indicators*" have an internationally established methodology but not regularly produced data; and "*Tier III indicators*" have no internationally established methodology, but the methodology is under development.

The purpose of the categorization was not to determine the importance of the indicators but to ensure that attention is paid to developing methodologies and establishing data collection mechanisms in countries for tier II and III indicators. As of 11 May 2018 the tier classification contains 93 Tier I indicators (UNSD, 2018b), which means that less than half of the selected indicators can be directly measured by most countries. In this regard, the measurement of the SDG indicators is expected to pose significant challenges for countries.

The focus of the present thesis is though on the use of indicators to assess progress towards SUD at the neighbourhood level in a European context. This leads directly to two foundational questions: Can SDGs provide guidance to local governments on how to assess progress towards SD at urban level? And if yes, which goals and targets are relevant to the city level and which to the neighbourhood level in Europe?

Though the SDGs framework was designed with national governments in mind, there is a growing consensus that progress at the local and subnational level will be critical to their success (Greene & Meixel, 2017). The 2030 Agenda is applicable to countries at all levels of development. The role of city governments in driving transformation from bottom up is specifically reflected through the inclusion of Goal 11 to *"Make cities and human settlements inclusive, safe, resilient and sustainable"*. The inclusion of a dedicated goal to cities was the result of a successful global campaign for an Urban SDG supported by over 200 mayors and local leaders. It is noticeable that "sustainability" is mentioned here as one of several sub-goals, without clarifying the interactions with other sub-goals. The author argues that issues such as inclusion, safety and resilience are closely linked to sustainability. To this day, it is a problem that the term sustainability is used very vaguely.

However, the relevance of cities goes far beyond Goal 11. As explicitly pointed out by the Global Taskforce of Local and Regional Governments, UNDP and UN-Habitat (2016, p. 6) in their roadmap for localising SDGs *"All of the SDGs have targets directly related to the responsibilities of local and regional governments"*. In the same report the concept of localisation refers to the "*process of taking into account subnational contexts in the achievement of the 2030 Agenda, from the setting of goals and targets, to determining the means of implementation and using indicators to measure and monitor progress*" (p.6). This means that the process of localisation does not only involve the implementation of bottom-up actions to support the achievement of the SDGs, but also the determination of locally relevant targets and indicators on the basis of the SDG framework.

In fact, as illustrated in the preceding findings of Cities Alliance (2015, p. 19), as much as 65% of the SDG targets are at risk without the involvement of local urban actors. Some countries are already working to advance SDG localisation. A European example is Germany, where the Federal Ministry of Economic Cooperation and Development supports local authorities to align their urban development plans with the SDG targets, with North Rhine Westphalia region as the first test bed (UCLC, 2017). Besides the individual country initiatives, new global networks and online knowledge platforms have also been created to share lessons learned and provide tools for "localizing" the SDGs ("Toolbox for localizing the sustainable development goals", n.d.). Nevertheless, despite some encouraging results, to many local authorities SDGs still seem as something far-off and/or unconnected to their own agendas.

Without a doubt, it is hard to envisage achieving a significant global progress on the SDGs by 2030 without an active role for city governments and other local leaders. For example, it is widely acknowledged, both by researchers (Broto & Bulkeley, 2013) and policy makers (The Global Commission on the Economy and Climate, 2014), that cities have a critical role in climate change mitigation. Additionally, city governments are typically responsible for delivering services and establishing policies across diverse domains that affect the daily lives of their populations, such as health, education, transportation and economy. However, it is difficult to translate 17 goals, 169 targets, and 232 indicators into locally relevant strategies and actions. Identifying the goals and targets of direct concern to cities and neighbourhoods can be a first step. In fact, all the SDGs have targets directly related to the responsibilities of local governments, but not all of these targets can be directly influenced at a smaller action level than the city. The relevance analysis in the following provides first insights on what is the share of relevant targets (as formulated in the 2030 Agenda) for cities and neighbourhoods in Europe.

2.2.1 Relevance Analysis

A review of the SDG framework to determine which of the SDG targets are relevant to European cities and neighbourhoods is here performed. Besides examining the targets one by one, the present author also consulted a report published by United Cities and Local Governments (UCLG) identifying which of the 169 targets matter to local and regional governments and leaders, but from a world-wide perspective (UCLG, 2015). Although the thesis focuses on aspects related to neighbourhood scale, it is important to also examine the city scale here. Depending on the context, the goals relevant to cities can be considered in a broader sense as potentially relevant to neighbourhoods. For this analysis, a target is qualified as relevant if progress is likely to be generated by (structural/physical, regulatory or soft) actions taken by municipal leaders at these two different urban scales, including also the possibility to influence the consumption patterns of residents or private businesses. To put it another way, a target is relevant if local authorities or other local leaders have the potential to directly influence progress toward achieving the target in their area.

This definition results in the exclusion of three general categories of targets as not relevant to European cities and neighbourhoods. First, the targets explicitly designed for “developing” or “least developed” countries are automatically not applicable to Europe in general (e.g. target 16.8: *“Broaden and strengthen the participation of developing countries in the institutions of global* *governance"*). Second, the targets explicitly limited to laws, regulations or policies that are exclusively managed at higher levels of government than the city (e.g. target 1.3: "*Implement nationally appropriate social protection systems and measures for all, including floors, and by 2030 achieve substantial coverage of the poor and the vulnerable*") are excluded. Third, targets addressing sustainable development issues that typically occur outside of the city or neighbourhood context, such as food security and sustainable agriculture (i.e. all targets within goal 2), marine resources conservation (i.e. all targets within goal 14), or wildlife protection and management are left out. In each of these categories, local leaders are unlikely to be able to directly influence progress toward achieving the target in their city or its constituent parts (i.e. neighbourhoods).

The relevance analysis reveals that the SDGs are highly relevant to European cities (about 40%), but action taken on a neighbourhood level can only slightly contribute to the progress towards achieving the goals (Table 2.1). Specifically, it was found that 24 of the 169 SDG targets (or 14%) are relevant to European neighbourhoods. However, looking at each goal individually, a significant percentage of relevant targets is observed in Goal 11 (cities), and a lower but measurable (i.e. ≥ 20%) share in Goals 1 (poverty), 3 (health), 4 (education), 5 (gender), 6 (water), 7 (energy) and 13 (climate). This means that aligning or relating neighbourhood actions to SDG targets is meaningful.

The relevance analysis simply indicates the share of targets under each goal that can be directly influenced by actions in cities and neighbourhoods. Using a different set of targets would lead to different results with regard to the relevance of each goal. In this sense, the analysis may seem counterintuitive. Therefore, it is worth highlighting that having a low share of relevant targets under a goal does not indicate that the goal is less relevant to European cities and neighbourhoods or that targets under that goal do not reflect imperative issues that require immediate action. For example, while infrastructure with regard to transportation is a fundamental aspect of neighbourhood sustainability, targets under SDG 9 mostly address industry-related infrastructure and research and development expenditures.

Table 2.1. Relevance analysis of SDG targets for EU cities and their neighbourhoods (Source: Present author).

SDG goal	Total targets	No of targets relevant for EU cities (target code)[a]	No of targets relevant for EU neighbourhoods (target code)[a]	Share of targets relevant for EU neighbourhoods[b]
1-Poverty	7	3 (1.2, 1.4, 1.5)	2 (1.4, 1.5)	29%
2-Hunger	8	1 (2.2, 2.4)	0	0%
3-Health	13	5 (3.4, 3.5, 3.6, 3.8, 3.9)	3 (3.4, 3.6, 3.9)	23%
4-Education	10	6 (4.1, 4.2, 4.3, 4.4, 4.5, 4.7)	2 (4.2, 4.4)	20%
5-Gender	9	4 (5.1, 5.2, 5.4, 5.5)	2 (5.2, 5.5)	22%
6-Water	8	5 (6.3, 6.4, 6.5, 6.6, 6.b)	2 (6.3, 6.4)	25%
7-Energy	5	3 (7.1, 7.2, 7.3)	1 (7.2)	20%
8-Economy	12	5 (8.3, 8.5, 8.6, 8.8, 8.9)	0	0%
9-Infrastructure	8	3 (9.1, 9.3, 9.4)	0	0%
10-Inequality	10	3 (10.1, 10.2, 10.3)	1 (10.2)	10%
11-Cities	10	9 (all except 11.c)	5 (11.1, 11.2, 11.3, 11.6, 11.7)	50%
12-Consumption	11	7 (12.2, 12.3, 12.4, 12.5, 12.7, 12.8, 12.b)	1 (12.5)	9%
13-Climate	5	2 (13.1, 13.3)	1 (13.3)	20%
14-Oceans	10	2 (14.1, 14.2)	0	0%
15-Land	12	4 (15.1, 15.2, 15.5, 15.9, 15.b)	1 (15.5)	8%
16-Justice	12	5 (16.1, 16.5, 16.6, 16.7, 16.10)	2 (16.1, 16.7)	17%
17-Parnership	19	3 (17.1, 17.14, 17.17)	1 (17.17)	5%
Total	169	70	24	14%

[a] Details on which code number refers to which SDG target is found in UNSD (2018a).

[b] Any percentage equal or above 20% is highlighted to indicate in which goals the higher shares are to be found.

2.2.2 EU-SDG Indicator Set

On the same period in 2017 the global SDG indicator set was published, EU established its own indicator set to monitor progress in an EU context towards SDGs (Eurostat, 2017b). The establishment of a Europe-oriented SDG indicator set, with strong links with EU policies and initiatives, such as Europe 2020 (European Commission, 2010a), the 10 Commission Priorities (European Commission, 2015a) and the Circular Economy package (European Commission, 2015c), was foreseen by the European Commission Communication (COM (2016) 739) "*Next steps for a sustainable European future*". This set complements the global SDG indicator set from an EU perspective and comprises 100 indicators (much fewer than the 232 indicators in the global framework) structured along the 17 SDGs and 2-4 sub-themes under each SDG (Table 2.2). The percentage of alignment with the UN indicator list is slightly more than 50% (51/100 indicators) (European Commission and Eurostat, 2017).

This indicator set constitutes an important attempt of regional adaptation of SDGs, where the intention is clearly not to cover all aspects of the SDGs or the entire suite of the UN's global indicators, but to focus on indicators relevant to the EU. For instance, under SDG 2 Zero Hunger, the EU-SDG indicator set solely addresses obesity as the flipside of hunger and a more relevant issue in the European context. Furthermore, the EU-SDG indicator set uses 41 multi-purpose indicators to monitor more than one goal (much more than the 9 multi-purpose indicators in global framework). One characteristic example is the indicator *"Share of renewable energy in gross final energy consumption"* that monitors progress towards three SDGs simultaneously – SDG 7 under the sub-theme *"Energy supply"*, SDG 12 under the sub-theme *"Energy consumption"* and SDG 13 under the sub-theme *"Climate mitigation"* – while the identical indicator in the global framework is only found under SDG 7.

Table 2.2. Sub-themes within the EU SDG Indicator set (Source: Adapted from Eurostat, 2017b)

SDG goal	**Sub-themes**
1-Poverty	Multidimensional poverty; Basic needs
2-Hunger	Malnutrition; Sustainable agricultural production; Adverse impacts of agriculture production
3-Health	Healthy lives; Health determinants; Causes of death; Access to health care
4-Education	Basic education; Tertiary education; Adult education
5-Gender	Gender-based violence; Education; Employment; Leadership positions
6-Water	Sanitation; Water quality; Water use efficiency
7-Energy	Energy consumption; Energy supply; Access to affordable energy
8-Economy	Sustainable economic growth; Employment; Decent work
9-Infrastructure	R&D innovation; Sustainable transport
10-Inequality	Inequalities between countries; Inequalities within countries; Migration and social inclusion
11-Cities	Quality of life in cities and communities; Sustainable transport; Adverse environmental impacts
12-Consumption	Decoupling environmental impacts from economic growth; Energy consumption; Waste generation and management
13-Climate	Climate mitigation; Climate impacts; Climate initiatives
14-Oceans	Marine conservation; Sustainable fishery; Ocean health
15-Land	Ecosystems status; Land degradation; Biodiversity
16-Justice	Peace and personal security; Access to justice; Trust in institutions
17-Parnership	Global partnership; Financial governance within EU

2.2.3 Discussion

From a first look, SDGs are suitable as a source for deriving core themes/criteria when designing an urban sustainability assessment framework or system. Looking deeper, it can be observed that a clear starting point is lacking; some SDGs deal with "areas of protection"[1] in the meaning of resources or values worth protecting (Udo de Haes, 1996), others with areas of need, others with objects (cities), and others are action-based (like changing patterns of production and consumption).

Furthermore, many of the containing targets are confusing; they mix up together many topics at the same time (i.e. too broad) and do not sufficiently distinguish between ends and means. From the present author's point of view, a clear systematisation of the topics and indicators to distinguish whether they concern "objects" such as cities, "areas of protection" such as climate, water, land and "processes" such as production and consumption patterns would be useful. Again, it becomes clear that different elements form a framework.

Along this, the incredibly large number of targets and indicators sometimes leads to a lack of focus on priorities. While the broad headings under SDGs seem relevant to any urban context, only 14% of the targets are relevant to European neighbourhoods. This translates to more than 20 targets that is still a significant number for consideration of aligning neighbourhood efforts with selected SDGs.

With regard to the situation in Europe, the publication of EU-SDG indicator set makes it evident that the EU has a high interest in adapting the 2030 Agenda to its own context. This indicator set is much shorter than the global indicator framework. This is the case due to a better illustration of the multidimensionality of indicators (called "multi-purpose" by the European Commission).

[1] the term "areas of protection" originates from early discussions of SETAC Working Group on Environmental Life Cycle Assessment (ELCA), and it is commonly found in literature on life cycle analysis.

This EU-approach reinforces the present author's concept in developing a framework of indicators (see Section 3.3). Sustainable urban development is inherently multidimensional and solutions along one dimension or theme may have positive (or negative) effects on other dimensions or themes. A multidimensional framework highlighting the interlinkages across different goals or themes is of paramount importance for a correct framing and improved narrative of SUD.

2.3 Sustainability Assessment of Neighbourhoods or Neighbourhood Development

Sustainability assessment methods of neighbourhoods are not new, but their proliferation and visibility have increased in recent years: up to now, several NSASs have been developed worldwide, all with varying end goals, approaches to measuring sustainability, scope and application areas. On the basis of recent studies and the present author's earlier work (i.e. Balouktsi et al. (2013) – an updated version of these results also fed into an unpublished report for the project R131 (Quartier Zukunft, 2017)), this section broadly critiques NSASs in order to question the epistemological and methodological approach they promote. The critique is built around questions, such as: Does the assessment method used include a long-time perspective? Does the system follow a balanced approach that combines environmental, economic, social and institutional aspects? Is the system designed to assess new or existing neighbourhoods? Or both? This analysis leads to the identification of certain shortcomings. Finally, it is evaluated what the identified shortcomings mean for the SUD of existing neighbourhoods.

Based on the critique, possible ways of addressing the deficiencies are suggested for NSAS which focus more on the dynamic nature of urban development process among others. These ways will ultimately be more appropriate for guiding sustainability policy and practice, not only in existing neighbourhoods in need of transformation, but also newly proposed ones.

2.3.1 A Global Overview

Many of the NSASs emerged from the further development and adaptation of their earlier building-scale versions to include the complexities of the urban scale (LEED-ND, BREEAM Communities, CASBEE-UD, DGNB-NSQ are only a few examples) and fundamentally follow a similar process in identifying and selecting performance categories and indicators, formulating specific targets for each indicator, and affixing ratings and labels to indicate the level of sustainability performance a project has achieved (Westerhoff, 2016). These are typically characterized by a singular focus on certification or labelling awarded by third parties on the basis of a performance assessment, making them well suited to external communication and marketing of urban sustainability. Exceptionally, on the other hand, less well-known NSASs exist, which were developed with the main purpose of functioning as "planning toolkits" to guide communities on the processes of sustainability planning, implementation and monitoring (e.g. HQE^2R and EcoDistricts). However, there is no solid track record of their application either because they never went beyond the testing phase or they were launched less than a couple of years back and therefore their use is still in the embryonic phase.

The present author identifies three main functional categories commonly associated with urban sustainability frameworks: (1) performance assessment, (2) certification and (3) planning – reflecting the varying motivations behind their development. A focus on "performance assessment" marks the importance of measurement and benchmarking as a means of determining, verifying and, thus, improving sustainability performance. This function may serve not only internal purposes, but also external ones (comparison of neighbourhoods and competitive benchmarking). Performance assessment may also (and usually does) take place specifically for the purposes of certification and/or labelling, which as a function is closely tied to marketing objectives. An emphasis on the design/planning process on the other hand, underlines the relevance of employing new approaches, techniques and forms of collaboration and knowledge co-creation in the application of the principles of SUD to planning and development practice. However, it should be noted that some tools combine many functions into one toolkit and it does not mean that a certification system cannot also be used, for example, as a checklist, to support the planning and decision-making process.

Regardless of their intended primary purposes and functions, all these kinds of frameworks are instruments allowing urban planners, local authorities and other key stakeholders to support an analysis of new urban developments, as well as of existing neighbourhoods, from an environmental, social and economic point of view. While they have been undeniably important in promoting the growth of sustainable neighbourhoods across the world, their deficiencies are also being increasingly recognized (Haapio, 2012; Luederitz et al, 2013; Berardi, 2013; Sharifi & Murayama, 2013; Westerhoff, 2016). This is addressed in the next subsection.

The recent proliferation of assessment frameworks can be illustrated through a global survey of existing examples around the world. As part of this thesis, a comprehensive survey effort and review of previous researches was undertaken (Krikke et al., 2011; Sharifi & Murayama, 2013; Vandevyvere, 2013; Gil & Duarte, 2013; Sullivan et al., 2014; Reith & Orova, 2015; Ayik et al., 2017) to identify currently available frameworks to guide the planning, assessment and implementation of SUD across different locations. Some of the critical points made by these researchers are fed into the discussions of the individual points of critique discussed in next section. Although it is probably the case that a great number of communities, towns and cities across the world have some sort of sustainability priorities, goals, or indicator frameworks/systems/sets in place, attempting to systematically scan and catalogue them all is considered impractical and beyond the scope of this research.

The focus of analysis here was on the internationally most visible neighbourhood-scale frameworks, designed to be applied across multiple urban contexts (national and international application-orientated frameworks). In addition, ease of access to their manuals has been a critical factor. The list provided in Table A.2 of Appendix A is, therefore, certainly not exhaustive, but rather illustrative of the variety of frameworks across countries, and even within the same country. The ones identified use a variety of terms to describe roughly the same urban scale of application, including “neighbourhood”, “community”, “district” and “precinct”. These terms are, therefore, used interchangeably in this section.

A discussion follows of the characteristics of the NSASs that are worth of critique. Where necessary, reference to specific frameworks or their application on specific case studies is made for illustration purposes.

2.3.2 Critique of Neighbourhood Sustainability Assessment Systems

Unbalanced Focus on Environmental Aspects and Lack of Appropriate Consideration of Socio-Economic and Institutional Aspects

One of the most debated issues relating to NSASs is the unbalanced focus on the environmental aspects of sustainability, by either considering a greater number of (sub)criteria or assigning a greater percentage of credits, versus the other three pillars/dimensions (social, economic and institutional). Various reviews on NSASs confirm this argument (Berardi, 2013; Sharifi & Murayama, 2013; Sullivan et al., 2014; Sharifi & Murayama, 2014; Ayik et al., 2017), including the present author's own research (Balouktsi et al., 2013). As a result, most frameworks tend to overlook social and economic aspects of sustainability, and the human factor of sustainability is vastly under-represented (Boyle & Michell, 2017).

However, investigating a tool's potential for sustainability coverage presupposes that there is a sufficient degree of clarity as to what is included in the term "sustainability" when dealing with the neighbourhood level. The majority of the NSASs are based on the three pillars of sustainability – environmental, social, and economic – with some additions or variations. Whereas the environmental pillar of sustainability relates to making decisions with the intent of protecting the natural environment and resources, the social pillar of sustainability is about ensuring the creation and sustenance of healthy and liveable communities by promoting equity, diversity, liveability, democracy and inclusion among others (Palich & Edmonds, 2013) The economic pillar of sustainability refers to making decisions with an eye to long-term economic benefits and economic prosperity, given the environmental constraints and costs.

At the same time, there is a growing desire to consider "institutional" sustainability as the fourth pillar/dimension of urban sustainability (Balouktsi et al., 2013). The need to expand the traditional, three-pillar perception of sustainable development came as a recognition that the process of achieving sustainability involves trade-offs among stakeholders, individuals, groups or institutions, with conflicting views, interests and priorities. Hence, this pillar complements the others by taking into account the participation of all community stakeholders in the decision making process and their interactions, but also the management and governance of these interactions. This is further analysed later.

Market-led Nature of Neighbourhood Sustainability Assessment Systems

Neighbourhood sustainability certification and labelling has had a significant impact in generating market recognition for sustainable neighbourhoods (Sharifi & Murayama, 2013). Certification has the potential to yield significant publicity and marketing benefits for a neighbourhood project using an NSASs (Garde, 2009). Nevertheless, there are a number of concerns for the case of existing neighbourhoods when the ultimate goal is to measure the absolute sustainability performance leading to a score or awarding of a label:

(1) When assessing an existing neighbourhood as an "object" according to its performance at a particular point in time (static state/ snap shot), there is the danger of stigmatizing it as "unsustainable" in case of a poor performance at the point of time of the assessment. The latter may discourage developers to deal with and invest in such neighbourhoods. It can be stated that especially in Germany this aspect increases the scepticism of cities towards such approaches.

(2) If the assessment aspect is in the foreground, activities such as the presentation of strategies, the identification of acting and affected stakeholders by each strategy, as well as a target adjustment as a result of feedback loops are generally neglected – the "action-guiding element" dwindles away.

In this sense, when working with urban sustainability assessment frameworks, it becomes crucial to ask what the particular object of assessment they were designed for is. This involves gaining an understanding of whether these were originally conceived for application to newly planned/built developments, or programmes of urban regeneration/"retrofitting", or both. As shown in

Appendix A, the majority of the well-known NSASs tend to focus on the assessment and certification of new neighbourhoods. Most of them are third party certification systems derived from the traditional building assessment systems and indeed are particularly useful for the planning and implementation of new neighbourhoods, since they can motivate developers to think more towards sustainable solutions already at an early stage. This calls, however, for more attention to be paid to improvement/regeneration of existing neighbourhoods in future – particularly in European countries, where the proportion of newly-built developments is negligible compared to the existing built environment stock.

Yet the idea that a single framework could satisfactorily cover both cases (new and existing neighbourhoods) is regarded as a challenging and potentially disadvantageous one. While some frameworks are designed with this dual purpose in mind (see Table A.1 of Appendix A), it is questionable whether assessment or certification has the same meaning in each case (Joss et al., 2015). It should be kept in mind that the collaborative processes required to build a new development, and to retrofit an existing urban area, especially those in the "free float" with several owners of land and buildings, may be radically different.

In reality, an existing neighbourhood changes and evolves continuously through time, and thus can only be seen as a process. Therefore, it is more appropriate to assess their progress (positive or negative development) over time instead of their performance at a given time, which leads to the next consideration.

Static and Snapshot Nature of Neighbourhood Sustainability Assessment Systems

What a framework typically determines is (1) whether and to what degree an urban area (either planned or existing) is sustainable, or (2) whether and how much progress is being made towards sustainable development (R. Reed et al., 2009). In the latter case, the assessment becomes deeper than just simple evaluation, since it considers the key and often missing factor of time dimension (De Iuliis, 2017). Such a lifetime approach towards projects, where progress is measured and changes (e.g. in climate, resources and economy) over time are tracked, makes possible to capture the intergenerational aspect of sustainability – by definition, sustainability is about securing the quality of life of both present and future generations.

Despite the importance of the time dimension, most of the current NSASs have not paid enough attention to it; they are predominantly outcomes-oriented (i.e. they only account of an absolute assessment of the performance relating to a specific point in time), providing rating and/or certification based on the assessment result (level of sustainability) achieved at a particular point in time. This is the case because the use of frameworks is often promoted by project developers alone (Berardi, 2015), whose interest in the project diminishes after the obtaining of certification at the construction completion stage. However, this practice might change soon, since there are already systems including post occupancy evaluation stages in their certification process. One example is Estidama Pearls (ADUPC, 2010) which awards the Pearls Operational Rating only after *two years* of project completion.

A static assessment approach might still be acceptable (but not optimal) for a building or for new real estate/neighbourhood developments, but certainly not for the transformation of existing ones. Static approaches fail to reflect the dynamic and constantly changing nature of existing neighbourhoods and their development. In this case, a more process-oriented (dynamic) approach including “distance to target” assessments makes more sense; namely, to measure the distance(s) between the current and the desired situation (in the form of short-term and long-term target) and specify whether they move in the right direction.

Within the context of a dynamic approach, establishing suitable mechanisms for monitoring and assessing the progress regarding the extent to which the various targets are achieved is essential for securing continuous improvement in the area. In this way, an understanding can be gained on how effective the plans are and what adaptations of targets and actions are required for progress towards sustainable development. As a result, the incorporation of the time dimension is necessary to ensure a more continuous, interactive process that can map the evolution of SUD (Berardi, 2013).

From the analysed frameworks (Appendix A), only a few follow the "distance to target" concept. The most recent example is the EcoDistricts Protocol (EcoDistricts, 2016) that is a process-based framework providing certification/endorsement for the process of SUD (more specifically certification is based on satisfaction of all process-related requirements specified in the protocol) and not the sustainability performance itself. The freely available version of the Protocol though does not describe these requirements in detail, making it hard to conclude on its effectiveness and completeness (also no related research can be found).

Prescriptive Nature of Neighbourhood Sustainability Assessment Systems

Another critical aspect often ignored or underemphasised in NSASs is the adaptation to the local context (Sharifi & Murayama, 2013; Komeily & Srinivasan, 2016), alongside the consideration of global challenges (e.g. climate change). Many frameworks are promoted as "blueprints" applicable to similar projects across different contexts (Joss et al., 2015). In other words, most systems are of rigid and prescriptive nature based on a flawed assumption that factors bearing upon urban life in neighbourhoods are somewhat fixed and can be predetermined (Kyrkou & Karthaus, 2011). This represents an oversimplified view of a complex reality that is impractical for the vast majority of existing neighbourhoods and holds the danger of ineffective waste of resources and time. Although a system itself may be replicable and generalizable, the SUD envisioned through it may be less so, since it is closely related to, and strongly conditioned by, local context (Joss et al., 2015).

Allowing for customisation and tailoring to reflect locally specific circumstances is therefore a necessity. In other words, the contents of frameworks, in the form of principles and indicators, should be defined in a more open-ended way. As correctly pointed out by Walton et al. (2005) *"sustainability assessment frameworks should not be prescriptive, but should instead be flexible enough to suit and be applicable to the area where they are to be applied"*. The importance of context and how it can lead to different results was illustrated in a study where three certified neighbourhoods from different parts of the world were assessed using three different NSASs (i.e. LEED-ND, BREEAM Communities, and CASBEE-UD). The application of the three assessment systems to each project led to different performance ratings (Sharifi & Murayama, 2014).

Inadequate Consideration of the Complexities and Multi-Stakeholder Participation Imperatives of Neighbourhood Development

Simply introducing flexibility in frameworks by giving more freedom to the users to define and select topics of interest is however not enough. Who is, or should be, involved in this definitional work is the next piece of this puzzle. While the definition of sustainability indicators may be traditionally seen as a task for experts (Joss et al., 2015), and therefore as a task traditionally based on a "top-down" approach, the systems supporting a more open process facilitate stakeholder participation that is key to both "citizen empowerment" (Walton et al., 2005) and "procedural equity" (Komeily & Srinivasan, 2015). Additionally, this increases the chance of obtaining greater stakeholder acceptance of the implementation plan, and therefore the viability of the system itself.

An open process typically means to invite local groups to define the contents themselves through a process of a debate among local stakeholders over what are the most important needs for their community followed by the development of context-specific indicators. In other words, open processes encourage a "bottom up" approach to this definitional work. Such open-minded systems that allow contextualisation and consideration of different perspectives without a predefined "recipe" of indicators, and therefore disconnect themselves from concerns such as aggregation, weighting and double-counting, are described in the context of the thesis as "indicator sets" (to distinguish them from closed indicator systems).

The majority of the systems do not specifically or sufficiently address this aspect. Most commonly the integration with regard to stakeholders is tackled by employing a set of process-related indicators to assess the systematic inclusion of a wide range of stakeholder interests, needs and concerns in the design and implementation process. In only a few cases the courses of action, as well as the decisions, with regard to bringing together city authorities, community-based groups, financiers, real-estate developers and all important district stakeholders to formulate shared sustainability goals are themselves encoded into the frameworks (theoretically, some good examples are the systems HQE2R (Charlot-Valdieu et al., 2004) and EcoDistricts (EcoDistricts, 2016) – particular applications have not been extensively reported). Therefore, there is clearly a need for more instruments focused on the processes as much as on the outcomes.

2.3.3 Discussion

Many of the existing approaches represented by currently available NSASs cannot adequately support the processes of SUD of existing neighbourhoods; they qualify as motivational tools and checklists, but for achieving actual and locally-relevant progress towards SUD: (1) they are too prescriptive and rigid; (2) they oversimplify the otherwise complex nature of urban development; (3) they fail to capture the long-term environmental, economic and social effects of the SUD process on the neighbourhood and its residents, among others (a summary of all shortcomings is provided in Table 2.3). Therefore, a need for dynamic, flexible and context-specific approaches involving various stakeholders and options for action along the entire SUD process are necessary for the further advancement of current NSASs from pure rating systems to planning and monitoring instruments accommodating “process-based” and “action-oriented” elements.

Table 2.3. Formulation of the argument for the advancement of NSASs (Source: Present author).

NSAS Deficiencies	Consequences for the SUD of existing neighbourhoods	Approaches to address these deficiencies
Unbalanced Focus on Environmental Aspects	Socio-economic aspects inherent to existing neighbourhoods are not adequately addressed and systems end up prescribing environmental interventions ill-suited and unacceptable for particular contexts	Rethink NSASs to better reflect an integrated and balanced approach toward sustainability that approaches environmental, socio-economic and institutional aspects as interrelated and co-dependent.
Market-led Nature	Systems are met with resistance from the local leaders out of fear for stigmatisation in case of a poor performance. Application of these systems is also associated with consultation fees that are not affordable for disadvantaged neighbourhoods.	Move from placing certification as the “final goal” – and therefore from “market-led” approaches – to placing emphasis on collaborative and inclusive stakeholder participation processes – and thus to “process-based” approaches incorporating civic priorities. This also implies to focus on the coverage of different perspectives rather than on avoiding overlapping to ease weighting and aggregation to a score.
Static and Snapshot Nature	Snapshot-like systems fail to reflect the dynamic and constantly changing nature of existing neighbourhoods and their development.	Introduce the time dimension to ensure a continuous, iterative, and relevant over the long-term assessment and monitoring.
Prescriptive Nature	Prescriptive frameworks oversimplify the SUD process and are largely inapplicable for existing neighbourhoods.	Introduce flexible, context-sensitive indicator sets than black-box systems. Hence, adopt an open indicator set that allows customisation to reflect local priorities
Inadequate Consideration of the Complexities and Multi-Stakeholder Participation Imperatives	Although the checklist-approach of systems with prescribed indicators and assessment procedures simplifies the assessment processes it does not support the SUD process in its entirety, from conception to implementation, and it does not leave room for adequate collaboration between various stakeholders.	Consider in detail the processes, decision-making, actors and conflicting objectives involved in SUD to develop integrated approaches.

2.4 Multi-criteria Decision Analysis (MCDA): A Participatory Decision-support Tool

Decision-making with regard to what actions to take in the context of sustainable urban development (SUD) is of a multi-criterial nature, like most complex everyday decisions of any kind. In particular, in the context of SUD decision-makers (DMs), either municipal authorities, representatives from the private sector or from communities themselves, face a range of alternative options (the latter used interchangeably with “solutions”, “actions” and “alternatives”) amongst which their most preferred ones have to be identified. In reality, decision problems rarely consider only one criterion, and no single best option usually exists which outperforms all the other options across all criteria.

Using structured approaches to support decisions involving multiple criteria and multiple DMs can improve the quality of decision-making and a set of methods, known under the collective heading multiple criteria decision-making or analysis (MCDM/MCDA) (Shukla et al., 2016), are useful for this purpose. MCDA problems generally comprise of five steps which are: problem structuring, definition of DMs’ preferences, definition of alternatives, definition of criteria and the final outcomes generated by the MCDA. The most basic classification of MCDA is into Multi Attribute Decision Making (MADM) and Multi Objective Decision Making (MODM).

The distinction between these two groups of methods is based on the number of alternatives under consideration and the generated results. MODM is suitable for evaluation of continuous alternatives for which constraints are predefined in the form of vectors of decision variables (Kumar et al., 2017), whereas MADM deals with the comparison of a discrete (countable), clearly delineated set of already known alternatives. This thesis particularly focuses on the application of MADM methods.

MCDA has been an active research field since the 1960s and produced numerous discreet methods, with the most well-known being among MADM methods:

- in the category of *outranking methods* – the ELECTRE family of methods pioneered by Roy (1985, 1991) and the PROMETHEE method developed by Brans et al. (1986).

- in the category of *value or utility function-based methods* – the Multi-Attribute Utility Theory (MAUT) developed by Keeney and Raiffa (1976), the Analytic Hierarchy Process (AHP) introduced by Saaty (1980), the TOPSIS technique created by Hwang and Yoon (1981) and finally the most elementary multi-criteria technique, (as called by Polatidis et al. (2006)), the Simple Additive Weighting (SAW).

For a quick and recent overview of the different MCDA models, including their strengths and weaknesses, one may refer to the review by Kumar et al. (2017), while the most comprehensive surveys of MCDA methods are provided by Guitouni and Martel (1998) and Figueira et al. (2005).

2.4.1 MCDA as an Alternative Approach to Traditional Methods for Prioritizing Interventions

As Shmelev and Rodríguez-Labajos (2009) highlight, MCDA presents an alternative paradigm that differs from the typical goal of classical operations research that is to find an optimal solution (i.e. overall maximum or minimum of a given objective function) subject to a set of constraints. Furthermore, determining an optimum in the sense of classical operations research relies on a number of assumptions that are often impractical for real life decision problems, such as the complete comparability of alternatives and clearly quantifiable data to base the evaluation and the final decision on (Oberschmidt, 2010).

The MCDA methodology also provides a useful alternative to the cost-benefit analysis (CBA) (Shmelev, 2012). So far CBA is perhaps the most employed approach, as well as the most widely accepted one amongst government and economists, to inform decisions on whether a particular project is worthwhile or to compare alternative projects to develop in an area. CBA entails the comparison of aggregated costs and benefits of different alternatives expected to accrue along a specified duration and provides DMs with a summary indicator (OECD, 2006).

To do so, CBA assigns a monetary value to non-monetary aspects that need to be considered, such as environmental quality and health effects among others. This makes all aspects of the decision problem easily comparable and under certain conditions, such an approach can work very well. For instance, several authors warn about converting all values into single metrics like monetary units (Saarikoski et al., 2016). However, CBA and some MCDA methods are not fundamentally different in this respect. Different capabilities are found in different methods. For example, SAW method is merely a weighted CBA (Polatidis et al., 2006).

Yet, MCDA is better suited to deal with the incommensurability of certain values, since monetization of non-monetary dimensions is not required. Additionally, they are designed to handle both quantitative and qualitative information. This means that MCDAs can include criteria which CBA cannot. This additionally makes MCDA more suitable for strategic decision making than CBA, especially when the decision itself at an early stage is less clearly defined.

Along with the advantages from a practical point of view, they can also be used to support group decision-making. Perhaps this justifies the suggestion by civil society organizations to use MCDA as a better tool in support of social deliberation and social decision-making (Gerber, 2013). They are therefore adequate for supporting the assessment of SUD actions with multiple criteria in the search of a compromised solution, instead of an optimum. A comprehensive comparison between MCDA and CBA in relation to different criteria is provided by Saarikoski et al. (2016).

MCDA has been widely applied in academic research, also in fields related to SUD, such as renewable energy planning (e.g. Gamboa & Munda, 2007; San

Cristóbal, 2011) and site selection for new infrastructure or housing (e.g. Al-Shalabi et al., 2006); but an interest in its application to support the evaluation of urban development proposals has only grown over the last decade (e.g. Gómez-Navarro, 2008; Crescenzo, 2018). Although government guidelines have already been produced for some countries on how to conduct an effective MCDA to support public authorities (e.g. see Dodgson et al. (2009) for the manual published by the UK Government), the methodology is not as standardised as CBA. In the European Commission's latest guide to CBA of investment projects though (European Commission, 2014a), it is explicitly recommended to "*switch to MCA with its multidimensional characteristics instead of forcing heterogeneous and diverse data into a quantitative economic calculus*" (p. 331) when it is difficult to express the costs and benefits of a project in measurable terms so that these measures can be fed in a CBA.

2.4.2 Discussion

It is not only scientific literature and case study experiments that view MCDA as a useful decision-support tool for complex decisions. Noteworthily, a study where 21 Dutch transport politicians, and therefore real DMs, were interviewed showed that: (1) they find the composite result of CBAs pretentious and therefore they use CBA in a non-decisive manner, and (2) they are interested in appraisal tools which show clearly to them the important trade-offs of different policies (Annema et al., 2015). In this sense, the present author recommends the use of MCDA as a tool to support the early stages of the action planning phase of SUD process (when many options are still under consideration) for first shortlisting the wide number alternatives and narrowing down to the most promising ones from a multi-stakeholder perspective. Then, one can switch to CBA for more detailed analysis when the solutions have been narrowed down. Furthermore, the present author recommends the use of MCDA methods that do not allow a high degree of compensation, and therefore the methods that support the strong sustainability concept (Figure 2.3). For this and other reasons that will be later explained in Chapter 4, the present author has employed the ELECTRE III method for demonstrating the selected hypothetical case study (see Chapter 5).

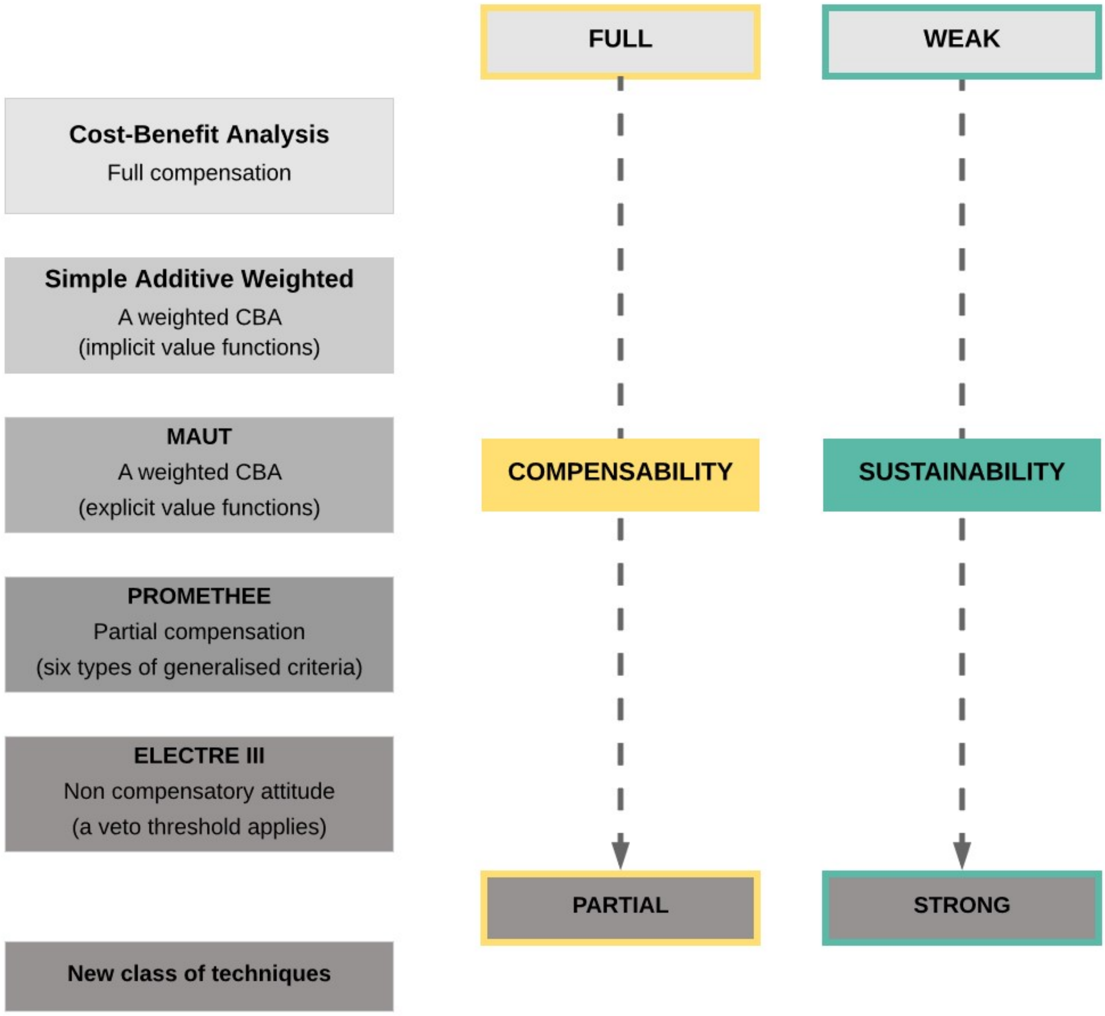


Figure 2.3. MCDA models facing compensability and sustainability (Source: Adapted from Polatidis et al. (2006)).

2.5 International Standards in the Field of Sustainable Urban Development

With the publication of the series of international standards within ISO/TC 59/SC 17 "*Sustainability in buildings and civil engineering works*" and the subsequent series of European standards CEN TC 350 "*Sustainability of construction works*", the last decade has seen great advancements in the standardization of sustainability assessment of buildings. However, the evolving world of international and European standards has only begun to address the need for standardization of rules and methods of sustainability assessment at the urban level a few years back. The new focus of international standardization activities has been particularly on cities and settlements, with the International Organization for Standardization (ISO) being at the forefront of this new effort. In May 2014, ISO published the first international standard for sustainability assessment at city-level that includes an explicit list of city-scale indicators and assessment methods. This standard is known as ISO 37120 "*Sustainable Development of Communities: Indicators for City Services and Quality of Life*" (ISO, 2014).

2.5.1 ISO 37120 as Part of ISO/TC 268 Standards

ISO 37120 was based on the Global City Indicators Facility (GCIF) framework, which was developed by the University of Toronto and was tested by more than 200 cities within the GCIF worldwide network (McCarney, 2017). This extensive work directly led to the creation of the ISO Technical Committee on Sustainable Development of Communities (ISO/TC 268) and the release of its first standard, ISO 37120. A further impetus to create ISO/TC 268 was also provided by the proliferation of assessment and certification frameworks for urban sustainability (McCarney, 2017), a trend earlier discussed (Section 2.3).

This international standard sets out and establishes methodologies to measure and manage the performance of urban services and quality of life – based on a set of indicators. It follows the six principles that are defined in, and can be used in accordance with, ISO 37101 "*Sustainable development in communities - Management systems - General principles and requirements*" (ISO, 2016). These six principles are referred to as "purposes" in the standard and include attractiveness, preservation and improvement of the environment, resilience, responsible resource use, social cohesion and well-being. ISO 37120 includes a set of 100 indicators (definitions and methodologies) structured around 17 themes (and in its latest version – i.e. ISO/FDIS 37120 – around 19 themes, adding themes such as food security, as well as culture and sport), representing key performance areas in city services and quality of life (Table 2.4).

Table 2.4. Themes covered in the new (draft) version of ISO 37120 (ISO, 2017).

ISO/FDIS 37120 Themes	
• Economy	• Safety
• Education	• Shelter
• Energy	• Solid waste
• Environment	• Sports and culture
• Finance	• Telecommunication
• Fire and emergency response	• Transportation
• Food security	• Urban planning
• Governance	• Wastewater
• Health	• Water
• Recreation	

Recognizing the global diversity of cities worldwide in terms of resources and capabilities, the entire set of indicators is divided into "core" indicators (mandatory to follow for those implementing this standard) and "supporting" indicators (serve only as a recommendation). Furthermore, the standard contains a special type of indicators that are not aimed at monitoring performance, instead at providing basic statistics and background information to help cities identify which other cities are appropriate for meaningful peer-to-peer comparisons. These are the so-called "profile" indicator. However, ISO 37120 does not provide any thresholds or a numerical target value for each indicator. Claiming compliance with this standard only involves the measurement of urban services and quality of life indicators.

In response to the successful publication of ISO 37120, the World Council on City Data (WCCD) was created to facilitate the adoption and implementation of the standard for cities worldwide. Specifically, WCCD provides ISO certification to cities on the basis of their data compliance to ISO standard, as well as a platform with open data from cities complying with ISO 31720. The level of certification awarded to each city ranges from "aspirational" to "platinum" (five levels) and depends on the quantity of the indicators reported and not the performance level achieved in each indicator.

So far eighteen European cities have implemented the indicators and reported them in the open data portal of WCCD (n.d.), with the Dutch cities taking the lead (i.e. Amsterdam, Rotterdam, Eindhoven, Heerlen, Zwolle and the Hague). Additionally, the cities range from metropolises (e.g. London, UK) to small towns (e.g. Aalter, Belgium), proving the standard's statement that it is "*applicable to any city, municipality or city administration that that undertakes to measure its performance in a comparable and verifiable manner, irrespective of size and location*".

Currently, ISO 37120 is under revision to align its indicators with the UN SDG framework (WCCD, 2017). Along with the revision of ISO 37120, as part of the series of international standards for cities within ISO/TC 268, two new standards are currently being developed (i.e. they are in "enquiry" stage) to complement ISO 37120. The ISO standard for Smart Cities (ISO 37122) will constitute an indicator catalogue (along with standardized definitions and methodologies) addressing the digital elements of urban planning and development, while the ISO Standard on Indicators for Resilient Cities (ISO 37123) will provide a list of indicators (along with standardized definitions and methodologies) assessing aspects of resilience, particularly in relation to infrastructures.

It is argued that the driving force for the development of these two new standards is the rising interest in the concepts of "smartness" and "resilience", as increasingly relevant issues in urban studies. This has led to an emerging trend to produce quantitative tools, indicators and international frameworks to measure smartness (Ahvenniemi et al., 2017) and resilience at the urban scale (Sharifi, 2016; UN Habitat, 2017). However, as ISO also states, smartness and resilience should be seen as embedded characteristics in the overarching process of sustainable development and not as separate agendas.

2.5.2 Discussion

Standardized indicators and methodologies are important in the sense that they provide a consistent approach to what is measured and how the measurement is to be performed. This facilitates comparability over time or with other cities, as it is highlighted by the ISO 37120 standard. Although sharing experiences and best practices is important, comparing urban areas with regard to their performances with the aim of ranking them or scoring them should not be a desirable task.

As a result of an analysis of current trends in standardisation activities, it can be stated that the description and assessment of urban sustainability are already dealt with in international standardization agenda, but this process is not yet completed; The standardization activities in this field go in different directions (quality of life, smartness, resilience) without establishing a recognizable relationship among them. Similar to the earlier analysis in relation to the status of NSASs, the approach standardization follows seems to be conceptually identical to dominant approaches that aim to compare/ assess cities and issue a certificate to them – without supporting processes to achieve their goals. The need for guidelines to support the practical implementation of SUD has already been recognized and formulated, but previous approaches have not yet matured from the perspective of the present author.

A final observation is that the standards introduce a typology of indicators (core, additional and profile indicators) that confirm the author's earlier approaches to distinguish indicators on the basis of whether they are actionable or only serve informational purposes. This confirms the author's view that presenting background information in combination to task of performance assessment is indispensable for the interpretation of assessment results. To summarise, it becomes clear that despite the availability of standards (existing and upcoming) in the flied of SUD there is currently a need for:

(1) a process-oriented approach that goes beyond the comparison and assessment of cities and offers concrete solutions for implementation

(2) a conceptual approach that supports the selection of relevant topics and appropriate indicators, including an adaptation to the local context

(3) a conceptual approach that distinguishes between states, goals and means to achieve one's goals

(4) a conceptual approach that incorporates the opportunities and willingness to act of local actors.

2.6 Summary

As a result of Chapter 2 it can be stated that:

- On the policy level, in the frame of currently adopted SDGs, many goals and targets exist that are relevant for SUD. With regard to standardization activities, relevant standards now exist that provide a large set of indicators to choose among. However, these are not always well structured and often have the character of a black-box of indicators. Up to now, there has often been a lack of opportunities to complement these indicator sets with indicators of local significance in solving specific local problems.

- Neighbourhoods represent an interesting level of action that can support SUD. However, there are no approaches to defining concrete system boundaries that are adapted to the particularities of the respective problems/questions/indicators.

- With regard to practical initiatives, various NSASs exist, but mainly in connection with a certification. There are deficits in process-based and action-oriented approaches.

- The actual decision on which actions to select for practical implementation, and therefore how to eventually allocate resources and budgets in order to achieve progress towards SUD, constitutes a multi-criteria decision problem. Appropriate methodological approaches are available, but they must be adapted and operationalized to support decisions in this direction.

Therefore, to sum up, there is a need to shift from outcomes-based to process-based planning approaches, involving local actors and incorporating local priorities. Additionally, it is necessary to shift away from frameworks and initiatives with a sole focus on how to define and measure sustainability for just purely comparative or certification reasons, to more “action-oriented” frameworks that link the use of indicators with actual possibilities for actions. Perhaps the most appropriate way to allow a gradual transition to more process-based and action-oriented approaches to SUD is to first promote and examine their success at the neighbourhood scale – the most fundamental unit of urban development and the minimum scale to take account of the social, economic and institutional aspects of SUD. The consideration of indicator-specific system boundaries for the “object of assessment” – namely, the neighbourhood – is indispensable, given that the impacts of many activities in the neighbourhood go far beyond its boundaries.

Furthermore, the present author acknowledges that there is a unique opportunity to align local efforts to newly adopted SDG vision, and especially SDG 11. Finally, to move from assessments to actions on the ground, formal procedures and tools as the ones provided by MCDA methods are needed to facilitate the decision process with respect to action planning. MCDA is a valuable tool that supports the problem structuring and the evaluation of alternative ways of action while incorporating the DMs’ (i.e. local actors) preferential system in the context of procedural equity. In problems such SUD, where multiple and often conflicting decision criteria are involved, an unanimous optimal decision cannot exist and should not be strived for.

3 A new Process-based and Action-oriented Overall Framework

"*Without a common framework to organize findings, isolated knowledge does not cumulate*." (Ostrom, 2009).

This chapter proposes a conceptual overall framework to support the planning phase of a neighbourhood-scale SUD that incorporates the principles of urban governance, participatory action and the philosophy of "think global, act local". This framework is combined with an adaptation to local needs. Although these principles are currently discussed in the literature, they have never been combined and translated before into a clear process-guiding overall framework that is general and flexible enough to be applicable across any local context in Europe. First, a short description of how neighbourhood is understood as an object of assessment and scale of intervention in the context of this research is provided (Section 3.1). Next, the three parts of which this overall framework is comprised are proposed. Those are:

(1) A step-by-step *process framework* to help researchers, community organisations and policy-makers at the city level to effectively organise the pre-implementation phase of the process of sustainable urban development (SUD) (Section 3.2).

(2) An *assessment framework* to support monitoring and assessing progress towards SUD. This is useful for the "assessment part" of the SUD process and involves the identification of important problem areas and themes actionable at the neighbourhood level as well as the selection of appropriate indicators (Section 3.3). Connections to the global sustainable development goals (SDGs) are also established.

(3) An *action prioritisation framework* to provide a common interpretive frame to evaluate strategies and actions as part of the "action planning" task of the SUD process (Section 3.4).

3.1 Neighbourhood as an Object of Assessment and Scale for Intervention

Neighbourhoods – here in the sense of city districts or specific parts of a city - are increasingly recognised as an appropriate object of assessment and level of action for investigating the possibilities of sustainable urban development. This is because it is considered as a more manageable "element" compared to the city. Moreover, in the same way a city should not be seen as a unit in isolation but in connection to others cities in a global urban system striving for sustainable development, a city cannot be considered sustainable if its constituent parts are unsustainable. In the past, it was already troublesome to adequately describe the city unit. It became necessary to introduce specific perspectives for selected issues – namely, the city as an administrative unit, the city as a system with energy and material flows, the city as a habitat (and biotope) or the city as an ensemble of buildings and infrastructures.

However, defining the spatial boundaries of a neighbourhood is deemed as an even more challenging task. So far, there is no uniform and generally accepted definition and interpretation of the term "neighbourhood". Perhaps the most up-to-date definition of neighbourhood is the one from the German geographer Olaf Schnur. He suggests: "*The term of living neighbourhoods refers to a vaguely defined centre of external and internal social activities within any one given context, a place of everyday life and individual social spheres which intersect in a territorial interrelationship of identity within a defined residential environment*" (translated from German) (Schnur, 2008). This "vaguely defined centre" can therefore be interpreted from several perspectives (Lützkendorf & Balouktsi, 2017):

(1) The neighbourhood as an (intermediate) level in a hierarchy of action levels, which are partly administrative: city municipality, building block/ group of buildings, individual building.

(2) The neighbourhood as an area the residents identify themselves and basis for the development of a higher sense of community in

connection with the perception as an immediate working and living environment. This is comparable to a “parish”.

(3) The district as a system with energy and material flows, import and export functions, possibly biotope.

A current topic of discussion is how to demarcate a spatial boundary that would be suitable for each specific topic, such as mobility, energy supply or quality of the local supply chains. In particular, using the concept of a process-based analysis and assessment of a SUD, the present author takes up two of these perspectives. On the one hand, the neighbourhood is described in the sense of a city component through its structural elements (i.e. hard infrastructure – buildings, urban space and utilities). The nature and extent of the inclusion of these elements as well as the spatial delimitation are influenced by the concrete questions to be pursued. To put it differently, the idea of a neighbourhood as a fuzzy concept not representing a single spatial unit, but instead comprising of overlapping areas defined on the basis of the concrete problem at hand, is taken up. On the other hand, the neighbourhood is seen as the living and working environment of specific local stakeholders (i.e. institutions, organisations and individuals) who can indirectly or directly influence neighbourhood development or are directly affected by it. Both ways of viewing the “object of assessment” are considered in the conceptual overall framework provided below:

3.2 A Process Framework: Organising the Process of Sustainable Urban Development

Sustainable urban development is a dynamic process that requires continual stakeholder engagement combined with continual monitoring, assessment and improvement. Such improvement involves an adjustment of sub-goals, indicators and strategies over time to more accurately reflect either the present situation or new realities. This section proposes a stepwise conceptual workflow model of the SUD process, known as the *process framework*, which includes the necessary feedback loops and dynamic relationships. It is grounded in transdisciplinary proactive stakeholder participation. This participation requires more than mere information and consultation as a means of increasing awareness of the complexity of transformation processes among stakeholders. Instead, it promotes the need to include the actual objectives of different local stakeholders into the entire development process. That process finally includes stakeholder learning and ensures transformative action that addresses both local and global issues.

The process framework addresses the perceived lack of a comprehensive conceptual model that incorporates all the fundamental principles of SUD over the entire development process, from pre-implementation (i.e. planning) to post-implementation. It does this in a practical stepwise manner. Besides the insights gained from the literature review of existing approaches (see section 2.3), it also integrates the knowledge and experience gained by the present researcher through participation in the collaborative project Urban Transition Lab 131 (R131), which aims to achieve SUD of the district of Karlsruhe Oststadt by means of a transdisciplinary process (Quartier Zukunft, 2017). This framework can be used as a guide and inspiration when discussing SUD in any local context. It should therefore be seen as a stimulant for reflection and dialogue rather than as a procedure to be scrupulously followed. It is also addressed to European standardisation bodies, such as CEN (European Committee for Standardization), that are looking to launch a standardised procedure to guide sustainable development on a neighbourhood level.

3.2.1 Requirements for Process Quality

Like any process, SUD can only be appropriately shaped and managed if specific quality requirements (QRs) are in place. In this context, the term "requirement" refers to any physical or functional need that the SUD process aims to satisfy. Because there is no universally accepted definition of what constitutes a high-quality SUD process, the present author addresses this deficiency through the development of a list of ten QRs (Table 3.1). The composition of the set of QRs was based on the most critical aspects of institutional sustainability discussed in the literature (Section 2.3) and drawn from the knowledge gained from participation in the R131.These requirements were later built into the step-by-step process model presented in the next section.

Such a list of QRs serves two functions. First, it offers a guide for how the process should be carried out to ensure that it includes critical aspects that contribute to institutional sustainability. Such QRs should therefore be defined prior to any planning or development activity. Second, in the post-implementation phase, QRs can be used to assess the soundness of the development process finally adopted, including planning, implementation and post-implementation. The QRs were therefore converted into indicators, here denoted as "process quality indicators", by developing them into assessments of performance. For this purpose, examples of how to measure success are also provided for each QR (Table 3.1). Although most measures are qualitative and often subjective, they can still provide a conceptual understanding and evidence that certain aspects have been considered.

It is important to note that the list of QRs distinguishes between two main types of stakeholder participation: public participation (QR6) and representative participation (QR2). *Public participation* is the process by which all neighbourhood residents who wish to participate can do so, whether they are individuals or organised groups. The main purpose of public participation processes is to give people space to openly voice their needs and concerns. Such processes can take multiple forms, including, for example, traditional face-to-face gatherings, such as public meetings, or more innovative forms, such as online platforms. The needs and concerns expressed in such settings may be taken into account in the plan if they are judged to be reasonable.

On the other hand, *representative participation* refers to the process by which only representatives of selected local stakeholder groups are invited to participate. This participation process could be characterised as an active one because its main purpose is not restricted to sharing information (a two-way exchange) but instead focuses on actively influencing decision-making. A SUD process should be democratic and effective; a balanced combination of public and representative participation should be achieved. Direct participation of the general public at every step and for every decision would result in an excessively time-consuming process leading to counteractive results and de-motivating effects for all the parties involved.

Table 3.1. Quality requirements (QRs) for the SUD process (Source: Present author).

(QR1) Transdisciplinary core team	
Description, including justification	Sustainable urban development projects are inherently of a multidisciplinary nature because they simultaneously cross a wide range of aspects and sectors of the built environment. *QR1 is met if the process itself (or individual parts of it) is led by a well-balanced transdisciplinary team that offers diverse and complementary knowledge, skills and expertise and is brought together in the earliest stages of the process.*
How to measure success?	5-point Likert scale: 1. Not at all – 5. Excellent *Excellent* is achieved if the project team includes experts and expertise from all relevant fields from the start

(Table 3.1 continues)

(QR2) Stakeholder participation and networking (representative)	
Description, including justification	Besides the promotion of procedural equity, which is an essential component of a central sustainable development principle (i.e. equity or justice/fairness), additional benefits of participation include distribution of power, capacity building, integration of stakeholder knowledge, better understanding of contextual issues, greater commitment to project goals and enhanced transparency and legitimacy of the decision-making process (ISO, 2011). *QR2 is met if the process enables the active involvement of representatives of both interested and affected parties in project decision-making to integrate their views, interests, values and requirements when defining the vision or preparing the action plan, for example.*
How to measure success?	5-point Likert scale:[2] 1. Not at all 2. Information and consultation: The degree of completion of the action plan is communicated to the stakeholders for their information or for receiving their views. The aim is to gain stakeholder acceptance of the plan. 3. Advice: Stakeholders are invited to provide feedback regarding a draft plan. Based on this input, the plan may be altered; the final decision though remains with the core team. 4. Partnership: Stakeholders are asked to actively participate in and influence the planning process by prioritising issues and planning actions. 5. Neighbourhood self-development: The core team empowers stakeholders to take on the dominant decision-making role.
(QR3) Non-discrimination	
Description, including justification	Non-discrimination and inclusion of vulnerable and marginalised social groups (like women, minorities and the disabled) in the decision-making process is particularly important in the context of social equality (UN Habitat, 2007). *QR3 is met if all these groups are well represented in the stakeholder participation process.*
How to measure success?	Percentage of vulnerable groups represented on the stakeholder team.

[2] based on the ladder of citizen participation of Arnstein (1969).

(Table 3.1 continues)

(QR4) Communication and transparency	
Description, including justification	Increased transparency towards the public with regard to the results of the SUD process and the organisation of the process itself is crucial. This transparency facilitates automatic monitoring, strengthens accountability and fosters a climate of trust. Additionally, public results increase public awareness and understanding of the issues and can lead to changed behaviour. *QR4 is met if the main content and results of the process (e.g. the goals, the targets and the action plan developed during the planning process) are clearly and transparently communicated to a wider audience than the few stakeholder representatives and in terms that are universally accessible.*
How to measure success?	5-point Likert scale: 1. Not at all – 5. Excellent *Excellent* is achieved when all important process and content results of the project are translated into easy-to-understand language and regularly posted on a website especially designed for this purpose.
(QR5) Clear division of responsibility	
Description, including justification	Without clearly defined roles and responsibilities for all stakeholders taking part in the decision-making processes, accountability, goals and interventions might be neglected. "Responsibility" refers to both organisational matters, such as meeting attendance, and to implementing the components of the action plan. *QR5 is met if responsibilities and roles for different tasks are clearly assigned to specific actor in the project.*
How to measure success?	Yes/no question: A *Yes* answer means that responsibilities and roles are clearly assigned and known by all stakeholders in the project.
(QR6) Public participation	
Description, including justification	The importance of public participation can be summarised into three points. First, public participation ensures a focus on the equal right of all citizens to participate in decisions in the context of democracy. Second, the quality of decisions can be improved by utilising the population's knowledge of the local context. Third, public participation improves trust and acceptance of subsequent decisions (Stirling, 2006). *QR6 is met if the process provides the possibility of open public participation at critical steps of the decision-making process, where all residents can express their beliefs, needs, preferences and expectations regarding the project.*
How to measure success?	Percentage of residents/users engaged in public consultation processes (for example, participation rate or social media subscribers)

(Table 3.1 continues)

(QR7) Encouraging learning	
Description, including justification	To achieve transformation, it is necessary to provide an environment where the various stakeholders can learn new perspectives, skills, competencies and practices to develop new conceptions of their own role (Singer-Brodowski et al. 2018). *QR7 is met if the process is used as an opportunity for learning, capacity development and experience sharing among the neighbourhood's various stakeholders.*
How to measure success?	Social learning is one of the most difficult aspects to measure in the context of a participatory approach. Wal et al. (2014) proposed an interesting method of measurement based on the construction of a perspective scoring table.
(QR8) Balanced consideration of crucial issues of both local and global relevance	
Description, including justification	Striking a balance between local and global goals and priorities is an ever-present necessity that considers the implications of local economic growth and global environmental problems (e.g. climate change). *QR8 is met if the process achieves a sufficient balance of global and local priorities.*
How to measure success?	Yes/no question: A *Yes* answer means that a balance between global and local interests has been achieved.
(QR9) Continued monitoring and reporting	
Description, including justification	Continued monitoring (measurement) of performance and compliance with the established requirements and targets is a critical stimulating factor for project success and allows actual progress to be made (Bosch et al. 2017). *QR9 is met if the process has in place a widely agreed measurement framework of both outcome-focused and process-focused performance indicators, as well as a regular reporting mechanism.*
How to measure success?	5-point Likert scale: 1. Not at all – 5. Excellent *Excellent* is achieved if extensive monitoring and reporting are consistently performed during all steps of the project's development to ensure that the SUD process was carried out according to the established quality requirements and sustainability goals and targets. Monitoring and reporting is carried out at frequent set intervals, the important outcomes of which are reported and published online every two years.

A process of SUD does not necessarily need to satisfy all of the QRs provided above. Each process will eventually take a different approach depending on the context. These requirements should be viewed as a collection of founding principles for an effective SUD process and for a smooth transition to the desired outcomes.

It is important to highlight that some QRs can be linked to SDG targets (UN, 2018a). Indeed, decision-makers should align QRs with thematic SDG targets to the extent possible. QR2, QR3 and QR6 can be regarded as conceptually similar to SDG targets 11.3 and 16.7 on inclusive participation. Moreover, QR7 is important for achieving SDG targets 4.7 and 12.8 on ensuring increased knowledge of sustainability in society. Finally, QR4 and QR5 are linked to SDG target 16.6, which reflects the importance of accountability and transparency in all institutions.

3.2.2 Overview of the Conceptual Model

Starting Point: Initiation

Initiation of an urban development process to make a neighbourhood more sustainable can occur in one of two ways (or their combination): top-down or bottom-up. A top-down initiation occurs when the local authorities respond to a specific problem or problems in an area under their jurisdiction. Top-down initiatives may be also triggered by researchers collaborating with local authorities in testing and implementing new approaches, such as urban living laboratories (Schneidewind, 2014). On the other hand, the idea of such a project may originate from the local community itself. A bottom-up initiation usually begins as an attempt of a local interest group (e.g. property owners' association) to harness a specific opportunity that serves their interests (e.g. urban improvement districts). It may also be driven by a network of local grass-roots associations and local residents seeking to secure the provision of specific services.

The Conceptual Model: Moving Ahead

After initiation, the focus shifts to the process model presented below. Eventually, regardless of how and by whom the process is initiated, participants from research institutions (e.g. universities, public and private research organisations), local government and civil society (e.g. neighbourhood associations) must be involved early in the process. This is highlighted by the model, which is designed to be flexible enough to apply in all cases – whether institutional actors or the neighbourhood itself initiate change. The conceptual model (Figure 3.1) represents a repeatable and transferable step-by-step working procedure for the organisation and planning of the development process itself, flowing from pre-implementation (i.e. planning phase) through implementation and post-implementation. The main emphasis is on the pre-implementation phase because decisions taken at this phase lay the groundwork for the next phases.

The model deconstructs the planning phase into a logical sequence of sub-phases and steps that structure this complex task. These phases are later explained in detail (see Sections 3.1.3 - 3.1.5). On the other hand, a detailed analysis of phases II (pre-implementation) and III (post-implementation) is out of scope of the present contribution. The conceptual process model can be applied in several ways and should not be considered a fixed workflow. It ensures that the quality requirements earlier identified are incorporated from the beginning and throughout the entire process. This is an expanded and more detailed version of the work created by the present author in WSBE17 Hong Kong (Balouktsi et al., 2017).

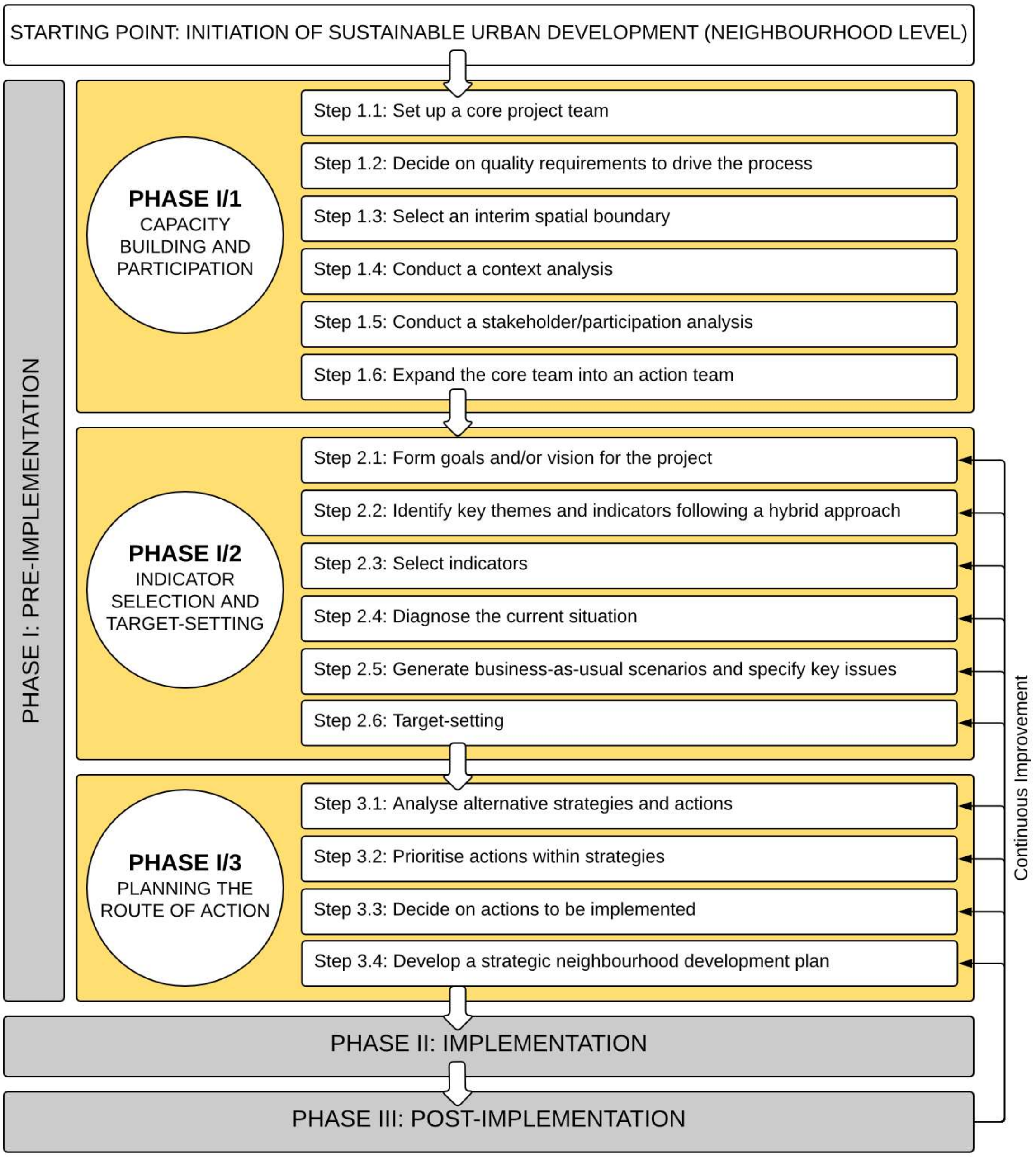


Figure 3.1. Overview of the step-by-step working procedure (Source: Present author).

In particular, for participation-related QRs, the model manifests varying degrees of and public participation for each step of the SUD process. Although the highest level of participation should generally be pursued in such processes to ensure a good “culture of governance”, this is neither reasonable nor meaningful for some steps of a highly technical nature. An overview of the degrees of participation for each step, as proposed by the present thesis, is provided in Figure 3.2 and later elaborated in more detail. As can be observed, the highest degree of participation undertaken by the model is “collaboration”. First, methods for “empowerment” are not common in Europe and are even strictly restricted by law in countries like Germany (Stelzle & Noennig, 2017). Furthermore, some have argued that without guidance and supervision by experts and by a local government community, self-development can eventually lead to undesired results.

Besides the degrees of participation with regard to what is the level of influence of the stakeholders on decision-making, different levels of participation can also be distinguished on the basis of tasks that participation aims to serve, which usually are as follows: a) problem identification, b) goal/target-setting and prioritisation, development/ assessment of solutions, c) immediate participation in implementation and d) participation in success control/feedback.

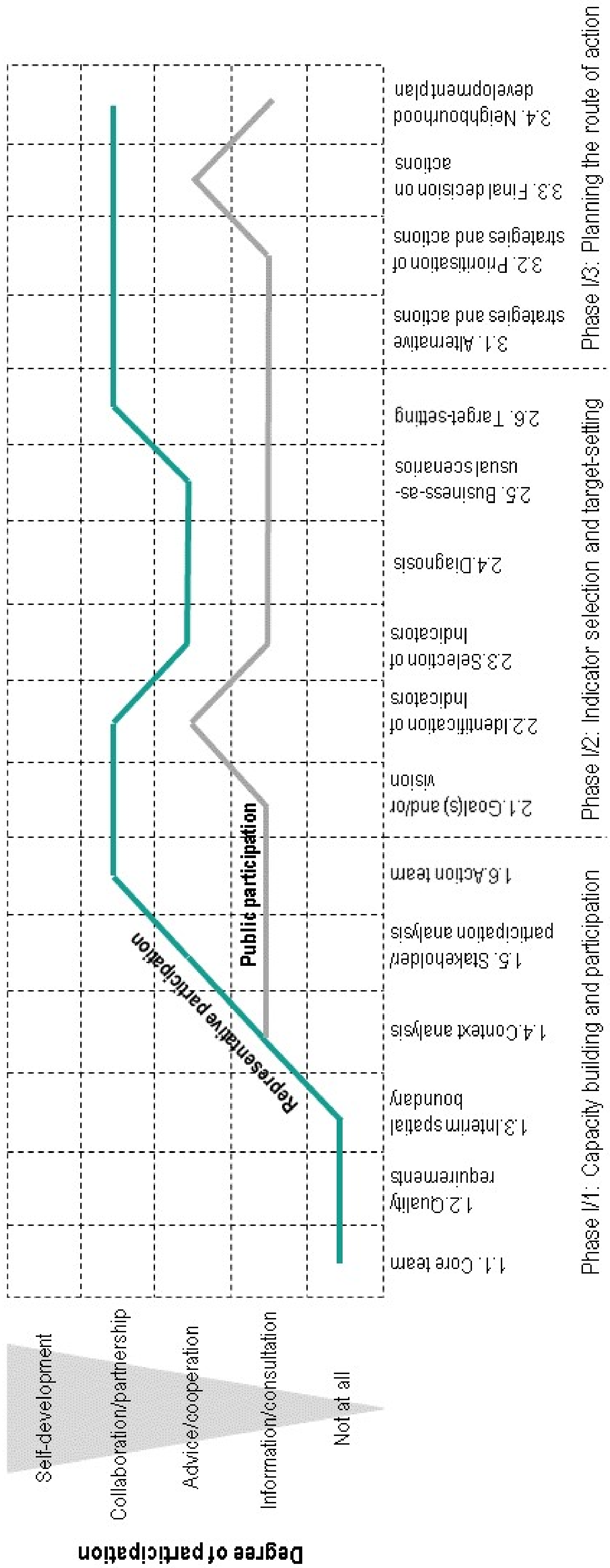


Figure 3.2. Varying degrees of participation per step (Source: Present author).

3.2.3 PHASE 1: Pre-implementation

The pre-implementation phase includes all the essential preparatory processes and procedures that existing neighbourhoods should consider before starting the actual development activity. It involves a wide range of procedures, from performance of technical tasks (such as different types of analyses and ex-ante[3] assessments) to the organisation and execution of social tasks (such as team building for strategic leadership, stakeholder mobilisation and participation and consensus building). The pre-implementation phase is further divided into three sub-phases, namely, Phase I/1: Capacity building and participation, Phase I/2: Indicator selection and target-setting and Phase I/3: Planning for the route of action.

3.2.3.1 Phase I/1: Capacity Building and Participation

This phase lays the foundation for collaboration and stakeholder participation. The detailed process flowchart for this phase is shown in Figure 3.3, and a detailed description of each step follows.

Step 1.1: Set up a Core Project Team

To adequately manage the SUD process, the composition of a committed transdisciplinary core team (CT) is required, mainly consisting of a coordinator and key prime consultants/experts from various backgrounds **(QR1)**. The transdisciplinary team approach is important for building a culture of collaboration and idea-sharing among representatives from multiple disciplines from the beginning. In the context of the overall process, the CT usually has a facilitating and steering role. This facilitating role includes educating local actors by making them aware of the meaning of, need for, benefits of, determinative factors of and possible solutions relating to SUD. Additionally, the role of the CT includes mediating conflicts of interest among different local stakeholders. On the other hand, the steering role includes securing the co-ordination, co-operation and collaboration of key actors

[3] The term “ex-ante” is a Latin phrase meaning “before the event”. The event is here the actual implementation of the action plan.

throughout the entire process, from pre- to post-implementation, which can only be successful if preceded by the education and commitment of the key actors. For example, when universities or research institutes take the lead, researchers on the transdisciplinary CT need to abandon the traditional role of the distant, objective scientist (Wittmayer et al., 2014). Besides the more traditional role of performing analyses, they also need to act as knowledge brokers, engaging participants in the process and empowering them to take action on problems. As the responsibilities of the CT increase, it evolves and focuses on engaging more people with local skills and experience (local stakeholders/representatives) and building the action team (AT) (see Step 1.6).

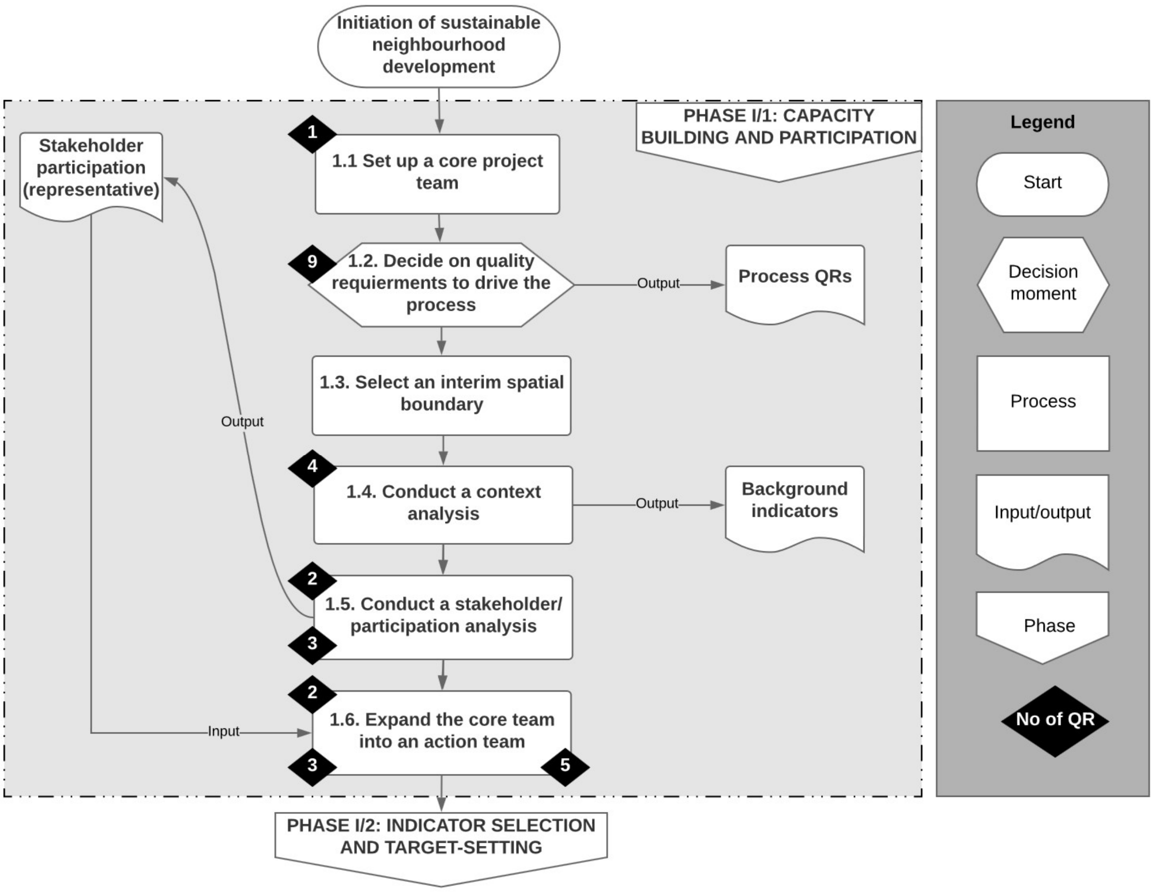


Figure 3.3. Detailed process flowchart for phase I/1(Source: Present author).

Step 1.2: Decide on Quality Requirements to drive the Process

Before starting the planning process itself, the CT should agree on how it will address, for example, the principles of participation and empowerment, non-discrimination and inclusion, and transparency and accountability. At this early stage, the CT can already establish QRs (“output” in Figure 3.3) to guide the process on the basis of these principles. Later, those QRs can be transformed into qualitatively measurable process indicators for measuring how well a process is performing (**QR9**). A robust and ready-to-use set of QRs useful for moving towards a transdisciplinary and participatory SUD process is provided above (Section 3.2.1).

Step 1.3: Select an Interim Spatial Boundary

The spatial boundaries of a neighbourhood cannot always be defined in a consistent way; instead, they must be adapted to the issues investigated and the indicators applied. Therefore, a neighbourhood may be a pre-defined administrative unit of a city, an area of study/application whose demarcation is made from a contextual perspective or an area with which the residents identify themselves. A different boundary line may be drawn for each specific problem under investigation. Therefore, the initial selection of the boundaries of the area of intervention should not be specified in an exact or fixed way based only on administrative geography (see section 3.1). Instead it is important to permit layering and overlapping so as to adapt to the different goals and issues under examination. The initial project boundary forms the basis for determining which resources, stakeholders and activities are present in the area and may affect or be affected by the SUD project.

Step 1.4: Conduct a Context Analysis

The selection of an approximate area of intervention follows a detailed context analysis to allow the CT to understand the characteristics of the area in which the SUD process is to be implemented. The main outputs from such an analysis are as follows:

(1) An inventory of all the tangible “elements” which make up the area (i.e. places, services, infrastructures and activities). It is important to document not only information on the tangible elements located within the interim spatial boundary but also to record the elements within the immediate surroundings of the boundary. At this stage, it is necessary to collect information on both the micro- and macro-location because the system boundaries drawn for the investigation of each specific indicator (selected in a later step) will eventually differ (based on the description in the previous step).

(2) A preliminary “stakeholder identification” provides information on local stakeholders (individuals, groups or organisations) that can affect or be affected by the development activities. This identification can lead to the establishment of a register in which basic information about each stakeholder is stored. Basic information could include, for example, the stakeholders’ names, contact information, positions, and potential roles in the SUD project. This information is later complemented by assessment-related information on each stakeholder (see next step).

(3) Background information and statistics on important factors characterising the socio-economic, demographic, geographical and climatic context of the area. This type of information represents factors that typically cannot be (directly) influenced by a particular intervention on a neighbourhood level but may have an important facilitating or inhibiting influence on the success of interventions. In the present thesis, background and context-related characteristics are treated as a separate category of indicators, referred to as “background indicators” (“output” in Figure 3.2). While background indicators are not measures of progress, they can help decision-makers understand why a neighbourhood performs the way it does. A generic set of background indicators is proposed in Section 3.3.6.

(4) Analysis of policies and of the legal and administrative framework within which the SUD project is to be carried out, including the

identification of project-relevant international, national or regional agreements.

(5) A non-technical summary consisting of the most significant conclusions of the context analysis that can be easily understood by non-experts, in particular, the local stakeholders identified in (2). Open communication **(QR4)** at this step contributes to developing a relationship of trust with local stakeholders, which constitutes a vital starting point for any discussions during the stakeholder engagement process.

It is important to note that it is advantageous to already involve local stakeholders in the context analysis, not as decision-makers, but as a source of information to overcome potential data gaps **(QR2)**. For example, it is difficult to gather information, for example, on neighbourhood-based social gatherings, cultural activities and community festivals if interviews are not conducted within the neighbourhood. In the same way, individuals identified in (2) can be interviewed to identify new stakeholder categories and contacts. In the field of stakeholder analysis methods, this is the well-known method of snowball sampling (M.S. Reed et al., 2009). The context analysis conducted here is naturally continued by a detailed analysis of stakeholders, or a participation analysis, as it is sometimes called.

Step 1.5: Conduct a Stakeholder/Participation Analysis

This step utilises the instrument of participation analysis (also called stakeholder analysis) to refine the characterisation of each stakeholder identified in the previous step. The analysis makes it possible to move from a general listing to an assessment of each stakeholder's influence/power, interests, motives and attitude in relation to the SUD project. Such an exercise is important and necessary for deciding on an appropriate engagement method for each stakeholder group and eventually for bringing the most salient stakeholders into the decision-making process. However, in addition to inviting powerful stakeholder groups to have an active role in the decision-making, representatives of vulnerable populations that will be most impacted by the plan must also be involved (**QR3**). This will help avoid situations of environmental, social and economic injustice. The literature proposes various methods for facilitating the process of stakeholder analysis. Because an in-depth analysis of these methods is outside of the present thesis's scope, past research will be used to engage in that analysis. Researchers who have extensively dealt with this subject are M. S. Reed et al. (2009), who provided one of the most comprehensive reviews, and Yang (2014), who classified all methods into two analytical perspectives, empiricism and rationalism. Both papers argued that no method is better than the others and that a combination of existing methods likely produces the most useful results. In any case, stakeholder identification and analysis need to take place periodically because stakeholders and their interests can evolve as the SUD process progresses. A stakeholder analysis should therefore not only be done at this step but also in future steps.

With regard to engagement methods, a variety of possibilities are also available to the core team, and the decision will depend on whether the purpose of participation is to inform, consult, cooperate, collaborate and/or empower. Regardless of the engagement approach eventually selected, the present author suggests that special attention should be paid to the creation of communication messages that simplify complex concepts and are tailored to the mental model of each targeted stakeholder. Useful conclusions on how to more effectively communicate environment-related topics to a non-technical public are available from Shome et al. (2009), who explored the psychology behind communicating the controversial topic of climate change. This step results in a list of interested stakeholders to be actively involved over the next steps ("stakeholder participation" as an "output" in Figure 3.3).

Step 1.6: Expand the Core Team into an Action Team

The next step is to convene stakeholders (shown as an "input" in Figure 3.3) into a working group made up of technical experts already in the CT, municipal officials and various representatives from the neighbourhood, such as representatives of neighbourhood associations, businesses, special interests and vulnerable groups (**QR2/QR3**). The resulting group is the action team. It is important that this team be built on the principles of shared authority and responsibility. This can be achieved though the establishment of formal protocols for decision-making and communication between the members (**QR5**). Those protocols should clearly define roles and responsibilities and requirements for meeting attendance. They should also require an agreement to keep an open mind, to respect differing opinions and values and to consider minority opinions when consensus is unattained. Such protocols ensure more transparent and democratic governance processes.

3.2.3.2 Phase I/2: Indicator Selection and Target-setting

This phase ensures the development of specific goals, indicators and targets for the neighbourhood improvement, thus aiding the assessment and monitoring of a neighbourhood's progress towards sustainability. The detailed process flowchart for this phase is shown in Figure 3.4, and a detailed description of each step follows.

Step 2.1: Form Goals and/or Vision for the Project

In this step, a neighbourhood sets generic long-term goals as essential elements of realising the overall vision of SUD. These goals can represent resources or values of particular importance with regard to environment, society and economy (i.e. the three traditional pillars of sustainability) that need to be protected or enhanced regardless of the local context. Attempts to improve the local environment without considering global issues, such as the protection of natural ecosystems to mitigate global warming, are not sufficient for addressing the imperatives of sustainable development. A top-down approach to the formation of goals is essential for considering and understanding the global consequences of local actions (top-down part of **QR8**). The task of goal formation can be solely assigned to the CT because a sound knowledge of sustainable development principles is necessary. However, the CT has to present the proposal to the AT for group discussion and social learning (**QR2**/**QR7**). Moreover, such general goals cannot become operational if they are not translated into specific themes that address the most critical local and global problems. Furthermore, these goals must be correlated with performance indicators to monitor progress towards solving these problems and achieving these goals. A further operationalisation of the goals is achieved in the next step.

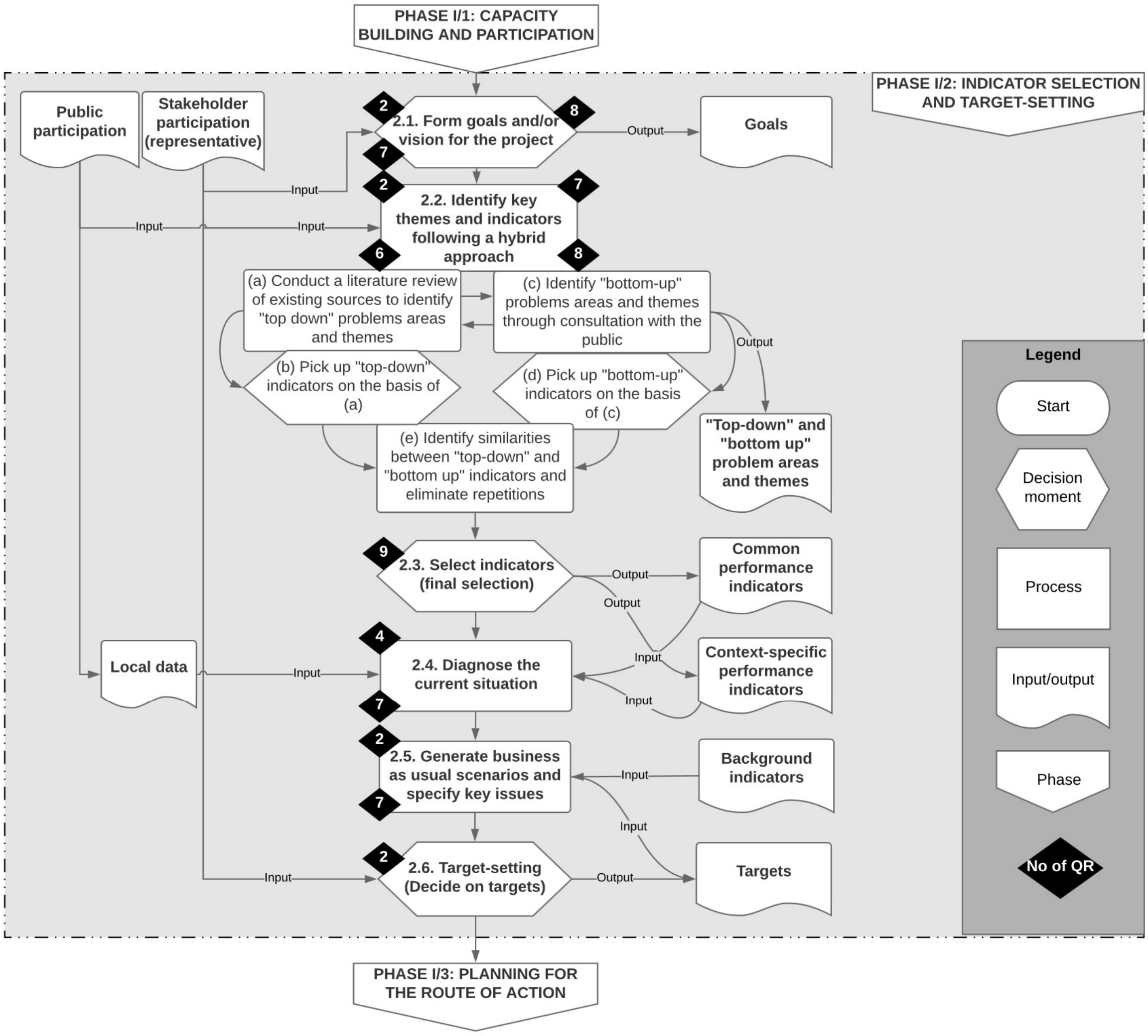


Figure 3.4. Detailed process flowchart for phase I/2 (Source: Present author).

Step 2.2: Identify key Themes and Indicators following a Hybrid Approach

In this step, the most critical local and global environmental, social and economic problems that need to be addressed in the neighbourhood are identified (**QR8**) by means of a hybrid approach (**QR2/QR6**). This is achieved according to the following steps:

(1) First, global priorities can be identified by the CT by evaluating past and current urban sustainability studies and practices. Eventually, each priority or problem area must be tied to one or more of the top-down goals identified in the previous step. Moreover, each problem area should be connected to specific performance indicators that will allow

the team to determine whether or not the problem is solved. The core team can be well served by adopting indicators from existing systems rather than developing their own unique metrics. This adoption presupposes an extensive review of what has already been put into practice and what will best suit the special characteristics of the neighbourhood under investigation (point (a), Figure 3.4). Achieving a certain level compliance with national or international standards is also critical (e.g. United Nations Sustainable Development Goals and International Organization for Standardization Sustainability Standards). Furthermore, it is essential that existing national or regional sustainability strategies are taken into account if available. This expert-driven process results in a set of significant issues, referred to as "common problem areas" in the present thesis, as well as a first draft of corresponding indicators (point (b), Figure 3.4), referred to as "common performance indicators". It is worth highlighting that the common problem areas identified should not only be viewed as an input to form the problem model, but also as an education and awareness-raising opportunity for non-technical participants (**QR7**). This opportunity occurs during the bottom-up processes of this step, outlined below.

(2) Second, the needs and desires of local stakeholders should be identified and accommodated through a bottom-up approach. To do so, interactive brainstorming sessions can be effectively used both in the decision team and in the context of a public workshop, where all ideas are recorded and nothing is criticised as impossible (point (c), Figure 3.4). As mentioned above, the identification of local problems should not be the only aim of such sessions and bottom-up processes, but the development of a public understanding of sustainability should also be a central focus. The specific issues and concerns (i.e. "context-specific problem areas") of the people should not be dismissed as unreasonable by the AT. Rather, they should be translated by the CT into a draft set of indicators unique to the neighbourhood's context (point (d), Figure 3.3), referred to as "context-specific performance indicators". Finally,

care should be taken that any repetitions between the two draft sets are eliminated (point (e), Figure 3.4).

The application of such a hybrid process for identifying critical issues and related indicators ensures that the model simultaneously contributes to local and global sustainability.

Step 2.3: Select Indicators

The list of indicators derived from the hybrid approach must be evaluated to ensure that the most relevant and realistic indicators are selected for assessing the progress towards SUD in the neighbourhood. To do this, indicators can be evaluated against a comprehensive set of ideal indicator characteristics, often called “selection criteria”. This task requires technical knowledge and therefore is completed by the team of experts, the CT. The concept of selection criteria is further outlined in the section dedicated to indicators (see Section 3.3.2). The same section also provides a specific set of selection criteria and summarises the most important qualities for indicators to have. Although the final filtered set is created by the CT, “weak” bottom-up indicators should not merely be rejected with no explanation. Instead, the facilitator should clearly point out and discuss the methodological flaws and reasons for omission to the rest in the AT. This will preserve the feeling of co-ownership generated in the previous two steps. Eventually, this task has two primary outcomes: a final set of “common performance indicators” and a final set of “context-specific performance indicators”, both providing the basis for the following diagnosis step and for monitoring success in post-implementation phase (**QR9**).

Step 2.4: Diagnose the Current Situation

Before planning future actions, the baseline performance of each of the selected indicators in the previous step should be specified. In other words, a diagnosis of the current situation in the neighbourhood on the basis of the selected indicators should be made. Although the calculations necessary for this step are considered an expert-driven task, the necessary data are gathered from all relevant stakeholders, both inside and outside the AT. For example, many indicators require the collection of survey data from residents and businesses in the neighbourhood, ranging from people's perceptions on different matters to objective consumption data. Especially in the latter case, the optional provision of such data by the neighbourhood population overcomes the issue of personal data protection that arises when such data are requested by different service suppliers (i.e. electricity and water). Once data are gathered, the meaning of results should be discussed within the AT, an important activity also from a learning perspective (**QR7**). Finally, public access to the results of the diagnosis should be ensured, as well as their presentation in an easy-to-understand format (**QR4**).

Step 2.5: Generate Business-as-usual Scenarios and Specify Key Issues

The previous step allows the AT to determine the key areas needing further improvement. At this stage, it is also essential to generate future no-action scenarios (i.e. what would or could be the future situation in the neighbourhood if no sustainable measures are implemented) on the basis of a target year. Doing so results in a more realistic view of the current "distance to target" (Walsh, 2000). Developing a business-as-usual (BaU) scenario typically requires a wide variety of inputs, such as data on demographic and socio-economic parameters, assumptions about how these parameters are expected to change and information on policies that may cause these changes. Therefore, no-action scenarios can also, in part, be built on future trajectories of the major background indicators (identified as "input" in Figure 3.4). Usually, BaU scenarios can be based either on historic projections or forecasts. The latter should be preferred if obtained from official sources because up-to-date trends are accounted for. With regard to participation, it is widely recognised that the process of scenario development to explore alternative futures can also be turned into a collaborative process to promote social learning and collective action (**QR2**/**QR7**).[4] This can apply to the development of both BaU scenarios and solution-based scenarios. After the generation of such no-action scenarios, the CT should determine whether the neighbourhood is already performing on some of the indicators as desired. As a result, they identify for which indicators

[4] Some interesting insights on the process of participatory scenario planning and its benefits are provided by Oteros-Rozas et al. (2015).

targets do not need to be defined and which are expected to perform at the same level or worse in the future.

Step 2.6: Target-setting

As a result of understanding how a neighbourhood is expected to evolve if no action is taken, the selection of appropriate interim targets (one or more per indicator) becomes more grounded in reality ("output" in Figure 3.3). In this context, "appropriate" means that targets should be attainable but also ambitious enough to mobilise decision-makers to move away from the status quo. Moreover, the term "interim" suggests that the viability of targets can be better judged after deciding on the set of actions (see step 3.3). Again, the selection of targets should be a collaborative task, and, therefore, it is performed by the AT (**QR2**). While targets drive the selection of actions, the selected actions iteratively refine the targets. Going even further in the process, the monitoring and evaluation in the post-implementation phase may also result in new or refined targets. Target refinement can therefore be seen as an iterative and continuous process, including several loops. Possible sources for short-term and long-term targets are current political and scientific debates, regional and national action plans, as well as existing targets in other comparable areas/regions.

3.2.3.3 Phase I/3: Planning the Route of Action

Once the targets have been set, the next step is to identify the measures of intervention needed to meet them. In order for the stakeholders to be able to address each specific problem, it is necessary to assign specific responsibilities and tasks to specific stakeholders. This should result in a clear road map, which is the last step indicated in this phase. The detailed process flowchart for this phase is shown in Figure 3.5, and a detailed description of each step follows.

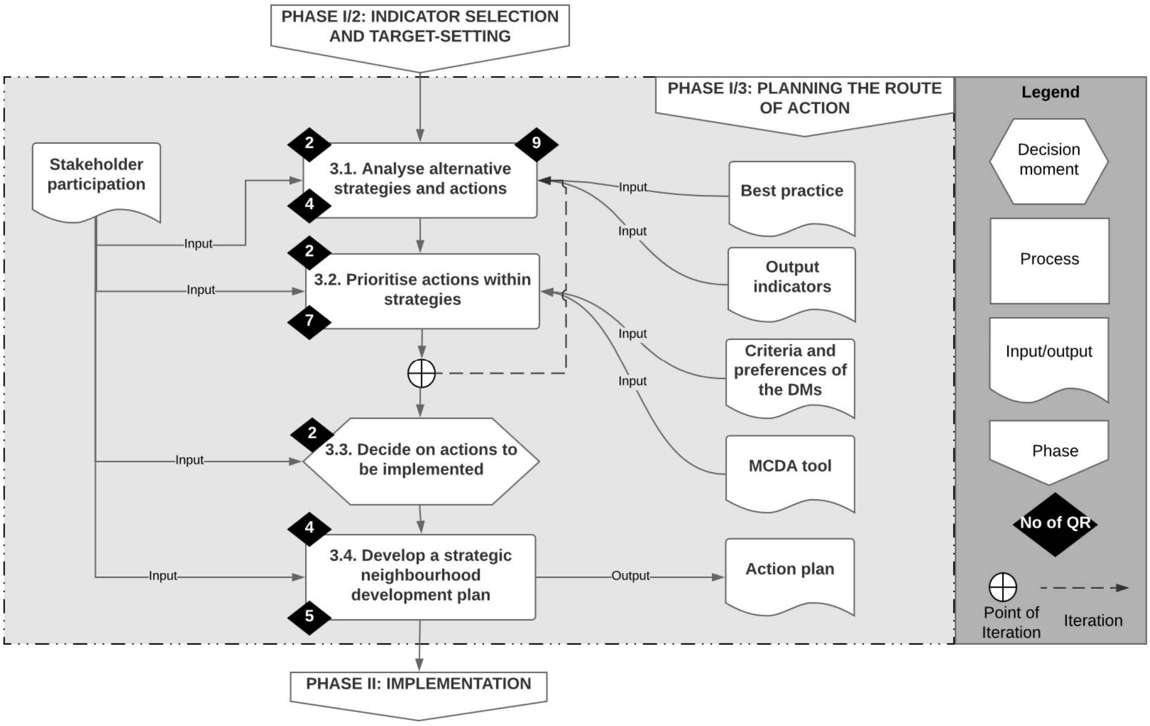


Figure 3.5. Detailed process flowchart for phase I/3 (Source: Present author).

Step 3.1: Analyse Alternative Strategies and Actions

The analysis of alternative strategies can be achieved through the development of a structured factsheet to systematise all necessary information. Such a factsheet may cover questions such as why this strategy is important, where (or for which cases) this strategy is relevant, what the possible areas of conflict are (and therefore possible barriers), and finally by whom this strategy can be best achieved and how. In the context of achieving an action-oriented approach, the present thesis proposes that the analysis of potential strategies and actions should be performed for each indicator so that it becomes part of an advanced indicator description factsheet (see section 3.3.6 for more details on what such a factsheet should look like). In other words, a preliminary identification of the acting stakeholders and their opportunities for action should already take place at this step. The development of a such a factsheet, especially in an online interactive format, can not only ease the dissemination of the strategies and actions within the AT but also act as a knowledge broker for the public (**QR4**). Transparency and open communication with regard to all potential factors and strategies can foster the acceptance of the planned changes by the "affected" stakeholders, who may react negatively to specific changes and jeopardise the plans. Such threats can occur as a result of target conflicts and unwillingness to cooperate.

Furthermore, it is useful to establish a preliminary list of potential output indicators as part of the description of the actions. This list can be used for monitoring the direct results of actions if those actions are eventually selected for implementation (**QR9**). It is reasonable that the analysis of alternative strategies be performed by the CT and that the set of completed templates is communicated to the rest of the actors in the AT. Thereafter, the CT can request feedback from the AT and evaluate their readiness to actively contribute to the implementation of different actions before the implementation phase begins (**QR2**). If the strategies (and the multiple actions contained within them) put together by the CT are accepted by the AT, the list of strategies forms the basis for the next step. If comments are provided, the facilitator modifies the selected strategies accordingly.

Step 3.2: Prioritise Actions within Strategies

The goal of this step is to define a catalogue of priority actions whose application will improve the sustainability of the neighbourhood. To select the best actions among the ones identified in the previous step, the CT needs to perform an evaluation according to different financial, technical, environmental or social criteria. Such criteria should be defined by the AT (**QR2/QR7**). Because the ultimate aim is to actively involve these stakeholders as actors in the actual implementation of the solutions, it is essential that their interests are reflected in the criteria. In order to compare interventions and prioritise them on the basis of the agreed upon criteria, MCDA methods can be utilised because they offer participatory elements and are well suited for complex and transdisciplinary decision-making. An MCDA framework is proposed by the present author as a decision support model for guiding collaborative prioritisation and selection of actions in the context of SUD (see section 3.4).

Step 3.3: Decide on Actions to be Implemented

In this step, the goal is to determine which actions prioritised by the MCDA will finally be implemented as part of the final action plan. These actions must achieve progress towards the different targets but also do so under specific budgetary constraints. It cannot be assumed that all possible combinations of actions are always viable for implementation. For that reason, a final step is proposed in this analysis: the best ranked actions should be checked according to their financial feasibility, either through a cost-effectiveness or CBA analysis, before the final choice.

Step 3.4: Develop a Strategic Neighbourhood Development Plan

A strategic neighbourhood development plan (SNDP) is a document outlining the commonly agreed upon vision for neighbourhood development (**QR2/QR4**). It can consist of two parts: (1) a clear representation of the baseline conditions of the neighbourhood, thus indicating the key issues to be addressed by the plan and (2) a strategic action roadmap for achieving progress towards a desired state, clearly indicating the specific binding targets and timelines, as well as the actors responsible for implementation of each action. Finally, the estimated net benefits and expected investment costs should also be clearly stated (on the basis of a comparison of the project scenario to the BaU scenario and presented in a percentage change) resulting from the implementation of each bundle of actions at each stage.

3.2.4 Discussion

As it can be seen the SUD process is quite complex; it incorporates several steps and feedback loops. The process quality requirements ensure the integrity of the process and alignment to the institutional principles of sustainable development. However, a high-quality SUD process in no way guarantees the delivery of the desired outcomes. In other words, it does not automatically equate with the achievement of a SUD once the agreed-upon strategies and actions become operational and physical and social changes to the neighbourhood actually occur. Instead, it guarantees the relevance to the local needs and a socially acceptable distribution of responsibilities and benefits. Furthermore, it ensures the continuity of the process in terms of overcoming difficulties, learning from successes and failures when they arise and adapting the path to the desired outcomes. After all, urban sustainability is not a fixed endpoint, but a continuously-evolving target. A summary overview of what QRs should be taken into account at the minimum for each step is shown in Table 3.2. While the description and sequence of the steps described above are not meant to be prescriptive, they are comprehensive and should provide a common framework for future discussion.

Table 3.2. Quality requirements (QRs) for each step of the pre-implementation phase of the SUD process (Source: Present author).

		QR1	QR2	QR3	QR4	QR5	QR6	QR7	QR8	QR9
Phase I/1	Step 1.1	●	-	-	-	-	-	-	-	-
	Step 1.2	-	-	-	-	-	-	-	-	-
	Step 1.3	-	-	-	-	-	-	-	-	-
	Step 1.4	-	●	●	●	-	-	-	-	-
	Step 1.5	-	-	●	-	-	-	-	-	-
	Step 1.6	-	-	●	-	●	-	-	-	-
Phase I/2	Step 2.1	-	●	-	-	-	-	●	●	-
	Step 2.2	-	●	-	-	-	●	●	●	-
	Step 2.3	-	-	-	-	-	-	-	-	●
	Step 2.4	-	-	-	●	-	-	●	-	-
	Step 2.5	-	●	-	-	-	-	●	-	-
	Step 2.6	-	●	-	-	-	-	-	-	-
Phase I/3	Step 3.1	-	●	-	●	-	-	-	-	●
	Step 3.2	-	●	-	-	-	-	●	-	-
	Step 3.3	-	●	-	-	-	-	-	-	-
	Step 3.4	-	-	-	●	●	-	-	-	-

Note: The bold dot indicates the intersection point between a step and a QR

3.3 An Assessment Framework: Monitoring and Assessing Progress towards Sustainable Urban Development

This section first proposes a conceptual and analytical framework to guide the development, selection and systematisation of indicators that ties together top-level concepts, such as "areas of protection", "protection goals" and "problem areas" (see Section 3.3.1). Second, it provides a current "top-down" way of thinking in the identification of the most urgent problem areas (seen as areas of action) for European neighbourhoods around which the development of a set of *common performance indicators* can and should be based (see Section 3.3.2). A critical element of this "top-down" approach to the identification of problem areas is that it also establishes linkages with SDG targets.

Third, on the basis of the identified problem areas and of established selection criteria, a set of *common performance indicators* is proposed to provide an example of an action-oriented indicator set that can be meaningful from a European perspective (see Sections 3.3.3-5). In the context of the thesis, a performance indicator set represents an open and flexible group of indicators which aims at stimulating action and not at rating or certification on the basis of aggregated (using weights) results. Therefore, in the design of the proposed set, complete independence between the indicators was not striven for to avoid double-counting.

Fourth, a set of *background indicators* is provided for illustrative reasons only, as it constitutes an important source of contextual information that can indicate potential barriers for achieving success under each performance indicator (Section 3.3.6). Finally, a concept to develop "advanced factsheets" for describing indicators in a way that clearly supports a process- and action-based approach is proposed (Section 3.3.7).

3.3.1 Conceptual Framework for Systematisation of Indicators

A conceptual framework offers a formal way of thinking about a topic area (Brown, 2009). Putting the indicators in an appropriate conceptual or analytical framework increases their usefulness. In the absence of a well-designed framework, the rationale behind the selection of indicators becomes incomprehensible to nonexperts (Nathan & Reddy, 2012). There is also the danger that the selection of indicators is influenced by the specific expertise and research interests of the creators, potentially resulting in an overly "dense" indicator representation in some areas (multiple indicators for essentially the same concern), and "sparse" or even no indicator representation in other important areas (Bossel, 1996). The systematisation and organisation of indicators is here achieved in two ways: 1) functional systematisation; 2) thematic systematisation.

3.3.1.1 Functional Systematisation

This type of systematisation involves the development of a typology of indicators depending on their *underlying function* (i.e. purpose), what they actually *intend to measure* (i.e. baseline, outcome/impact, output or process?), and finally whether they can be "*directly influenced*" by interventions of local actors inside the individual district (e.g. the energy consumption of residential buildings can be directly influenced by the neighbourhood's residents). The latter distinction has also been analysed in the work of Lützkendorf and Balouktsi (2017) and is considered particularly important in order to orient the focus and efforts in more actionable (or action-oriented) and empowering indicators. Indicators themselves do not guarantee actions, but they can become the catalysts that stimulate and mobilise local actors to deliver the desired outcomes and outputs. To this end, action-oriented indicators arguably offer more realistic and useful decision support tools for action planning.

Based on the above-mentioned indicator capabilities, the classification of indicators into four different categories is proposed: 1) *performance* indicators; 2) *output* indicators; 3) *background* indicators; 4) *process quality* indicators. The process steps from which each specific category of indicators results has already been briefly shown in the description of the process framework in a basic and schematic way (Section 3.1.2). The capabilities of each indicator type are shown in an illustrative fashion in Figure 3.6 and described below.

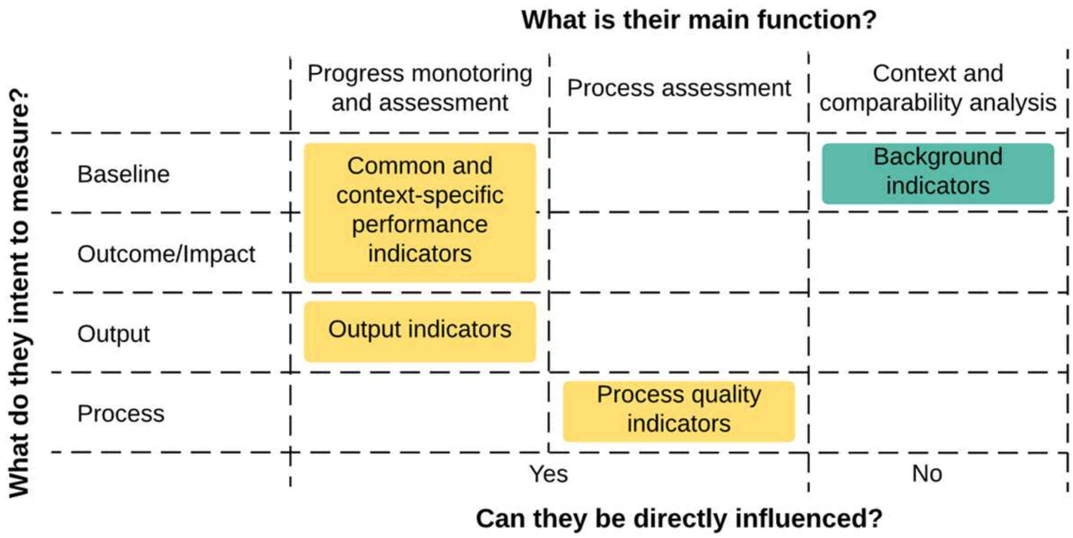


Figure 3.6. Illustration of the capabilities of each indicator type (Source: Present author)

Progress Assessment and Monitoring: Performance and Output Indicators

Within the conceptual framework, the intended function of the first two types of indicators is to assess and monitor progress toward the desired end state of the neighbourhood. In the pre-implementation phase, and specifically during the diagnosis step (see earlier Figure 3.4), *performance indicators* serve as measures of *baseline* performance (e.g. energy-related greenhouse gas emissions expressed in CO_2 equivalent per capita), providing information on the current level of neighbourhood sustainability, while for ex-post assessments they serve as measures of *outcome/impact* (e.g. percent reduction/increase in energy-related greenhouse gas emissions compared to the baseline value). They therefore intend to measure and monitor the more pervasive long-term changes in neighbourhood conditions that (at least partially) result from the interventions. In other words, they provide a broad picture of whether the desired changes (expressed through the targets set) are actually occurring.

Depending on whether they are derived from a “top-down” (expert-led) or “bottom-up” (citizen-led) approach, performance indicators are further organised into two different sets: a) a core set of EU common (and therefore comparable) indicators derived in a “top-down” manner and relevant across the majority of European neighbourhoods; and b) a local set of context-specific (and therefore unique) indicators derived in a “bottom-up” manner drawing attention to local deficiencies and problems not already addressed by the core set of common indicators. The importance of incorporating both common and context-specific indicators has already been outlined at several places in the present thesis. For the purposes of this research, only a set of common performance indicators has been proposed (see Section 3.3.5) to provide an example of an action-oriented indicator set embedding the most important sustainability concerns from a European perspective. Naturally, it was impossible to come out with a generic set of context-specific performance indicators, as they are always case-specific (the thesis does not focus on a specific case study).

Choosing only indicators measuring the final impact may mean that a range of immediate results (and also benefits) is missed, preventing decision makers from understanding the pathway to this impact. As a complement to *performance* indicators, the use of *output indicators* is therefore suggested. Output indicators help measure and monitor the immediate outputs/results (i.e. goods and services) generated by each intervention (e.g. number of smart-energy meters installed). These outputs are the first step toward realising the targets set in connection to performance indicators. Output indicators are therefore seen as intermediate” indicators, while performance indicators are seen as “final” indicators in the logical framework. As stressed in Section 3.2.3.3, output indicators per action should be selected and presented already in the pre-implementation phase while planning the possible route for action (i.e. in step 3.1 as part of the analysis of alternative strategies and actions). The “how” is better demonstrated on the basis of examples in later sections of the thesis (see Section 3.3.7, and specifically Part C of the indicator description).

Context and Comparability Analysis: Background Indicators

Generally speaking, the establishment of a core set of common performance indicators provides the possibility of performing cross-neighbourhood comparisons, but it does not ensure comparability among neighbourhoods. The present author is of the opinion that comparing neighbourhoods with regard to their performances for the sake of ranking them or scoring them should not be a desirable task. However, under the precondition of comparability, an exchange of experience between "peer" neighbourhoods can be very useful. In other words, it is argued that the promotion of comparability would facilitate a more meaningful exchange of best practices between local authorities. The contextual differences (i.e. geographic, social, economic and political differences) across neighbourhoods need to be taken into account for such a task. This is here achieved through the definition of a set of *background indicators* for the neighbourhood scale (a proposed indicator set is presented in Section 3.3.6). This approach was developed in parallel with, but independently from, the development of the ISO 37120 standard that also proposes indicators with a similar functionality (i.e. the "profile indicators" – see Section 2.5).

Background indicators mainly provide basic statistics and background information (i.e. an informative reference) about the neighbourhood and are not designed to assess performance, since they "cannot be influenced" (at least, not directly) by interventions of local actors. In other words, their purposes are to highlight the circumstances and characteristics of a given area that are not amenable to, or appropriate for, local intervention. While these indicators do not aim to measure progress, they can help decision makers to understand why a neighbourhood performs the way it does, what may inhibit the success of specific strategies and which other neighbourhoods could be of interest for peer-to-peer learning. For example, the unemployment rate in the neighbourhood is not a parameter readily amendable to local action, but it provides an indication that achieving changes in home-energy efficiency will be challenging if this is accompanied with an increase in rent. Furthermore, background indicators can function as "early warning" indicators, in the sense that they can highlight future needs in certain cases. For instance, an increasingly aging population in an area, although it is a trend that cannot be influenced, can predict the need for more barrier-free buildings in the area.

No targets are defined as reference lines for these indicators on the neighbourhood level (contrary to performance indicators), but for some of them, targets can be set at greater spatial scales (e.g. city or region level). Finally, the future trajectories of the development of major background indicators can also be used for building future no-action scenarios relative to which the targets assigned to different performance indicators will be specified. This was already mentioned as a possibility in step 2.5 of the process framework and is better demonstrated in Section 3.3.6.4 by means of the common performance indicator "energy-related greenhouse gas (GHG) emissions expressed in tonnes CO_2 equivalent" as an example.

Process Assessment: Process Quality Indicators

Finally, for an effective sustainable neighbourhood development process, it is important to not only develop and select indicators for monitoring the outcomes and outputs of the intervention plan, but also the planning and implementation process itself. Within the proposed conceptual framework, this is achieved through the inclusion of a set of *process quality indicators*. This was already described in detail under step 1.2 of the process framework, together with the possibility to develop a set of process quality indicators on the basis of the specific quality requirements proposed by the present author. It does not, therefore, need to be analysed again here.

3.3.1.2 Thematic Systematisation

After having defined a typology of indicators, the top-down concretisation (i.e. operationalisation) of the sustainability concept, adapted to the object of assessment "city" and "city district" or "neighbourhood" (in accordance with SDG 11), into constitutive elements, based on which suitable indicators can be identified, is necessary. This thesis follows a combination of a goal-oriented and a problem-oriented approach to the hierarchical decomposition of sustainability into the set of indicators that can be directly influenced: the performance indicator set (the process quality indicator set was earlier treated).

Although both are top-down approaches, they use very different information as starting points.

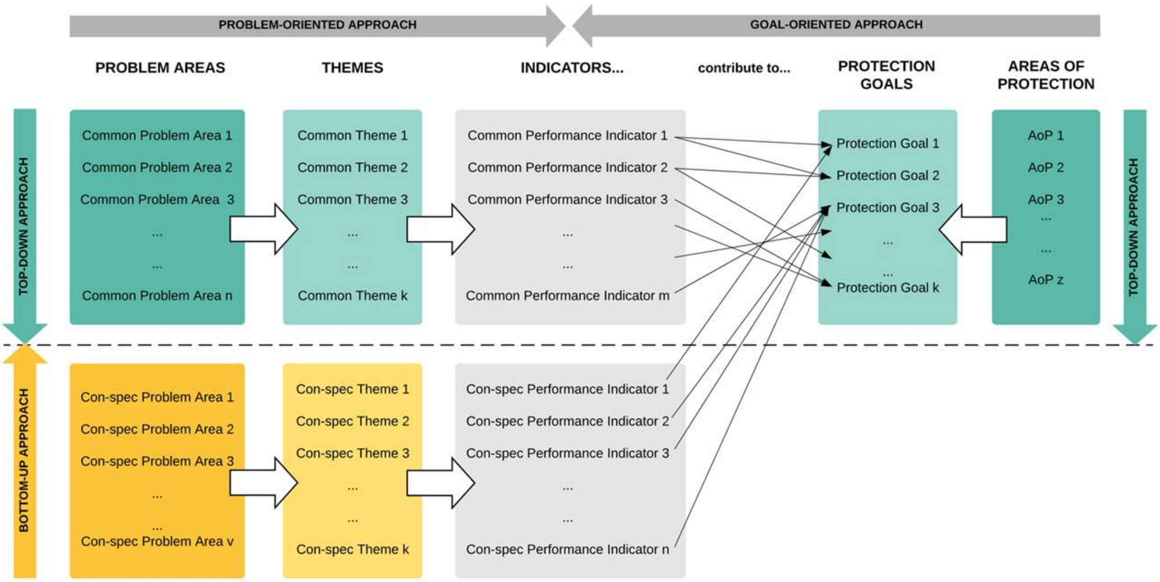


Figure 3.7. Illustration of how the two top-down approaches (goal-oriented and process-oriented) are combined (Source: Present author). Note: the abbreviation "Con-spec" refers to "Context-specific".

With regard to the goal-oriented approach, one could start by defining the main subject matter related to the 17 goals as a generally accepted and potentially highly influential framework of goals. Most, if not all, SDGs have urban implications (the same does not apply to the targets if one goes deeper in the analysis. as shown in Section 2.2). However, there are no clear boundaries among the SDGs, and it is hard to delineate a clear starting point. Therefore, the *starting point* here is the notion that there are "resources" or "values" of particular importance that need to be protected or enhanced, not only today but also for future generations: the so-called areas of protection (AoPs). Although the AoP concept originates from early discussions of SETAC Working Group on Environmental Life Cycle Assessment (ELCA), it can be expanded to include social and economic "resources" or "values" worth protecting. In ELCA, the AoPs are commonly used are human health, natural environment and natural resources (Finnveden et al., 2009).

As shown in Table 3.3, this list is here enlarged, including a total of seven AoPs, grouped along the three traditional pillars of sustainability dealing with the "*what*", namely environment (planet), society (people) and economy (prosperity). Governance as the fourth pillar dealing with the "*how*" is not operationalised here using the derivation of AoPs to describe it, but it has its own starting point, which is comprised of the quality requirements described in the process framework. Solely using the three- and four-pillar concepts, which are dominant in both scholarly and political debates on sustainability and sustainable development, on which to base the identification of indicators brings diverse problems (e.g. normative ambiguity and the problem of integration).

The goal-based approach proposed herein is partially inspired by the way the core aspects and indicators are defined in the international standards on sustainability in building construction, ISO 21929-1 (ISO, 2011). According to ISO 21929-1 (ISO, 2011), the system of indicators shall contain indicators that impact one or more core AoPs. Core AoPs (as defined in section 4.3.1 of the standards) are as follows:

- Ecosystem
- Natural resources
- Health and well-being
- Social equity
- Cultural heritage
- Economic prosperity
- Economic capital

However, the core AoPs identified in the standard are relevant to the assessment at a building scale and not a neighbourhood scale, and consequently they were not adopted unchanged. For instance, as one can observe in Table 3.3, the framework makes it explicit that the social equity incorporated here refers to a certain type of equity. Social equity can be divided into its two most basic dimensions: outcome-based equity (i.e. equity in outcomes) and procedural equity (i.e. equity in processes). Outcome-based equity deals with the equal distribution of services to meet basic needs and life opportunities to realise one's full potential (Chapple, 2014, p. 32), while procedural equity deals with inclusive, accessible and authentic engagement and democratic representation (and voice) in planning and implementation processes of sustainable urban development programs (Park, 2014; Chapple, 2014, p. 32). Satisfaction of certain quality requirements of the process framework automatically leads to safeguarding procedural equity. Thus, it is not part of the AoPs framework (Table 3.3). A final minor differentiation from ISO 21929-1 (ISO, 2011) is that economic capital is replaced by economic stability (recognised by Neugebauer et al. (2016) as an economic AoP).

Table 3.3. Formulation of a set of globally valid protection goals on the basis of core AoPs (adjusted from ISO 21929-1) for developing neighbourhood-based sustainable development plans (Source: Present author).

Pillar	Area of protection	Protection goal
Environment	Natural Resources	G1: Conserve and sustainably use the nonliving natural resources (energy, water, raw materials and land), regardless of whether locally sourced or imported
		G2: Ensure the preservation or enhancement of biodiversity (flora and fauna) in the local area
	Natural Ecosystem	G3: Protect natural ecosystems from negative impacts from emissions and waste products on the local and global environment
Society	Human health and well-being	G4: Protection of human health from hazards and risks from man-made environmental pollution
		G5: Promotion of human health and well-being through improving the quality of life in the local area
	Social (outcome-based) equity	G6: Protection of social equity in outcomes and reinforcement of inclusion and solidarity
	Cultural heritage	G7: Protection of the built cultural environment, built heritage, as well as cultural values
		G8: Protection of aesthetic and urban development quality
Economy	Economic stability	G9: Preservation of the economic structure and value in the local area
	Economic prosperity	G10: Preservation and reinforcement of the economic prosperity of the residents and businesses in the area

Furthermore, the framework presented here does not restrict itself to only defining AoPs. The broad AoPs are further translated into a set of ten general “protection goals” (Table 3.3). Assigning goals to each AoP increases the understanding of the public and decision makers of what needs to be accomplished in the long term. This general top-down structure is, however, too abstract to be used as the sole basis for the derivation of specific indicators. It is rather useful for differentiating broad thematic areas and their indicators as to whether they have an effect on one or more protection goals or dimensions of sustainability. The subjects of multieffects and multidimensionality were first taken up in an official way in ISO 21929-1: 2011. This idea is adopted and further enhanced here through the presentation of the common problem areas, common sustainability themes and common performance indicators (described in the following sections) in an original multidimensional and multieffectual way, not only indicating the importance of the potential impact (as in ISO 21929-1) but also distinguishing between positive and negative effects (shown in Table 3.16 under Section 3.3.2.12).

With regard to the problem-oriented approach, the following 10 problem areas have been identified as important in political and scientific discourse, relevant for the European setting and compatible with the goals: 1) over-exploitation of scarce natural resources (energy, raw materials, fresh water); 2) the continued growth of land use; 3) loss of biodiversity; 4) climate change; 5) air pollution; 6) solid waste generation; 7) noise pollution; 8) reduced feeling of personal safety and public security; 9) unequal access to basic services and infrastructure; and 10) unequal access to affordable and adequate housing. The process and rationale behind the identification of these problem areas as Europe’s most pressing environmental, social and economic problems that offer opportunities for neighbourhood-level action are fully explained in the next subsections.

The ten “problem areas” allow a practical operationalisation of the sustainability goals. They act as a “filter” reducing the complexity inherent in analysing the broad range of topics covered in the goals. With the help of this filter, the selection of relevant common themes and indicators to represent them is significantly more focused on central issues and problems that are addressed in public and academic discourse. Accordingly, a phenomenon must fulfil two criteria in order to qualify as a “problem area”: it must violate one or more of the established sustainability goals and be classified as a problem in scientific, political and/or social discourse. The latter implies that additional “problem areas” can also be defined on the basis of a “bottom-up” approach serving as a basis for the derivation of the context-specific performance indicators.

The necessity of such a combined approach can be reasonably justified by the deficits of the conceivable alternatives: the main objection to an exclusively goal-oriented approach is that the number of themes to be processed without an intermediate filter would be too extensive. By contrast, an approach based solely on today’s most urgent problems, either from a high-level or local perspective, would entail the risk that negative, and therefore unsustainable, developments/trends against the sustainability model may be ignored if they are not (yet) perceived as problems by society. Thus, the irreversible destruction of natural environment or cultural values, for example, is fundamentally incompatible with sustainable development because it restricts the options for action of future generations. This must apply, irrespective of whether this destruction is currently regarded as a serious problem by society or not.

3.3.2 Rationale behind the Selection of “Problem Areas”

In a general sense, problem areas can be seen as broad issues that describe complex and nontrivial problem situations currently placing an environmental, social and/or economic pressure on the world and society as a whole. This distinguishes them from the term “areas of protection”, which are values and resources that need to be protected even if conceived as not being at risk yet. However, since the framework is targeted to neighbourhoods located in Europe, the term “common problem areas” here refers to broad issues that appear as urgent in the European context; the neighbourhood scale can be seen as a type of provider of solutions in this regard. It is important to note that wherever considered necessary for a clearer analysis, the present author narrowed down (i.e. broke down) the broad problem areas into more specific topics denoted as “common themes”.

In particular, the following process has been followed to identify the most urgent problem areas for Europe that are potentially actionable at smaller urban scales. First, a deep screening of the *SDGs* and *related targets* pre-identified in Section 2.2 as potentially relevant to European neighbourhoods was initially performed to check how they are connected and whether certain targets share common themes. This also involved an examination of the list of sustainable development indicators to understand how the targets will be monitored. This immediately led to a preliminary identification of a set of broad problem areas potentially relevant to the European context and influenceable/actionable at the neighbourhood level.

Second, the preliminary set of problem areas was checked against the *EU SDG indicator set*, which reflects the EU’s own policy priorities, to broadly confirm its importance for the European context and to identify additional pressing issues for the European region that are not explicitly addressed in the SDG targets. One example is the growing problem of noise pollution in Europe, which – although, in principle, is closely related to both SDG 3 (health) and SDG 11 (cities) – is a completely unaddressed problem area in the SDG framework at the target and indicator levels.

Finally, based on the definition of “problem area” outlined in the first paragraph, it was also necessary to check whether Europe is on track to meet its own targets in certain areas on the basis of *official statistics* or *academic research*. This would determine the problem areas with an urgent need for problem solving or investigation at finer scales of analysis. Therefore, in this thesis, “common problem areas” and “common themes” denote the priority problem areas and themes that should be embraced by any SUD neighbourhood plan in one way or another, even if not identified or perceived by the residents and other local stakeholders as problems.

The process described above resulted in a set of 10 common problem areas and 17 common themes (Table 3.4) described in more depth in the immediate following small subsections and used as a basis for the proposed common performance indicator set later presented.

Table 3.4. The decomposition of problem areas into themes and their linkages with the relevant SDG targets (Source: Present author).

Problem area	**Theme**	**Relevant SDG targets**
Overexploitation of scarce natural resources (energy, raw materials and fresh water)	Nonrenewable energy resources	7.2, 7.3, 8.4, 12.2
	Material resources	8.4, 12.2
	Freshwater resources	6.4, 6.3
Continued growth of land use	Land use	11.3
Loss of biodiversity	Biodiversity	15.5, 15.9
Climate change	GHG emissions	13.2
Air pollution	Particulate matter	11.6, 3.9
Solid waste generation	Solid waste generation	11.6, 12.5
	Solid waste recycling and reuse	12.5
Noise pollution	Noise pollution	-
Reduced feeling of personal safety and public security	Road safety	3.6, 11.2
	Personal security	11.7
Unequal access to basic services and infrastructures	Access to basic services	1.4
	Access to public transport	11.2
	Barrier-freeness	11.2, 11.7
Unequal access to affordable and adequate housing	Affordable housing	11.1
	Adequate housing	11.1

This approach comes not only as a response to the need for localising SDGs to bring them down to region, city and community levels, but it can also be valuable in raising awareness among stakeholders of local-to-global (and vice versa) interactions.

3.3.2.1 Problem Area 1: Overexploitation of Scarce Natural Resources (Energy, raw Materials and fresh Water)

It is a well-known fact that availability of natural resources is in decline, while population growth continues. The World Wildlife Fund (WWF) estimated that in 2005 the global population's demand for natural resources exceeded the planet's regenerative capacity by about 30 percent (WWF, 2008, p. 2). The most recent estimates are even more alarming, with WWF noting that "*by 2012, the equivalent of 1.6 Earths was needed to provide the natural resources and services humanity consumed in one year*". (2016, p. 15). However, as underlined in "Vision 2050" proposed by the World Business Council for Sustainable Development (WBCSD), humankind can live well and within the limits of the planet, but only with radical changes in its values and practices (WBCSD, 2010). In this sense, there is an urgent need for communities at different scales, and therefore also for neighbourhoods, to start dealing with natural resources, especially the scarce ones, in more efficient and sustainable ways.

The natural resources may be classified in a number of ways, such as (a) renewable or nonrenewable; (b) biotic (living and organic material) or abiotic; and (c) stocks, funds or flows, among other classifications (Alvarenga et al., 2016). Natural resources whose availability is finite and cannot be regenerated within human lifetimes (stocks/nonrenewable resources), or natural resources that can be regenerated within human lifetimes but not perpetually (funds/potentially renewable resources), are considered as "scarce" when the demand exceeds or is expected to exceed supply flow. The different resources under each category are illustrated in Figure 3.8[5].

Considering the global concern over scarcity and the urgency of the matter, it is argued that the set of common themes and indicators should address the entirety of nonrenewable and potentially renewable resources, regardless of the scale of assessment (building, neighbourhood, city, region or nation). In the present framework, this is achieved in the following way: the problem area "overexploitation of scarce natural resources" discussed in this section

[5] it is based on the definition of "stocks", "funds" and "flows" provided by Dewulf et al. (2015).

addresses all nonrenewable resources, along with the freshwater resources under three individual criteria: i) nonrenewable energy resources; ii) raw material resources (referring to metallic and nonmetallic minerals); and iii) freshwater resources. Land, biodiversity and fresh air are treated as individual problem areas, namely under "continued growth of land use" (see Section 3.3.2.2), "loss of biodiversity" (see Section 3.3.2.3) and "air pollution" (see Section 3.3.2.5) respectively.

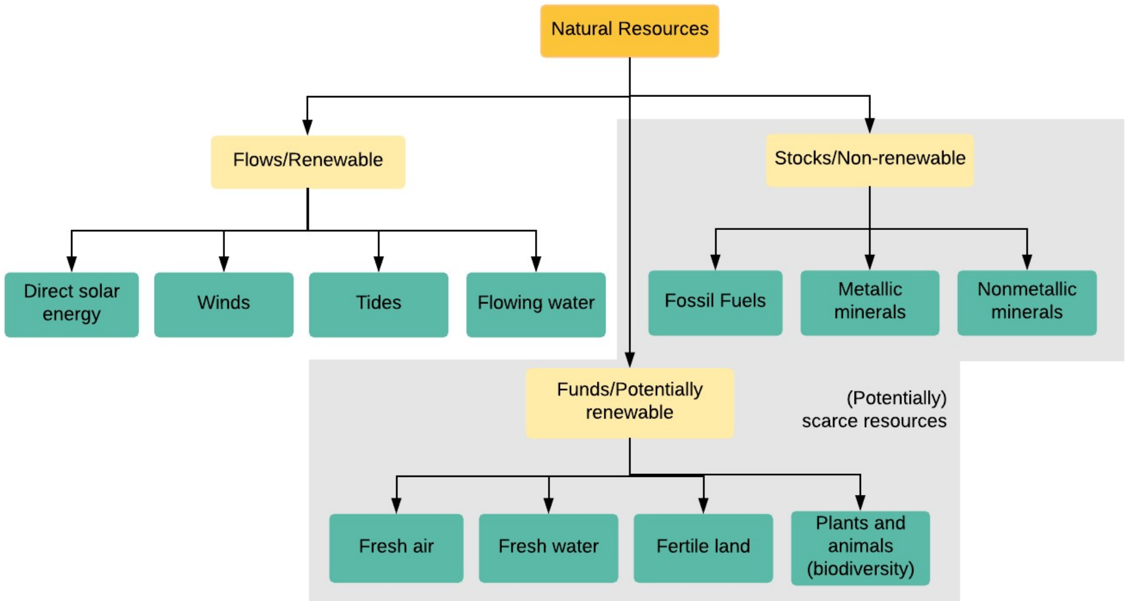


Figure 3.8. Classification of natural resources (Source: Present author)

The logic behind treating nonrenewable energy resources, raw material resources and freshwater resources under the same problem area is that a similar three-step strategy can be employed for all to tackle the scarcity problem:

(1) Reduce their demand.

(2) (Re)use their waste streams for productive purposes (such as use of waste energy to supply district heating, use of recycled materials to modernise buildings and infrastructure and reuse of waste water for irrigation purposes).

(3) Substitute their use with renewable alternatives (such as use of renewable energy sources to supply electricity, use of plant-derived materials to modernise buildings and infrastructure and harvesting of rainwater to use for domestic purposes).

This agrees with and expands the “new stepped strategy”, proposed by van den Dobbelsteen (2008) and incorporating the cradle-to-cradle philosophy (McDonough & Braungart, 2002), for an efficient energy-resource conservation. This three-step approach can later be translated into appropriate indicators and actions.

The growing pressure on the limited supply of energy, raw materials and freshwater resources is also reflected in the SDG framework through dedicated targets under goals 6, 7 and 8. In the case of the theme “nonrenewable energy resources” it can be considered as associated to SDG targets 7.2 and 7.3 on renewable energy and energy efficiency, but only indirectly, in the sense that mainly final energy demand is treated and not the protection of energy resources at their sources. Raw material resource consumption and resource efficiency in general are directly linked to two targets in the SDG framework (UNSD, 2018a): target 8.4 (“Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with…” (p. 8)) and target 12.2 (“By 2030, achieve the sustainable management and efficient use of natural resources” (p. 12)). It is important to note that the “material footprint” indicators under these two targets account for four types of materials (i.e. biomass, metals, nonmetallic minerals and fossil fuels), including nonrenewable energy resources. Therefore, the first theme is eventually directly connected to these two SDG targets. This clearly shows the high interconnectivity between the SDG targets.

Finally, freshwater resources are treated under target 6.4, which in part reads as follows: “By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity…” (UNSD, 2018a, p. 7). Furthermore, the cross-cutting importance of utilising wastewater as a strategy for reducing the consumption of fresh water is highlighted in target 6.3, which seeks to halve the proportion of untreated wastewater and substantially increase its recycling and safe reuse globally, among others.

In the European setting, there are several policies covering the suggested themes, some with specific EU targets. This indicates their importance and urgency, and examples are as follows:

- The Europe 2020 strategy sets a target of increasing the share of renewable energies in gross final energy consumption to 20% by 2020, while by 2030, the share should further increase to at least 27%, according to the 2030 Climate and Energy Policy Framework. Looking deeper at the progress achieved so far in each EU country, official statistics of 2015 revealed that although some countries already exceeded their national binding targets in this respect, others are much further behind (European Parliament, 2017).

- Several European policies put forward objectives and actions for sustainable consumption and production and resource efficiency, namely the Sustainable Consumption and Production (SCP) and Sustainable Industrial Policy (SIP) initiatives (COM (2008) 0397), the Roadmap to a Resource-Efficient Europe and the circular economy package.

- Ensuring water use in appropriate quantities is one objective of the Water Framework Directive 2000/60/EC (WFD).

With regard to the proposed framework, the three themes, in addition their direct linkages to the AoP “natural resources”, are also indirectly associated with the AoP “natural ecosystem”, and in certain cases, “social equity” and “economic prosperity”. An analysis per theme of contributions to specific protection goals and justifications (where considered non-self-explanatory) are provided (Table 3.5).

Potentially negative influences are also indicated. These should not prevent decision makers from including the respective themes in their frameworks, since most of the negative impacts are avoidable if appropriately considered when developing or selecting strategies and actions.

Table 3.5. Contribution of themes "non-renewable energy resources", "raw material resources" and "freshwater resources" to the different AoPs and protection goals (Source: Present author).

Common theme	**It contributes (positively/negatively) to…**		**Rationale**
Non-renewable energy resources	++ G1 ++/- G2	Natural resources	**Primary goal for this theme** Limiting the demand for fossil fuels, and consequently their extraction, leads to reduced soil degradation and biodiversity loss in and around the extraction area (effect on global biodiversity). Conversely, transition to renewable energy, as a strategy to minimise fossil fuels use, may come with a cost to local biodiversity (discussed in the extensive review by Gasparatos et al. (2017)).
	+ G3	Natural ecosystem	Burning fewer fossil fuels equals fewer GHG emissions, and it therefore contributes to the preservation of ecosystem services.
	+ G9	Economic stability	It can contribute in the medium- and long term to economic stability, since it enhances energy security and/or self-sufficiency in the local area in the case of renewable energy exploitation as a strategy (ISO, 2017).
	+ G10	Economic prosperity	Reduced energy demand in buildings leads to reduced household energy costs.

Note: The signs "++" and "- -" indicate primary (or direct) positive and negative influences, respectively, while "+" and "-" indicate secondary (or indirect) positive and negative influence, respectively.

(Table 3.5 continues)

Common theme	It contributes (positively/negatively) to…		Rationale
Raw material resources	++ G1 ++ G2	Natural resources	**Primary goal for this theme** Positive influence on biodiversity for the same reason outlined in the previous theme.
	+ G3	Natural ecosystem	Materials are associated with embodied energy and embodied GHG emissions, and therefore a minimised material consumption leads to reduced GHG emissions.
	+/- G10	Economic prosperity	It can be positive or negative, depending on the case.
Freshwater resources	++ G1 ++ G2	Natural resources	**Primary goal for this theme** There is a direct connection between water-resource conservation and biodiversity preservation (Vörösmarty et al., 2010).
	+ G3	Natural ecosystem	Freshwater supply requires energy to extract and deliver to end users, and therefore reduced water demand also leads to reduced energy consumption and GHG emissions.
	+ G10	Economic prosperity	Reduced water demand in buildings leads to reduced household water costs.

3.3.2.2 Problem Area 2: Continued Growth of Land Use

Similar to the earlier-mentioned resources, utilisable land is a scarce resource, and therefore it is especially important to use the available land as efficiently as possible. In particular, covering the land with impervious surfaces (soil sealing) is regarded as one of the most detrimental effects of land take in terms of its environmental impact (EEA, 2016). Soil sealing disrupts/alters important ecosystem functions, such as the natural nutrient and water cycling, which affects everything from provision of food and water to flood mitigation and climate regulation. In addition to the issue of soil sealing, inefficient land use in urban areas leading to urban sprawl also contributes to the proliferation of cars and the increase in travel distances and consequently to the levels of energy consumption.

This problem area is highly relevant for cities and urban areas, and the urgency to be tackled at this level is also acknowledged by the SDG framework in its urban target 11.3: “By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries” (UNSD, 2018a, p. 11). It also includes a related indicator on efficient land use (indicator 11.3.1) that measures the relationship between land consumption and population growth, rather than the land uptake in an absolute manner. This is reasonable, since intensive urbanisation is expected to continue and new houses will still need to be built in future. Aspiring to reduce the sealing of new land to zero by 2030 would be unrealistic.

Urban expansion patterns differ from region to region. As far as Europe is concerned, an extended research analysing the relationship between population and household number development in 188 European cities to the growth of urban land area and per capita living space showed that in some regions (e.g. East Germany) land consumption further increases, even where the population has declined or the household numbers have decreased (Haase et al., 2013). This finding suggests that even Europe, which is characterised by its compact cities, suffers from unsustainable urban growth in certain areas. This concern is also reflected at a European policy level (e.g. the Roadmap for Resource-Efficient Europe launched in 2011 as part of the Europe 2020 Strategy), as well as in the EU SDG indicator framework, which includes indicators capturing the changes in and efficiency of artificial land use (indicators sdg_15_40 and sdg_15_30). Therefore, overgrowth of land use qualifies as a critical problem area in Europe, requiring action by cities.

In the case of neighbourhoods, though, it is difficult to answer the question to whom to attribute the urban growth if two or more neighbourhoods are adjacent or in close proximity. However, it is still possible to investigate land-use efficiency down to the scale of neighbourhoods by separately investigating single types of uses (e.g. artificial land cover for residential buildings per capita). Furthermore, it is an appropriate scale for integrating strategies for mixed-land use, densification and infill of vacant areas within the neighbourhood. With this in mind, the theme "land use" to represent the problem area (it mainly is a short name of the problem area; distinction into more themes was not found to be necessary) has been included in the framework. The linkage with the framework's goals and AoPs is shown below (Table 3.6).

Table 3.6. Contribution of the theme "land use" to the different AoPs and protection goals (Source: Present author).

Common theme	It contributes (positively/ negatively) to…		Rationale
Land use	++ G1 ++ G2	Natural resources	**Primary goals for this theme**
	+ G3	Natural ecosystem	There is a strong link between urban density of a settlement and consumption of fossil fuels, which on its side is associated with GHG emissions (Norman et al., 2006).
	+/- G5	Human health and well-being	Urban densification may be positive only up to a certain level; it can also increase the risk of adverse effects on well-being (Conticelli et al., 2017).

Note: Same as Table 3.5.

3.3.2.3 Problem Area 3: Loss of Biodiversity

All natural resources are connected to each through an intricate chain of interrelationships. Loss of global biodiversity, for instance, can be seen as one of the impacts of overexploitation of all the other scarce resources, with a more direct causal link to land use and land-cover change when it comes to biodiversity loss occurring at the city/local level. As in the case of an unsustainable growth of land-use coverage, a loss in biodiversity not only threatens the production of all the necessary sources (e.g. food, wood, fuel and medicines) for the economic development and resilience of societies, but also causes changes in essential ecosystem functions, such as carbon sequestration, climate regulation and air filtering (ISO, 2017). The rationale of including biodiversity as an important theme on its own in the conceptual framework lies in the practical consideration that, at an action level, biodiversity conservation or enhancement actions should be undertaken independently of efficient land-use planning actions. Both themes, although highly interconnected, lead to different opportunities and types of strategies and actions at the local level.

Globally, concerns on the issue of the biodiversity are increasing. The World Economic Forum (WEF) placed “biodiversity loss and ecosystem collapse” among the top 10 global risks in terms of impact and likelihood in its annual global risk report for 2015 (World Economic Forum, 2015). The first globally concerted response to the biodiversity crisis was the adoption of a set of internationally agreed-upon targets known as the Aichi Biodiversity Targets (CBD Secretariat, 2010). This is further reinforced and complemented through the main SDG goal directly related to Biodiversity and Habitat, Goal 15 on terrestrial ecosystems, and SDG target 15.9, which explicitly calls for the integration of ecosystems and biodiversity values, not only into national but also local planning and development processes (it also explicitly mentions one of the Aichi targets in its respective indicator, 15.9.1). Furthermore, SDG 15 includes a target directly related to biodiversity loss as a problem in need of fixing by 2020, namely target 15.5: “Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species.” (UNSD, 2018a, p. 16).

Besides its well-acknowledged global significance, the European Commission also has adopted its own biodiversity strategy with the headline target to “halt the loss of biodiversity and ecosystem services by 2020, to restore ecosystems in so far as is feasible, and to step up the EU contribution to averting global biodiversity loss” (European Commission, 2011, p. 2). However, despite the policy efforts, Europe is not on track to meet its target by the specified deadline, and much stronger efforts are needed (European Commission, 2015c).

The inclusion of a criterion on “biodiversity” in the framework is therefore considered indispensable. Aside from its relevance to European political agenda, local biodiversity action plans at the neighbourhood level are not only possible, but also highly relevant for reinforcing residents' engagement in the dialogue and for helping residents to take greening actions themselves (Beumer & Martens, 2015). The connections to the various AoPs and goals are provided below (Table 3.7).

Table 3.7. Contribution of the theme "biodiversity" to the different AoPs and protection goals (Source: Present author).

Common theme	It contributes (positively/negatively) to…		Rationale
Biodiversity	++ G2	Natural resources	**Primary goal for this theme**
	+ G3	Natural ecosystem	Plants contribute to carbon sequestration, climate regulation and air filtering (ISO, 2017).
	+ G7	Cultural heritage	Biodiversity and culture are often seen as two intersecting narratives: biodiversity can shape the cultural local environment, in the sense of local values, beliefs and norms to practices (Pretty et al., 2008).

Note: Same as Table 3.5.

3.3.2.4 Problem Area 4: Climate Change

Climate change is undoubtedly the global environmental risk attracting the most attention at present, and is, according to the Intergovernmental Panel on Climate Change (IPCC, 2007), one of the most serious contemporary challenges to achieving a sustainable society. A collective response of nations to the urgency of tackling climate change and an important moment in history is marked by the long-term goal of the Paris Agreement to keep the increase in global average temperature to well below 2°C compared to preindustrial levels. This global agreement on climate change mainly commits the UNFCCC Parties (i.e. the 196 countries that signed the agreement) to take action on climate change. Although the 2030 agenda stemmed from a distinctly separate intergovernmental negotiation process, the two agendas are closely interdependent. In the SDG framework, climate action is a goal on its own (Goal 13), and the activities undertaken as part of the Nationally Determined

Contributions (NDC) under the Paris Agreement can be considered as directly related to target 13.2: "Integrate climate change measures into national policies, strategies and planning" (UNSD, 2018a, p. 14).

However, actions limited at national or regional levels are not sufficient to reach such an ambitious target. Particularly, the binding target for European Union to reduce GHG emissions at least by 40% by 2030 compared to 1990 (Liobikienė & Butkus, 2017) as Europe's commitment to the long-term goal of the Paris Agreement places a strong demand for climate action by cities in Europe. In fact, already more than 60% of the EU cities have some sort of local climate plan in place (Reckien et al., 2018). In some countries, such as Denmark, France, Slovakia and the UK, the adoption of such local plans is even compulsory for municipalities. Furthermore, Europe has its own climate network, the EU Covenant of Mayors (CoM) initiative, that supports the diffusion of best practices and helps cities share knowledge on planning for climate mitigation (Neves et al., 2016).

Curiously, though, the lowest availability of climate change plans is found in Southern European cities, although they are the most exposed to future climate impacts according to projections (an analysis of the potential reasons behind this can be found in Reckien et al., 2015). Another important point to note is that although it is evident that the EU demonstrates leadership in international climate-mitigation efforts, it is projected that currently implemented measures will not allow the EU to meet its 2030 goal (Climate Action Tracker, 2017). This suggests that there is still ample room for progress in Europe, both as a whole and in individual cities.

Perhaps experimenting with and integrating related solutions at a neighbourhood level first as a learning opportunity before citywide application is the best possible approach for cities that do not yet have the necessary resources or capacity for large-scale projects. The possibilities for neighbourhood-level actions, particularly for addressing this problem area, are analysed in more detail as part of the hypothetical case (see chapter 5). Finally, the interest in testing ambitious efforts to push the boundaries of climate action at neighbourhood scale is also reinforced by new and still-evolving concepts, such as “low-carbon” neighbourhoods (Genus & Theobald, 2016), as well as “carbon-neutral” or “climate-neutral” neighbourhoods (Erman, 2014).

How the theme “GHG emissions” fits into the proposed framework is described below (Table 3.8). It is remarkable that strategies and actions aiming at reducing GHG emissions have the potential to contribute (directly and indirectly) to 7 out of 10 goals of the framework. This makes it a theme, which if holistically addressed, can be combined with multiple positive effects for the neighbourhood and the city as a whole, in addition to its contribution to global efforts (this argument is further developed in chapter 5).

Table 3.8. Contribution of the theme “GHG emissions” to the different AoPs and protection goals (Source: Present author).

Common theme	**It contributes (positively/negatively) to…**		**Rationale**
GHG emissions	+ G2	Natural resources	Tree planting as a strategy to reduce GHG emissions through carbon sequestration also enhances biodiversity.
	++ G3	Natural ecosystem	**Primary goal for this theme**
	+ G4	Human health and well-being	Research indicates that low carbon actions can result in numerous health benefits, as depicted in Figure 3.9 (Milner et al., 2012)
	+ G6	Social equity	Same as above
	+ G7 & G8	Cultural heritage	There is research suggesting that GHG emissions can lead to the acceleration of material decay of historic buildings (Viles, 2002).
	+ G10	Economic prosperity	Low carbon actions in the building sector (i.e. energy efficient renovations) decreases the household energy costs.

Note: Same as Table 3.5.

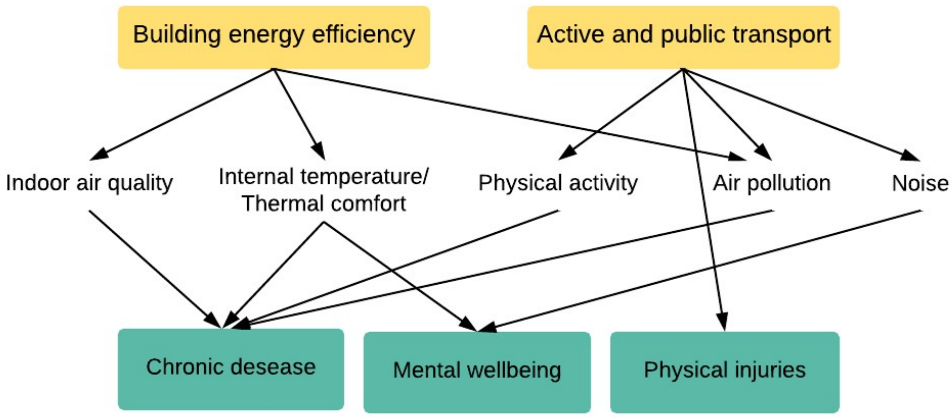


Figure 3.9. Key pathways to health of climate change mitigation strategies relevant to neighbourhoods (Source: adapted from Milner et al. (2012)).

3.3.2.5 Problem Area 5: Air Pollution

Air pollution is undoubtedly a major problem in urban areas and consists of many pollutants. Six key pollutants that harm people's health and the environment are: particulate matter $PM_{2.5}$; particulate matter PM_{10}; ground-level ozone (O3); nitrogen dioxide (NO_2); sulphur dioxide (SO_2); and carbon monoxide (CO). The most harmful pollutant, fine particulate matter (PM2.5), is considered the most harmful one, as these particles are able to penetrate deeply into the respiratory tract and therefore can increase death rates from respiratory infections/diseases and lung cancer (among others). The SDG framework specifically includes two targets and two indicators focused on air pollution to emphasise the importance of this problem area, and approaches it from two different perspectives:

(1) As an adverse environmental impact particular to cities through target 11.6 – "By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management" (UNSD, 2018a, p. 12) and its impact indicator, 11.6.2, to measure the levels of fine particulate matter ($PM_{2.5}$ and PM_{10}) in cities.

(2) As a health determinant/risk factor through target 3.9 – "By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination" (UNSD, 2018a, p. 4) and its impact indicator, 3.9.1, to assess the mortality rate attributed to air pollution.

Other than its global relevance, this problem area is particularly important for Europe as a region, and not only because of the inclusion of an indicator dedicated to particulate matter (i.e. the indicator "sdg_11_50" – see European Commission and Eurostat (2017)) in the EU SDG indicator set. The EU has set an annual target value for $PM_{2.5}$ concentrations (25 µg/m^3) since 2008 (in the Directive 2008/50). However, despite the progress achieved over the last decade, several cities are still above these limits, according to the findings of the recently published "Air Quality Atlas for Europe" by JRC that explores the main emission sources of particulate matter in 150 European cities (Thunis et al., 2017). It should also be noted that the threshold value recommended by the World Health Organization (WHO) is 10 µg/m^3, and nearly all 150 cities have their $PM_{2.5}$ levels exceeding this. An even more recently published official European report translates the exposure to fine particulate matter ($PM_{2.5}$) into specific health impacts and claims that it caused the premature death of more than 400,000 Europeans in 2014 (EEA, 2017, p. 56).

This evidence makes it clear that this problem remains unresolved for a considerable number of European cities, and it is a problem that comes with detrimental consequences to human life. The question arises of whether it is relevant for action at the neighbourhood level. In addition to a high level of $PM_{2.5}$ caused by industry and agricultural activities in the peripheries of the cities (which cannot be influenced at a neighbourhood level), transport emissions and residential heating (the latter particularly in Eastern European countries) also represent important contributions to $PM_{2.5}$ levels in European cities (Thunis et al., 2017). This offers an opportunity to tackle this problem at a neighbourhood level; therefore, the addition of the criterion "particulate matter" in the proposed framework was judged as essential (Table 3.9). An additional benefit is that actions in this field have the potential to contribute to more than 50% of the goals, either directly or indirectly, making it one of the most cross-dimensional and significant themes of the framework.

Table 3.9. Contribution of the theme "particulate matter" to the different AoPs and protection goals (Source: Present author).

Common theme	It contributes (positively/negatively) to…		Rationale
Particulate matter (PM)	+ G2	Natural resources	PM is a health determinant not only for humans, but also animals.
	++ G3	Natural ecosystem	**Primary goal for this theme**
	++ G4	Human health and well-being	**Primary goal for this theme**
	+ G6	Social equity	Homes in air-polluted areas tend to be cheaper, and therefore the health of low-income populations is more likely to be at greater risk from the harmful effects of air pollution (Dings & Jensen, 2011).
	+ G7 & G8	Cultural heritage	PM represents an aesthetic issue and is also an agent of chemical degradation potentially most harmful to cultural heritage (Grau-Bové & Strlič, 2013).
	+G10	Economic prosperity	Air pollution in general has significant economic impacts, increases medical costs and reduces employees' productivity, among others (EEA, 2017).

Note: Same as Table 3.5.

3.3.2.6 Problem Area 6: Solid Waste Generation

Many cities generate more solid waste than they can dispose of (ISO, 2017). Hoornweg et al. (2013) point out that waste is currently being generated faster than other environmental pollutants, including greenhouse gases. Along with air pollution, increased waste generation is treated in SDG framework as a major environmental impact of cities under target 11.6 – “By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management” (UNSD, 2018a, p. 12) and indicator 11.6.1, which measures urban solid waste being regularly collected, with adequate final discharge. The need for a proper waste management is also expressed under target 12.5 – “By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse” (UNSD, 2018a, p. 13), which likely implies a certain hierarchy of waste strategies, placing a priority on prevention and reduction (although reuse should always come before recycling). This is logical, as recycling is not an energy-free process.

At the European level, there are already regulatory institutions and instruments establishing the legal validity of the waste hierarchy. For instance, the EU Waste Framework Directive (2008/98/EC) establishes the waste hierarchy as a priority order, where “the following waste hierarchy shall apply as a priority order in waste prevention and management legislation and policy: (a) prevention; (b) preparing for re-use; (c) recycling; (d) other recovery, e.g. energy recovery; and (e) disposal” (European Commission, 2008, p.10). In the same directive, recycling targets for specific materials (paper, metal, plastic and glass) are also established to a minimum of overall 50% by weight to move waste up the hierarchy. Additionally, waste is treated as a resource in the more recent Circular Economy Package (European Commission, 2015c), which establishes an action programme with measures covering the whole cycle from production and consumption to waste management.

On the basis of the discussion above, it is argued that, first, the treatment of waste generation as a common problem area for the European context is of vital importance, and second, this should be broken down at a minimum in two major criteria: “waste generation” to reflect the highest level of waste hierarchy, and “waste reuse and recycling” to sum up the rest. Although one may argue that these issues are more relevant for the city level, the emergence of the “zero-waste neighbourhood” concept (Van der Leer, 2016a; 2016b), although still in the development and experimentation phase, provides a wide range of decentralised, small-scale solutions that can be applied by neighbourhoods. An analysis of contributions per theme to specific protection goals (and justifications where considered non-self-explanatory) are provided (Table 3.10).

Table 3.10. Contribution of the themes “waste generation” and “waste reuse and recycling” to the different AoPs and protection goals (Source: Present author).

Common theme	It contributes (positively/ negatively) to…		Rationale
Waste generation	+ G1	Natural resources	Less waste generation means less land take for landfill.
	++G3	Natural ecosystem	**Primary goal for this theme**
	+ G4	Human health and well-being	If extensive waste generation or inappropriate waste collection in an area leads to “waste mountains” the danger goes beyond only the environment; it also affects human health (Hansen et al., 2002).
Waste reuse and recycling	++ G1	Natural resources	**Primary goal for this theme**
	++G3	Natural ecosystem	**Primary goal for this theme**
	+ G4	Human health and well-being	The arguments of the previous theme under this goal also expand here.

Note: Same as Table 3.5.

3.3.2.7 Problem Area 7: Noise Pollution

Noise pollution is one of the most complex and pervasive problems which is expected to continue to grow as urbanisation proceeds (Science for Environment Policy, 2017). Recognising the serious implications of prolonged exposure to noise for both physical and mental public health (WHO, 2011; Science for Environment Policy, 2017), the European Environmental Noise Directive (END) was adopted in 2002 (European Parliament and Council, 2002). The directive requires member states to prepare and publish, every five years, noise maps and noise-management action plans for agglomerations with more than 100,000 inhabitants, as well as major roads, railways and airports, in consultation with the concerned public (European Commission, 2017). In doing so, the directive is considered as the world's biggest and most ambitious programme of strategic noise reduction (Murphy & King, 2014).

However, despite the directive, according to the findings of the World Health Organization (WHO), noise continues to be the second-biggest environmental health threat in Europe, just after air pollution (WHO, 2011; European Commission, 2017). Specifically, the European Environmental Agency (EEA) suggests that at least one in four Europeans are exposed to potentially harmful (i.e. above 55 decibels (dB) L_{den}[6]) road-traffic noise levels (EEA, 2014). Although noise pollution is related to SDG 3 (health) and SGD 11 (cities), it is not explicitly mentioned in any of their targets.

Based on the above-mentioned findings, though, it is a highly relevant issue in the European context that can and should be measured, audited and tackled at the neighbourhood level. How it fits into the proposed framework is shown below (Table 3.11).

[6] For noise mapping, the EU gives the threshold of 55 dB (A) for a 24-hour (day-evening-night) noise level (Lden) and 50 dB (A) for a night-time noise level (Lnight) (a threshold at which negative effects on human health can be observed).

Table 3.11. Contribution of the theme "noise pollution" to the different AoPs and protection goals (Source: Present author).

Common Theme	It contributes (positively/negatively) to…		Rationale
Noise pollution	+ G2	Natural resources	Noise pollution does not affect only humans, but adverse effects can also be found in the health and distribution of animal species.
	++ G4 & G5	Human health and well-being	**Primary goals for this theme**
	+ G6	Social equity	Homes in noisy areas (and often with polluted air) tend to be cheaper, and therefore the health of low-income populations is more likely to be at greater risk from the harmful effects of noise (Dings & Jensen, 2011).
	+ G10	Economic prosperity	Prolonged exposure to noise is associated with concertation difficulties and loss of productivity, and consequently it also comes with disadvantages for economic prosperity.

Note: Same as Table 3.5.

3.3.2.8 Problem Area 8: Reduced Feeling of Personal Safety

The feeling of personal safety within the context of an urban area can be described as the sense of safety (freedom from physical or psychological threats) one feels when walking, cycling or driving in an urban area. This makes it a wide-ranging problem area that can be broken down in two broad themes: road safety and crime prevention. Both are major societal issues, explicitly acknowledged by the global SDG framework. Road safety is addressed under target 3.6 – "By 2020, halve the number of global deaths and injuries from road traffic accidents" (UNSD, 2018a, p. 4) and its associated indicator (3.6.1) that confusingly measures the "death rate due to road traffic injuries" rather than the absolute number of deaths; additionally, no mention of injuries is found. Perhaps these points have already been debated within the UN team, and clarifications of how progress is to be tracked will be provided in future. In any way measured, lack of road safety – in addition to being a cause of death (and therefore linked to SDG3) – is also a key indicator of road infrastructure performance (Masterton et al., 2017), whether this is addressed at a national, regional or local level. It can therefore also be considered as linked to SDG11 (and specifically target 11.2, where "road safety" is mentioned, but the associated indicator only addresses the access to public transport).

In the case of crime prevention, it is explicitly addressed in target 16.1, which seeks to "significantly reduce all forms of violence and related death rates everywhere", and under which a mixture of objective (i.e. measured on the basis of official crime statistics) and subjective (i.e. measured on the basis of victimisation surveys) indicators are used to monitor progress. It is also part of target 11.7 (UNSD, 2018a, p.12) – "By 2030, provide universal access to safe, inclusive and accessible, green and public spaces…" (and specifically, indicator 11.7.2), and it is therefore also linked to the quality of life in cities and communities.

With regard to the relevance of the above-mentioned issues in the European context, both themes are part of the EU SDG indicator set. Indeed, as far as road safety is concerned, although Europe has made much progress over the last 15 years, statistics report that more than 26,000 people died on the roads of the European Union in 2016, i.e. the equivalent of a medium town (European Commission, 2018). This figure denotes somewhat of a stray from the EU 2020 target path adopted in 2010 (European Commission, 2010b).

With regard to the feeling of safety, statistics on the basis of surveys conducted in 2013 report that among the EU population, 28% of people felt very safe when walking home at night, while 25 % felt a bit or very unsafe (Eurostat, 2017a). This average number is, however, not representative for all countries, as some of them report very high proportions of people rating their security at low levels (e.g. Bulgaria) (Eurostat, 2017a). The latter percentage suggests the significance of the issue for Europe.

To investigate both issues, the neighbourhood level is more than appropriate, since residents have intimate knowledge of their neighbourhoods and their problems. For instance, local knowledge can facilitate authorities to locate the primary sources of road accidents in the area (e.g. where the speed limit or stop signs are not effective or where the common crash locations are) or the "hot spots" of crime. Additionally, tackling these issues in neighbourhoods not only contributes to improved well-being, but also to the success of the strategies promoting walking and cycling as a key part of efforts to mitigate climate change and reduce air pollution. The contributions of these two criteria to the framework's goals are provided below (Table 3.12).

Table 3.12. Contribution of the themes "road safety" and "crime prevention" to the different AoPs and protection goals (Source: Present author).

Common theme	**It contributes (positively/negatively) to…**		**Rationale**
Road safety	++ G5	Human health and well-being	**Primary goal for this theme**
	+ G10	Economic prosperity	Injuries as consequences of inadequate road safety can significantly disturb the economic prosperity of the families (households) of injured people due to increased health costs.
Crime prevention	++ G5	Human health and well-being	**Primary goal for this theme**
	+ G10	Economic prosperity	Crime in an area, either actual or perceived, can negatively impact the "liveability" of the area, and consequently the economic prosperity of businesses (Economist Intelligence Unit, 2011).

Note: Same as Table 3.5.

3.3.2.9 Problem Area 9: Unequal Access to basic Services and Infrastructure

Accessibility to key services, amenities, infrastructure and fair housing is commonly cited as a fundamental measure of social equity (Dempsey et al. 2011; Chapple, 2014, p. 33). Indeed, conventional wisdom suggests that improved accessibility provides opportunities to residents who cannot walk, cycle or drive, either due to physical (e.g. advanced age or disabilities) or financial reasons (e.g. not owning a car), to comfortably meet their basic needs. “Accessibility”, though, is a broad concept that encompasses all aspects of access to anything of importance.

Equitable access to basic services is achieved through a combination of measures: the actual provision of some of the services within walking distance for all the residents and users in a neighbourhood and/or the provision of public transport within walking distance as a mean of accessing them. In the latter case, not only is the provision of public transport stops within close proximity important but also the frequency of the provided service (Lei & Church, 2010). Furthermore, to achieve greater social inclusiveness, not only is spatial (and in certain cases, temporal) accessibility to basic services and transportation important, but also barrier-free accessibility and universal design for buildings and public spaces. These considerations led to the division of this problem area into three themes – namely, “access to basic services”, “access to public transport” and “barrier-freeness”; although these are somewhat interdependent, they are characterised by distinct possibilities for action. Unequal access to decent (i.e. structurally and functionally adequate and affordable) housing is treated as an individual problem area (see next section).

With regard to “access to basic services”, it is conceptually identical to SDG target 1.4, which calls for “access to basic services” (as part of SDG 1 on poverty), but without specifying which services it actually does include. What constitutes basic services varies considerably from region to region, depending on the economic conditions. From the present author’s point of view, a proper description of basic services that can apply to a European context is offered by ISO/FDIS 37120 (ISO, 2017) with its indicator “basic service proximity”, which provides a series of services and distances to be considered, including access to green areas and selective waste collection points (indicatively described in Table 3.13). It is important to highlight that this methodology is based on the proximity concept of basic services initially introduced by the European project CAT-MED (Changing Mediterranean Metropolises Around Time), conducted between 2009-2011 (CAT-MED, 2009). The EU SDG indicator set does not include an all-encompassing indicator as such, and spatial accessibility is only examined in relation to access to health care to represent the EU's health policy expressed, among others, in the 2014 Commission Communication "on effective, accessible and resilient health systems" (European Commission, 2014b).

Table 3.13. Distances to be considered for basic service types (Source: ISO (2017)).

Basic services		**Distance to be considered**
Food and everyday products	Basic food product supply	300 m
	Market supply	500 m
Public or private education centres	Nursery school	300 m
	Primary school	300 m
	Secondary school	500 m
Public or private health centres	Health-care centres	500 m
	Hospitals	1000 m
Social centres	Community social services centres and senior citizens' day centres	500 m
Sports centres	Public usage sports facilities	500 m
Cultural centres	Public libraries, museums and other cultural centres	500 m
Entertainment centres	Cinemas, theatres and other leisure centres	500 m
Selective waste collection points	Places for selective waste collection (organic, paper, glass and packaging)	100 m
Green area	Public Park	400 m

In relation to "access to public transport", the SDG framework highlights the need for sustainable public transport in its urban goal under target 11.2, which reads, in part: "By 2030, provide access to…sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations…" (UNSD, 2018a, p. 11). The last part of the target also implies that accessibility to public transport stops and stations should not only be available in close proximity to most residents in an area, but also be designed for "barrier-freeness" to support people with disabilities. With regard to Europe, sustainable urban mobility planning is at the top of its political agenda. Not only is a related indicator included in the EU SDG indicator set, but an active promotion of the concept of sustainable urban mobility also takes place in the EU though guidelines and funding for related projects under the European Regional Development Fund, amongst others (Brannigan et al., 2017).

Finally, the aspect of “barrier-freeness” can also be considered as related to urban SDG target 11.7, which partly reads as follows: “By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for…older persons and persons with disabilities”. This thematic area is of current interest in Europe, since demographics are changing toward an ageing population and a significant increase in the number of elderly citizens (Creighton, 2014). Yet, remarkably, it is not explicitly addressed in the EU’s indicator set for SDGs. However, the increasing need for “barrier-free accessibility” is considered in the ‘European Disability Strategy 2010-2020: A Renewed Commitment to a Barrier-Free Europe’, in which it is identified as a main area for action together with, for instance, participation, equality, employment, education and training.

In any case, to better accommodate the mobility needs of elderly and disabled people, buildings and streets in every neighbourhood in Europe will have to be transformed accordingly. Neighbourhood-level action should at least tackle barrier-freeness in public spaces and streets. Although good practices exist in some European countries (e.g. Germany has provided design principles for ‘barrier-free’ buildings and open spaces through the series of DIN 18040 standards, while Norway, going even further, has set a specific target to be universally designed by 2025 (Norwegian Ministry of Children and Equality, 2009), such examples are very few, making the improvement in this area necessary. The overall linkages of all three selected themes to the framework are provided below (Table 3.14).

Table 3.14. Contribution of the themes “access to basic services” and “access to public transport” to the different AoPs and protection goals (Source: Present author).

Common theme	It contributes (positively/ negatively) to…		Rationale
Access to basic services/ Access to public transport (*treated together here as they contribute to the same goals)*	+ G3	Natural ecosystem	Actions in both theme areas can potentially lead citizens to use their cars less and consequently to reduced greenhouse gas emissions and local air pollution.
	+ G4 & G5	Human health and well-being	Reduced environmental pollution (see above) leads to less damage to human health. Further, the modal shift from car to walking/cycling as well as to public transit (Morency et al., 2011) is associated with higher volumes of daily physical activity. Finally, an increased access to green areas, as a basic service, is associated to good mental health (Kent & Thompson, 2014).
	++ G6	Social equity	**Primary goal for this theme**
	+ G9	Economic stability	An increased density of retail, leisure, educational and transport services and opportunities strengthens the economic competitiveness and attractiveness of the area.
	+ G10	Economic prosperity	A reduction in personal car trips and an improvement in the human health and well-being potentially contribute to reduced household costs for transportation and health care.
Barrier-free accessibility	+ G5	Human health and well-being	Barrier-free accessibility to public spaces leads to fewer accidents and less frustration for people with disabilities.
	++ G6	Social equity	**Primary goal for this theme**

Note: Same as Table 3.5.

3.3.2.10 Problem area 10: Unequal Access to Adequate and Affordable Housing

The sustainable transformation of the housing sector to address inequalities against the urban poor is guided by SDG target 11.1: "By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums" (UNSD, 2018a, p. 11). Although addressed under SDG11, adequate housing conditions are closely linked to better health and better quality of life, among other benefits. While the SDG framework proposes to aggregate the components of structural adequacy, sufficient living area and affordability of houses (amongst others) in a composite indicator (i.e. indicator 11.1.1), in the present framework, "affordable housing" and "adequate housing" are treated as two different themes, with "inadequate housing" referring to one or more of the following conditions: a) housing in bad repair (e.g. leaking roof, damp walls, floors or foundation, or rot in window frames or floor); insufficient living area (e.g. when more than three people share the same room and an adequate kitchen unit); or c) inadequate access to basic sanitary facilities (such as a bath, shower or indoor, flushing toilet).

This approach is more in line with the approach followed by the EU SDG indicator set, which also includes four different indicators to address these issues. The rationale behind separating the problem area into these broad themes is that they lead to different types of action. A need for "affordable housing" leads to action related to the provision of more social housing in the area, often resulting in the construction of new and affordable housing complexes to accommodate this need, whereas the handling of "inadequacy of housing" in a structural or functional sense mainly leads to renovation actions. Both themes are relevant for many European countries, with countries in the southern part of Europe reporting extreme housing cost overburden rates (Eurostat, 2017b), while the current migration crisis has definitely worsened the overall housing conditions in the region, a trend that seems set to continue in the coming few years.

Finally, it is also worth pointing out that the strategies to increase the energy efficiency of the building stock as part of the efforts to reduce the neighbourhood's carbon footprint should always be combined with efforts to maintain affordability for the residents. This constitutes an additional reason why "affordability" should be an essential concern in every SUD neighbourhood plan. Table 3.15 provides a holistic overview of the different connections of the selected themes.

Table 3.15. Contribution of the theme "affordable housing" and "adequate housing" to the different AoPs and protection goals (Source: Present author).

Common Theme	It contributes (positively/negatively) to…		Rationale
Affordable housing	+ G5	Human health and wellbeing	Affordable housing leads to a reduced feeling of financial insecurity and related stress.
	++ G6	Social equity	**Primary goal for this theme**
	++ G9	Economic stability	**Primary goal for this theme**
	++ G10	Economic prosperity	**Primary goal for this theme**
Adequate housing	++ G5	Human health and well-being	**Primary goal for this theme**
	++ G6	Social equity	**Primary goal for this theme**
	+ G8	Cultural heritage	An improvement of structural or functional quality of a residential building may also lead to an improvement of its aesthetic quality.

Note: Same as Table 3.5.

3.3.2.11 Additional Important Problem Areas Unaddressed

Resilience is widely recognized as a pre-requisite for achieving sustainability. Resilience is acknowledged both explicitly and implicitly in a range of the proposed SDG targets. Target 1.5 represents the core resilience target, as follows: "By 2030 build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters" (UNSD, 2018a, p. 1). However, vulnerability to climate-related extreme events is a highly differential phenomenon across places and contexts. Emphasis on resilience presupposes that certain types of shocks and/or stressors and of certain magnitude have already been experienced in a particular area or are expected to be experienced in future. at a given time. Therefore, it presupposes an indication of a certain degree of exposure. For this reason, it has not been considered as a common problem area or theme in the assessment framework, but it is recommended to be examined and included in the list of context-specific themes if future forecasts on the basis of historical trends or scenarios suggest a worrisome future.

3.3.2.12 Summary

In summary, progress in one problem or thematic area may contribute to more than one protection goals and even affect more than one AoPs. Table 3.16 outlines the framework consisting of: a) the seven core AoPs and nine protection goals of sustainable development most relevant to a neighbourhood, b) the common problem areas and themes that affect these goals and AoPs, and c) their interactions presented in a multidimensional and multieffectual way. The identification and clear presentation of the various inter-linkages and their quality (i.e. positive/negative and direct/indirect) is vital to help keep a concise assessment framework and limit the number of needed indicators.

Table 3.16. Contribution of the proposed common problem areas and themes to the different areas of protection and related protection goals as defined in Table 3.3 (Source: Present author).

			ENVIRONMENT			SOCIETY					ECONOMY	
Common Problem Area	**Area of Protection and related Goal(s)** / **Common Theme**	Positive progress if…	NATURAL RESOURCES		NATURAL ECOSYSTEM	HUMAN HEALTH & WELLBEING		SOCIAL EQUITY	CULTURAL HERITAGE		ECONOMIC STABILITY	ECONOMIC PROSPERITY
			G1[1]	G2[2]	G3[3]	G4[4]	G5[5]	G6[6]	G7[/]	G8[8]	G9[9]	G10[10]
Over-exploitation of natural resources (energy, raw material and fresh water)	Nonrenewable energy resources (consumption)	↓	++	++/-	+	o	o	o	o	o	+	+
	Material resources (consumption)	↓	++	++	+	o	o	o	o	o	o	+/-
	Fresh water resources (consumption)	↓	++	++	+	o	o	o	o	o	o	+
Continued growth of land use	Land use	↓	++	++	+	o	+/-	o	+	o	o	o
Loss of Biodiversity	Biodiversity	↑/→	o	++	+	o	o	o	+	o	o	o
Climate change	Greenhouse gas (GHG) emissions	↓	o	+	++	+	o	+	+	+	o	+
Air pollution	Particulate matter	↓	o	+	++	++	o	+	+	+	o	+

Note: The number of "pluses" indicates the importance of the potential positive impact, while the number of "minuses" the opposite: the signs "++" and "- -" indicate primary (or direct) positive and negative influence respectively, while "+" and "-" secondary (or indirect) positive and negative influence respectively. The sign "o" indicates a neutral relationship.

(Table 3.16 continues)

Common Problem Area	Area of protection and related goal(s) / Common Theme	Positive progress if…	ENVIRONMENT			SOCIETY					ECONOMY	
			NATURAL RESOURCES		NATURAL ECOSYSTEM	HUMAN HEALTH & WELLBEING		SOCIAL EQUITY	CULTURAL HERITAGE		ECONOMIC STABILITY	ECONOMIC PROSPERITY
			G1[1]	G2[2]	G3[3]	G4[4]	G5[5]	G6[6]	G7[/]	G8[8]	G9[9]	G10[10]
Solid waste generation	Solid waste generation	↓	+	o	++	+	o	o	o	o	o	o
	Solid waste recycling	↑	++	o	++	+	o	o	o	o	o	o
Noise pollution	Noise pollution	↓	o	+	o	++	++	+	o	o	o	+
Safety & security	Road safety	↑	o	o	o	o	++	o	o	o	o	+
	Personal security	↑	o	o	o	o	++	o	o	o	o	+
Unequal access to basic services and infrastructure	Access to transport	↑	o	o	+	+	+	++	o	o	+	+
	Access to basic services	↑	o	o	+	+	+	++	o	o	+	+
	Barrier-freeness	↑	o	o	o	o	+	++	o	o	o	o

Note: Same as above (p. 132)

(Table 3.16 continues)

Common Problem area	Area of protection and related goal(s) / Common Theme	Positive progress if…	ENVIRONMENT			SOCIETY					ECONOMY	
			NATURAL RESOURCES		NATURAL ECOSYSTEM	HUMAN HEALTH & WELLBEING		SOCIAL EQUITY	CULTURAL HERITAGE		ECONOMIC RESILIENCE	ECONOMIC PROSPERITY
			G1[1]	G2[2]	G3[3]	G4[4]	G5[5]	G6[6]	G7[7]	G8[8]	G9[9]	G10[10]
Unaffordable and inadequate housing	Affordable housing	↑	o	o	o	o	+	++	o	o	++	++
	Adequate housing	↑	o	o	o	o	++	++	o	+	o	o

General note: same as above (p. 132)

[1]G1: Protection of **natural resources**/ Sustainable use and management of natural resources

[2]G2: Preservation of **biodiversity** (flora and fauna)

[3]G3: Protection of **natural ecosystems** from negative impacts from emissions and waste products on the local and global environment

[4]G4: Protection of **human health** from hazards and risks from man-made environmental pollution

[5]G5: Promotion of **human health and well-being** through improving the quality of life in the local area

[6]G6: Protection of **social equity** and reinforcement of inclusion and solidarity

[7]G7: Protection of the **built cultural environment**, **built heritage**, as well as **cultural values**

[8]G8: Protection of **aesthetic and urban development quality**

[9]G9: Preservation of the **economic structure and value** in the local area

[10]G10: Preservation and reinforcement of the **economic prosperity** of the residents and businesses in the area

3.3.3 Criteria for a Systematic Selection of Common Performance Indicators

Various indicators are typically available to represent specific problem areas or to assess the progress toward certain goals. Examining the existing indicator sets usually results in long lists of potential indicators per problem/subject area. Reducing the number of indicators to a manageable and optimal set inevitably requires that selection criteria are defined (Tanguay et al., 2010). The application of clear selection criteria encourages a more transparent and systematic selection process and ensures that only high-value indicators are finally selected to inform the subsequent decision-making processes (Niemeijer & De Groot, 2008). It also ensures that the subjectivity of the selection process is reduced, and the number and choice of indicators can be more easily validated.

For decades, various indicator quality criteria have been suggested as the desirable characteristics of indicators that are fit for this purpose (e.g. Maclaren, 1996; Hardi & Zdan, 1997; Kopfmüller, 2001; Niemeijer & De Groot, 2008). A review of 17 studies of the use of urban sustainable development indicators by Tanguay et al. (2010) revealed that the most dominant approach to devising indicators in social sciences is the SMART (i.e. Specific, Measurable, Achievable, Realistic and Time-bound) approach, first proposed by Schomacker (1997). The same authors concluded that the quality criteria most frequently mentioned as desirable are found under the following headings: “credible”, “universality”, “data requirements and availability”, “comprehensible”, “links with management” and “spatial and temporal scales of applicability”.

Based on these most widely acknowledged criteria, and the specific purpose of the present research to compile an indicator set to fit well with the overall proposed framework of goals and problem areas, eight quality criteria (QC) were used for the compilation of the *common performance indicator* set presented in Section 3.3.4. Among them, four QCs (specifically QC1, QC5, QC6 and QC8) can also be employed for the selection of context-specific performance indicators. Concerning the type of QCs comprising the set, these can be distinguished into scientific quality criteria (QC1 and QC2); functional quality criteria (QC3 and QC4); quality criteria from the point of view of users (QC5, QC6 and QC7); and pragmatic quality criteria (QC8).

RELEVANCE TO THE FRAMEWORK (QC1): Each indicator should have a strong link to at least one of the 10 protection goals of the conceptual framework. Furthermore, indicators should effectively integrate the different dimensions of sustainability, balancing to the greatest extent possible the environmental, economic and social aspects. Each indicator should also be well indicative (representative) of a given problem area and theme of the conceptual framework. However, “completeness” (in terms of covering the entire scope of each problem area and theme through the selected indicators) should not necessarily be striven for if the number of indicators is to be kept at a reasonable level. Up to two representative indicators for each identified theme are sufficient to stimulate action toward a certain direction. The purpose is to keep the assessment task as manageable as possible to dedicate more power to processing strategies and actions connected to each indicator (this becomes part of the indicator description and is explained in detail in Section 3.3.7).

METHODOLOGICAL DEVELOPMENT (QC2): Each indicator should be based on an internationally established methodology or standard. This is also one of the two main criteria used in the global indicator framework to classify indicators by tiers (see Section 2.2). This criterion is more likely to be satisfied if a similar indicator is also being used in other international or European indicator frameworks. This reinforces and is closely linked to the next criterion, QC3.

COMPATIBILITY (QC3): The use of a common indicator set across Europe requires that indicators are compatible between different neighbourhoods. This criterion is more likely to be fulfilled if the indicators selected are in accordance with the indicators found in systems/sets used by European or international organisations. However, an international system may not fit perfectly in Europe’s specific context. Furthermore, the indicators should emphasise common interests and concerns shared by European neighbourhoods to increase their applicability and acceptance across different contexts.

SCALABILITY (QC4): It is of key importance to find or develop indicators that are multiscale in the sense that they can be linked with corresponding indicators on the city level. In other words, the indicators should be broad enough to allow, with minor adjustments, a quantitative aggregation to a corresponding indicator on the city level. The importance of multiscale assessments has started being acknowledged by several researchers (Scholes et al., 2013; Zermoglio et al., 2005; Yigitcanlar et al., 2015). As Yigitcanlar et al. (2015) argue, while focusing on a specific scale provides invaluable insights, multiscale assessments are necessary for more effective political and decision-making processes. The present author supports the latter view and acknowledges that indicators operational for both neighbourhood and city scales can open up possibilities to feed "bottom-up" information from a neighbourhood scale, often being of "higher resolution" and based on data obtained from local stakeholder groups, upwards to a city scale to also test the accuracy of city total estimates. To put the latter concept differently, when an indicator is relevant for both neighbourhood and city scales, findings generated from the assessment of an adequate number of (representative) neighbourhoods within a city with this indicator (using the same protocols, and with the same units of measure) can then be aggregated upwards and translated with confidence into city scale. This of course presupposes that the scaling rules for the phenomena under assessment are well understood (Scholes et al., 2013).

DIRECTIONAL CERTAINTY (QC5): Each indicator should be easily interpreted, with no uncertainty about the direction the indicator should move to signify progress toward sustainability. Indicators providing ambiguous signals (if it is not clear how to interpret them – e.g. an increase in the indicator value) are not considered suitable. This criterion is essential for both common and context-specific indicators.

POSSIBILITY TO SET TARGETS (QC6): For an indicator, it must be possible to formulate one or more targets, either in the form of a quantified end value or a directional target (specifying the direction of change in qualitative terms – many times, criterion QC5 is sufficient for this purpose). The definition of targets for indicators in a scientific as well as socio-political context is primarily necessary for three reasons: they form reference lines from which measured indicator values can be evaluated in terms of comparisons between the targets and the actual situations; they serve politicians as an orientation for the detailed design of measures; and they serve social actors as guidelines for their actions. Initially, as a source for the determination of such targets, politically determined target values are to be used. If such values do not exist, socio-political or scientific debates (and practices in other countries, cities or neighbourhoods) can serve as orientation.

POLITICAL RELEVANCE (QC7): Each indicator should be consistent with significant sustainability-related policy goals, standards or commitments already in existence at different levels of urban planning. Therefore, in addition being relevant to the specific sustainability goals comprising the conceptual framework, they should also have a strong link to inspiring, strategic and high-level goals corresponding to current global visions for a sustainable world (i.e. SDGs).

DATA AVAILABILITY (QC8): Data for each indicator (or methods to obtain the data) should be easily available and of sufficient quality. Keeping the data-collection process affordable, as well as limited in time and effort, is important, and therefore, indicators should be based on data that either: a) are available from the project team or other stakeholders directly involved in the planning process; b) can be easily compiled from public data sources; or c) can be easily collected from interviews with key stakeholders, intercept surveys or household self-completion surveys (e.g. via online survey tools), maps and on-site observations. Indicators that require, for instance, extensive or in-depth household personal interviews are not suitable as they usually are too expensive and time consuming to undertake (of course, it is assumed that a participatory process of SUD, as the one proposed in the *process framework*, would stimulate the voluntary provision of personal data through, for example, online surveys). The same applies to indicators that require extensive recalculations and very detailed data for their assessment, such as footprint-type (or consumption) indicators. The proposed indicator set contains, however, some footprint-type or consumption-based indicators that are expected to become common in the near future (i.e. material consumption). Additionally, indicators evaluated as being of very high relevance (for example, they touch upon topics that are high on the political agenda), but for which data availability at the moment is insufficient, have not been precluded from the set. They remain on the list as “aspirational” indicators for consideration when the data situation changes. The aim for their inclusion is also to point out to politicians or even statistical authorities that the use of such indicators requires an improvement of the corresponding data.

While an ideal indicator will meet all the criteria listed above, in reality this is often not the case. Rather, the quality criteria noted above are meant to act as a guide against which indicators can be evaluated during the indicator selection process to ensure that only the “strongest” indicators from the ones identified appear on the final indicator set. However, QC1 and QC5 are seen as essential quality criteria in the context of this thesis, such that indicators failing to fully satisfy either of them have been excluded. In other words, QC1 and QC5 have been used as “one-out-all-out” criteria.

In addition to the application of quality criteria in the selection of indicators, another possibility of reducing the number of indicators is the index formation. This can be illustrated by the example of Goal 4 (“Protection of human health from hazards and risks from man-made environmental pollution”) and the respective problem area ‘air pollution’. In this case, for example, the aggregation of air emissions is possible for an ‘air pollution’ index. This could summarise up to six single indicators (i.e. NO_2, SO_2, O_3, CO, PM10 and PM2.5) with an index. In addition to a reduction in the number of indicators, this would also mean better communicability of the indicator set. However, with an index synthesis, important information may be neglected or masked in overall findings, in this case with regard to the exact substance-related causes of increased pollution and resulting need for action. This can lead to wasted effort taken for inappropriate action. Therefore, although the present author is not against the use of indices when supplemented with information on the individual indicators (i.e. in the form of a detailed annex), in the context of the thesis, the focus was to select the simplest indicators possible.

Along with the consideration of the above-noted criteria, care has also been taken that the different indicators selected are as independent as possible to avoid excessive overlapping. This is an additional consideration that helps to keep the number of indicators at a reasonable level. Overlapping and double-counting per se are not concerns if the different indicators are not aggregated into indices and are assessed independently, which is the recommendation in the context of an action-oriented indicator set, as the one proposed here. It is often useful, or even necessary, to examine an issue from different perspectives (and consequently with the use of different indicators with overlapping content) to get an understanding of its causes or basis. This is essential in the context of an action-oriented approach.

3.3.4 Most Promising Indicator Sources, according to the Selection Criteria

One does not need to break new ground with the formation and selection of indicators but can rely on already existing urban sustainability indicator systems and sets. The "setting the scene" part of the thesis gave a comprehensive overview of the numerous systems and sets, some focusing on the neighbourhood level and others constituting important international initiatives on a city-scale, out of which suitable indicators can be selected. A lack of indicators and data can no longer be used as a pretext for no or delayed action toward sustainable urban development by city governments.

To construct an effective set of common performance indicators according to the selection criteria identified in the previous section, three sources were mainly used: the two fundamental sources also used for identification of the problem areas and themes, namely the global indicator framework for Sustainable Development Goals (SDGs), and the EU SDG indicator set, and the ISO/FDIS 37120 (previously ISO 37120:2014).

The selection of the two SDG-linked documents for sourcing indicators automatically ensures high levels of compatibility and political relevance (as per QR3 and QR7). In other words, it is ensured that that the indicators selected underpin (to the greatest extent possible) the shared global vision for change behind the SDGs. The idea behind screening the global and European SDG indicator sets was not to simply copy them over and use them at the neighbourhood level. Many indicators cover issues that are irrelevant for the neighbourhood scale, and therefore critical evaluation of which of the issues covered by the indicators assigned to each of the targets identified as related (as shown in Table 3.5) can be translated into neighbourhood-scale indicators. From the analysis of the global indicator framework, only five out of 232 indicators were found appropriate for adjustment and down-scaling to the neighbourhood scale, while the analysis of the respective EU framework revealed additional highly relevant indicators for issues not covered in the global framework.

In parallel, ISO/FDIS 37120 was used as a source of city-level indicators with an international orientation likely to influence or even be integrated into future city-, district- and neighbourhood-level assessment systems, and therefore also satisfying the criterion of compatibility (QC3). Additionally, it was chosen as a source more closely compatible to the neighbourhood scale compared to the two SDG-based frameworks. Using ISO/FDIS 37120 as a standardised set of indicators is more likely to satisfy the criterion of methodological development (QC2). Finally, using indicators conceptually related to the ones found in an international city-level standard on a local level provide greater potential to satisfy the criterion of scalability (QC4).

It turned out, however, that in some cases, it was necessary to use additional sources or formulate new indicators in order to adequately reflect the proposed themes. Additional sources screened for appropriate indicators were the EU FP7 project FASUDIR (Friendly and Affordable Sustainable Urban Districts Retrofitting) (Zukowska et al., 2014) and the smart-city performance measurement framework CITYkeys (Bosch et al., 2017). Both projects are relatively recent and were designed to serve the European reality; finally, their indicator sets were conceptually based and resulted from extensive reviews of other urban sustainability systems, sets and initiatives as well as collaborative work between different research institutes and municipalities across Europe. Although not widely applied, these characteristics make them an interesting source of indicators.

3.3.5 A Common Performance Indicator Set

Based on the above considerations, Figure 3.10 shows the set of common performance indicators selected for representing the common sustainability themes and problem areas discussed in the previous sections. The intention of providing such a set is not prescriptive, but illustrative – namely, to indicatively suggest a limited number of indicators that can serve as a starting point. In some cases, common performance indicators are broken down into sub-indicators to be more specific and lead to a more effective identification of strategies.

As one may notice, the indicators included in the proposed indicator set are all quantitative and primarily objective (in terms of the way the information is collected). Yet, in general, using objective indicators alone is not sufficient to understand people's perceptions and thoughts. A narrow focus on what can only be measured more readily and objectively should be avoided. For example, with regard to the common theme “personal security”, both an objective and a subjective indicator are included in the framework. A low burglary rate in a neighbourhood is neither always correlated to an increased feeling of safety nor these two indicators always lead to the same set of actions. While property crime can be fought through an increased surveillance, the feeling of safety can also be strengthened through an increased involvement in community activities along practical measures against crime.

Although subjective indicators typically require surveys, and therefore an extra investment in time and effort, are valuable as a supplement to today’s emphasis on objective data. Subjective experiences of one’s life in the neighbourhood, if combined with objective data, can lead to more definitive conclusions regarding a certain theme, and in certain cases can also reveal new information on problems and circumstances that cannot be captured with objective indicators. Other themes where objective and subjective data can be meaningfully combined are the “noise pollution” and “access to public transport”.

For example, the “percentage of persons in the neighbourhood affected by noise pollution” can be, on the one hand, objectively defined through on-site measurements of Lden (day-evening-night sound level) according to ISO 1996-2 (ISO, 1987) (this is the method recommended by ISO/FDIS 37120 (ISO, 2017)), and on the other hand, subjectively defined through the carrying out of socio-acoustic surveys and social surveys which include questions on noise effects according to ISO/TS 15666 (ISO, 2003) (this is the method recommended by the EU SDG indicator framework (European Commission & Eurostat, 2017). The same applies to the case of “percentage of residents with convenient access to public transport”: it can be objectively determined as the percentage residents living within a certain distance of public transit running at frequent time intervals (again, ISO/FDIS 37120 (ISO, 2017) shows preference to the objective approach), whereas it can be subjectively determined as the share of residents reporting low or very low level of difficulty in accessing public transport (once more, the EU SDG indicator framework (European Commission & Eurostat, 2017) follows the subjective approach).

Furthermore, one may observe in Figure 3.10 that the set includes indicators describing material and waste flows where data are available only for a few neighbourhoods. In view of the high relevance of these indicators, and to encourage neighbourhoods (or city municipalities) to initiate data production, the author considered that they should remain in the set of common performance indicators. Therefore, the set also contains indicators expected to have poor data availability. For other neighbourhoods (or cities), the list of common performance indicators could provide an incentive for starting to produce the necessary data on a regular basis.

One recommendation for neighbourhoods interested in applying such an indicator set is to go beyond the functional and thematic systematisation proposed here and also systemise the set by means of a three-tier approach similar to the one used for the classification of global SDG indicators (see Section 2.2). In this way, these indicators are kept among the set while at the same time, the various degrees of their practical maturity are identified. The author did not attempt to pursue this, because data availability greatly depends on local circumstances and therefore can be heterogeneous across neighbourhoods. In other words, attempting to classify the indicators into the three tiers would be counterproductive and misleading.

The absence of possibilities to obtain data in the desired quality, desired spatial delimitation or for the desired time/period is a very practical and common problem faced by neighbourhoods, and one that requires continually adjusting the application of indicator sets. Recognising this problem, the present thesis suggests, where possible, to propose substitute indicators until appropriate data or methods become available, as part of the indicator description. This is touched upon in the following section (3.3.7), together with other aspects.

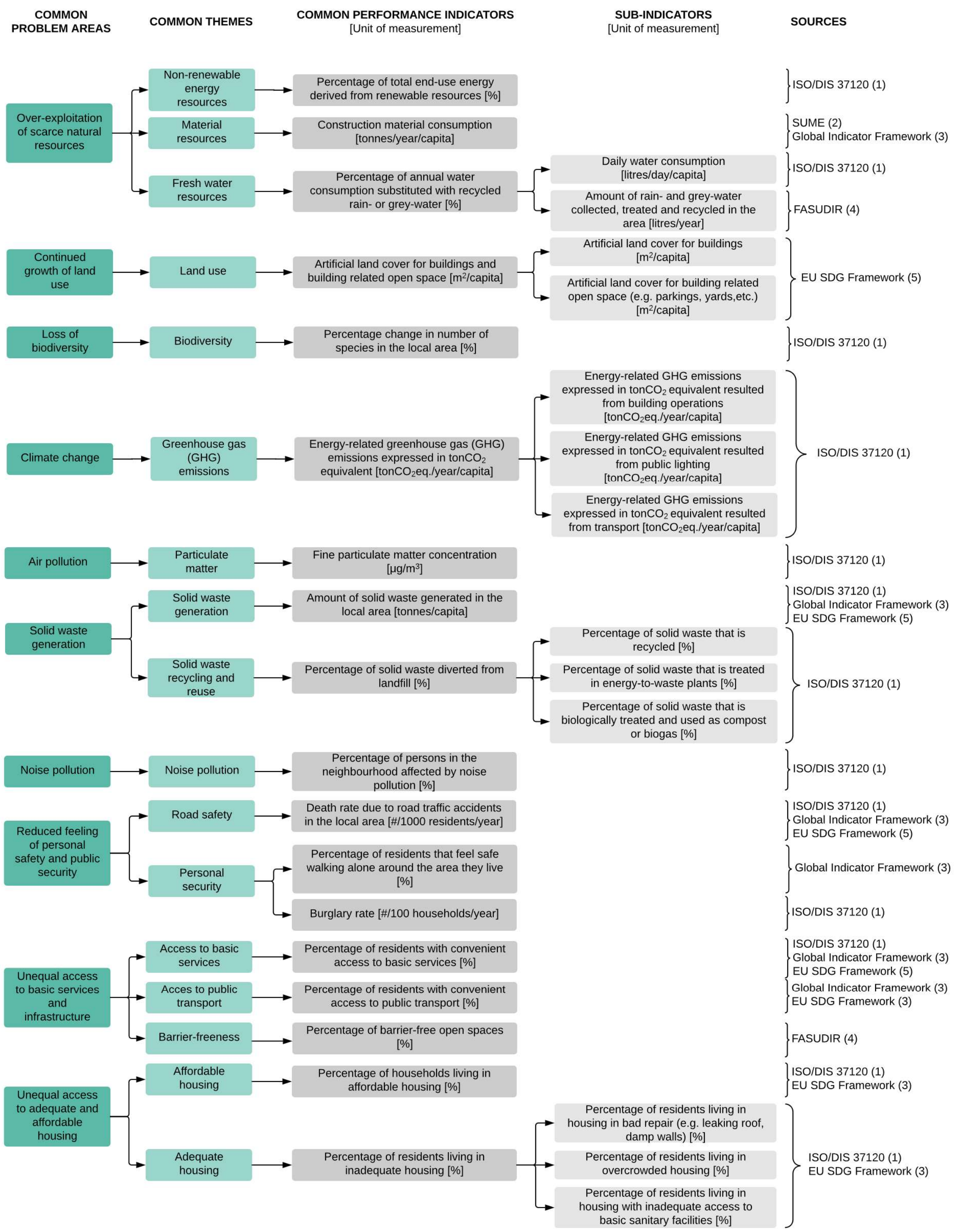


Figure 3.10. The set of common performance indicators (and sub-indicators) (Source: Present author). Note: The sources where conceptually identical or related indicators can be found are also indicated, where: (1) ISO (2017); (2) Schremmer & Stead (2009); (3) UN (2018); (4) Zukowska et al. (2014); (5) European Commission & Eurostat (2017).

3.3.6 A Background Indicator Set

Whereas performance indicators are valuable for pointing out where more efforts are needed to achieve the desired status, they are not likely to provide information about why this is the case. To give context to performance values (among other reasons earlier described in Section 3.3.1), the employment of background indicators – here in the sense of unassessed background information – is necessary. A set of such indicators is depicted in Figure 3.12, where the background indicators are categorised into eight themes: (1) Population and social conditions, (2) Economy, (3) Education, (4) Housing and building conditions, (5) Urban design (6) Transport habits, (7) Climate conditions (8) Cultural heritage.

The aspect of *population and social conditions* refers to the demography, migration, concentrations of poverty and income inequality in the neighbourhood. These indicators mainly reveal the diversity and heterogeneity of the resident population in the area and may be indicative of social exclusion (e.g. in the case of high levels of income inequality) and social deterioration (e.g. in the case of significant poverty concentrations), the character of the neighbourhood (e.g. quiet and family-oriented, busy and student-oriented, etc.), and therefore the particular needs of its population, as well as its potential future needs on expansion (e.g. population increases and high numbers of students may potentially have implications on future urban planning and housing needs).

The aspect of *economy* examines the unemployment and full employment rates, number of businesses located in the neighbourhood, and average household income. These factors give insight into the level and diversity of economic activity in a neighbourhood. They may reveal future needs on transforming the character of the neighbourhood into more dynamic and mixed-use or the need for social housing to accommodate low-income families. Furthermore, the financial situation of residents may also be indicative of the “adequacy” of the housing conditions or a potential unwillingness to undertake energy-efficient renovations without sufficient financial subsidies.

With regard to *education*, the level of education of a neighbourhood's residents may be indicative of their overall well-being and financial situation. However, just defining the level of education cannot provide sufficient insight into the level of awareness of environmental problems and therefore the potential support the environmental projects may receive. For this reason, the inclusion of a background indicator specific to sustainability knowledge (see Figure 3.12) is considered necessary. Assuming that during a SUD project more people will become aware of sustainability matters, this can also function as a performance indicator. Furthermore, a digital skills indicator is taken into consideration, which is useful to detect whether there are significant concentrations of digital exclusion in a neighbourhood. Indeed, also Europe has a recently develop digital skills indicator (European Commission, 2016), but it is not part of the EU SDG Indicator framework (European Commission & Eurostat, 2017). As in the previous case, this indicator can also be addressed as a performance indicator, because possibilities for action on the neighbourhood level exist.

As far as the *housing and building condition* is concerned, this aspect on the one hand provides indications on the housing conditions. For example, information on the persons per unit or living space per person provide indications on whether there are crowded or underutilized living spaces within the neighbourhood. On the other hand, indicators such as vacancy rate provide insights into current and future housing needs of the neighbourhood. While a low vacancy rate indicates a shortage of dwellings and an upward pressure on house prices, a high vacancy rate may be an indication of a decline in housing demand and indirectly of the attractiveness of the neighbourhood. Alternatively, it shows a mismatch between housing supply and demand.

With regard to building conditions, proper knowledge of the age of buildings in a neighbourhood is fundamental to interpreting the results of several of the selected common performance indicators. For example, building age can provide valuable insights into the energy efficiency of the building stock (which influences the sub-indicator dealing with the energy-related GHG emissions from building operations), as well as its overall condition (e.g. in relation to the indicator "percentage of residents living in inadequate housing”). The average building age can be combined with an indicator showing the renovation potential; the percentage of buildings built before the 1970s. This period marks the time around which stricter insulation requirements started being introduced in Europe.

With regard to *climate conditions* and *cultural heritage*, aspects such as mean near surface temperature in cold and warm months or the number of historic and heritage buildings clearly affect the efforts on increasing the energy efficiency of the building stock in the neighbourhood. The first aspect is indicative of the level of energy demand for cooling and heating purposes in the neighbourhood and the second aspect constitutes a challenging factor for achieving high levels of energy efficiency in the area; historic buildings require special energy efficiency solutions that are sympathetic to their historic character.


BACKGROUND THEME
BACKGROUND SUB-THEMES
BACKGROUND INDICATORS [Unit of measurement]
SUB-INDICATORS [Unit of measurement]
SOURCES
Population and social conditions
Social conditions
Percentage of residents living below the national poverty line [%]
ISO/DIS 37120 (1)
Global Indicator Framework (3)
EU SDG Framework (5)
Percentage of residents living below 50 per cent of the national median income [%]
Global Indicator Framework (3)
Gini co-efficient of inequality [-]
ISO/DIS 37120 (1)
Demographics
Annual population change [%]
Birth/deaths
Migration flow
ISO/DIS 37120 (1)
Percentage of residents per age category and gender [%]
Percentage of residents that are foreign born [%]
Percentage of residents that are new immigrants [%]
Number of university students per 1000 residents [#]
ISO/DIS 37120 (1)
Economy
Bussiness structure
Number of business per 1000 residents [#]
Financial situation of residents
Average household income [€]
ISO/DIS 37120 (1)
Unempoyment rate per age and gender category [%]
ISO/DIS 37120 (1)
Global Indicator Framework (3)
EU SDG Framework (5)
Percentage of persons in full time employment per age and gender category [%]
ISO/DIS 37120 (1)
Education
General educational level
Number of higher education degrees per 1000 residents [#]
ISO/DIS 37120 (1)
EU SDG Framework (5)
Financial situation of residents
Percentage of residents with digital skills per age category [%]
Global Indicator Framework (3)
CITYKeys (6)
Percentage of residents with sustainbility knowledge per age category [%]
CITYKeys (6)
Housing and building conditions
Housing conditions
Total number of households [#]
Number of persons per dwelling [# persons per dwelling]
Living space per person [m²/person]
Ownership and vacancy
Percentage of vacant dwelling units [%]
Rental dwelling units as a percentage of total dwelling units [%]
ISO/DIS 37120 (1)
Building stock age
Average residential building age [#]
Residential buildings built before 1970 as a percentage of total residential building stock [%]
Present author
Urban design
Density
Population density [#]
ISO/DIS 37120 (1)
Parking places
Number of parking places [#/capita]
Number of on-street parking places per capita [#/capita]
Number of indoor/off-street parking places per capita [#/capita]
FASUDIR (4)

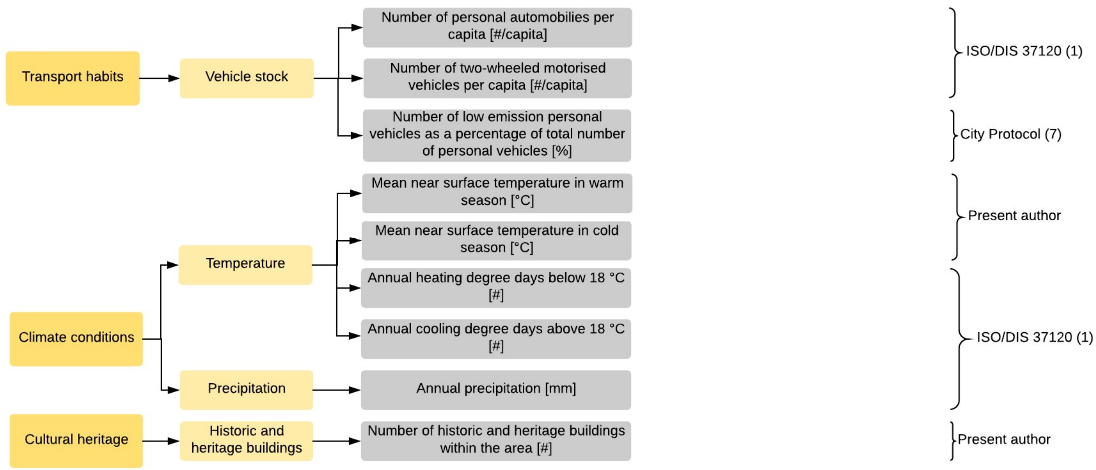


Figure 3.11. The set of background indicators (and sub-indicators) (Source: Present author). Note: The sources where conceptually identical or related indicators can be found are also indicated, where: (1) ISO (2017); (2) Schremmer & Stead (2009); (3) UN (2018); (4) Zukowska et al. (2014); (5) European Commission & Eurostat (2017); (6) Bosch et al. (2017); (7) City Protocol Society (2015).

3.3.7 Development of a Three-part Fact Sheet to Describe Indicators

The final list of common performance indicators and context-specific indicators that best suits the neighbourhood's characteristics can only be acknowledged and widely accepted if the indicators are first clearly and precisely described. The development of a "fact sheet" for each individual indicator that contains all necessary fields and presents available information in a unique template is necessary.

The present author composed such a fact sheet to serve three purposes critical to the success of different steps in the process (see Section 3.2): first, to optimise the assessment process and information management by identifying alternative information sources and/or measurement/calculation procedures as well as listing all possible data requirements and sources, together with their providers. This purpose is covered by "Part A" of the following proposal for a fact sheet and is useful for the diagnostic step (i.e. Step 2.4, "Make a diagnosis of the current situation").

The second purpose is to provide the possibility to document the actual output of the diagnosis (baseline value) and assess the result against established target values. This is covered by “Part B” of the fact sheet and is useful for documenting the baseline value obtained in Step 2.4 following the advice provided in Part A of the fact sheet, along the specific BaU scenarios and target values specified in Step 2.5 (“Generate business-as-usual scenarios and specify key issues”) and Step 2.6 (“Target-setting”). It is also useful for reporting the roadmap of actions chosen to achieve the specified targets, and therefore the results of Step 3.3 (“Decide on actions to be implemented”) This is more of a worksheet than a fact sheet, and only its form can be generalised. The input represents specific data of actual neighbourhoods.

The third and last purpose is to identify strategies that can stimulate progress in the specific area the indicator addresses and analyse these strategies according to: (1) the implementing individuals or groups of stakeholders (also denoted as “active/acting” stakeholders); (2) their options/opportunities for action under this strategy; (3) the individuals or groups of stakeholders affected by decisions and/or actions of active stakeholders (also denoted as “passive/affected” stakeholders)[7]. To put it differently, this fact sheet, besides guiding the measurement (or calculation depending on the case) and data-collection process, also intends to establish an initial informational basis to orient the action-planning process. This constitutes a new, enlarged approach to describing indicators and is represented by “Part C” of the fact sheet that is the practical output of Step 3.1 (“Analyse alternative strategies and actions”). The approach is enlarged in the sense that it does not only cover calculation and assessment-related aspects of an indicator (as is usually the case with existing indicator frameworks), but also action- and actor-related components.

To summarise, an enlarged “indicator fact sheet” therefore consists of the following parts (also depicted in Figure 3.12):

[7] The categorisation between active and passive stakeholders was first introduced by Grimble and Wellard (1997).

Part A: *General description and classification of the indicator*, including specifications for its measurement/calculation.

Part B: *Indicator worksheet and roadmap*, which represents a case-specific living document.

Part C: *Strategies*, including relevant stakeholders and possible actions to stimulate progress in the area the indicator addresses.

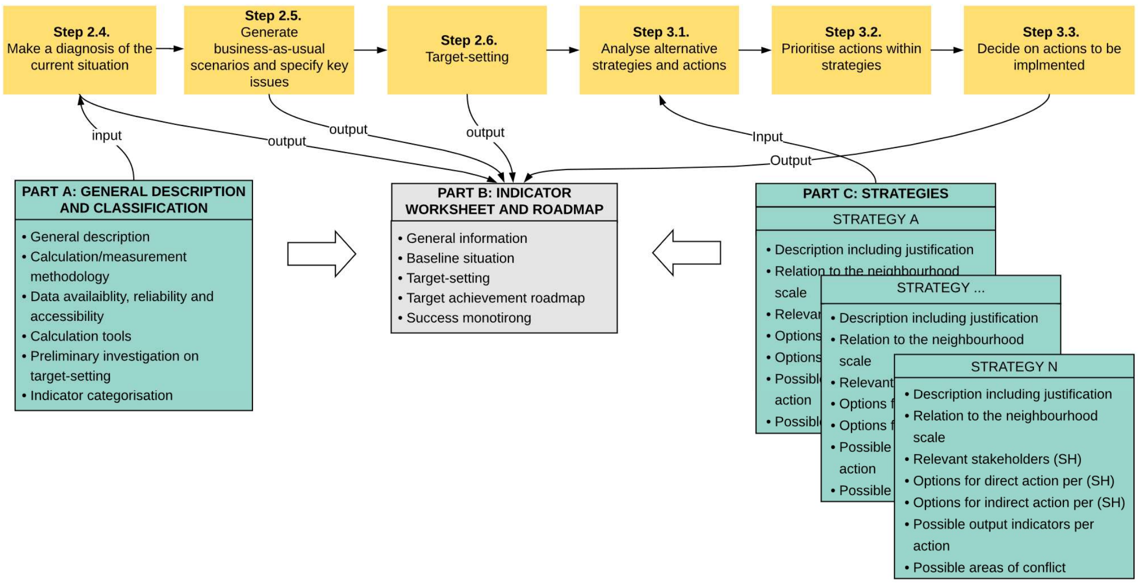


Figure 3.12. The three-part fact sheet and its relation to selected steps of the process framework (Source: Present author).

3.3.7.1 Part A: General Description and Classification of an Indicator

In short, Part A starts with the general description of the indicator, which is followed by all necessary information on how to measure/calculate it (Table 3.17). These two components of Part A constitute key pieces of information typically found in the description of an indicator. Following this, the focus shifts to the provision of detailed information on expected data availability, reliability and accessibility, a less commonly found analysis in the different indicator frameworks, but still an approach employed by a fair number of them.

(A good example of an indicator framework with detailed information on data requirements analyses is the European project CITYkeys (Bosch et al., 2017)). Usually, the more sophisticated an indicator is and the greater the number of (problem) source points the indicator is assigned to, the more complex the calculation procedure and the larger an amount of data the indicator requires. To this end, the provision of simple and clear information in an organised way is necessary to guide the core or action team in the diagnosing step.

An additional element under the data-related field of the fact sheet is the possibility to identify substitute indicators to be temporarily used instead of the indicator under investigation in case good-quality data are not available or accessible (row A.11 of Table 3.17). Often, it is hard to directly use a selected indicator due to missing or insufficient (in terms of quality) data. This is a common problem in urban development endeavours. If, however, several indicators exist that can be used to describe the same theme, the temporal replacement of an otherwise highly suitable and representative indicator for this theme, with indicators lower in relevance and suitability but still likely to lead to right conclusions about the actual state, is seen as more appropriate than not addressing a theme at all.

For example, the energetic quality of residential buildings (criterion) can be described and assessed in several ways – namely, in terms of the energy demand, energy consumption and specifications for envelope and building services. As noted in the description of QC8 (Section 3.3.3), none of the common performance indicators should be rejected if data for it are not available in an accurate and timely fashion. Rather, this should form the basis for identifying data and capacity gaps to guide the design of data generation and collection strategies, while substitute indicators are used in the meantime.

Part A also includes a field dedicated to the provision of necessary preliminary information to form the informational basis upon which the two subsequent steps in the process can be built: Step 2.5 ("Generate business-as-usual scenarios and specify key issues") and Step 2.6 ("Target-setting"). The intention is to identify any existing target that may help and motivate the decision makers to set ambitious targets themselves for a neighbourhood. Identified targets may range from high-level targets (i.e. Europe-wide, national or regional targets) to lower-level targets, such as targets from comparable cities or neighbourhoods. While working on an indicator, though, it may be decided that the precise determination of a target value is not possible or useful for the time being. This information module is still meaningful, since the existence of targets on a certain topic and on different policy levels directly suggests the political relevance and importance of the topic. Again, a novel element here is the possibility to identify all the critical external factors/variables that, if significantly changed by the target year, will influence the level of the indicator. With the precondition of data availability, these variables should be considered in the BaU scenarios, along with internal factors (i.e. ongoing policy actions driven by the city) that can only be defined on a case-to-case basis.

Finally, Part A ends with a clear and in-depth categorisation and characterisation of the indicator on the basis of its strengths and weaknesses in relation to quality criteria (QC) (earlier shown in Section 3.3.3), their placement in the indicator set with regard to selected AoPs and goals (Table 3.3 in section 3.3.1.2), as well as their interaction with other indicators. Further, it was considered important to link indicators to other widely used conceptual frameworks, such as the PSR or DPSIR framework (here, the DPSIR has been selected), as well as the global SDG vision. Particularly with regard to the latter, to the present author's knowledge, there is no framework placing its indicators within the UN SDG framework (the goals and their targets) in a systematic way, except ISO 37120 in the recently published report by WCCD (2017). The present approach was developed independently from ISO's approach.

Table 3.17. Part A: General description and classification of an indicator (Source: Present author)

Indicator name Problem area/Theme:		**Name of the indicator** *The problem area and criterion to which the indicator is assigned.*
GENERAL DESCRIPTION		
A.01	Definition	*A brief explanation of this indicator*
A.02	Description including justification	*A detailed description of the indicator and reasoning or logic for having the indicator*
CALCULATION/MEASUREMENT METHODOLOGY		
A.03	Object of assessment (system boundaries)	*Short text further characterising the object of assessment, including information on the system boundaries*
A.04	Calculation methodology or rule	*Does the indicator come from a standardised methodology, and if yes, which one? Indication on the methodology or rule whereby the indicator is/should be calculated and a detailed description of the necessary variables for its calculation.*
A.05	Measured parameters and related units	*Are there any parameters directly measured, and in what unit of measurement are they recorded?*
A.06	Reference unit	*What reference unit(s) is used?*
DATA AVAILABILITY, RELIABILITY & ACCESSIBILITY		
A.07	Data requirements	*What kind of data is needed?*
A.08	Data availability and providers	*Where can data for this indicator be located/ found?*
A.09	Expected reliability	*Is the data available expected to be reliable?*
A.10	Expected accessibility	*Is the data available expected to be accessible?*
A.11	Substitute data and indicators	*Are there any possible substitute indicators in case good-quality data are not available or accessible?*
CALCULATION TOOLS		
A.12	Calculation and assessment tools	*Reference to specific questionnaire/survey techniques for qualitative indicators, or calculation software and tools for quantitative indicators.*
PRELIMINARY INVESTIGATION ON TARGET-SETTING		
A.13	Desired direction of change	*Is an increase or decrease in the indicator value interpreted as a desired direction of change?*
A.14	Target value	*Are there any general or specific target values?*
A.15	Key factors for projections	*Which background information and/or national developments are/can/should be used for the generation of the business-as-usual scenarios?*

(Table 3.17 continues)

INDICATOR CATEGORISATION		
A.16	Strengths and weaknesses	*What are the strengths and weaknesses of the indicator in relation to the quality criteria (QC) used for selecting indicators?*
A.17	Application cases	*Is this indicator suitable only for specific application cases, or does it apply to all types of neighbourhoods?*
A.18	Indicator type	*Qualitative or quantitative?* *Core performance indicator or context-specific indicator?*
A.19	Placement in the DPSIR framework	*Where is this indicator placed within the DPSIR framework?*
A.20	Placement in the SDG framework	*Where is the indicator placed within the SDG framework (with regard to its 11 goals and 169 targets)?*
A.21	Placement in the indicator set	*Where is this indicator placed within the indicator set (with regard to AoPs, goals and SD dimensions)?*
A.22	Interactions with other indicators	*Is it expected that the indicator interacts with other indicators, either synergistically or antagonistically?*
DATA AND INTERPRETATION…*What is the baseline value of the indicator, what is its target(s), and what are the planned actions selected to achieve this target(s)?* PART B ▶		
STRATEGIES …*What are the available strategies and (direct and indirect) actions per stakeholder to achieve progress in the area this indicator addresses?* PART C ▶		

3.3.7.2 Part B: Indicator Worksheet and Road map

Part B is intended for use in a specific neighbourhood-development project as a dynamic work and documentation sheet (i.e. living document), and not as an informative or instructive fact sheet, as it is the case for Part A and Part C. This part mainly brings together and visualises the actual outputs of a number of steps of the planning phase (Table 3.18). In particular, this living document aims to:

(1) Report the baseline state of the neighbourhood, which is mainly the result of the indicator calculation/measurement as part of Step 2.4.

(2) Report the agreed-upon targets to be achieved (if any), as well as assessing and visualising (in a diagram, ideally) the current distance to

target. This mainly involves reporting the outputs of Step 2.5 and Step 2.6.

(3) Describe a preliminary road map of actions for the achievement of each target. This activity is informed by the wisdom obtained in Steps 3.1, 3.2 and 3.3., but its results can be finally used as an input in Step 3.4.

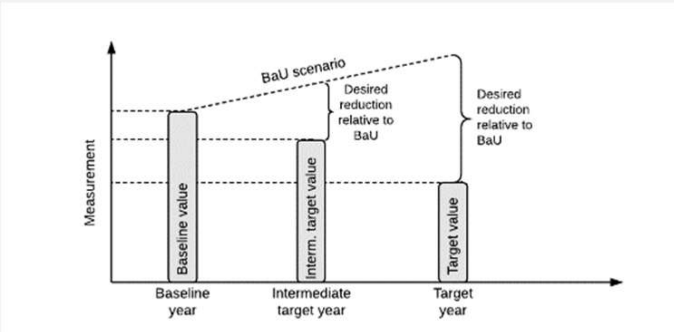
(4) Report the periodicity of data collection, measurement and assessment agreed upon, so as to monitor success with regard to whether the predefined target(s) is on track for fulfilment.

This is called a living document, not only in the sense that information can be added as one encounters it along the SUD process, but one can also revisit input at the points in time the success control is performed and adjust the target achievement path, or the target(s) itself, if judged unrealistic.

Table 3.18. Part B: Indicator worksheet and road map (Source: Present author).

Indicator name Problem area/Theme:		**Name of the indicator** *The problem area and theme to which the indicator is assigned.*
GENERAL INFORMATION		
B.01	Short name of the neighbourhood under investigation	*Name of the specific neighbourhood whose initial state is to be determined and whose development is to be assessed.*
B.02	Relation pf the topic/indicator to the topic specific development goals of the neighbourhood	*Indication of linkage to development priorities and goals of the specific neighbourhood.*
BASELINE SITUATION		
B.03	Baseline value/situation and baseline year	*Specification of qualitative and/or quantitative information to characterise the initial/actual status in the specific neighbourhood.*
B.04	Data situation/data sources in the specific neighbourhood	*Evaluation of the general data situation and information in the specific neighbourhood. On what data was the derivation of the baseline value based? Is there any need to build structures to better fulfil the data requirements for the next assessment cycles?*

(Table 3.18 continues)

TARGET-SETTING		
B.05	Desired direction of change	*(Qualitative) Specification of the target direction, taking into account the information in **A.13** ("increase", "stability", "decrease")*
B.06	Target year(s)	*Specification of a target year or period (and/or intermediate target years/periods)*
B.07	External and internal factors in BaU scenario(s)	*The developments of which external and internal factors have been considered in the generation of the BaU scenario(s)?*
B.08	Projected BaU scenario(s) in the target year	*How is the status in the specific neighbourhood expected to evolve to the target year if no action is taken to achieve progress?*
B.09	Target value, incl. intermediate targets (as applicable)	*Specification of a target value to be attained by the target year specified in **B.06** (and/or intermediate target values) as far as possible and reasonable. Alternatively, if no target value can be specified, a rate of change (annual or of a longer timeframe) can be given here.*
B.10	Data visualisation	*Translation of B.03 and B.05-B.09 into a diagram (example below)* 
TARGET ACHIEVEMENT ROADMAP		
B.11	Proposed/planned action to achieve the target(s)	*Presentation of information on the selected actions for the achievement of each target (milestone), the active/affected stakeholders involved for each action in the form of an easy-to-understand timeline or Gantt chart if possible.*
SUCCESS MONITORING		
B.12	Periodicity of measurement/ calculation and assessment	*Presentation of a plan on how often the indicator should be measured/calculated to assess whether the predefined target(s) is on track for fulfilment.*
STRATEGIES …*What are the available strategies and (direct and indirect) actions per stakeholder to achieve progress in the area this indicator addresses?* PART C ▶		

3.3.7.3 Part C: Strategies

Typical fact sheets on indicators focus on their descriptions. This is completely sufficient for a purely assessment-based approach. However, an action-guided approach requires supplementing information on the actors involved and their options for action, as well as the stakeholders potentially affected by each option. This will be introduced below as a suggestion and contribution to the current discussion.

For an indicator, there are as many "Part Cs" as the number of the strategies that can be employed for achieving progress in the area the indicator addresses. Similar to the other parts, Part C (Table 3.19) starts with the provision of general information on the strategy, also providing the possibility to specify whether there are opportunities for "scaling up" a strategy at a city level. Often, neighbourhoods are used as testing grounds for the application of alternative methods and solutions before trying to actually solve a city-wide problem.

Following this, the focus shifts to the most important component of Part C, the actor- and action-specific analysis of the indicator. The initial step is to identify all key stakeholders that could actively influence (i.e. active stakeholders) or be affected by (i.e. passive stakeholders) the implementation of the potential actions constituting the strategy. The importance of investigating the active stakeholders per each strategy is self-evident in the context of an action-oriented approach. In the case of passive/affected stakeholders, their proactive consideration is essential, not only from an ethical point of view (i.e. a social equity) but also from a strategic point of view, since if ignored, they may shift from "passive" to "active" by mobilising themselves and collectively opposing a decision against their interests (Gustavsson & Elander, 2016). On the other hand, they can become "active" in a positive way by using the provided infrastructures in a sustainable way.

"Direct possibilities to act" include all the actions associated with the strategy that are in the direct control of each key active stakeholder, while "indirect possibilities to act" include all the actions associated with the strategy that can only be indirectly influenced by each key active stakeholder. For instance, although the "city authority" is an important implementing agency, especially when it comes to the provision of the necessary infrastructure, it does not have a central role in every single field of action, and its power is often restricted to just motivating and stimulating private actors to act through tambourines (information and training), carrots (financial incentives) or sticks (regulatory actions) (Azevedo et al., 2013). Whether regulatory actions are considered "direct" or "indirect" actions depend on the level of their enforcement. Within the context of the present thesis, actions are classified as "direct". All these considerations lead to the classification of actions shown in Figure 3.13, to be utilised in Part C (under C.04 and C.05). Additionally, the possibility to already have a defined list of potential output indicators for direct and indirect action is important to provide the necessary basis for monitoring their future implementations, if chosen.

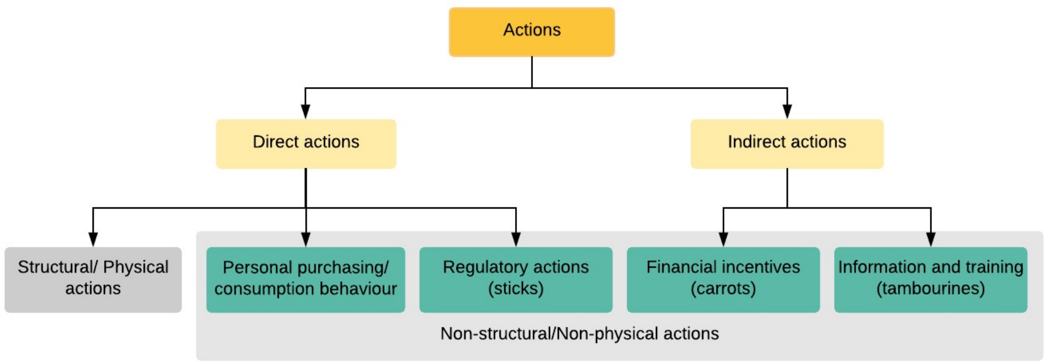


Figure 3.13. Classification of actions (Source: Present author)

Part C also includes an analysis of all potential conflict and tension situations that may arise in relation to the strategy. Conflicts may arise between two competing interests (e.g. public vs private interests), often called "conflict of interest", or between two targets/aspects (e.g. the pursuit of one strategy/action may constrain, counteract or even make impossible the implementation of another). To make the best decision on how to deal with an action, one should know about any competing interests or targets that may have to be faced, as it makes it possible to proactively create strategies to eradicate them.

It is argued that Part C-like analyses are very useful for generating awareness and understanding of the general possibilities for action, which naturally leads to obtaining acceptance and acquiring competencies for applying the chosen strategies.

Table 3.19. Part C: Strategies (Source: Present author).

Strategy Name		***Name of the strategy, providing its focus***
GENERAL DESCRIPTION		
C.01	Description incl. justification	*Why is the strategy important, and therefore should one choose it? If the strategy is essential for meeting specific requirements of European regulations and policies, it should be discussed here.*
C.02	Relation to the neighbourhood scale	*Why and how closely this strategy is related to the neighbourhood scale? Can this action be scaled up to the city level?*
ACTOR AND ACTION-SPECIFIC ANALYSIS		
C.03	Relevant active and passive stakeholders	*A list of all key stakeholders that could actively influence or be affected by the implementation of the strategy.*
C.04	Direct possibilities to act per active stakeholder	*A list of all the actions associated with the strategy that can be directly influenced by each key stakeholder, broken down into "structural/physical actions" and "regulatory actions".*
C.05	Indirect possibilities to act per active stakeholder	*A list of all the actions associated with the strategy that can only be indirectly influenced by each key stakeholder, broken down into "financial incentives" and "information and training".*
C.06	Possible output indicators per group of action	*List of potential output indicators per direct and indirect action defined in C.04 and C.05.*
POSSIBLE AREAS OF CONFLICT		
C.07	Common conflicts of interest	*Are there any competing interests between the relevant stakeholders that typically arise (e.g. public vs. private interest) when pursuing this strategy?*
C.08	Commonly conflicting targets/actions	*Can the pursuit of the strategy/action constrain, counteract, or even make impossible the implementation of another?*
EXISTING TOOLS AND GUIDANCE		
C.09	Useful tools and guidance	*Are there any official tools or guidance useful for further concretising the strategy?*

3.3.7.4 Example: Fact sheet for the indicator "Energy-related greenhouse gas (GHG) emissions expressed in tonnes CO_2 equivalent".

Below is an illustrative example of the author's concept for the extended description of indicators (only Parts A and C). A theme has been selected that is of high importance for cities and neighbourhoods. Many European countries have already in place regulations that mandate the development of local climate-protection plans by their cities. Many of them are currently working on achieving the status of "climate-neutral" (this was described in more detail in Section 3.3.2.4).

Challenge 1: To define the Emission Sources (i.e. system boundaries) and Accounting Method

As highlighted by UN-Habitat (2011), it is not "cities" themselves that emit GHGs, but rather particular production and consumption activities by households, businesses and institutions. The same applies to any urban unit, including "neighbourhoods". GHGs are therefore allocated to a neighbourhood on the basis of either a) being produced within the geographical boundary defined for the neighbourhood (production-based approach – accounting at source point); or b) being generated as a result of use or consumption of goods and services by the residents or users of the neighbourhood, as well as the consequent waste generation (consumption-based approach – accounting at end-user point) (Satterthwaite, 2008; Wright et al., 2011).

These two different views of how neighbourhood GHGs may be accounted for are linked to the capacity and responsibility of different groups of actors (city authority, consumers) to act on limiting the sources and activities that cause the greatest impacts (Yetano Roche et al., 2014). In Case A, responsibility is assigned to the producers of emissions – and therefore to the actors in charge of the actual sites of the emitting processes (Wright et al., 2011). In Case B, responsibility is assigned to the final consumers of goods and services irrespective of where they are produced (emissions are associated with their manufacture and transport), and therefore to the actors representing the demand side.

In the case of cities, typically, the choice is made between an accounting procedure as per Case A or B to avoid double counting in their inventories. An illustration of the two approaches is provided in Figure 3.15. For the development of mitigation strategies, though, the situation is different. It is increasingly recognised that effective policy making needs to consider both approaches in a complementary fashion (Paloheimo & Salmi, 2013; Yetano Roche et al., 2014). Indeed, only by looking at both sides can efficiency, sufficiency and consistency strategies be combined.

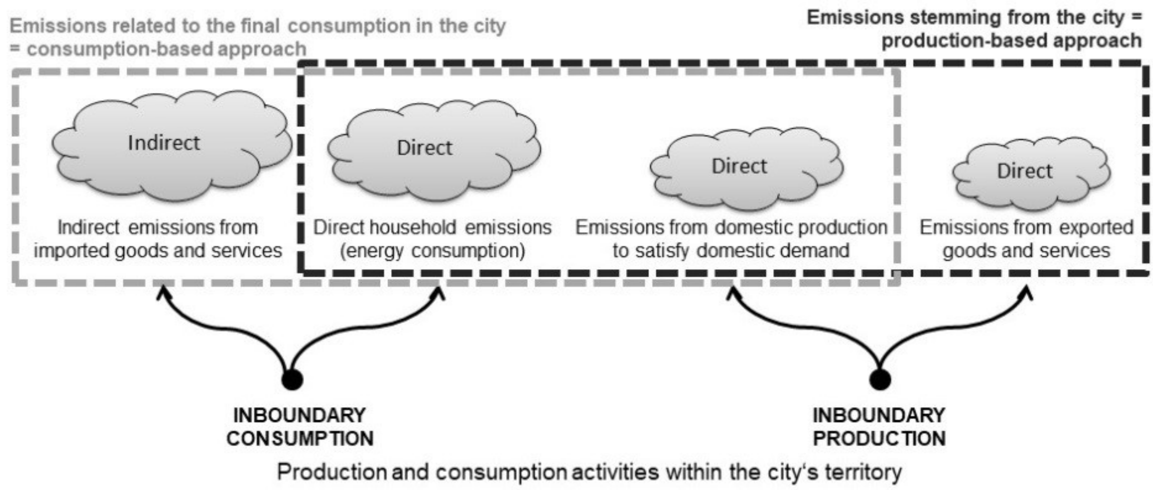


Figure 3.14. Illustration of the consumption-based and production-based approach to GHG emissions accounting (Source: Present author).

However, at the neighbourhood level, the use of a “consumption-based approach” is advisable, since the largest proportion of emissions, if not all, results from the consumption patterns of the neighbourhood. Large production processes – such as the sectors of energy, chemicals and construction materials – usually happen outside the boundaries of a neighbourhood, and sometimes even the city.

It is recommended to structure the main contributors of emissions according to key fields of action. This allows for an effective and comprehensive accounting of the GHG emissions resulting from the neighbourhood and its residents.

Particularly, the following three fields of action are recommended for the neighbourhood scale:

(1) **Buildings**: Retrofitting of the existing building stock is one of the most typical neighbourhood-scale projects for reducing GHG emissions. It is therefore an important field of action, but a distinction should be made between emissions from publicly owned buildings and privately-owned buildings, as the implementing stakeholders differ for each case.

(2) **Public lighting**: Projects targeted to increase the energy efficiency of public lighting (used here as general term to describe any type of public outdoor lighting and traffic lighting) can be first piloted and tested within a neighbourhood's boundary before being upscaled to the city as a whole. Therefore, the inclusion of emissions from electricity consumed for public lighting is considered as relevant for instigating neighbourhood-scale interventions in this field of action.

(3) **Transport**: This includes emissions from all vehicles belonging to local residents and businesses (i.e. used for private and commercial transport), while emissions from public transport are considered as more relevant to be tackled at the city level. For example, the replacement of conventional buses with electric ones cannot be considered a neighbourhood-specific action. Although commercial transport may be negligible in residential areas, the present author recommends its inclusion as a source that can be influenced.

Challenge 2: Data Collection

Each field of action taken into account for this indicator has its own challenges when it comes to the availability and collection of data. In general, there are diverse data sources that can be employed. Neighbourhood-specific consumption data and measurements compete with neighbourhood typologies – or rather, statistical data – that has been gained on a higher administrative level. The way out of this dilemma is to develop a rough-calculation model for the first assessment round that can be expanded, depending on the presence of data and concrete questions. In practice there should always be a mix. Especially in the area of transport, local field research is often unavailable or too time-consuming to obtain, so work with neighbourhood typologies is logical here.

Building typologies are also often employed to solve the problem of personal data protection, hindering energy suppliers to provide consumption information of individual homes. One way to solve the problem is the optional provision of such data by the residents and businesses themselves. When local stakeholders, either individuals or organisations, are more actively involved in the process of sustainable neighbourhood development (following the *process framework* earlier described), they are usually more willing to provide such data. Experiences from Karlsruhe in relation to the research project R131 (Quartier Zukunft, 2017) show that intensive cooperation with relevant organisations – for example, the 'tenants' association' or the 'homeowners' association' – strengthens confidence and increases the willingness to surrender specific details, including energy consumption of single buildings.

Table 3.20. Part A of the indicator "Energy-related greenhouse gas (GHG) emissions expressed in tonnes CO_2 equivalent" (Source: Present author).

Indicator name Problem area/Theme:		**Energy-related greenhouse gas (GHG) emissions expressed in tonnes CO_2 equivalent** Climate change/GHG emissions
GENERAL DESCRIPTION		
A.01	Definition	*The indicator estimates the aggregate GHG emissions from primary energy consumption or demand (including fossil fuels used to generate electricity and district heating outside the area) for all purposes in building operations and street lighting in the local area, as well as fuels used for private vehicles belonging to the local residents and businesses, in tonnes CO_2 equivalent per capita per year.*

(Table 3.20 continues)

A.02	Description including justification	This indicator tracks total greenhouse gas (GHG) emissions in ton of CO_2 equivalent (tCO2e), broken down by source. Greenhouse gases (GHGs) are atmospheric gases that absorb infrared radiation that would otherwise escape to space; thereby they contribute to rising Earth's temperatures and cause changes in the global climate. There are seven major GHGs, the so-called "Kyoto basket" of GHGs: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and four types of fluorinated gases, also called F-gases (hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), nitrogen triflouride (NF3) and sulphur hexafluoride (SF_6)). Global warming potential of these gases varies widely, from several years to centuries. Using each gas' individual global warming potential (GWP), they are being integrated into a single indicator expressed in units of CO_2 equivalents. In an urban context, GHG emissions mainly result from the following activities/fields of action: electricity and heat production, land use change, transportation, buildings, and finally production and consumption of goods. At a neighbourhood level, however, the most relevant ones are transportation, street lighting and buildings. Therefore, GHG emissions from these three areas of intervention can be considered a useful indicator to assess the adverse contribution the neighbourhood-related activities are making to climate change.
CALCULATION/MEASUREMENT METHODOLOGY		
A.03	Object of assessment (system boundaries)	The application of the "consumption-based approach" is advisable for the system boundary definition as the most relevant for neighbourhood scale. This should include: For all buildings located within the boundary of the neighbourhood: • the GHG emissions generated by combustion processes that are attributable to heat generation within buildings (scope 1). The GHG emissions generated from the extraction, processing and transport (happening usually outside the neighbourhood) of the energy sources (e.g. natural gas, petroleum) required to generate heat within the neighbourhood should also be allocated to the district according to the consumption-based approach. • The GHG emissions from the generation of the electricity and heat (district heating) required for the buildings in the neighbourhood generated outside the district as external energy production (scope 2). For public lighting in the neighbourhood: • The GHG emissions from the generation of the electricity required for the public lighting (and traffic signals) in the neighbourhood generated outside the district as external energy production (scope 2).

(Table 3.20 continues)

A.03	Object of assessment (system boundaries)	For the transportation of all residents and users of the neighbourhood[a]: • GHG emissions generated from car-owning households. Following the consumption-based approach, the estimation of the kilometres travelled per private vehicle should go beyond the territorial boundaries and also account for the journeys, e.g. to holiday destinations. • GHG emissions generated from the commercial transport (incl. the transport of public-sector employees for business purposes) either by allocating them to the enterprises/ public bodies located in the district or to the resident population as an overhead ("ecological backpack").
A.04	Methodology	The indicator is calculated as the aggregate CO_2eq. emissions from the activities reported in **A.05** over a calendar year and per capita by multiplying the fuel consumption or demand data associated with each activity by the respective emission factors (for example, expressed in tonnes of CO_2 equivalent/kWh). The "emission factor" is a coefficient which allows the conversion of activity data into GHG emissions. It represents the average amount of GHG emissions released per measurement unit of a certain activity under specific operation conditions. In this sense, site specific data on the exact quantity of GHG emissions released is not needed. Of course, this method presupposes that emission factors are available from an official source for the activity to be measured. For specific activities where emission factors found in literature are not representative, site-specific or local emission factors should be determined. There is still no global harmonised protocol for accounting of GHG emissions at the city and smaller scales. Instead there are a number of international frameworks for GHG emissions inventory of urban regions. The international standard ISO/FDIS 37120[b] recommends the use of the Global Protocol for Community-Scale GHG Emissions (GPC)[c] as a multi-stakeholder consensus-based protocol for developing international recognized and accepted community-scale GHG accounting and reporting. However, GPC is more appropriate for city-scale emission inventories. The specific sub-sectors of GPC that also partly apply to the system boundary description given in A.05 are: residential buildings, commercial buildings and facilities, institutional buildings and facilities (it also includes public lighting) and on-road transportation (it distinguishes between in boundary and transboundary transportation).
A.05	Measured parameters and related units	In the building sector, direct measurements of the total annual consumption of grid-bound energy sources on the neighbourhood level can be provided by the local grid operators in kilowatt hours (kWh). Measured values per building (multiple owners) can also be obtained, if compliance with data protection is ensured.

(Table 3.20 continues)

A.05	Measured parameters and related units	A building typology can also be extracted through the utilisation of GIS systems. These values are required for calculating the building stock's heating and electricity demand, if measured consumption data are not available. In the transport sector the direct measurement of emissions or fuel consumption is difficult. These are usually estimated values with the starting point being the determination of the neighbourhood-specific vehicle stock.
A.06	Reference unit	tonnes CO_2 eq. per capita (resident) per year
DATA AVAILABILITY, RELIABILITY & ACCESSIBILITY		
A.07	Data requirements	• Energy consumption data for each energy source category • Building typology to estimate energy demand for buildings, if energy consumption data is missing • Primary energy factors for different energy source categories (to convert final energy consumption data to primary energy consumption data) • Emission factors for different energy source categories • Number of private vehicles in the neighbourhood • Annual travelling distances per capita • Residents' population
A.08	Data availability and providers	Expected data sources for energy consumption data: • Energy utility or provider • Residents and businesses Expected data sources for emission factors (examples): • Default emission factors published by the European Commission[d] • IPCC (Intergovernmental Panel on Climate Change) – Emission Factor Database (EFDB)[e] • DEFRA (Department for Environment, Food & Rural Affairs) – Emissions Factors Toolkit (EFT)[f] Expected data sources for annual travelling distances per capita: • Residents Expected availability: High for energy consumption data, while low for annual travelling distances per capita. The latter should be obtained through surveys.
A.09	Expected reliability	Monitoring data of energy combined with emission factors are expected to have high reliability.

(Table 3.20 continues)

A.10	Expected accessibility	High, dependent on the accessibility of energy consumption data. For buildings data for (central) heating and cooling maybe more easily accessible then consumption for appliances.
A.11	Substitute indicators	None
CALCULATION TOOLS		
A.12	Calculation tools	A comprehensive overview of GHG reporting schemes and calculation softwares is provided in a recently published report by the Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR) and the Federal Office for Building and Regional Planning (BBR)[g]. The most recent international example not considered in the above-mentioned report is the freely accessible and easy to use Excel-based tool CURB[h] developed by the World Bank.
PRELIMINARY INVESTIGATION ON TARGET-SETTING		
A.13	Desired direction of change	Decrease ↓
A.14	Target value	<u>Emission reduction targets (in CO_2 equivalents) for Europe[i]:</u> • 20 percent below 1990 level by 2020 • 40 percent below 1990 level by 2030 • 80-95 percent below 1990 level by 2050 <u>Emission reduction targets (in CO_2 equivalents) for Germany[j]:</u> • 55 percent compared to 1990 by 2030 • 80-95 percent below 1990 level by 2050 <u>Emission reduction targets (in CO_2 equivalents) for Baden Württemberg[k]:</u> • 25 percent compared to 1990 by 2020 • 90 percent below 1990 level by 2050
A.15	Key factors for projections	Energy use and emissions across all areas should/can/are projected for the target year on the basis of the following: <u>Background indicators, i.e. local or citywide developments</u>: • **Annual population change**: on the basis of this indicator the future growth or shrinkage of the neighbourhood population can be forecasted. This assumes that the growth in energy use and emissions across all areas of intervention will be proportionate to neighbourhood wide or citywide population growth.

(Table 3.20 continues)

A.15	Key factors for projections	• **Change in the mean near surface temperature:** historical trends on the change (increase/decrease) in the mean near surface temperature for the city can be extrapolated for the target year. The climate of a city determines the energy needs for heating and cooling throughout the year and therefore influences the GHG emissions. National developments: • **Change in the energy mix**: in some countries massive changes in the energy mix is expected due to the growing incorporation of renewable energy technologies. This technological advancement influences positively the emissions factors, and therefore the GHG emissions associated with the grid-supplied electricity for buildings and public lighting.
INDICATOR CATEGORISATION		
A.16	Strengths and weaknesses	Strengths: high *compatibility*, i.e. policy relevance (linkage to EU policies and SDGs) and high *scalability*. Weaknesses: considerable documentation and data collection, subject to uncertainties in case of transport data or energy demand data, i.e. problematic *data availability*
A.17	Application cases	Applicable to all types of neighbourhoods
A.18	Indicator type	☒ Quantitative ☐ Qualitative ☒ Common performance indicator ☐ Context-specific indicator
A.19	Placement in the DPSIR framework	☐ Driver ☐ Pressure ☐ State ☐ Response ☒ Impact
A.20	Placement in the SDG framework	With regard to SD-Goals: SDG 13 With regard to SDG-Targets under goal 13: Target 13.2
A.21	Placement in the indicator framework	With regard to main area(s) of protection: ☐ Natural resources ☒ Natural ecosystem ☐ Human health and well-being ☐ Social equity ☐ Cultural heritage ☒ Economic stability ☐ Economic prosperity

(Table 3.20 continues)

A.21	Placement in the indicator framework	With regard to Protection Goals: Direct contribution to: G3 Indirect contribution to: G2, G4, G6, G7, G8, G10 With regard to sustainability dimensions: ☒ Environment ☐ Society ☐ Economy
A.22	Interactions with other themes/ indicators	Included in the framework: fine particulate matter ($PM_{2,5}$), noise pollution (from transport), access to public transport, road safety, biodiversity (due to less air pollution) Others: external costs, ozone (O_3), urban heat island effect, employment, technological innovation, fuel poverty

Footnotes:

a. Inspired partly by the German project "Anforderungen an energieeffiziente und klimaneutrale Quartiere (EQ)". More information can be found in Brenner (2013).

b. It refers to the updated draft of the standard "ISO 37120:2014 – Sustainable development and resilience of communities – Indicators for city services and quality of life".

c. GPC is the result of a collaborative effort between the World Resources Institute (WRI), C40 Cities Climate Leadership Group (C40), and ICLEI-Local Governments for Sustainability (ICLEI). It is also supported by other international organisations such as the World Bank, UNEP, and UN-Habitat. More information can be found in WRI et al. (2014).

d. For more information, see Koffi et al. (2017).

e. For more information, see IPCC (2018).

f. For more information, see DEFRA (2017).

g. For more information, see BBSR and BBR (2017)

h. CURB stands for "Climate Action for Urban Sustainability" (World Bank, n.d.)

i. As expressed in the European Council "*Conclusions on 2030 Climate and Energy Policy Framework*" in October 2014. (European Council, 2014)

j. In accordance to Germany's Climate action plan 2050 (BMUB, 2016). Targets are also specified per sector: for example, 67 – 66 % for buildings and 42 – 40 % for transport.

k. In accordance to the Baden-Württemberg Climate Protection Act of July 2013.

With regard to Part C, there are numerous strategies within each respective field of action mentioned above. Table 3.21 provides an example of how Part C could look like for the typical strategy "Energy efficient retrofit/renovation of buildings" of the field of action "buildings". More strategies and associated actions for this particular field of action are mentioned under Chapter 5 (i.e. the analysis of the hypothetical case study).

Table 3.21. Analysis of the strategy "energy-efficient retrofit/renovation of buildings" in the field of action "buildings" (BU) as a component of "Part C" of the indicator "Energy-related greenhouse gas (GHG) emissions expressed in tonnes CO2 equivalent" (Source: Present author).

Strategy A Indicator:		**Energy-efficient retrofit/renovation of buildings** Energy-related greenhouse gas (GHG) emissions expressed in tonnes CO_2 equivalent
GENERAL DESCRIPTION		
C.01	Description including justification	Energy-efficient renovation of buildings is instrumental for reaching the EU 2020, 2030 and 2050 goals, i.e. the 20%, 40% and 80-95% GHG emission reductions compared to 1990 levels, as shown in **A.16**. By renovating the building envelope (renovation of windows, exterior wall insulation, insulation in the attic and basement walls, etc.) a very high energy saving potential can be tapped. Additionally, a more efficient use of energy can be achieved through replacement of inefficient building equipment and appliances (e.g. old boilers, conventional HVAC systems and conventional bulbs) with newer and more efficient ones. Except the renovation of **public buildings**, which usually falls within the decision sphere of public authorities, the renovation rate of **private buildings** in general is influenced by regulatory law, funding instruments and soft measures such as information, marketing and training.
C.02	Relation to the neighbourhood scale	Any construction measure to improve an existing building primarily falls under the control/decision-making power of the owner (either public or private) or is subject to the regulations placed by the national legislator. Possible economies of scale at neighbourhood level arise when an owner owns larger portfolios in close proximity to one another (e.g. a municipal housing company). However, this effect is more due to the ownership structure than the spatial structure.

(Table 3.21 continues)

ACTOR AND ACTION-SPECIFIC ANALYSIS		
C.03	Key active and passive stakeholders	Primarily active stakeholders: • Municipal Authorities [MA] • Building Owners [BO] Primarily passive/affected stakeholders: • Tenants [T] • Local workforce/craftsmen [LW]
C.04	Direct possibilities to act for **MA**	With regard to structural/physical actions: **A1. Energy-efficient renovation/retrofit of all public/city-owned buildings**, incl. the: **A1_1.** improvement of building envelope; **A1_2.** substitution of inefficient space heating and hot water equipment with more efficient one; **A1_3.** substitution of inefficient cooling equipment with more efficient one; **A1_4.** substitution of inefficient equipment and appliances with more efficient ones; **A1_3.** adoption of an energy efficient lighting strategy combining daylight and occupancy sensors Note: Selected public/city-owned buildings can also be retrofitted to exceed national standards for the purpose of demonstration and "lead by example" With regard to regulatory actions: **A2. Adoption of sustainable procurement standards** for the purchase of net zero emission buildings in case of public buildings With regard to change in the personal purchasing/consumption behaviour: A2 fits also here
C.05	Direct possibilities to act for **BO**	With regard to structural/physical actions: **A1. Energy-efficient renovation/retrofit of privately-owned (residential and commercial) buildings**, incl. all actions identified in **A1** of the previous row With regard to change in the personal purchasing/consumption behaviour: **A2. Purchase of environmentally responsible construction products**
C.06	Direct possibilities to act for **T**	With regard to change in the personal purchasing/consumption behaviour: **A1. Adoption of a more energy-efficient behaviour** following the advice on the efficient operation of building's technical equipment (e.g. in the form of handbook) provided by property owners and housing companies (see B1 for BO)

(Table 3.21 continues)

C.07	Indirect possibilities to act for **MA**	**B1. Promotion of energy-efficient renovation/ retrofit of privately-owned buildings**: With regard to financial incentives: **B1_1.** utilisation of national grant programmes for urban rehabilitation[a] With regard to information and training: **B1_2.** provision of energy consulting services (incl. campaigns) **B1_3.** development of a training program on energy efficient retrofitting of local workforce
C.08	Indirect possibilities to act for **BO**	With regard to financial incentives: None With regard to information and training: **B1. Provision of a "building use guide" to tenants/building users** to enable them to use the building's technical equipment more efficiently.
C.09	Possible output indicators[b]	**For actions under group A1 for both MA and BO** • Number/surface area of buildings retrofitted [#/m^2] • Number/surface area of buildings insulated [#/m^2] • Number of boilers replaced [#] • Number of lamps replaced [#] • Number of cooling and ventilation units replaced [#] • Number of electrical appliances replaced [#] • Number/surface area of buildings with an improved lighting strategy [#/m2] • Number/surface area of buildings retrofitted to exceed national standards [#/m2] **For actions under group B1 for MA** • Rate of customer participation (real customers/targeted customers) in the energy consulting services [%] • Rate of participation (real participants/targeted participants) in awareness raising campaigns [%] • Number of participants in the local workforce training programme [#] **For actions under group B1 for BO** • Number of building use guides distributed [#]

(Table 3.21 continues)

POSSIBLE AREAS OF CONFLICT		
C.10	Conflicts of interest	• Conflict with the private building owners'/housing associations' economic interests, when they rent their properties to others It is a matter of question how to persuade homeowners and other building owners to undertake renovations if they are the ones who pay but get no benefit (e.g. lower energy costs and improved air quality), the so-called "tenant-owner" dilemma[c]. This problem is even more intensified in the case of strict tenancy protection laws and social housing, where the rent is kept low by the municipalities and therefore it is usually hard to pass on investment costs to tenants. • Conflict with the tenants/users economic and social interests. In some counties, where the tenancy laws are not strict, the renovation costs may be shifted to tenants in the form of an increase in the rent cost. In neighbourhoods that need to be upgraded, this can have an impact on the availability of affordable housing for certain residents and lead to changes in the neighbourhoods' social composition. One possible measure for the resolution of this conflict locally is the use of housing agreements with the housing industry which ensure the affordability of the rents after the energy efficient renovation.
C.11		• Conflict with preserving the historical building fabric and unique characteristics of local building culture When monuments and buildings of historical and visual significance are included in this strategy, the implementation of standard energy saving solutions may conflict with the ambition to protect their cultural and historic values[d]. The neighbourhood level is key to the resolution of this conflict locally where these buildings can easier be treated case by case. • Structural conflict with district heating Once buildings are well insulated, the demand for district heating decreases. In this regard, the improvement of building energy efficiency comes into conflict with the development and expansion of district heating schemes, since they are economically viable only when a dense "heat load" (i.e. high concentrated demand for heat) exists.
EXISTING TOOLS AND GUIDANCE		
C.12	Useful tools and guidance	The results of a great deal of EU-funded projects focusing on the building renovation can be found on the EU server CORDIS[e]

Footnotes:

a. One successful example is the kfW programmes in Germany (Information available at Energy-efficient urban redevelopment (n.d.)).

b. Partly adopted from Neves et al. (2016).

c. For more information, see Broc et al. (2015).

d. An interesting research of energy efficiency policies and practices in eleven countries and also touches upon this issue is provided by Nieboer et al. (2012).

e. For more information, see European Commission (2015d).

3.3.8 Discussion

A top-down approach to define a conceptual and analytical assessment framework has been discussed. This framework consists of common problem areas, themes and performance indicators relevant for the European context and actionable on a neighbourhood level. These common problem areas, themes and performance indicators are also interconnected in an integrated manner on the basis of their contribution to ten “top-level” protection goals. Yet, this approach does not exclude the possibility of defining context-specific problem areas, themes and indicators; Local priorities can also be systematised according to this assessment framework in the context of a hybrid approach.

Furthermore, this framework does not limit itself to the assessment task itself, but invents a new way to link performance indicators to specific possibilities for action. Hence, it also positions itself as bridge from “analysis” of the current situation to “action” planning. Key learning points from the general endeavour to develop such a framework that can feed into current neighbourhood sustainability assessment systems and approaches are the following:

(1) Without a clear and predefined framework, the application of indicators may become less meaningful if not dangerous in the sense of: (1) over representing specific research interests while missing out important priorities for European urban areas, and (2) wasting time and resources for aspects that cannot be significantly influenced by actions driven by local actors.

(2) Developing an assessment framework with clear linkages to particular SDG targets is possible and – as the present author suggests – necessary. Any neighbourhood in Europe compiling the common problem areas, the common themes and, under specific circumstances (i.e. data availability), the common performance indicators described in these sections would also be in a very good position to report on progress towards various targets across SDG 1, SDG 3, SDG 6, SDG 7, SDG 8, SDG 11, SDG 12 and SDG 13, and SDG 15. If many

European neighbourhoods were to adopt them all as part of their indicator sets, the chances for achieving a sustainable urban development that do not only positively impacts the local situation but also contributes to global and regional priorities would be greatly improved.

(3) In the effort of compiling an appropriate performance indicator set, one should not focus on elaborating new and ingenious indicators, since numerous indicator sets are available, but rather to develop a set of well-defined selection criteria to use for identifying and eventually selecting the most appropriate indicators. The common performance indicator set is comprised of 18 indicators and demonstrates that it is possible to create a small, but also conceptually robust, substantially complete and generalizable (on a Europe-wide scale), indicator set to measure progress towards SUD on a neighbourhood level when clear selection criteria are in place. While this is a large number in terms of effort required to assess them and their potential impact (as demonstrated though the advanced fact sheets), it is smaller than in most sets in literature. The large sets of indicators proposed in various related assessment systems raise concerns regarding the validity and usefulness of their approaches. However, the indicator set presented in the context of this thesis only serves for inspiration. The most important message to have in mind is that in any case systems should be replaced by "open sets" of indicators allowing for multiple perspectives in order to take account of the specific information needs and the concrete options for action of individual actors. Therefore, the number of indicators plays a secondary role.

(4) Indicators by their nature only capture a small portion of the situation in a neighbourhood. They are valuable for pointing out where more work is needed to achieve the desired status, but they are not likely to provide information about why this is the case. The consideration of background indicators is also necessary in current practices.

(5) The descriptions of indicators should not be limited to aspects related to their measurement and assessment. Assessment is not end in itself

and strategies can already be crafted as part of the indicator description, in a similar way as done in the “advanced factsheets” developed by the present author to clearly support a process- and action-based approach.

3.4 An Action Prioritisation Framework: Evaluating, Prioritising and Selecting Strategies and Actions

In addition to making a sustainability diagnosis and defining appropriate transition targets, identifying, understanding, quantifying and finally selecting actions (also called interventions, alternatives, solutions or options) are equally important for bringing about positive change. Because the challenges and problems in urban areas are often complex, many possible solutions can be considered. In order to prioritise the available actions, it is of critical importance to understand where the greatest potentials and risks lie.

This identification requires a decision-making framework (i.e. procedure) and decision support tools that enable decision makers to evaluate the effectiveness of neighbourhood-specific transition actions against a diverse range of often conflicting criteria (e.g. financial, ecological, social and political) to select the most promising solutions. MCDA constitutes an appropriate set of methods for supporting SUD due to its flexibility and ability to facilitate the dialogue between stakeholders, analysts and scientists (Munda, 2005; Cinelli et al., 2014). However, the systematic undertaking of MCDA requires specific procedures, methods and tools to be available. This section provides a standardised and transparent decision procedure that integrates MCDA as a tool to help decision makers to this end (Figure 3.15).

Roy (1990) distinguished between four major stages of the decision procedure with regard to multiple criteria decision problems: definition of alternatives, definition of criteria (i.e. parameters characterising the decision problem), synthesis and modelling of the decision makers' preferences, and solving the problem. The structure of the standardised procedure for this thesis expands Roy's major stages and was partly inspired by previous work in this field (Belton & Steward, 2002; Markl-Hummel & Geldermann, 2014). It is a more detailed breakdown of Step 3.1 "Analyse alternative strategies and actions" and Step 3.2 "Prioritise actions within strategies" (Figure 3.15), beginning with problem structuring and ending with moment when specific solutions are selected to be integrated into an action plan.

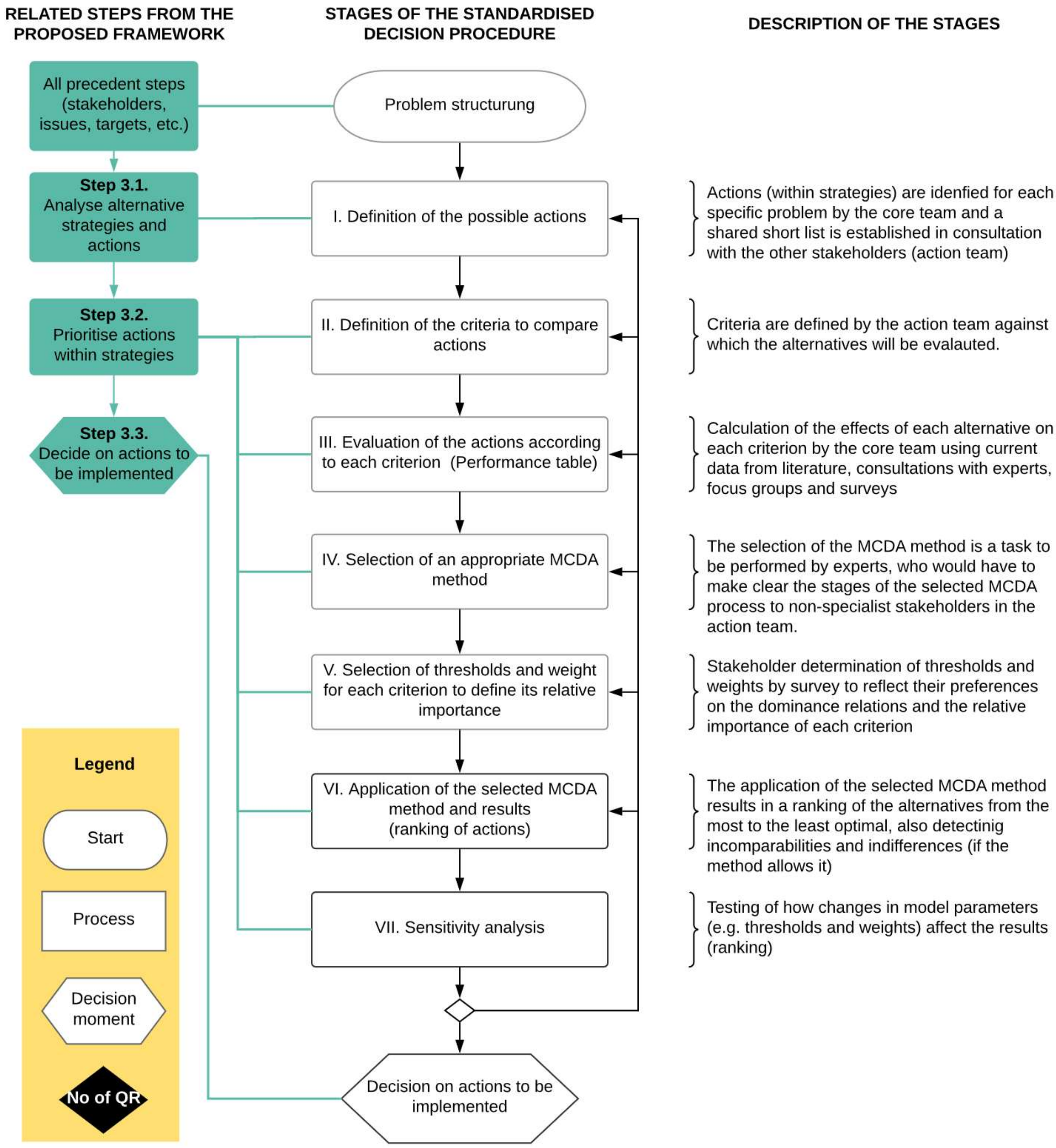


Figure 3.15. Phases of the action prioritisation framework on the basis of typical MCDA procedures (Source: Present author). Note: The processes and decision moments highlighted in "green" represent individual steps of the process framework (see also Figure 3.5).

As illustrated in Figure 3.15, the full process of applying the standardised procedure involves seven main steps. These steps are demonstrated in the hypothetical case study in Chapter 5 with the help of a web tool designed by the present author (described in Chapter 4). Once the context of the problem has been clarified, the key steps are to specify alternatives to be evaluated;

agree on the criteria (starting with criteria suggested in the framework of this thesis in Section 3.4.1); evaluate different alternatives against the agreed criteria; agree on the MCDA method; select preference and indifference *thresholds* (if the selected MCDA method requires it) and weight the criteria to reflect different stakeholder priorities; apply the selected MCDA method to obtain first results; and, finally, explore the dependence of these initial results on initial assumptions through sensitivity analyses.

The first and second steps of the decision procedure provide insights into how each action performs and may be sufficient to inform decision-making without attempting to prioritise those alternatives in an explicit way. Most people can intuitively select an option from a small set when those options are evaluated according to a small number of criteria. However, for a large number of options and/or criteria, the cognitive limits of the human brain interfere, so proceeding beyond this step is necessary. The implementation of the standardised procedure should not obligatorily be accomplished in a linear order from phases I to VII. Especially, phases I and II can be reversed (Keeney 1992; Markl-Hummel & Geldermann, 2014) in order to leave more flexibility for the creation of innovative alternatives. This flexibility depends on the degree of flexibility that is possible in the decision-making process according to demands of DMs.

On the basis of the standardised procedure offered in this section, the later Chapters of the thesis (Chapters 4 and 5) focus on the outranking MCDA method ELECTRE III. Decision-makers in municipal politics and city administration often have to deal with incomplete information and to decide between alternatives that are not always directly comparable (Markl-Hummel & Geldermann, 2014). Additionally, when it comes to evaluating a large number of options against a large set of criteria, it is practically impossible to identify superior alternatives that best fulfil all criteria. To support decision-making in this context, it is more useful to provide a ranking of options than a single solution. Outranking methods, as already discussed in literature section (2.4), employ pairwise comparisons and produce a ranking of alternatives. Therefore, they are well suited for applications in SUD planning.

3.4.1 Criteria for the Evaluation, Prioritisation and Selection of Strategies and Actions

Decisions pertaining to sustainable neighbourhood development solutions have to reconcile different and sometimes conflicting objectives. For example, when a city authority becomes a decision-maker (DM), environmental objectives are often in conflict with financial factors and short-term political interests that satisfy the electors' priorities. Additionally, a large number of stakeholders are involved in implementation solutions, and their diverse interests must be reflected in the criteria.

The criteria tree presented in Figure 3.16 contains a set of generic criteria against which decision makers can evaluate the feasibility and impact of proposed solutions. The criteria tree forms the heart of the standardised procedure of the action prioritisation framework and is comprised of two criteria groups. One criteria group examines the feasibility of solutions from different perspectives – that is, whether a solution can be successfully completed from a financial, technical, temporal and social point of view. The other criteria group examines the overall impact of the solution, whether positive or negative, on the progress towards SUD; it determines how well a solution would work on its intended objective. Finally, the two groups are represented by six evaluation criteria and eleven discrete criteria.

According to many researchers (Yavuz & Altay, 2015; Zak, 2016), an average person can handle a maximum of nine criteria because of the general limitations of abstract thinking. When the number of the criteria is more than nine, the aggregation of criteria into groups is generally recommended. To be comprehensive and to cover all necessary criteria, the literature suggests eleven criteria as an upper limit. This is still an acceptable number (Zak, 2016). Of course, the criteria of "initial investment cost", "annual running costs" and "external funding opportunities" can be combined into one criterion with some modifications – the "life cycle cost". This will result in a model is based on nine main criteria.

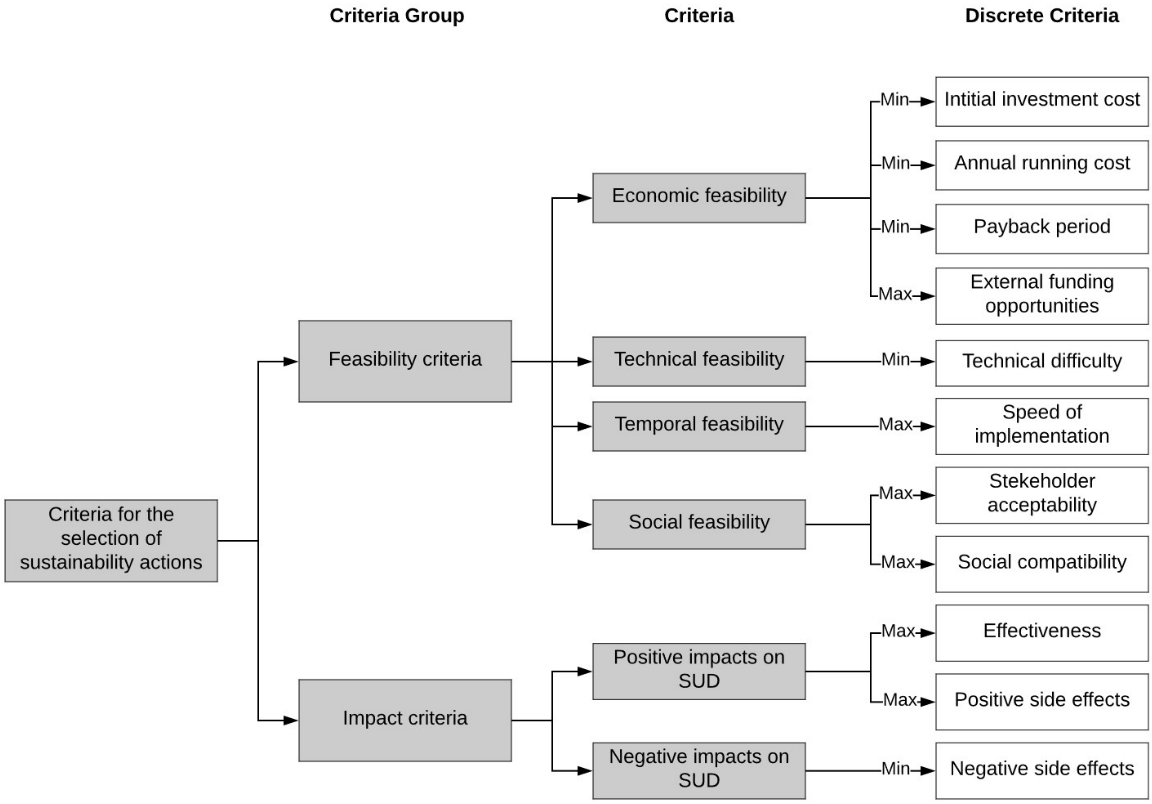


Figure 3.16. The multiple-criteria tree for evaluating SUD strategies and actions, where: "Min" indicates that the objective should be to minimise the respective criterion, while "Max" indicates the opposite (Source: Present author). Note: The illustration is not exhaustive. The presentation does not imply any ranking or weighting of the named criteria.

This tree was developed on the basis of a literature survey of climate actions assessment and prioritisation. The survey included (1) studies and frameworks developed by national and international organisations (Scrieciu et al., 2011; BBSR & BBR, 2017); (2) tools, such as the CLIMACT Prio Tool (IHS, 2014; Olivotto, 2014), BEST Cities Tool (Price et al., 2016) and CURB tool developed by the World Bank (World Bank, n.d.); (3) studies of climate protection action plans for specific cities (e.g. KEK et al., 2011) and (4) work of individual researchers (e.g. Markl-Hummel & Geldermann, 2014). The generic tree was developed to ensure that each criterion is preferentially independent of the others. However, it should be noted that under the criterion group dealing with the financial feasibility, the criterion "external funding opportunities" is not independent from the criterion "initial investment cost" because the first will lower the latter. Anyhow, there is no direct correlation between them.

3.4.1.1 Financial Feasibility

Traditionally, financial feasibility assessment is an integral requirement underpinning decisions on urban development projects and particularly important for both public and private investors. For example, a survey performed among all municipalities in Baden-Württemberg (Markl-Hummel & Geldermann, 2014) found that they ranked criteria of a financial nature the highest. In simple terms, an assessment of financial feasibility examines whether an option is financially realistic or within given resource constraints considering all potential costs. One aspect of this can also be an assessment of the profitability of an action – for example, how soon an investment can result in capital gains. Additionally, a city's potential access to external funding to cover part of SUD costs should also be examined because financial feasibility is considered an important driving force behind a municipality's choice of solutions. To this end, the proposed financial feasibility criteria are as follows:

Initial investment cost – minimised criterion. It includes the initial cost to local government (capital cost) resulting from the realisation of the action. For example, for an extension of a public transport network, the criterion would take into account the costs of construction of new sections of roads for public transport, new stops, digital information boards to equip the stops and many other factors. This criterion should be quantified as much as possible. Otherwise, a subjective evaluation on the basis of a qualitative scale can take place.

Furthermore, external funding reduces the initial investment cost. Such funding can be provided, for example, by grants from regional, national or EU government bodies – or as a result of public-private partnership (PPP) business models. If a municipality has already secured funds, it can directly include these funds in the calculation of initial investment cost as a negative cost (and therefore leading to reduced investment costs). However, the existence of external funding options is usually only known when making a first selection of actions for further analysis. For this reason, "external funding opportunities" is considered in the proposed MCDA model as a separate qualitative criterion (explained below).

Annual running costs – minimised criterion. This criterion includes energy costs for the operation of the building/infrastructure that arise from the use of energy sources (i.e. oil, gas, solid fuels, district heating, electricity), water costs, maintenance costs and capital replacement costs (if any are necessary during the reference study period). Actions targeting sustainability may lead to significant energy and water savings. Therefore, a high initial investment cost may be balanced by long-term gains through low annual running costs.

The initial investment combined with the overall running costs across the lifespan (or a specific reference study period) of a solution partly make up the life cycle costs of the solution.

Payback period – minimised criterion. This criterion represents the length of time required to recover the initial investment cost. The payback period of a given intervention is an important determinant of whether to undertake that intervention because longer payback periods are typically considered undesirable. To calculate payback period in years (without discounting), the initial investment cost of a solution is divided by the annual savings. Although a simple payback calculation does not consider a variety of factors (e.g. energy cost inflation), it is easy to understand. Moreover, because many of the factors it ignores cannot be determined precisely, such a calculation may be accurate enough for decisions made at an initial stage.

External funding opportunities – maximised criterion. This criterion determines whether and to what extent external funding opportunities and support programmes exist. It can be evaluated on a qualitative scale, ranging from “no funding opportunities” to “very attractive funding opportunities” that can be quantified using an interval scale (e.g. 1-5).

3.4.1.2 Technical Feasibility

Technical difficulty – minimised criterion. This criterion encapsulates both the technical complexity and knowledge factor of a considered alternative. This is important because although deep technical know-how may be required for the implementation of a considered action due to its complexity, it may already be a common practice in a country. This is a qualitative criterion (e.g.

ranging from "very high" to "very low") that can be quantified using an interval scale. This is an important criterion also in the sense that an action of high technical difficulty entails a higher risk of complications during its implementation. Thus, it requires that the technical know-how be available to the municipality. Additionally, interventions involving greater technical difficulty often result in higher costs.

3.4.1.3 Temporal Feasibility

In traditional project management, financial and technical analyses are always accompanied by temporal feasibility analyses, which determine the required duration of the project, an important parameter influencing how resources are distributed along the specified time period. Longer time periods are linked with higher risk and uncertainty. It helps distinguishing between easy solutions and the ones need more planning.

Speed of implementation – maximised criterion. This criterion evaluates the typical duration (in years) required for the implementation of a considered action (i.e. project), from initial design to completion. City governments need to be cautious in funding projects that would bring substantially increased obligations and that would "lock in" public financial resources over the long term. This criterion, together with "effectiveness" (explained in 3.4.1.5), are important for identifying key short-term opportunities (i.e. "quick wins"). As a general rule, quick wins refer to actions that can be realised in less than 24 months and with a satisfactory effectiveness (with regard to the intended objective). By including quick wins alongside larger and more investment-intensive interventions in an action plan, municipalities can effectively demonstrate the added value produced by the plan and more easily engage people in contributing to the reductions until the longer-term benefits of the plan become apparent.

3.4.1.4 Social feasibility

Social feasibility is complementary to financial, technical and temporal feasibility. It is concerned with gaining people's acceptance regarding the project to be launched. In an ideal case, municipalities should ask individual local residents about their willingness to accept certain solutions in order to determine specific percentages of social acceptability. However, because this process is rather impractical and time consuming, two other criteria (stakeholder acceptability and social compatibility) are available, which can indirectly provide information on social acceptability.

Stakeholder acceptability – maximised criterion. This criterion examines what the action team and stakeholder advisory team, as representatives of the main stakeholders and local residents in the area, think of the available options. Although conventional wisdom suggests that involving local stakeholder groups in the decision-making process from the very beginning increases the chances of a higher acceptability rate, the evaluation of this criterion on the basis of individual actions/solutions is essential to a successful SUD plan. Therefore, voting by the team and additional stakeholders can reveal the stakeholder acceptability in percentages.

Social compatibility – maximised criterion. "Social compatibility" and "social acceptability" are not the same, but they are highly linked to each other and thus are treated as one criterion. Social compatibility indicates the extent to which a solution is compatible with people's current frame of mind and does not challenge their values and habits (Bosch et al. 2017). Solutions with low social compatibility (i.e. requiring that people significantly change their mindset or challenging the ways they normally do things) are usually met with a low degree of low social acceptability. This makes implementation of such solutions very difficult. For example, car sharing requires a significant shift in people's mindset and travel habits. This was also revealed in a EU-wide survey carried out in 2014 (Fiorello et al., 2016), which found that only a minority (i.e. less than one third) of the respondents were interested in a car-sharing service, and even fewer considered this service as an actual alternative to car ownership. However, one solution may be scored differently in different countries because social compatibility is highly affected by the prevailing socio-cultural values, beliefs and collective experiences. Information on social compatibility can be fairly easily retrieved from a discussion with the action team, literature sources and common sense.

3.4.1.5 Positive Impacts

Effectiveness – maximised criterion. This criterion evaluates the potential of an action to contribute to the specific reduction target for one indicator relative to other possible actions. For example, the (potential) effectiveness of an action to reduce the traffic noise level in a neighbourhood is evaluated on the basis of its noise reduction potential. This can be expressed in terms of both an absolute amount (e.g. the maximum potential noise reduction in dB(A) obtained with a specific measure) and relative proportion (i.e. reduction in percentages).

Positive side effects – maximised criterion. This criterion examines whether and to what extent an action synergistically works towards its intended objective while advancing other environmental, social and economic objectives. Such so-called co-benefits increase the likelihood of an action's success by engaging more diverse communities of interest and by demonstrating compelling added value for them (SSG, 2017). An action delivering multiple benefits at once is also more cost-effective. However, an action may also be associated with unintended adverse consequences (co-harms). The present study includes such co-harms as welcome additions to the MCDA model by categorizing them according to a separate evaluation criterion, denoted as "negative side effects" (later explained in 3.4.1.6). For actions to be "no-regret", they should not only *be c*ost-effective and involve co-benefits but also be free of hard *negative side effects* with other objectives. For these and many other reasons, municipalities must seek comprehensive coverage of potential co-benefits and co-harms to avoid counterintuitive results (SSG, 2017).

Several attempts to develop an ordinal scoring method for mapping the interactions between SDGs and their targets have been observed in the literature. Those methods can easily be transferred to the analysis of synergies and trade-offs between specific actions undertaken in the frame of a certain theme and other themes. One of the most comprehensive goal-interaction scoring frameworks was developed by Nilsson et al. (2016) and used by the International Council for Science (ICSU) (Griggs et al., 2017). In that framework, interactions between SDGs and targets were classified on a seven-point scale: The scores assigned to the positive interactions are +1 (“enabling”), +2 (“reinforcing”), or +3 (“indivisible”). The scores characterising the trade-offs are -1 (“constraining”), -2 (“counteracting”), and -3 (“cancelling”). However, the simplified version of this scoring method (i.e. a five-point scale, ranging from -2 “trade-off” to +2 “synergy”) developed by Iacobuta and Höhne (2017) was later adopted for the hypothetical case study (Chapter 5). This is because too narrow divisions between different scores may lead to a higher susceptibility to error.

3.4.1.6 Negative Impacts

Negative side effects – minimised criterion. This criterion examines whether and to what extent a considered action works against other environmental, social and economic objectives. This criterion ensures that all the benefits accruing as a result of an action do not come at the cost of a significant degradation in other objectives.

3.4.2 Discussion

Translating the decision process with respect to action prioritisation into a standardised or formal procedure improves the bindingness of the overall exchange between stakeholders. Integrating MCDA models at the core of this procedure allows performing the action prioritisation task in an effective way, and thus, contributing to take better decisions. Perhaps one of the most important phase of this formal procedure is the decision on which criteria to account for in the problem. Decisions pertaining to SUD solutions have to reconcile different and often conflicting objectives. The extensive literature survey shows the broad range of criteria that are considered specifically for the evaluation and selection of actions for climate protection. The same, and even to a greater extent, applies to SUD actions for which climate protection is only one objective. However, commonalities in the recommended criteria in all these sources can be observed. In this sense, the most often identified ones have been gathered in a non-exhaustive exemplary criteria tree (see Figure 3.16) which can serve as a fundamental value system to be customised for the local circumstances.

3.5 Summary

This chapter presented an overall process-based and action-oriented conceptual framework, targeted at researchers, community organisations and policy-makers who need guidance in effectively organising the pre-implementation phase of the process of SUD on the neighbourhood level. It was presented as such that it generic and flexible enough to be applicable across any local context in Europe. This overall framework constitutes an alternative proposal to up-to-now predominant approaches that are more indicator- and outcomes-focused (to serve their underling purpose that is certification). Before introducing the different parts of the overall framework (Figure 3.17), a short description of how neighbourhood is understood as an object of assessment and scale of intervention in the context of this research was provided (Section 3.1). Next, the three parts of which this overall framework is comprised were explained.

The proposed overall framework is characterised as *process-based* because it effectively incorporates fundamental aspects supporting institutional sustainability, such as collaborative and participatory decision-making, into a detailed step-by-step workflow representing the decomposed form of the SUD process. This was done in its first part (Part 1 – Figure 3.17), the so-called *process framework* (Section 3.2). The focus in this part is then on how to organise and improve the processes of SUD (with a focus on the pre-implementation phase) on neighbourhood level and not on the neighbourhood itself as an "object". The transformation of the latter cannot be effectively achieved anyhow without the collaboration of a wide variety of local stakeholders to help identifying the local priorities and implementing holistic strategies and actions on the basis of partnerships.

On top of that, the proposed overall framework is characterised as action-oriented, because it focuses on the identification of important problem areas and themes and indicators that are *actionable* at the neighbourhood level (in the European context) to assess and monitor the progress towards SUD. It supports the idea of an open indicator set that allows different perspectives to be captured on the basis of what aspects can be influenced by actions in the local area and by local actors. As an extension to this, it also provides practical ways of linking indicators to strategies and actions, while also providing connections to the SDGs. This was achieved in the second part of the overall framework (Part 2 – Figure 3.17), the so-called *assessment framework* (Section 3.2). This part can also be seen as a zooming-in of a certain group of steps of the *process framework*, dealing with the diagnosing and assessment of the current situation. In other words, the assessment framework provides a detailed guidance for handling specific aspects of the assessment task that is an integral part of the process framework.

Finally, in the attempt to move from assessment-centric approaches to action-oriented approaches, it is necessary to not only connect indicators to specific possibilities for action and specific actors that can implement them, but also to provide guidance on how to evaluate strategies and actions as part of the "action planning" task of the SUD process. This was achieved in the third part of the framework, the so-called *action prioritisation framework* (Part 3 – Figure 3.17). Again, this framework concretises further a specific group of steps of the *process framework*, representing all the processes that come after the assessment task – the decision-making processes with regard to what is the best route of actions.

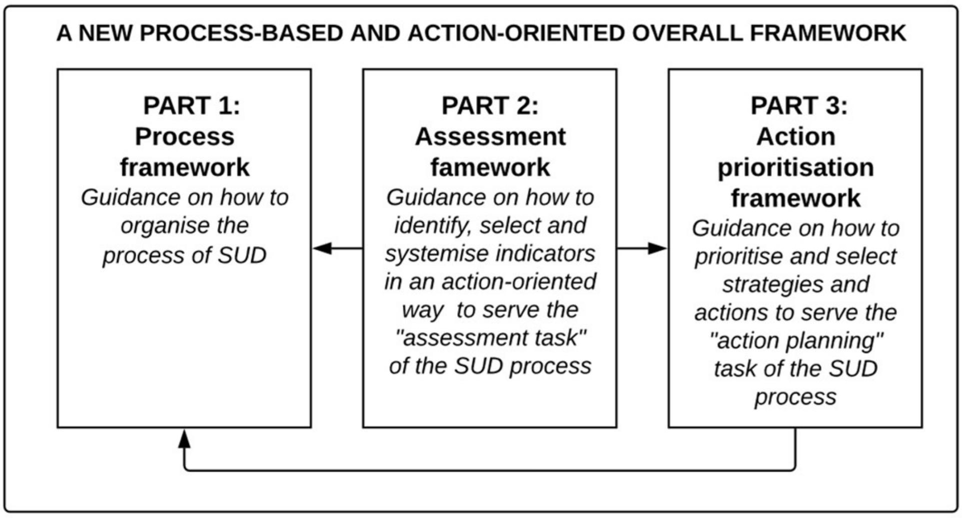


Figure 3.17. Illustration of the overall three-part framework (Source: Present author)

4 Development of a Web-based Decision Support Tool with ELECTRE III for a Customised Ranking of Actions

"Nothing is more difficult, and therefore more precious, than to be able to decide." Napoleon Bonaparte (1769-1821)

This chapter establishes a web-based software tool developed to handle the computational aspects of ELECTRE III and make the overall MCDA process more illustrative, transparent, and comprehensible. First, the reasoning behind the choice of ELECTRE III method is laid out (Section 4.1). Second, the methodological steps of ELECTRE III are explained and all formulas associated with each step are provided (Section 4.2). Third, the main features and visualisation possibilities of the web-based tool by a means of a simple case study taken from literature are presented (Section 4.3). Explanations are also provided on the validation procedure followed to ensure that the own developed tool provides correct results. Finally, the results of the endeavour to develop an own tool for the purposes of the next chapter are discussed (Section 4.4).

4.1 Why ELECTRE III Method?

One of the aims of the present thesis is to demonstrate the benefits and applicability of the *action prioritisation framework* by means of a hypothetical case study. To do so, the selection of an MCDA method well suited to support decision-making dealing with the evalaution of SUD actions is indispensable, as seen in Figure 3.15 (Stage IV). This is the subject of this section. The analysis of the hypothetical case study itself is not dealt with here, but is treated as a separate Chapter (Chapter 5).

To begin with, it is important to stress that no single MCDA method exists that suits best to any decision situation and their appropriateness depends on the context within which they are employed (De Montis et al. 2004; Yatsalo et al. 2016). Yet, among the most widely applied MCDA methods (i.e. ELECTRE, PROMETHEE, MAUT, AHP; TOPSIS and SAW – as briefly introduced in Section 2.4), outranking methods (i.e. ELECTRE and PROMETHEE families) are particularly appropriate for decision making situations where the DMs: (a) have to handle conflicting and incommensurable criteria with heterogenous measurement scales and desire to avoid their aggregation in one single aggregate function; (b) are not willing to allow complete compensability among criteria, i.e. the possibility that a very bad performance on a criterion is offset by a very good performance on another criterion. Evaluating SUD actions falls into this category of decision situations, and should be handled as such.

Among the ELECTRE-type and PROMETHEE-type methods, ELECTRE III was identified and chosen as an appropriate method for the purposes of this research. This choice is also in line with the recommendation by Salminen et al. (1998) – who investigated the use of ELECTRE III, PROMETHEE I, II, and SMART methods in the context of different real applications to environmental problems – i.e. to better use ELECTRE III when the simoultaneous application of several methods for the same problem is not possible. The particular reasons that led the present author to choose this method are discussed below after a brief overview of all ELECTRE methods. Conversely, to provide a brief overview for all PROMETHEE methods was not pursued in the context of this thesis. Nevertheless, for interested readers, a comprehensive literature review on PROMETHEE methodologies and applications can be found in Behzadian et al. (2010).

Main Features and Types of ELECTRE Methods

The ELECTRE (ELimination Et Choix Traduisant la REalité) method is a family of multi-criteria decision analysis (MCDA) methods first developed in Europe in the mid-1960s by Bernard Roy (1968, 1991), driven by his own motivation to solve real-world problems encountered by SEMA (Société d'Economie et de Mathématiques Appliquées) clients (Assad & Gass, 2011, pp. 764). As earlier mentioned (in literature - Section 2.4), but more precisely, ELECTRE is an outranking method relying on pairwise comparisons: alternatives (sometimes also called options or actions or solutions) are compared in pairs with respect to each criterion to establish a degree of dominance of one alternative over another.

The ELECTRE methods possess certain properties that make them well-suited to addressing interdisciplinary and complex questions (Mendoza & Martins, 2006) as is the case of a SUD. First, ELECTRE methods are capable of handling any number of qualitative and quantitative criteria (also called attributes or decision variables) simultaneously; this makes them flexible to use. Second, the ELECTRE family of methods can support a strong heterogeneity in evaluation scales in the modelling of such diversified notions such as emissions, cost, aesthetics, technical feasibility and noise. Whatever the nature of scales, every computational procedure can run with the original performances of the actions on the criteria without necessitating the use of any normalization or valuation technique to aggregate all the criteria in a common scale.

Third, ELECTRE models allow the state of incomparability, which occurs when there is no clear evidence of dominance between two alternatives. This original characteristic brings an important additional information to the DMs in the sense that it calls attention to the alternatives that may need a more detailed examination and prevents premature, oversimplified conclusions. Finally, and more importantly in the context of a strong sustainability, ELECTRE methods are fundamentally non-compensatory. This characteristic is very useful for alerting decision makers to particularly poor performances on some criteria. It is also worth noting that in ELECTRE methods, weights are only seen as importance coefficients assigned to the criteria and not as trade-offs (Cinelli et al., 2014).

On the other hand, it is argued that many of the compensatory MCDA techniques, such as the weighted sum model, use simpler algorithms, are easier to communicate, and potentially have less problems in gaining acceptance from stakeholders (Jeffreys, 2004; Cinelli et al., 2014). Indeed, ELECTRE methods are analytically sophisticated and may be considered relatively complicated mathematically. The problems of stakeholder acceptability and mathematical complexity can however be handled by using/developing user friendly softwares or web applications that support ELECTRE methods and allow a high quality graphical representation of the results (as the web tool developed by the present researcher – see Section 4.3).

In general, the family of ELECTRE methods consists of six different variants: ELECTRE I, II, III, IV, Tri, and IS. They differ both operationally and with respect to types of decision problems they are designed to solve (Govindan & Jepsen, 2016). ELECTRE I, Iv and IS are applicable to the *choice problematic* (which deals with the selection of a small set of best alternatives), ELECTRE II, III and IV are concerned with the *ranking problematic* (which deals with the construction of an ordering of the alternatives from the best to the worst), and finally ELECTRE Tri is used for the *sorting problematic* (which deals with the assignment alternatives to predefined categories).

In regard to the ELECTRE methods concerned with the task of ranking of alternatives – which is the focus of the present thesis – their main difference lies in that ELECTRE II solely relies on true criteria, while the other two methods use pseudo-criteria that allow the construction of a fuzzy outranking relation (see the next section for detailed explanations). Comparing now ELECTRE III and ELECTRE IV, their main difference is that the latter does not use the relative importance coefficients for the criteria, or in other words criteria weights (Govindan & Jepsen, 2016). To provide an extensive description of the theoretical and mathematical principles the ELECTRE methods are grounded on, as well as of their strengths, weaknesses, extensions and applications is not aimed at here; related comprehensive analyses can be found in Figueira et al. (2005, 2010, 2016).

Main Arguments in Favour of Selecting ELECTRE III

The present author chose ELECTRE III for the following reasons. First, ELECTRE III has a solid track of applications in several fields related to SUD such as engineering and infrastructure investment and environmental assessments (Figueira et al., 2013). Compared to the other methods of ELECTRE family, ELECTRE type III has been the most popular method (Zamani-Sabzi et al., 2016). Second, particularly important is also that this method has a substantial track record of its usefulness in solving complex problems in a multi-stakeholder setting (Norese, 2006).

Third, compared to the PROMETHEE methods dealing with the ranking problem (i.e. PROMETHEE I with partial ranking and PROMETHEE II with complete ranking), ELECTRE III employs veto thresholds, in addition to the discrimination thresholds (indifference and preference). In other words, while the definition of indifference and preference thresholds is also required by PROMETHEE methods, this is not the case with the veto threshold. However, the use of veto thresholds strengthens the non-compensatoiriness of the method (Figueira et al., 2010). Indeed, a higher degree of compensation is reported for PROMETHEE methods (Polatidis et al., 2006; Cinelli et al., 2014), as also earlier illustrated in Figure 2.3.

Finally, although the adequate availability of user friendly softwares for the case of PROMETHEE methods presents a strong argument in favor of their selection (Cinelli et al., 2014; Kumar et al., 2017), the poor graphical capabilities of the currently available ELECTRE III softwares provide the ideal opportunity to contribute to filling a gap in this specific field; this is further explored in Section 4.3.

4.2 ELECTRE III Methodology

4.2.1 Basics

ELECTRE III is a well-established MCDA method concentrated on solving ranking problems with a discrete set of alternatives. It consists of *n* alternatives $\alpha_{1,\ldots,}\ \alpha_{i,\ldots}\alpha_n$ that are evaluated in terms of *m* criteria $f_{1,\ldots,}\ f_{j,\ldots}f_m$. The evaluation of the criterion f_j for the alternative a_i is denoted as $f_j(a_i)$.

In a similar fashion to the other ELECTRE family methods, ELECTRE III relies on the construction and exploitation of the outranking relations to get a final ranking of alternatives. For ELECTRE III this is done as follows (Giannoulis & Ishizaka, 2010) and as depicted in Figure 4.1:

(1) **Construction of an outranking relation**: the alternatives are pairwise compared (a_k, a_λ) to determine their outranking relation. One can say that "alternative a_k outranks a_λ" (denoted by a_k S a_λ)[8], if "a_k is at least as good as a_λ" with regard to the majority of criteria, while it is not significantly worse with regard to the other criteria within the limits set by the veto threshold. Therefore, three types of outranking relations may occur: a_k is "*indifferent*", "*weakly preferred*" or "*strictly preferred*" to a_λ depending on how large is the difference between the performance of the alternatives and the thresholds given by the DMs. All outranking relations are collected in the so-called credibility table (see Section 4.2.2).

(2) **Exploitation of the outranking relation**: Two pre-rankings (also called pre-orders) are then produced with two antagonist procedures (ascending and descending distillation). The combination of the two pre-rankings gives the final ranking (see Section 4.2.3).

[8] S stands for the French word 'surclasse', which means 'outranks'

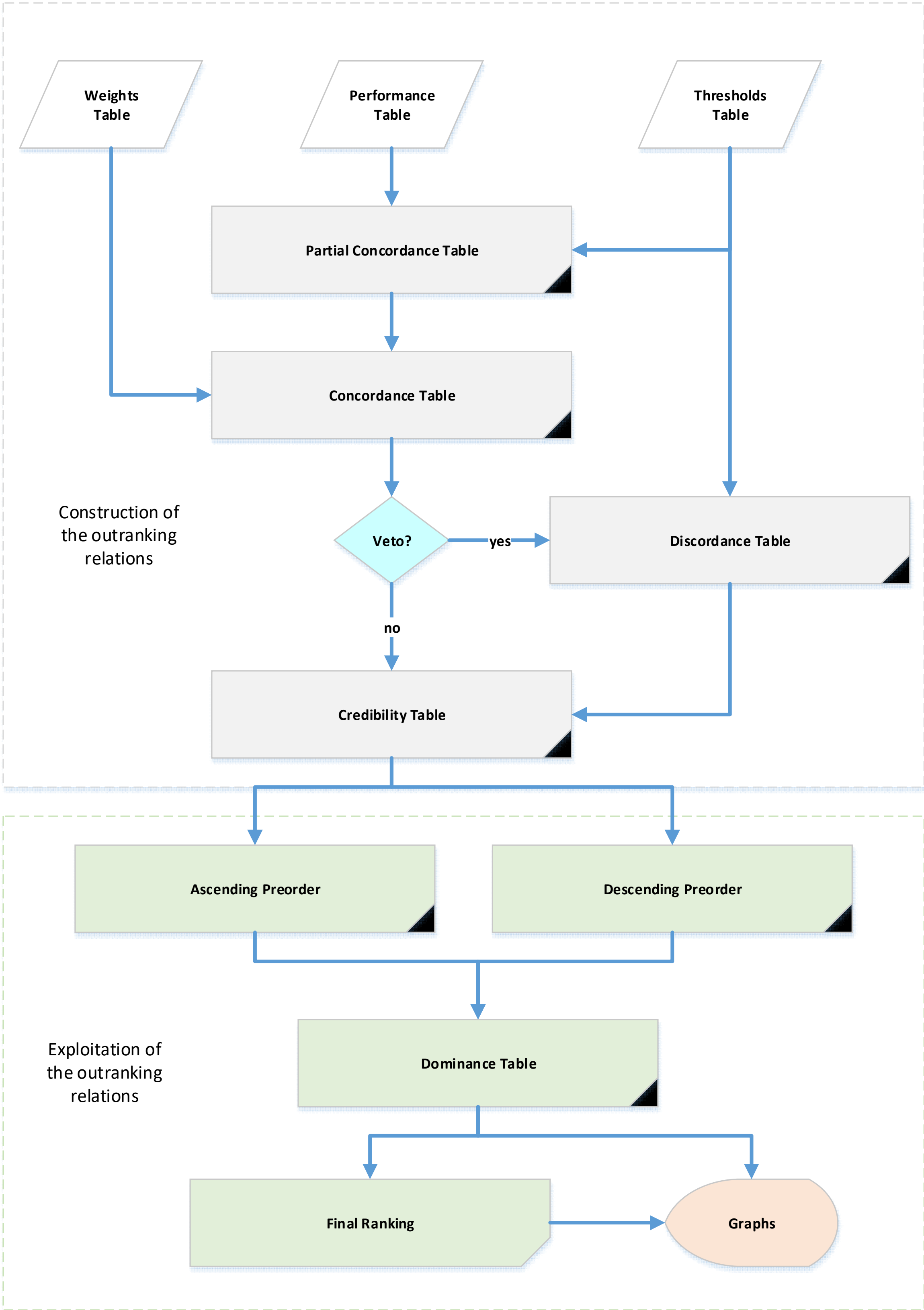


Figure 4.1. ELECTRE III process (Source:Present author).

4.2.2 Constructing the Outranking Relations

Pseudo-criteria

As true criteria are described the criteria which do not have thresholds. The determination of which option is preferred is only dependent on the scores the alternatives obtained on these criteria. In other words, no matter how minor their differences in their scores are, the alternative with the highest score is always preferred. In order to take account of imprecision, uncertainty and inaccurate determination in complex decision problems, ELECTRE III applies pseudo-criteria in building the outranking relation. To define a pseudo-criterion two different thresholds are used to model the preference of the DM: a) an indifference threshold q_j which defines the difference in criterion f_j that the DM deems insignificant; b) a preference threshold p_j which defines the minimum difference above which one alternative is considered absolutely preferred over another one on criterion f_j. Between indifference and strict preference a zone of "hesitation" is formed that represents the weak preference.

Finally, ELECTRE III also uses a third threshold, the so-called veto threshold v_j. The veto threshold represents for the criterion f_j the smallest (negative) difference that fully invalidates (raises "veto" against) the outranking relation. In the general case, q_j, p_j, v_j are functions of $f_j(a_k)$, namely $q_j(f_j(\bullet))$, $p_j(f_j(\bullet))$, $v_j(f_j(\bullet))$. Typically, the functions of q_j, p_j, v_j are linear and in the simple case they are constant for each criterion regardless of a_k. Also holds $\boldsymbol{q_j < p_j < v_j}$. In addition to the thresholds, preferences are also encoded through a weight vector $w = (w_1, \dots, w_j, \dots, w_m)$.

The construction of outranking relations is accomplished by testing two perspectives: the concordance and discordance of the statement "a_k outranks a_λ". In the calculation of the concordance and discordance indexes the DM's preference on various criteria are accounted for as explained below.

Concordance Index

To accept the assertion "a_k outranks a_λ" ($a_k \, S \, a_\lambda$), first a concordance analysis, or the so-called *concordance test*, needs to be conducted. This involves the computation of a concordance index, denoted here as $C_j(a_k, a_\lambda)$. This index indicates the strength of the arguments that support the assertion "a_k outranks a_λ" ($a_k \, S \, a_\lambda$) in relation to a criterion, denoted here as f_j. The values of $C_j(a_k, a_\lambda)$ can range between **0** and **1** (which reflects the notion of fuzziness employed in ELECTRE III, compared to ELECTRE I and II, where the values of the concordance and discordance tables are binary, that is, 0 or 1), where: $C_j(a_k, a_\lambda) = 1$ indicates the highest degree of credibility of the assertion, while, conversely, $C_j(a_k, a_\lambda) = 0$ indicates that the assertion is false/invalid. The concordance index is computed according to the following procedure:

Partial concordance indices (Equation (4.1)) are first computed for all $j \in \{1,2..,m\}$ as follows:

$$C_j(a_k, a_\lambda) = \begin{cases} 0 & \Delta \leq -p_j \\ \frac{\Delta + p_j}{p_j - q_j} & -p_j < \Delta < -q_j \\ 1 & \Delta \geq -q_j \end{cases} \tag{4.1}$$

Where: $\Delta = \begin{cases} f_j(a_\lambda) - f_j(a_k) & \text{if direction of } f_j = \min \\ f_j(a_k) - f_j(a_\lambda) & \text{if direction of } f_j = \max \end{cases}$

And,
q_j: indifference threshold for the criterion f_j
p_j: preference threshold of the alternative on the criterion f_j
$f_j(a_i)$: performance of the alternative a_i as regards to the criterion f_j
direction of f_j = min: when the objective is to minimise the criterion f_j
direction of f_j = max: when the objective is to maximise the criterion f_j

The computation of partial concordance indices is followed by the computation of the comprehensive concordance index (Equation (4.2)) as a weighted sum:

$$C(a_k, a_\lambda) = \frac{\sum_{j=1}^{m} w_j C_j(\alpha_k, \alpha_\lambda)}{\sum_{j=1}^{m} w_j} \tag{4.2}$$

Here,
W_j: weight of the criterion f_j

Discordance Index

After assessing the strength of the indications that support the assertion $a_k\ S\ a_\lambda$ on the basis of the *concordance test*, the strength of the indications against this assertion are also assessed through the *discordance test*, which considers the veto threshold. The discordance test necessitates the computation of a discordance index $D_j(a_k,\ a_\lambda)$ for the criteria to which a veto threshold is assigned. The veto threshold, say v_j for criterion f_j, allows for the possibility of $a_k\ S\ a_\lambda$ to be refused or *vetoed* – regardless of the performance present in other criteria – if the difference of performances between the two alternatives (shown as Δ in Equation (4.1)) on this criterion is greater than, or equal to, the value of the veto threshold. The discordance index for each criterion is defined as follows (Equation (4.3)):

$$D_j(a_k, a_\lambda) = \begin{cases} 0 & \Delta \geq -p_j \\ \frac{\Delta + p_j}{p_j - v_j} & else \\ 1 & \Delta \leq -v_j \end{cases} \tag{4.3}$$

Where,
p_j: preference threshold of the alternative on the criterion f_j
v_j: veto threshold for the criterion f_j

Δ: the performance difference with respect to the criterion f_j (see Equation (4.1)).

Figure 4.2 depicts a schematic diagram of how the partial concordance indices and discordance indices are calculated.

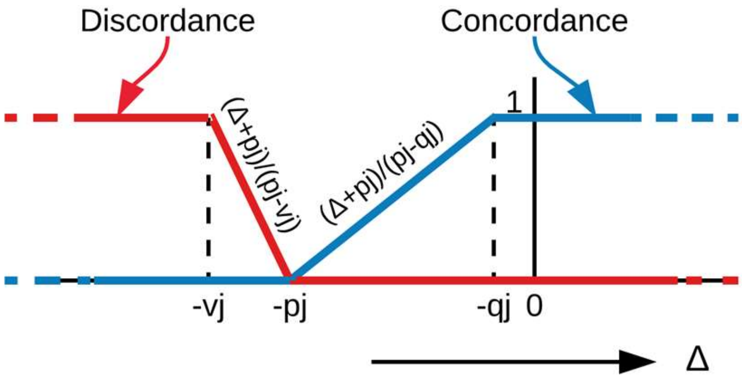


Figure 4.2. Illustration of how "a_k outranks a_λ" (*ak S a)* is evaluated for any pseudo-criterion (p, q, v) (Source: Present author).

Degree of Credibility

By combining the above-mentioned indices, namely the concordance (Equation (4.2)) and discordance indices (Equation (4.3)), the degree of credibility of the outranking assertion a_k *S* a_λ, denoted here as $\sigma(a_k, a_\lambda)$, is defined as follows (Equation (4.4)):

$$\sigma(\alpha_k, \alpha_\lambda) = \begin{cases} C(\alpha_k, \alpha_\lambda) \cdot \prod_{j \in \Omega} \frac{1 - D_j(\alpha_k, \alpha_\lambda)}{1 - C(\alpha_k, \alpha_\lambda)}, & \Omega = \{ j \in \{1, .. m\} : D_j(\alpha_k, \alpha_\lambda) > C(\alpha_k, \alpha_\lambda) \} \\ C(\alpha_k, \alpha_\lambda), & \text{Otherwise} \end{cases} \quad (4.4)$$

Equation (4.4) implies that if the discordance index is strictly above the concordance index, then the *degree of credibility* is equal to concordance index reduced in direct relation to the importance of those discordances (Giannoulis & Ishizaka, 2010). If not, then the *degree of credibility* is equal to the concordance index. Moreover, it is noticeable that if on at least one criterion (i.e. any $j \in \Omega$) the veto threshold is crossed ($D_j(\alpha_k, \alpha_\lambda) = 1$), then the *degree of credibility* is automatically 0 ($\sigma(\alpha_k, \alpha_\lambda) = 0$). Finally, the individual degrees of credibility are collected in a credibility table, which may be asymmetric with regard to the two degrees of credibility attached at each pair of alternatives (Giannoulis & Ishizaka, 2010).

4.2.3 Exploiting the Outranking Relations

The exploitation of the outranking relations gathered in the credibility table can be divided into two phases: First, two preliminary rankings (also called pre-orders), a descending ranking (from the best-rated alternatives to the worst) and an ascending ranking (from the worst-rated alternatives to the best), are constructed with the help of the so-called distillation procedures (Tervonen et al., 2007; Giannoulis & Ishizaka, 2010). Second, a final ranking is computed based on these two preliminarily rankings.

First Phase: Constructing the two Preliminary Rankings

The distillation procedures work by iteratively cutting the fuzzy outranking relations (the ones indicated in the credibility matrix) with descending *λ-cutting* levels (Tervonen et al., 2007). With a given cutting level λ_c, alternative a_k outranks alternative a_λ ($a_k S^{\lambda_c} a_\lambda$) if the following holds (Equation (4.5)):

$$a_k S^{\lambda_c} a_\lambda \; iff \begin{cases} \sigma(\alpha_k, a_\lambda) > \lambda_c & \alpha nd \\ \sigma(\alpha_k, a_\lambda) > \sigma(a_\lambda, \alpha_k) + \varphi\big(\sigma(\alpha_k, a_\lambda)\big) \end{cases} \tag{4.5}$$

where $\varphi(\cdot)$ is the distillation threshold (Equation (4.6)), usually defined as (Belton & Stewart, 2002):

$$\varphi(x) = \beta_0 + \beta_1 * x \tag{4.6}$$

For parameters β_0 and β_1 the values selected are $\beta_0=0.3$ *and* $\beta_1=-0.15$, as recommended by Roy and Bouyssou (1993). This leads to the following (Equation (4.7)):

$$\varphi(x) = 0.30 - 0.15 * x \tag{4.7}$$

The two preliminary rankings (descending, ascending) are constructed in an iterative fashion. In each step, using the Equations (4.5) and (4.7) and the credibility table, the columns λc-power and λc-weakness, as well as the column qualification (score) – which is derived from the differences of the λc-power and λc-weakness – are developed for all the alternatives (e.g. see Tervonen et al., 2007). The alternaitves with the highest or the lowest qualification (score) are distillated, depending on whether the distillation is descending or ascending. The procedure is repated using the reduced credibility matrix (i.e. with distillated alternatives removed). The procedure is presented as an Algorithm (Table 4.1):

Table 4.1. The process of distillation presented as an algorithm (Source: Adapted from Tervonen et al. (2007)).

Algorithm of Distillations
1) Determine the maximum value of the credibility indices in the set under consideration. Assign this to λ_{max}.
2) Determine $\lambda_c = max\{\sigma(a_k, a_\lambda) \ni \sigma(a_k, a_\lambda) < \lambda_{max} - \varphi(\lambda_{max})\}$, where (a_k, a_λ) belong to the set under consideration.
3) If $\lambda_c = 0$, end this distillation.
4) Determine for each alternative its qualification score, that is: the difference between the number of alternatives it outranks and the number of alternatives that outrank it. Outranking is determined according to λ_c.
5) The set of alternatives having the largest (or smallest, if the distillation is ascending) qualification is the current distillate.
6) If the number of alternatives in current distillate is larger than 1, repeat the process from step 2 inside the distillate.
7) Form a new set under consideration by removing the distillated alternatives from the current one. If this set is not empty, repeat the process on the new set from step 1.
8) The final pre-orders are ranked so that the alternatives in the first distillate are given rank 1, in the second rank 2, etc.

Second Phase: Constructing the Final Ranking

In this phase, the two complete pre-orders generated in the first phase, Z_1 and Z_2, are intersected to compute the final partial pre-order in such a way the following relations hold when comparing the alternatives (adapted from Tervonen et al. (2007)):

- a_k $\boldsymbol{P^+}$ a_λ (*a_k is strictly or weakly preferred over a_λ*) if:

$$\left(\overbrace{a_k > a_\lambda}^{Z_1} \wedge \overbrace{a_k > a_\lambda}^{Z_2}\right) \vee \left(\overbrace{a_k = a_\lambda}^{Z_1} \wedge \overbrace{a_k > a_\lambda}^{Z_2}\right) \vee \left(\overbrace{a_k > a_\lambda}^{Z_1} \wedge \overbrace{a_k = a_\lambda}^{Z_2}\right)$$

- a_k $\boldsymbol{I}$ a_λ (*a_k is indifferent to a_λ*) if

$$\overbrace{a_k = a_\lambda}^{Z_1} \wedge \overbrace{a_k = a_\lambda}^{Z_2}$$

- a_k $\boldsymbol{R}$ a_λ (*a_k is incomparable to a_λ*) if

$$\left(\overbrace{a_k > a_\lambda}^{Z_1} \wedge \overbrace{a_\lambda > a_k}^{Z_2}\right) \vee \left(\overbrace{a_\lambda > a_k}^{Z_1} \wedge \overbrace{a_k > a_\lambda}^{Z_2}\right)$$

These relations are gathered in the so-called dominance matrix (table) from which the final ranking is derived. This method of obtaining the final ranking from the two pre-orders is here called “classical ranking”. Another way of obtaining the final ranking is to compute the median of the sum of the ranks each alternative obtains in the asceding and descending ranking and then rank the alternatives starting from the ones with lowest sum. This is here called “median ranking”. Both ways of deriving the final ranking are considered in web-based tool *ElectreIII_R* as explained in the following section.

4.3 Development of the Web-based Decision Support Tool ElectreIII_R

4.3.1 General

As highlighted by several researchers (e.g. Cinelli et al., 2014; Mustajoki & Marttunen, 2017), the availability of software support to implement an MCDA method, manage the information and visualise the results in a clear and dynamic manner can provide considerable additional value for the user (i.e. the analyst or the DMs). It can also be an important reason for choosing one method over the other. Software tools, in addition to handling the computational aspects of an MCDA task, they make the realisation of the MCDA process more illustrative, transparent, and comprehensible (Mustajoki & Marttunen, 2017). In the case of ELECTRE III methods, although there are software tools freely available, their graphical representation is often limited to a diagram representing the ranking or sorting of the considered alternatives (Cinelli et al., 2014). In relation to this, an additional observation is that they do not distinguish the unrelated alternatives in the graphical representations of the rankings they provide.

Furthermore, all the functional tools available are traditional desktop applications, meaning that they require installation on a local computer[9]. Finally, additional disadvanteges that affect their ease of use and functionality are that: (a) they have no interactive and dynamic attributes to add and remove alternatives on a permanent or temporary basis, (b) they do not provide interactive and dynamic graphical features and (c) they do not provide the possibility to download the various tables and charts.

Having regard to the above-mentioned shortcomings, a user-friendly web-based software tool was developed to be used in the implementation of the

[9]According to most recent literature in the field (Kumar et al., 2017), the only web-based tool freely available for implementing ELECTRE III is Electiovis, which, however, requires Adobe Flash Player. The latter fact makes it currently problematic, as Adobe Flash Player is banned from many devices for security reasons.

ELECTRE III method. This is referred to as *ElectreIII_R* and was developed using R programming language and combining the R-packages *Shiny* (Chang et al., 2017) and *Shinydashboard* (Chang & Borges Ribeiro, 2017). These two packages allow building web applications that can provide interactive data visualizations (see Section 4.3.2). Shiny is an R-package that contains a set of functions allowing to build interactive web applications by solely using R. Shinydashboard package is similar to Shiny and is used for the creation of dashboards.

In order to validate the results obtained by *ElectreIII_R*, in addition to testing it with data from literature-based case studies, an algorithmic workflow for ELECTRE III, referred to as *ElectreIII_Diviz*, was also constructed using an open-source software platform called *Diviz* (see Section 4.3.3). This is a software tool that provides the possibility to design complex algorithmic workflows by selecting calculation elements (called modules) from a pre-defined list and connecting them in an MCDA calculation workflow (Meyer & Bigaret, 2012). Thus, to use Diviz does not necessitate any programming skills, but only to understand the functioning of each calculation module (Meyer & Bigaret, 2012). It is important to mention that in the development of both *ElectreIII_R* and *ElectreIII_Diviz*, care was taken that the input data format was exactly the same to facilitate the comparison of the results.

4.3.2 Description of ElectreIII_R

ElectreIII_R was developed to offer an interactive and user-friendly web-based software tool that supports the action prioritisation task on the basis of action rankings generated by ELECTRE III method (following the equations described in the previous section). The tool itself does not provide a list of actions that can be implemented for the achievement of SUD, but it only assists in the application of ELECTRE III method for any set of actions and any set of criteria as inputted in the tool. Practically, it can therefore be used for any multi-criteria decision-making situation beyond SUD aiming at obtaining a customised ranking of actions as an output. In the context of this thesis, ElectreIII_R was specifically used for supporting the ranking – and therefore prioritisation – of SUD actions making use of a hypothetical case scenario that is expected to emerge more often in the near future: a neighbourhood planning towards climate neutrality. The purpose of this section is only to explain and demonstrate the computational and graphical capabilities of the web-tool, while its application on the hypothetical case study is presented in Chapter 5. The framework and technical features of the tool are briefly explained in Appendix B.

Testing and Validation Process

During its development, one of the ways to verify the correctness of the outputs generated by the tool was to run the input data sets of two specific real-world case studies of decision making from literature (Ros, 2011; Fancello et al., 2014) and cross-check whether the outputs of ElectreIII_R are identical with the ones presented in these two case studies. It is important to highlight that these two specific case studies from literature were chosen for the verification process of the tool not due to their relation to the subject of SUD, but solely because they apply Electre III algorithms to investigate their decision making problems and provide a clear and complete data set.

Specifically, the case study conducted by Fancello et al. (2014) deals with the comparison of ten different road sections in Italy with respect to six criteria determing safety conditions (i.e. peak hour factor, % heavy vehicles, degree of saturation, adjustment factor for lane width, safety potential and accident rate). On the other hand, the one performed by Ros (2011) deals with the decision problem of finding which is the best hotel among six alternatives for a congress taking place in Finland, again on the basis of six criteria (i.e. distance to the congress, distance to downtown, sports equipment, restaurants, stars and services).

However, to remove any doubt, in addition to testing the tool through literature-based case studies, the results were also cross-checked with the Diviz tool, which is later described (see next section). In other words, all the available datasets, both the ones obtained by literature and the one constructed by the present author (for the purposes of the hypothetical case study – see Chapter 5) were run and compared using both ElectreIII_R and Diviz as part of the testing and valiadation process of the first.

Demonstration of Possibilities for Inputs and Results

The dashboard of the ElectreIII_R web application has three parts: (1) the header, which provides a title (2) the sidebar, which contains menu items that determine the content in the main body, and (3) the main body, which displays the result represented by the menu item of the sidebar selected each time. As Figure 4.3 shows, the sidebar of the dashboard has three distinct areas – *Input Data*, *Results* and *Graphs* – with corresponding options, which can be displayed or hidden depending on a button click.

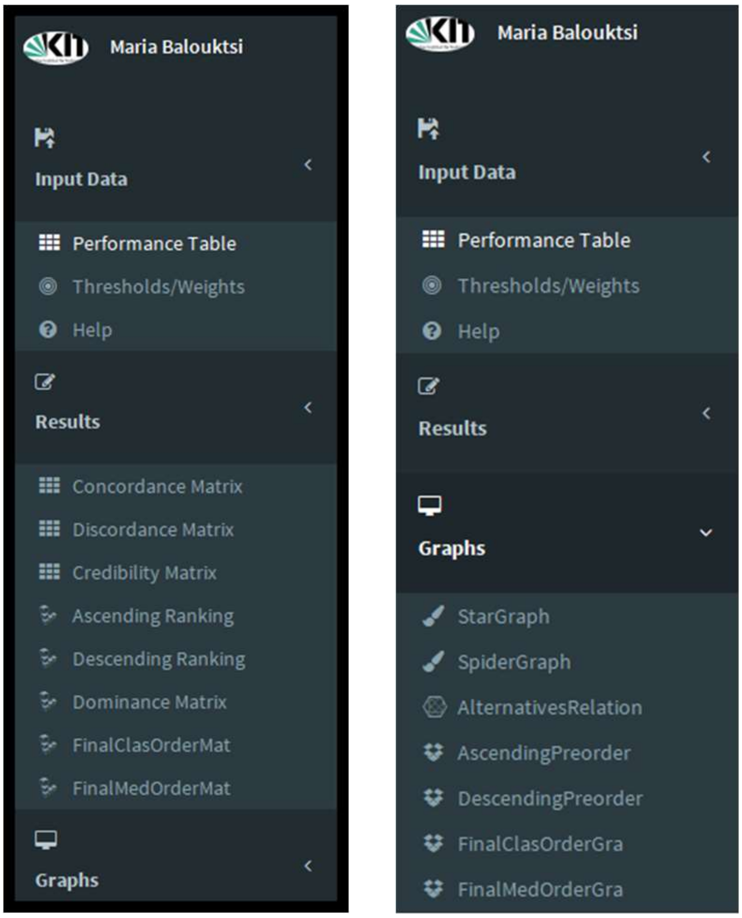


Figure 4.3. Screen shot of the sidebar of the tool ElectreIII_R, showing the three parts: The *Input Data*, the *Results* and the *Graphs* (Source: Present author).

The first area, called *Input Data*, shows the different options for data entry. The tool accepts data in comma-separated value (*.csv) file format, as follows:

The performance table is given in the form:

	,	$\mathbf{f_1}$	,	$\mathbf{f_2}$	, … ,	$\mathbf{f_m}$
$\mathbf{Alt_1}$	,	P_{11}	,	P_{12}	, … ,	P_{1m}
$\mathbf{Alt_2}$	,	P_{21}		P_{22}	, … ,	P_{2m}
.	,	.	,	.		.
.	,	.	,	.	, … ,	.
.	,	.	,	.		.
$\mathbf{Alt_n}$	,	P_{n1}	,	P_{n2}	, … ,	P_{nm}

Where $\boldsymbol{f_i}$ is the name of criterion $\boldsymbol{i}$, $\boldsymbol{Alt_j}$ is the name of alternative $\boldsymbol{j}$ and $\boldsymbol{P_{ji}}$ is the value of the performance table of alternative $\boldsymbol{j}$ for criterion $\boldsymbol{i}$.

The thresholds table is given as:

	,	$\mathbf{f_1}$	,	$\mathbf{f_2}$	, … ,	$\mathbf{f_m}$
ind	,	In_1	,	In_2	, … ,	In_m
pref	,	Pr_1		Pr_2	, … ,	Pr_m
veto	,	V_1	,	V_2	, … ,	V_m
preferenceDirection	,	Pd_1	,	Pd_2	, … ,	Pd_m

Where the following relation should apply: ind (indifference threshold) < pref (preference threshold) < veto (veto threshold). the preferenceDirection elements are the words max or min.

Finally, the weights table is given as:

	,	$\mathbf{f_1}$	,	$\mathbf{f_2}$	, … ,	$\mathbf{f_m}$
weights	,	w_1	,	w_2	, … ,	w_m

The input table formats accepted by the tool are fully compatible with the input table formats used in the workflow created using the Diviz software (described in the next section). A great advantage of the web-based tool is that the data tables inputted are not static in the tool's environment, but they function as user-editable spreadsheets; in other words, the user can dynamically (a) change all table values and (b) add and subtract alternatives on a permanent basis. Furthermore, alternatives can be removed and restored with a simple option ("alternatives drop" – see the right side of Figure 4.4). To achieve all these capabilities, as well as the scrolling capabilities of the tables, the R-package *rhandsontable* (Owen, 2018) was used. Figure 4.4 shows a screenshot of the interface used for the different data entries, using the data set (i.e. six hotels evaluated against six criteria) from the case study performed by Ros (2011) as an example (no relation to the actual topic of the present thesis).

The second area, *Results*, concerns the options for calculating the various ELECTRE III tables, as well as the related rankings. The calculations are made combining the *Electre3_SimpleThresholds* function (Prombo, 2014) and R scripts developed by the present author. In the calculation, the ELECTRE III algorithmic logic and mathematical relations earlier mentioned in this chapter are fully applied resulting in the following five tables: *Concordance matrix*, *Discordance matrix*, *Credibility matrix*, *Dominance matrix*, *Ascending ranking* and *Descending ranking*.

The tool provides two different ways to create the final ranking (as also described in the methodology section). The first way uses the *dominance matrix* and the alternatives are sorted by specifying a value for each alternative Alt_j representing the number of the alternatives over which Alt_j is preffered (indicated by the letter "P" – see Figure 4.5) minus the number of alternatives preferred over the alternative Alt_j (indicated by the letters "NP" – see Figure 4.5). The other way uses the two partial rankings (the ascending and descending rankings) and adds together the two ranking numbers for each alternative to classify the alternatives from the better ranking (lowest sum) to the worst (highest sum). Rankings are made with two functions created in R by the present author and named as: *electreIII_classicRank* and *electreIII_medianRank* (not published yet on CRAN/GitHub). Figure 4.5 shows screenshots of the main results. It is important to highlight that in all cases it is possible to download these results in comma-separated value (*.csv) files, which are readable by Excel.

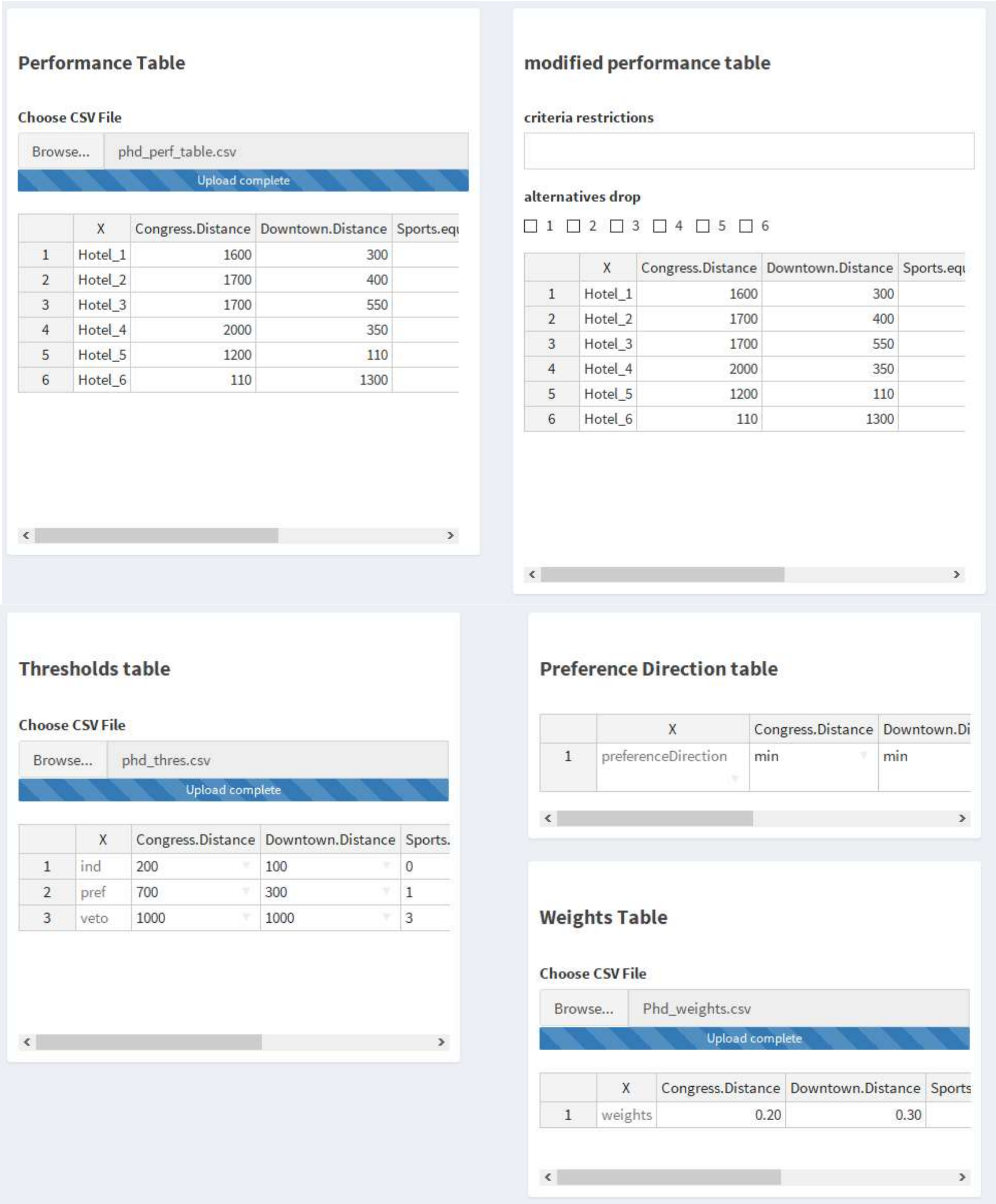


Figure 4.4. Screen shots of the data entries in ElectreIII_R (Source: Present author). Note: The data set shown here in relation to the decision problem of selecting a hotel among six alternatives is taken from Ros (2011) and is used for demonstration purposes only (no relation to the topic of SUD).

Concordance Matrix

Download

	Hotel_1	Hotel_2	Hotel_3	Hotel_4	Hotel_5	Hotel_6
Hotel_1	1.00	1.00	0.90	0.90	0.78	0.80
Hotel_2	0.90	1.00	0.90	0.90	0.59	0.80
Hotel_3	0.57	0.72	1.00	0.75	0.58	0.70
Hotel_4	0.62	0.76	0.86	1.00	0.59	0.70
Hotel_5	0.50	0.50	0.70	0.70	1.00	0.40
Hotel_6	0.50	0.50	0.60	0.50	0.70	1.00

Credibility Matrix

Download

	Hotel_1	Hotel_2	Hotel_3	Hotel_4	Hotel_5	Hotel_6
Hotel_1	1.00	1.00	0.90	0.90	0.78	0.00
Hotel_2	0.90	1.00	0.90	0.90	0.59	0.00
Hotel_3	0.00	0.72	1.00	0.75	0.58	0.00
Hotel_4	0.62	0.76	0.86	1.00	0.59	0.00
Hotel_5	0.00	0.00	0.00	0.00	1.00	0.00
Hotel_6	0.00	0.14	0.00	0.07	0.00	1.00

Dominance Final Ranking Matrix

Download

	Hotel_1	Hotel_2	Hotel_3	Hotel_4	Hotel_5	Hotel_6
Hotel_1	I	P	P	P	P	P
Hotel_2	NP	I	P	P	P	P
Hotel_3	NP	NP	I	NP	R	R
Hotel_4	NP	NP	P	I	R	R
Hotel_5	NP	NP	R	R	I	NP
Hotel_6	NP	NP	R	R	P	I

Final Classical Ranking

Download

alternative	ranking
Hotel_1	1
Hotel_2	2
Hotel_4	3
Hotel_6	3
Hotel_3	4
Hotel_5	4

Final Median Ranking

Download

alternative	ranking
Hotel_1	1
Hotel_2	2
Hotel_6	3
Hotel_4	4
Hotel_5	4
Hotel_3	5

Figure 4.5. Screen shots of the resulting tables as part of ELECTRE III method (Source: Present author). Note: Same as Figure 4.4.

The third area in the dashboard, *Graphs*, offers the user the possibility to display various inputs (i.e. the performance table) and results (specific to ELECTRE III), with a series of graphs (seven in number). Furthermore, all the graphs provide different options of customisation to the user, and therefore different versions of the graphs can be created depending on the information the user selects to display.

The first two graphs, *StarGraph* and *SpiderGraph*, are plots representing the performance table in different ways (illustrated in Figure 4.6 and Figure 4.7). Although their shapes (i.e. polygons) and purposes (i.e. to compare the performances of alternatives with regard to the different criteria) are identical, the underlying formulas used to create the graphs are different. *StarGraph* describes the performance achieved by an alternative in relation to the overall sum of the performances achieved by all alternatives for each criterion, according to Equation (4.8):

$$P_{ij} \rightarrow P_{ij} \,/\, \sum_{i=1}^{n} P_{ij} \tag{4.8}$$

Where,
P_{ij}: the performance of alternative Alt_i on the criterion f_j

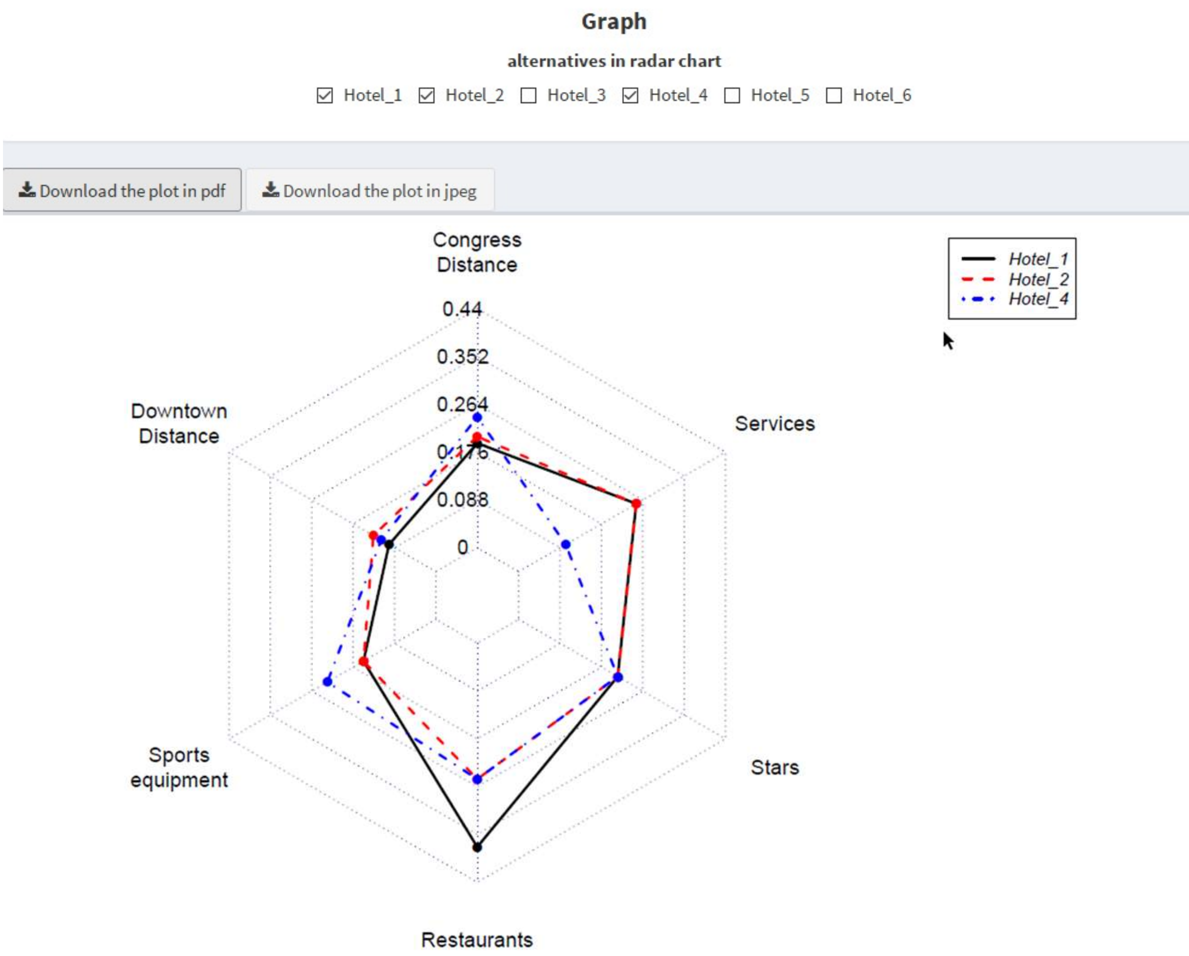


Figure 4.6. Screen shot of the *StarGraph* (Source: Present author). Note: Same as Figure 4.4.

SpiderGraph normalises the values of the performance table by replacing the values of each column (i.e. the performance values obtained for each criterion) with the following values (Equation (4.9)):

$$\text{For max direction} \quad P_{ij} \xrightarrow{\max} \frac{P_{ij} - \min\ P_{ij})}{\max(P_{ij}) - \min\ P_{ij})} \qquad (4.9)$$

$$\text{For min direction} \quad P_{ij} \xrightarrow{\min} \frac{P_{ij} - \max(P_{ij})}{\min(P_{ij}) - \max\ P_{ij})}$$

Where,

min (P_{ij}): is the minimum performance value found in the performance table for the criterion f_j

max (P_{ij}): is the maximum performance value found in the performance table for the criterion f_j

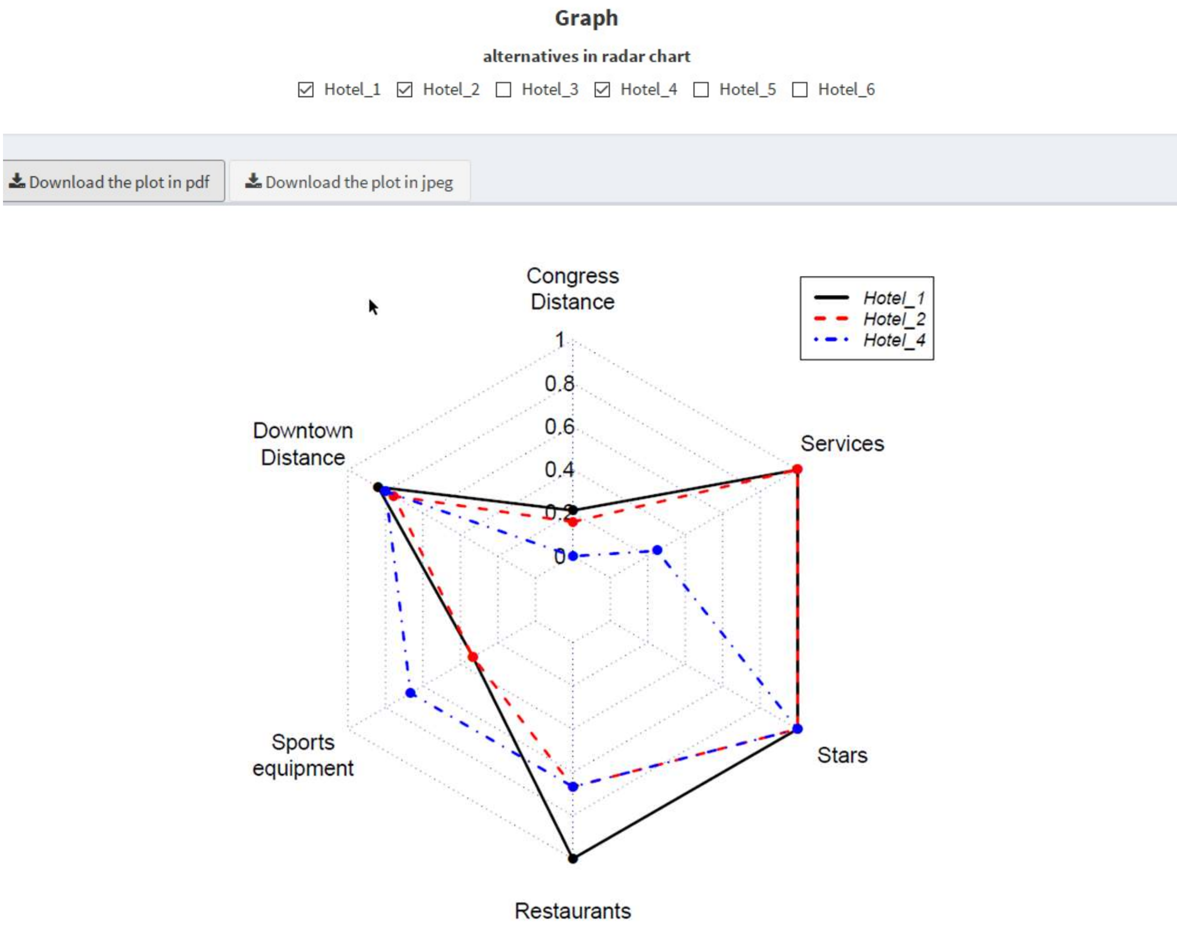


Figure 4.7. Screen shot of the SpiderGraph (Source: Present author). Note: Same as Figure 4.4.

As observed, Equation (4.9) differs as to whether the direction of the criterion is max or min; this is necessary to ensure that the optimal performances are close to 1 and the less optimal close to 0. Both *StarGraph* and *SpiderGraph* were plotted using the radarchart function of the {fmsb} R package (Nakazawa, 2017). Also, in both cases, the graphs can be downloaded into either a PDF or JPEG file.

With regard to the graphical representation of the MCDA method-specific results, the graph *AlternativesRelations* (Figure 4.8) illustrates the strengths of the relationships of dominance that arise between the alternatives as provided in the credibility matrix (earlier shown in Figure 4.5). In this graph, one can choose a specific cutoff value to only display the relationships with a degree of credibility from a certain level and above. The graph was developed using the visNetwork function of {visNetwork} R package (Almende et al., 2017) and is downloadable in HTML format.

The last four graphs *AscendingPreorder*, *DescendingPreorder*, *FinalClasOrderGra* and *FinalMedOrderGra* represent the rankings of the alternatives as calculated using the ELECTRE III method. It should be noted that the tool offers the possibility to depict the final rankings on the basis of the two methods (i.e. classical and median) either in a fully analytical way, where for each alternative the pre- and post-ranked alternatives are shown separately, or in a way where the alternatives of the same class in the ranking – if associated with each other (i.e. if comparable) – are grouped into the same rectangle (the "frozen" option in Figure 4.9). In both cases the *dominance matrix* was taken into account to define which options are incomparable.

Illustrating the state of incomparability between actions, a distinct feature of ELECTRE III method, is an important capability of the tool absent from other tools implementing this method, such as Diviz (see next section). The graph of the final ranking in the way mentioned above has been achieved with a clever algorithm, which is absent from the so-called electre III R packages. The functions created are named *FinRankDiagrElectreIII* and *FinRankDiagrElectreIIIz* (not published yet on CRAN/GitHub). For all the ranking-related graphs, the renderDiagrammeR function of the {DiagrammeR} R package (Sveidqvist et al., 2017) was used. These graphs are also downloadable in HTML format.

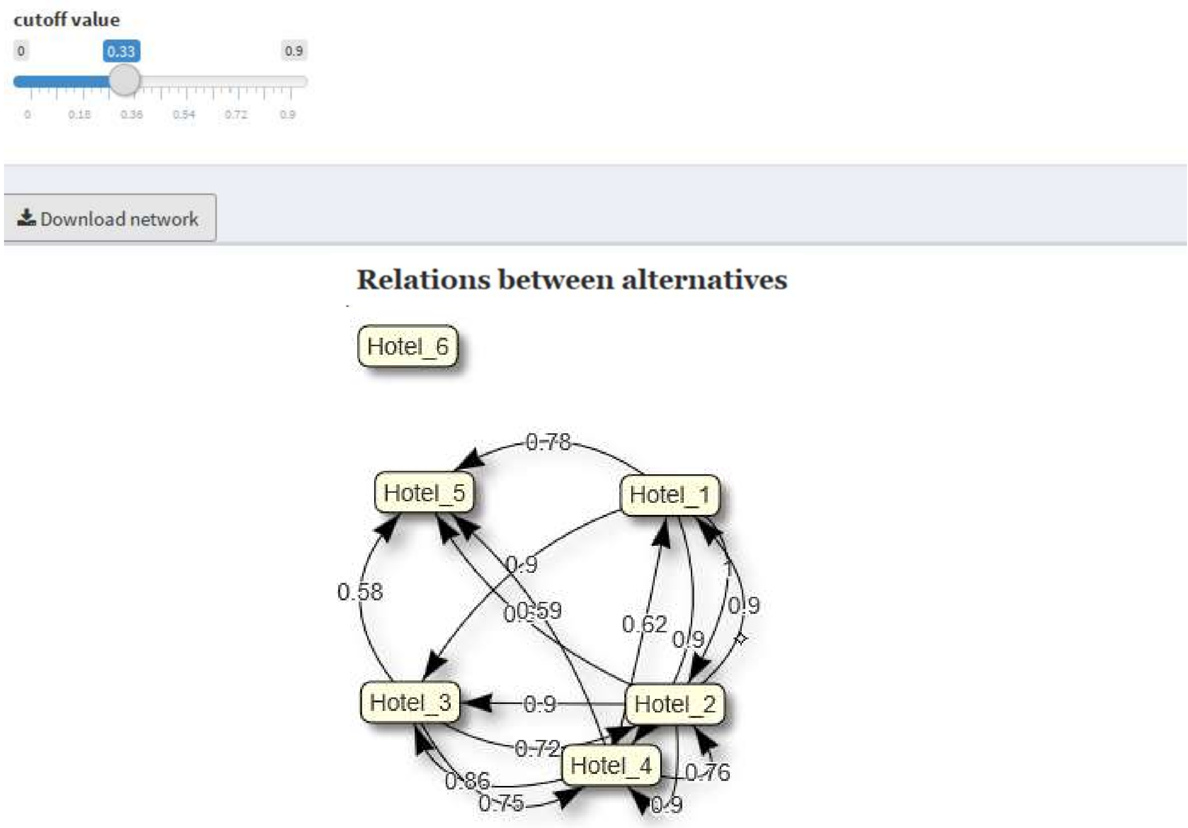


Figure 4.8. Screen shot of the AlternativesRealtions graph (Source: Present author). Note: Same as Figure 4.4.

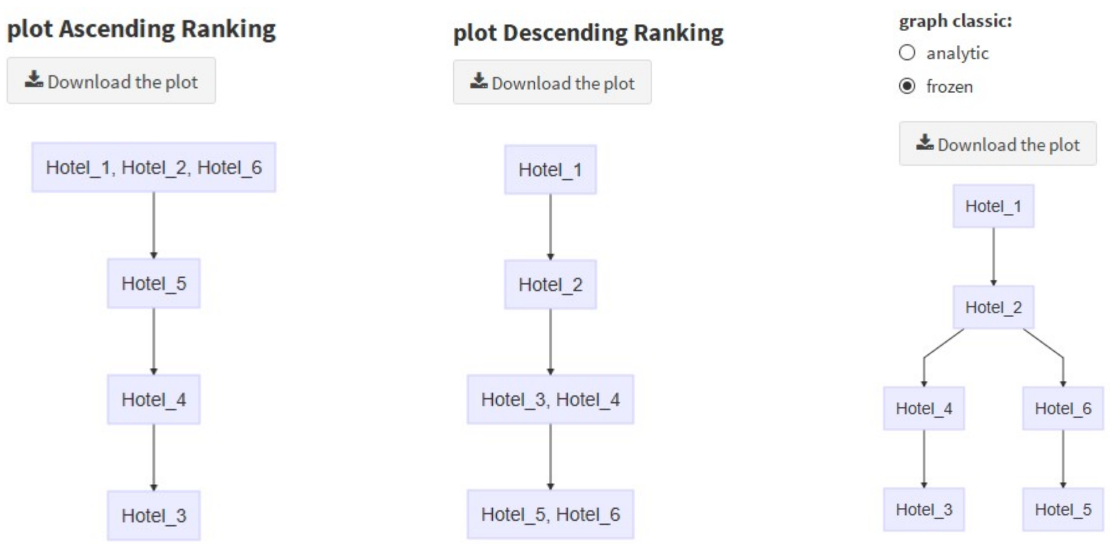


Figure 4.9. Screen shots showing (from left to right) the ascending ranking, the descending ranking and the final ranking. Note 1: The options showed as being at the same position in the final ranking (e.g. Hotel_4 and Hotel_5), but in different boxes, are the incomparable alternatives. Note 2: Same as Figure 4.4.

4.3.3 Validation of ElectreIII_R Against Diviz

Diviz constitutes one of the initiatives of the Decision Deck Project (Decision Deck Consortium, 2018). It is a software based on the XMCDA standard that enables the so-called *algorithmic MCDA* (Cailloux et al., 2014): the design of computational components performing independent computational steps used in one or multiple MCDA methods. The easiest way to build an original MCDA method in Diviz is by selecting one or more elementary computational elements from a pre-defined list of elements (provided by the software itself) and properly chaining them through the use of connectors. A detailed description of how workflows can be managed with the Diviz software is not provided here (more information can be found in Meyer and Bigaret (2012)).

Using the Diviz capabilities, a workflow for Electre III was created, which receives exactly the same input (*.csv) files as the tool created with R (i.e. ElectreIII_R) to facilitate comparison and control of the results for the same problems (Figure 4.10). The workflow consists of the following groups of modules necessary for performing ELECTRE III computations: (1) three modules that read the inputs (i.e. the performance table, the thresholds table and the weights table) that are followed by three modules that convert the three inputs from *.csv format to XMCDA format (i.e. *csvToXMCDA-performanceTable* module); (2) the *ElectreConcordance*, *ElectreDiscordances* and *ElectreOutranking* modules that compute the concordance, discordance, and credibility tables, respectively; (3) the *ElectreDistillation* module that performs the ascending and descending ranking according to the setting selected in the module; (4) finally, the *ElectreDistillationRank* module that performs the final ranking in two ways (i.e. the classical and median way to easily compare the results obtained by the ElectreIII_R tool). The remaining modules are to run the various plots.

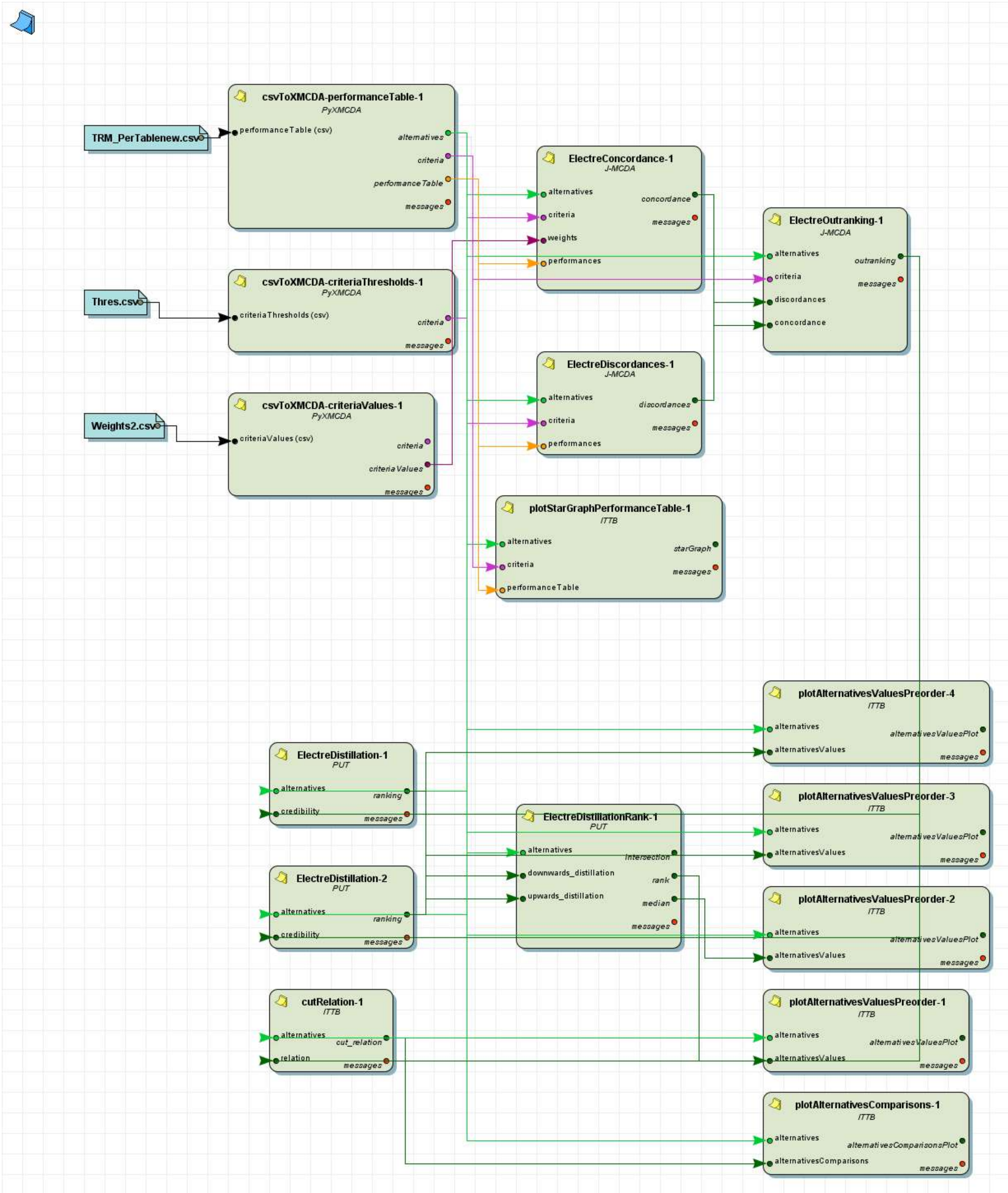


Figure 4.10. Screenshot of the ELECTRE III workflow developed in Diviz (Source: Present author).

First, the spider graph for the performance table is executed by the *plotStarGraphPerformanceTable* module. Essentially, it extracts all the spider graphs for all alternatives. Figure 4.11 indicatively shows the graphs for only two alternatives. One can observe that the graphs provided by Diviz fall short compared to ElectreIII_R (see Figure 4.7) both in terms of quality of and variety of options.

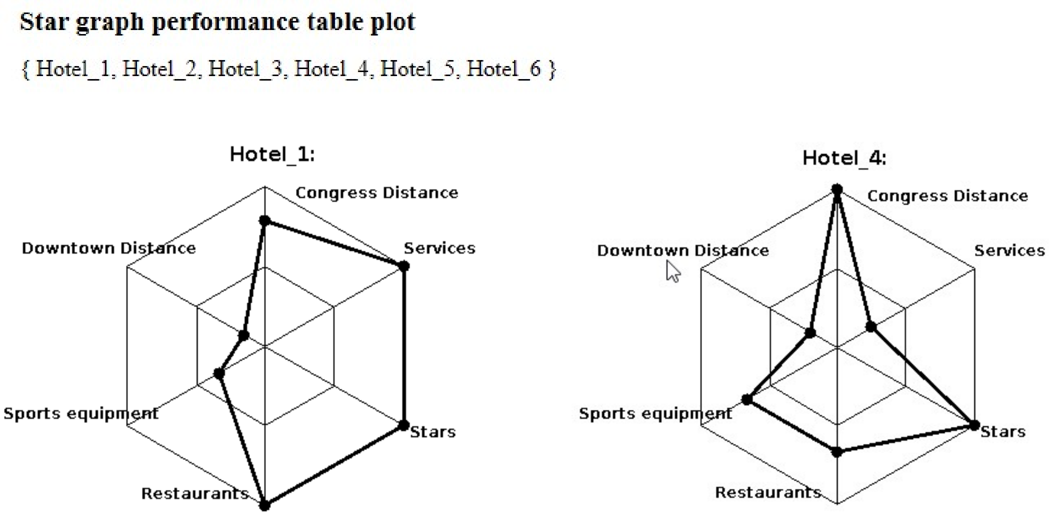


Figure 4.11. Indicative spider graphs extracted from Diviz (Source: Present author). Note: Same as Figure 4.4.

For obtaining the relationships between the options created by the credibility table, the modules *cutRelation* and *plotAlternativesComparisons* are used. The graph (Figure 4.12) is similar to the one produced by the ElectreIII_R (Figure 4.8) with a cutoff value of 0.33. It is noticeable that all values above 0.33 are marked as 1. Additionally, the cutoff value cannot be changed dynamically, as in ElectreIII_R, but after each change one has to re-run the program.

Finally, the *plotAlternativesValuesPreorder* module is used for ranking graphs. As shown in Figure 4.13, the resulting ascending ranking, descending ranking and final ranking are exactly the same as the ones produced by ElectreIII_R (Figure 4.9). The only difference is, however, that in the final ranking produced by Diviz alternatives that are incomparable to each other cannot be distinguished.

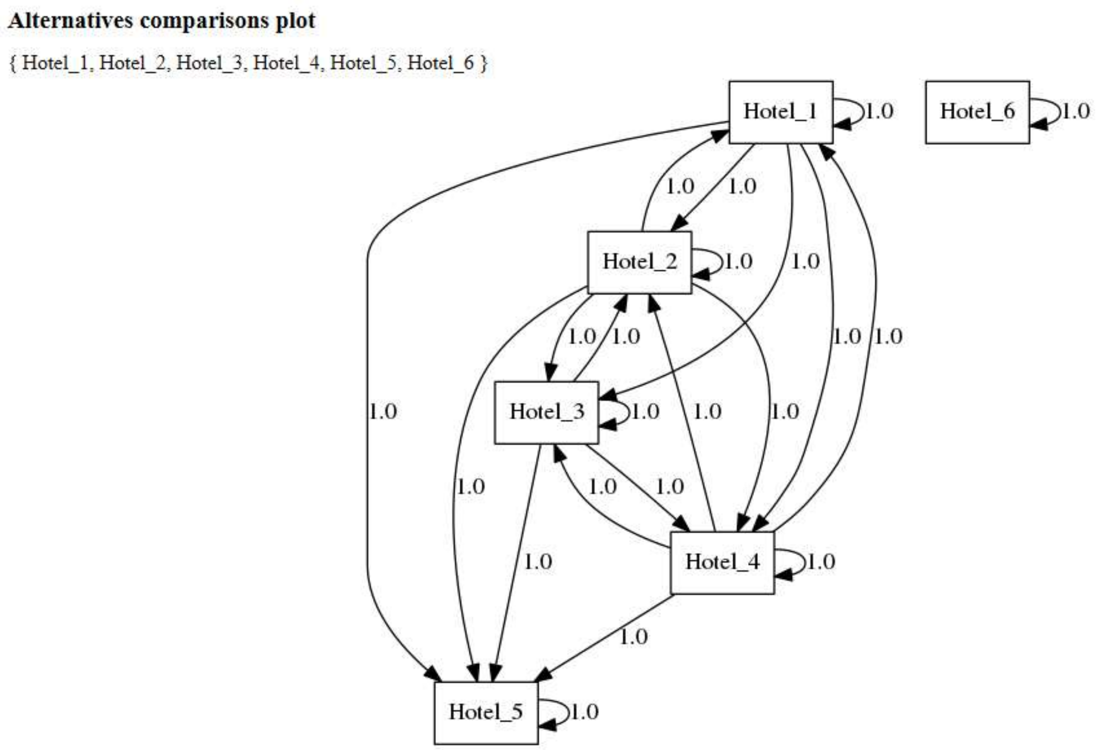


Figure 4.12. The alternative relations as extracted from Diviz (Source: Present author). Note: Same as Figure 4.4.

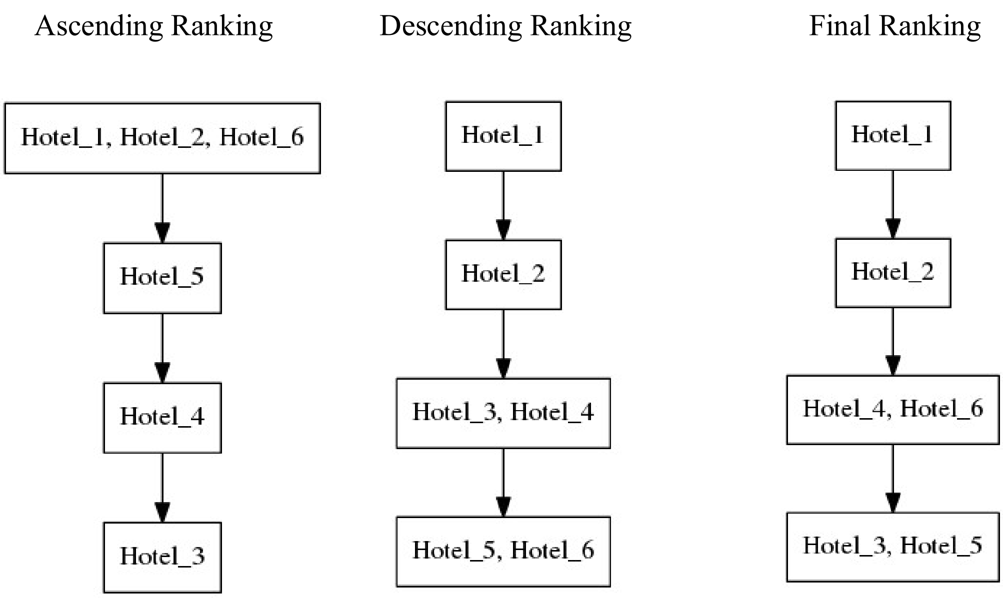


Figure 4.13. The various rankings as extracted from Diviz (Source: Present author). Note: Same as Figure 4.4.

4.4 Discussion and Summary

Prioritising SUD actions is a complex decision process that usually relies on imprecise, indeterminate and uncertain criteria. Therefore, with its pseudo-criteria, ELECTRE III is judged as particularly suited to handle this problem. It furthermore allows: (1) to avoid the problem of computing an aggregate performance for each alternative on the basis of incommensurable and conflicting criteria, (2) to identify and distinguish between indifferent and incomparable alternatives, and (3) to reinforce the non-compensatory character of the decision-making with the veto threshold.

To facilitate the computations of the ELECTRE III method and produce high-quality visualisations of the results, a web-based tool, called *ElectreIII_R*, was developed by using the R language and the Shiny and Shinydashboard packages. It is well-achknowedged that having software support present to implement an MCDA method, as well as manage the information and visualise the results in a clear and dynamic manner, can provide considerable advantages. Along with handling the computational tasks, software tools make the overall MCDA process more transparent and comprehensible.

ElectreIII_R runs in a dynamic way, provides a complete set of graphs, has many options for changing various parameters and can be easily uploaded to a web server and run from any station. Compared to Diviz, the latter clearly has fewer possibilities than the first, in terms of lacking a dynamic way of running and changing various parameters, in terms of the quality of the extracted graphs and results, and finally in terms of web application execution capabilities. Yet, the greatest advantage of Diviz lies in that it is relatively easy to program and has modules that can, with proper programming, provide a variety of MCDA methods. Finally, the validity of the results the web-based tool produces were cross-checked for various examples from literature, and in all cases the results generated were identical.

5 Climate Action Planning in the Light of COP21: A Hypothetical Case Study

"While the problem can sometimes seem overwhelming, we can turn things around – but we must move beyond climate talk to climate action" (Ted Turner, 2014).

This chapter applies the action prioritisation framework (Section 3.4) to a hypothetical case study, with the help of ELECTRE III method and the web-based tool ElectreIII_R (Chapter 4). First, the overall importance of striving for "nearly climate neutral" neighbourhoods is discussed (Section 5.1), which is the underlying topic of the hypothetical decision situation – that is, decision on climate mitigation actions to achieve this ambitious status. Next, the actual application of ELECTRE III to the hypothetical case study and demonstration of the usefulness of the method follows (Section 5.2). Finally, a discussion and summary of results of the chapter are provided (Section 5.3).

5.1 The Need for Nearly Climate Neutral Neighbourhoods

In the assessment framework, climate change is identified as one of the most important problem areas, not only as being one of the most serious contemporary challenges to achieving a sustainable society, but also seeing its tackling as an opportunity to reap the additional benefits that come with it (Section 3.3.2.4). Climate protection serves the preservation of the natural living conditions. As earlier mentioned, the Paris Agreement calls for a considerable reduction of the global GHG emissions so as to keep global warming to well below 2 (or 1.5) degrees Celsius. However, this target cannot be met without massive transformation in cities and neighbourhoods.

Indeed, it is worth reminding that already more than 60% of the EU cities have some sort of local climate plan in place (Reckien et al., 2018). However, to achieve the COP21 targets, and the related EU target in response to COP21 (see Table 3.20 of Section 3.3.6.4), not any type of climate plan is sufficient; all cities should strive to limit their emissions as close to climate neutral[10] as possible – in other words, to reach close to 90% GHG emission reductions. There are countries that acknowledge the imperative of achieving deep reductions of GHG emissions in their cities; for example, Germany aspires to have a "nearly climate neutral" (i.e. 80 to 95% compared with 1990 levels) building stock by 2050 (BMUB, 2016). Such intensified mitigation and adaptation strategies pursued at the city level have also consequences for neighbourhoods. However, climate neutrality is easier said than done. There are various paths for a nearly climate neutral neighbourhood and various actions to choose among. This is the subject matter of the hypothetical case study below.

[10] The term "climate neutral" is often used as a buzzword for the term "net zero emissions".

5.2 Hypothetical Case Study on the Choice of Actions Towards Climate Neutrality

The choice between different actions (also called alternatives, solutions, interventions or options) for the realisation of a climate neutral neighbourhood can be assigned to Step 3.3 “Decide on actions to be implemented” and therefore the fifth “moment of decision” during the implementation of a SUD on a neighbourhood level (previous Figure 3.4). This moment of decision and its two immediate preceding steps are structured according to the standardized procedure earlier outlined in Figure 3.16 and illustrated here on the basis of a hypothetical case. The purpose is to demonstrate (by means of the web-based tool designed by the present author – see Section 4.3) the general contribution of the multi-criteria approaches to the process of decision-making for action planning in the context of SUD on neighbourhood level. This is done by using the example of climate action planning as an integral part of it.

For European cities, the decision to move towards climate neutrality (either as a whole or with respect to specific neighbourhoods functioning as test beds for new solutions) can be viewed as a newly emerging and increasingly important decision situation. Related research has already been undertaken on this topic in Europe as part of the INTERREG IVC (CLUE, 2015). Moreover, despite limited in number, real examples of European cities (such as Berlin (City of Berlin, 2014) and Copenhagen (City of Copenhagen, 2012)) and neighbourhoods (e.g. see Janssens et al., 2016) striving towards climate or carbon neutrality already exist. Additionally, interventions targeting at reducing energy use and associated GHG emissions can generally be considered as “low-regret” as they make a major contribution to urban sustainability with multiple co-benefits, as will be later illustrated in the course of the hypothetical case study. As highlighted by United Nations (UN, 2009), “*climate neutrality,…, is not simply a goal to reduce global warming, but also a way to address some of those environmental, economic and social challenges that are part of the broader sustainability agenda for urban areas*” (p.3).

While the decision to pursue climate neutrality on a local level, as well as the concept itself, are new, they involve a mixture of decisions with which municipalities are traditionally faced on a regular basis. One example is the renovation of public buildings to preserve them or improve their current performance. However, the achievement of such an ambitious target presupposes the consideration of more innovative solutions exploiting renewable energy and smart technologies, or even solutions exploiting the potential of carbon sequestration of plants to balance out the remaining CO_2 emissions. In any case, each project typically competes with other similar projects (e.g. typically different departments of a municipality are responsible for building sector actions and transport sector actions) for a place in the priority list and resources out of the same and often limited budget. On this basis, the different actions are classified into different areas of intervention later in the analysis.

Among the two main categories of MCDA methods (see Section 2.3), the hypothetical case study specifically aims at illustrating how Multi-Attribute Decision Making (MADM) can aid the structuring of the decision-making process. In theory, Multi-Objective Decision Making (MODM) methods can aid in finding the optimal solution (also known as the superior solution) among the candidates according to different objectives/criteria (e.g. Asadi et al., 2012). The method selected for this attempt is ELECTRE III.

Typically, in such a decision, more than one DM is involved. They can be integrated into the process by means of group decision methods (e.g. Leyva-Lopez & Fernandez-Gonzalez, 2003; Shanian et al., 2008). Even when a decision is taken by a single DM (the city authorities in this particular case) it may affect multiple stakeholders, whose interests need to be taken into account. The presented hypothetical case illustrates the broad range of preferences of the potential concerned parties in a generalized way in the context of a sensitivity analysis performed by defining and comparing four "extreme" preference profiles of DMs. These DMs represent the most common cases that can be found in most municipalities.

5.2.1 Stage I: Definition of the Possible Actions

This section shows neighbourhood-specific actions to achieve the climate neutrality target in the areas of intervention buildings (BU) (Table 5.2). As neighbourhood-specific actions are viewed all those actions that can be effectively delivered at a neighbourhood scale by a city authority (the main decision maker in this investigation). Listings have been developed also for the other neighbourhood-specific areas of intervention (as previously identified in Section 3.3.6.4), that is, public lighting (PL) and transport and mobility (TRM). Furthermore, listings have also developed for local energy production (LEP) and carbon sequestration (CS) as they are important for balancing out the remaining emissions in the context of a goal to reach a nearly climate neutral status. However, due to limited time, it is not possible here to run a large number of analyses. Therefore, an MCDA was only performed for actions listed under the BU area of intervention. The rest of the listings are shown in Appendix C for informational purposes only.

The selection of the most important mitigation actions to populate the different generalised lists (presented in Table 5.2 and in Appendix C) was based on potentially influential literature resources (either in the form of reports, tools or databases), some dealing exclusively with the neighbourhood level, some with the city level, and others with both. Specifically, these include:

- two official reports of related German projects published with the involvement and collaboration of several Federal Ministries: one focusing on energy-efficient and climate-neutral urban districts in the German context published as part of the research programme "Experimental Housing and Urban Development" (Brenner, 2013), and one dealing with CO_2-neutralilty in both cities and neighbourhoods and investigating case studies from all over the world published as part of the research programme "General Departmental Research" (BBSR & BBR, 2017);

- the reporting guidelines by the European organisation "Covenant of Mayors for Climate and Energy" (Neves et al., 2016), which is a network of more than 7,000 local and regional authorities voluntarily committed to reducing their emissions. The classification into the areas of intervention earlier described is mainly based on this specific document.

- the CURB tool (Climate Action for Urban Sustainability), which is a free and accessible Excel-based tool designed by world class experts and developed by the World Bank in partnership with C40 Cities Leadership Group (The World Bank, n.d.). Also an earlier report published again by the World Bank including an analysis based on approximately 70 good practices in carbon-neutral urban design from all over the world is included (Kennedy et al. 2010).

- the BEST Cities Tool developed by the Lawrence Berkeley National Laboratory (Price et al., 2016) and designed to provide city authorities with reduction strategies to reduce city-wide carbon dioxide (CO_2) and methane (CH_4) emissions.

- the ClimateTechWiki database that offers detailed information on a broad set of mitigation and adaptation technologies (ClimateTechWiki, n.d.).

The candidate actions selected for the hypothetical case are not only categorised under areas of intervention and different action categories, but also into: a) "direct" actions, denoted as *A1, A2, ..., An* and including all actions associated with assets and infrastructures that are in the direct control of city authorities; b) "indirect" actions, denoted as *B1, B2, ..., Bn* and including all actions associated with assets and infrastructures that are not in the direct control of city authorities, but can be influenced in an indirect way (i.e. through subsidies, campaigns and training possibilities among others).

In some researches with MCDA applications (e.g. Markl-Hummel & Geldermann, 2014), also a neutral alternative, "doing nothing", is introduced and compared against the others. In the light of the climate neutrality target, this should not be considered as an option. It is impossible to achieve such an ambitious target by leaving difficult areas of intervention "untouched".

Table 5.1. Examples of mitigation actions with respect to Buildings (BU). "Direct" action categories are denoted as *A1, A2, …, An*, while "indirect" action categories are denoted as *B1, B2, …, Bn*.

Area of intervention	**Action category**	**Actions**
BU_ Buildings	**A1**. Energy-efficient renovation/ retrofit of all public/ city-owned/ municipal buildings	**BU_A1_1.** Improvement of building envelope
		BU_A1_2. Substitution of inefficient space-heating and hot water
		BU_A1_3. Substitution of inefficient cooling
		BU_A1_4. Substitution of inefficient lighting
		BU_A1_5. Substitution of inefficient appliances and electronics
		BU_A1_6. Installation of occupancy sensors
		BU_A1_7. Integrated retrofit/renovation action (all above)
	A2. Improvement of the energy management in all public/ city-owned/ municipal buildings	**BU_A2_1.** Installation of energy management solutions and smart meters
		BU_A2_2. Annual energy audits
	A3. Greening of all public/ city-owned/ municipal buildings	**BU_A3_1.** Installation of green roofs
	B1. Promotion of energy-efficient renovation/ retrofit of privately-owned buildings	**BU_B1_1.** Provision of energy efficiency consulting services (incl. campaigns)
		BU_B1_2. Provision of retrofit grants and subsidies
		BU_B1_3. Provision of local workforce training on energy efficient retrofitting
	B2. Promotion of energy management in privately-owned buildings	**BU_B2_1.** Distribution of smart meters to businesses and residents
	B3. Promotion of green roof programmes for privately-owned buildings	**BU_B3_1.** Provision of green roof consulting services (incl. education campaigns)
		BU_B3_2. Provision of green roof grants and subsidies
		BU_B3_3. Provision of local workforce training on green roof knowledge

However, one could argue that, for instance, a big surplus of renewable energy production in the local area may completely balance out the energy consumption associated with buildings, without resorting to any energy-efficient measures in this area of intervention. First of all, this is considered an unacceptable alternative, from the point of view that renewable energy technologies are usually embodied-emissions intensive products, or in other words thy are associated with high embodied (also called indirect or “grey”) emissions for their production. Although actions targeting the reduction of embodied emissions associated with buildings and infrastructures are not included in the produced lists, the present author supports their inclusion into considerations where possible. Additionally, this is not in line with the UN’s strategy specifying that striving for climate neutrality means to achieve net zero emissions of GHG by first reducing such emissions as much as possible, and then develop mechanisms to offset the remaining unavoidable emissions (UN, 2011).

In this area of intervention BU, the biggest challenge for the reduction of GHG emissions lies in improving the energy condition of existing building stock. In developed national economies, the annual rate of new building constructions does not exceed 1.5% (BBSR & BBR, 2017). ThereforeTable 5.1 focuses on what city authorities can do to improve the existing building stock and provides a mix of: traditional actions associated with energy efficient renovation (BU_A1_1-5 and partly BU_A1_7); actions integrating smart technologies that can effortlessly support efficient resource usage, such as smart meters and smart lighting (BU_A1_6, BU_A2_1 and BU_B2_1); nature-based solutions associated with energy savings, such as green roofs (BU_A3_1 and BU_B3_1). Of course, it should be noted that for indirect measures, although examined here as part of the action package, it is difficult to define particular GHG emission reductions.

5.2.2 Stage II: Definition of the Criteria

The criteria tree (Figure 5.1) has been created based on the generalized set of evaluation criteria (Figure 3.17 in Section 3.4.1) and adapted to the concrete hypothetical case. With regard to financial feasibility, the criteria tree structured for the hypothetical case only considers the *initial investment cost*. The criteria “annual running costs”, “payback period”, “external funding opportunities” are excluded from the analysis due to the lack of generalized and concentrated data/information on these parameters in the literature. Especially, the latter one is highly dependent on the local context and, if included, the evaluation of actions against it later on would have to be purely based on fictional data.

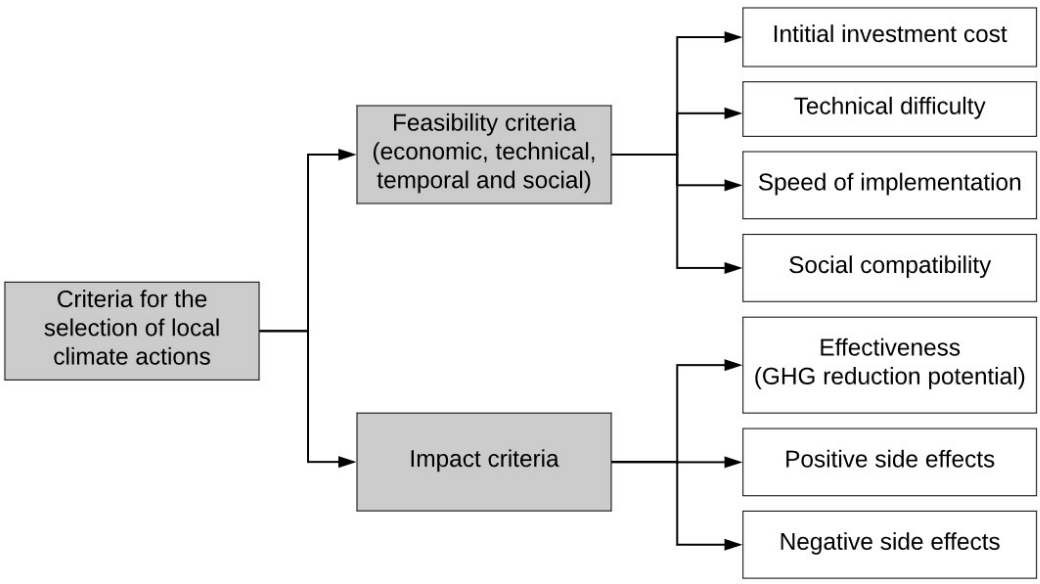


Figure 5.1. Criteria tree for the selection of local climate actions for a climate neutral neighbourhood (Source: Present author).

Given this, the financial feasibility investigation may be considered as limited. However, *initial investment cost*, or in other words the initial cost to government, is a useful criterion from the perspective of capital budgeting to address GHG emission reductions. Usually municipalities have large constraints concerning the initial investment and not all measures can be realised at once (Markl-Hummel & Geldermann, 2014). In any case, in a real setting the best ranked alternatives should always be checked according to a complete financial feasibility analysis before the final choice. Another highly context-dependent criterion omitted from the present analysis is the stakeholder acceptability. Again, fictional data would have to be constructed for its inclusion. Eventually, the 17 alternatives across the area of intervention BU are analysed according to the criteria described in Table 5.2 and Table 5.3.

Table 5.2. Description of scale of the selected feasibility criteria (Source: present author)

CRITERION	MIN/ MAX	UNIT	DESCRIPTION OF SCALE	
INITIAL INVESTMENT COST: Is it a financially realistic option?	Min	Qualitative scale 1-5	Very low	The estimated capital cost to plan and implement the action is very low/negligible (e.g. < 1.000 € for a neighbourhood with 3.000 residents)
			Low	The estimated capital cost to plan and implement the action is low (e.g. between 1.000 – 5.000 € for a neighbourhood with 3.000 residents)
			Moderate	The estimated capital cost to plan and implement the action is moderately high (e.g. between 5.000 – 20.000 € for a neighbourhood with 3.000 residents)
			High	The estimated capital cost to plan and implement the action is high (e.g. between 20.000 - 40.000 € for a neighbourhood with 3.000 residents)
			Very high	The estimated capital cost to plan and implement the action is high (e.g. > 40.000 € for a neighbourhood with 3.000 residents)
TECHNICAL DIFFICULTY: Is technical support for design, implementation and maintenance of this option necessary?	Min	Qualitative scale 1-5	Very low	No specialised knowledge is needed for the implementation of the action
			Low	Little specialised knowledge is needed for the implementation of the action
			Moderate	Although technical experience is required for the implementation of the action, it is a fairly mature practice among cities
			High	Relatively complex action with serious technical knowledge and experience required for its implementation.
			Very high	Complex action with serious technical knowledge and experience required for its implementation..
SPEED OF IMPLEMENT-ATION: How much time will it take to design and implement the action?	Max	Qualitative scale 1-3	Low	The action is expected to take less than 1 year to design and implement
			Moderate	The action is expected to take between 1-3 years to design and implement
			High	The action is expected to take more than 3 years to design and implement
SOCIAL COMPAT-IBILITY: Does the solution fit with people's "frame of mind"? Would local residents accept it?	Max	Qualitative scale 1-3	Low	The solution differs considerably from the usual way of doing things and/or from existing norms and values making difficult for people to accept the solution – potentially associated with low support
			Moderate	The solution has certain aspects that differ from the usual way of doing things (i.e. users or others involved will need to get accustomed to it), but requires no major changes in norms or values.
			High	The solution is largely (or fully) compatible with the current way of doing things, or with existing norms and values. No or only slight adjustments are needed.

Table 5.3. Description of scale of the selected impact criteria (Source: Present author)

CRITERION	MIN/ MAX	UNIT	DESCRIPTION OF SCALE	
EFFECTIVE-NESS (GHG Reduction Potential): How well would it work on reducing GHG emissions (in relation to the other actions)?	Max	Qualitative scale 1-3	Low	The action's potential to contribute to the GHG emissions reduction target is only limited in relation to the other actions (e.g. < 1%).
			Moderate	The action's potential to contribute to the GHG emissions reduction target is moderate in relation to the other actions (e.g. between 1-5%).
			High	The action's potential to contribute to the GHG emissions reduction target is large in relation to the other actions (e.g. > 5%).
POSITIVE SIDE EFFECTS: Does it contribute to other sustainability objectives?	Max	Qualitative scale 1-5	None	There is no apparent positive synergy between the action and other sustainability objectives specified in the action plan or in general.
			Low	The action creates the environment that facilitates positive synergies with other sustainability objectives specified in the action plan or in general (one or more "+1").
			Moderate	The action always leads to positive synergies with one or two other sustainability objectives specified in the action plan or in general (only one or two "+2", no limit for "+1").
			High	The action always leads to positive synergies with three or four other sustainability objectives specified in the action plan or in general (three or four "+2", no limit for "+1")
			Very high	The action always leads to positive synergies with five or more other sustainability objectives specified in the action plan or in general (five or more "+2", no limit for "+1")
NEGATIVE SIDE EFFECTS: Does it lead to trade-offs with other sustainability objectives?	Min	Qualitative scale 1-5	None	There is no apparent trade-off between the action and other specific sustainability objectives in the action plan or in general.
			Low	The action creates the environment that facilitates trade-offs with other sustainability objectives specified in the action plan or in general (one or more "+1").
			Moderate	The action always leads to trade-offs with one or two other sustainability objectives specified in the action plan or in general (only one or two "+2", no limit for "+1").
			High	The action always leads to trade-offs with three or four other sustainability objectives specified in the action plan or in general (three or four "+2", no limit for "+1")
			Very high	The action always leads to trade-offs with five or more other sustainability objectives specified in the action plan or in general (five or more "+2", no limit for "+1")

It should be clarified that in the case of the criteria *positive side effects* and *negative side effects*, a scoring first is performed based on impact direction (positive/negative) and occurrence likelihood (Table 5.4), according to the approach developed by Iacobuta and Höhne (2017). The actual scoring of each mitigation action is provided in Appendix D. In the end, as described in Table 5.7, the number of “+1s” and “+2s” (in the case of synergies), or “-1s” and “-2s” (in the case or trade-offs) are converted into a qualitative scale (ordinal scale). Hence, the evaluation was preferred to be based on a range than an aggregated summary of positive and negative scores. As a result, the high degree of subjectivity entailed in the assignment of an absolute score for each interaction is somewhat minimised.

Table 5.4. Scoring system on the basis of likelihood of occurrence of positive and negative side effects in relation to climate actions (Source: adapted from Iacobuta & Höhne (2017))

Scoring	Description
-2 Trade-off	Climate mitigation action always leads to the specified negative impact. However, the impact strength depends on the context (city/country)
-1 Enabling trade-off	Climate mitigation action creates the environment that facilitates the negative impact. Occurrence of this impact depends on the context (city/country)
0 Uncertain	The impact direction depends on the context (city/country). The impact can become a (direct or enabling) synergy or trade-off depending on
+1 Enabling synergy	Climate mitigation action creates the environment that facilitates the positive impact. Occurrence of this impact depends on the context (city/country)
+2 Synergy	Climate mitigation action always leads to the specified positive impact. However, the impact strength depends on the context (city/country)

5.2.3 Stage III: Selection of an Appropriate MCDA Method

In the present case, the goal is not to find out the optimal solution for the particular area of intervention under study, but to assist the municipality in finding the best suited compromise of a list of defined solutions. ELECTRE III (Elimination and Choice Translating Priority III) was chosen to analyse the decision problem for the reasons outlined in Section 4.1. In short, ELECTRE III is appropriate for treating ambiguity and ill-defined or qualitative data (which is the case with the hypothetical case study examined here) that are issues predominantly present in the early decision making on action planning. In these early decision-making phases, the main purpose is usually to filter a long list of alternatives down to a shorter list for more detailed analysis and consideration by DMs.

To this end, the rankings provided by ELECTRE III method are useful to help reach a final decision among stakeholders more quickly and effectively by drawing their attention to particular solutions for further critical interpretation and consideration. However, it should be highlighted that the rankings themselves do not constitute a definitive answer. Finally, the preference functions and threshold levels, although making the decision process more demanding (as such that more parameters need to be defined compared to more simple methods) help the DMs to fully understand the problem and form their preferences in a consistent manner.

5.2.4 Stage IV: Creation of the Performance Matrix

The evaluation of the actions against the criteria established in Table 5.2 and Table 5.3 was based on a review of existing body of literature (Table 5.5) dealing with analyses and evaluations (mostly qualitative) of climate mitigation actions against diverse criteria. The knowledge was complemented with own experiences where necessary (to fill in information gaps). The latter was considered acceptable, because the case study treated here is hypothetical and employed for illustration reasons only. The results are shown below (Table 5.6).

Table 5.5. Literature sources utilised per criterion for finding performance evaluations for the set of predefined actions (Source: Present author).

Criterion	Literature
Initial investment cost	CURB tool (The World Bank, n.d.); BEST Cities Tool (Price et al. 2016); Kennedy et al. (2010)
Technical difficulty	CURB tool (The World Bank, n.d)
Speed of implementation	BEST Cities Tool (Price et al. 2016)
Social compatibility	partially BBSR and BBR (2017)
Effectiveness	BEST Cities Tool (Price et al. 2016); Kennedy et al. (2010)
Positive side effects	IPCC (2014, p.); CURB tool (The World Bank, n.d.); BEST Cities Tool (Price et al. 2016); Iacobuta and Höhne (2017); SSG (2017)
Negative side effects	IPCC (2014, p.151); CURB tool (The World Bank, n.d.); Iacobuta and Höhne (2017); SSG (2017)

Table 5.6. Decision matrix for the area of intervention Buildings (BU) (Source: Present author).

		Initial investment cost (scale 1-5)	Technical difficulty (scale 1-5)	Speed of implementation (scale 1-3)	Social compatibility (scale 1-3)	Effectiveness (scale 1-3)	Positive side effects (scale 1-5)	Negative side effects (scale 1-5)
EXISTING MUNICIPAL BUILDINGS	**BU_A1_1.** Building envelope	Moderate	Moderate	Moderate	High	Moderate	High	None
	BU_A1_2. Space-heating and hot water	High	Moderate	High	High	Moderate	High	None
	BU_A1_3. Cooling	High	Moderate	High	High	Moderate	High	None
	BU_A1_4. Lighting	Low	Low	High	High	Moderate	High	Low
	BU_A1_5. Appliances and electronics	Low	Very low	High	High	Low	High	Low
	BU_A1_6. Occupancy sensors	Low	Low	High	High	Low	High	Low
	BU_A1_7. Integrated retrofit/renovation action	High	High	Moderate	High	Moderate	High	Low
	BU_A2_1. Energy management solutions and smart meters	Moderate	High	Moderate	Moderate	Moderate	High	Low
	BU_A2_2. Annual energy audits	Moderate	Moderate	Moderate	High	Moderate	High	None
	BU_A3_1. Green roofs	Moderate	High	Moderate	High	Moderate	Very high	Low

(Table 5.6 continues)

		Initial investment cost (scale 1-5)	Technical difficulty (scale 1-5)	Speed of implementation (scale 1-3)	Social compatibility (scale 1-3)	Effectiveness (scale 1-3)	Positive side effects (scale 1-5)	Negative side effects (scale 1-5)
EXISTING PRIVATE BUILDINGS	**BU_B1_1.** Energy efficiency consulting services (incl. campaigns)	Low	Low	High	High	Low	Very high	Moderate
	BU_B1_2. Retrofit grants and subsidies	Very High	Very low	Moderate	High	High	Very high	Moderate
	BU_B1_3. Local workforce training on energy efficient retrofitting	Low	Low	High	High	Low	High	Low
	BU_B2_1. Distribution of smart meters to businesses and residents	Moderate	Low	High	Moderate	Moderate	High	Low
	BU_B3_1. Green roof consulting services (incl. education campaigns)	Low	Low	High	High	Low	Very high	Moderate
	BU B3_2. Green roof grants and subsidies	High	Very low	Moderate	High	Moderate	Very high	Moderate
	BU_B3_3. Local workforce training on green roof knowledge	Low	Low	High	High	Low	High	Low

5.2.5 Stage V: Definition of Thresholds and Weights of the Criteria

Next step is the definition of the thresholds and weights for each criterion. A threshold is a boundary value that is chosen to establish limits to a criterion. As described in section 4.2, three types of thresholds are used in ELECTRE III to take into account the imperfect nature of evaluations:

(1) the preference threshold, denoted by p_i, to define the point from which an action is preferred in relation to another action.

(2) The indifference threshold, denoted by q_i, to define an interval within two actions which are considered equal.

(3) The veto threshold, denoted by v_i, to define a limit beyond which the credibility of the outranking relation of two actions is refused.

The selected thresholds for the hypothetical case study are shown in Table 5.7. Since all the criteria are expressed in qualitative scales (based on five levels or less), for simplicity, the indifference threshold was set to “0” (in other words any difference matters) and the preference threshold to “1”. In the case of the veto function for each criterion, the selection was made on the basis of ensuring that potentially “no-regret” actions are higher ranked than the rest. “No regret” actions are here defined as the actions that can bring positive results (GHG emissions reductions) without a serious lock-in of financial and technical resources, and most importantly without involving hard trade-offs (negative side effects) with other sustainability objectives.

To this end, for the first two criteria, veto has been set to “4” to avoid that an action with a “very high” investment cost (i.e. scored with “5”) will outrank an action with a “very low” cost (i.e. scored with “1”) if performing better on the rest of the criteria, and similarly that an action with a “very high” level of technical difficulty – and therefore technical effort – will outrank an action with a “very low” technical difficulty. The same applies to the criterion *positive side effects* to ensure that under any circumstances actions associated with "very high" potential for synergies are ranked higher that the ones with non-apparent positive side effects (however, as shown in Table 5.6 in the case of BU actions, all of them score either "high" or "very high" on this criterion – thus, essentially, the veto selected is inactive for the ranking of this particular set of actions). In the case of negative side effects, the veto threshold is set to more conservative levels, that is to "3", to indicate the particular importance of this criterion with regard to no-regret actions. For the next three criteria, *speed of implementation*, *social compatibility* and *effectiveness* the veto function is disabled (i.e. it is set to "3", which is anyway greater than any difference in performances that can occur on these criteria).

Table 5.7 additionally shows the direction of preference for each criterion, denoted as dp_i. For this initial analysis the weights (w_i) are assumed equal, to reflect a situation where no criterion is favoured over another. However, in reality this is not usually the case. Weights that individual DMs attribute to each criterion vary considerably. For example, when a municipality with restricted resources is unable to find external funding to finance a great part of the climate actions, it is logical that greater importance will be given to cost-related criteria.

Table 5.7. Selected thresholds and direction of preference for each criterion (Source: Present author).

	Initial investment cost (scale 1-5)	Technical difficulty (scale 1-5)	Speed of implementation (scale 1-3)	Social compatibility (scale 1-3)	Effectiveness (scale 1-3)	Positive side effects (scale 1-5)	Negative side effects (scale 1-5)
q_i	0	0	0	0	0	0	0
p_i	1	1	1	1	1	1	1
v_i	4	4	3	3	3	4	3
dp_i	min	min	max	max	max	max	min
w_i	0.143	0.143	0.143	0.143	0.143	0.143	0.143

5.2.6 Stage VI: Results of the MCDA

Based on the performance values the 17 actions in the BU area of intervention obtained under consideration of seven criteria (Table 5.6), and on the determination of the different preference functions (Table 5.7), ELECTRE III has been performed using the ElectreIII_R tool (see Section 4.3). On the basis of the credibility table (Figure 5.1) and its visualization (Figure 5.2), already first conclusions can be drawn on the relations between actions. For example, looking at the actions BU_B1_2 and BU_B3_2, it already becomes clear that they will end up at the same position in the final ranking (the same degree of credibility occurs both ways – i.e. "0,86" – see Figure 5.2), but not at which position exactly. The final result of ELECTRE III is a partial ranking allowing for incomparability, which is built through the intersection of two primary pre-rankings, the ascending and the descending ranking (all depicted in Figure 5.3).

One can observe that nearly all "low-hanging fruit" actions – namely, the actions that are of low cost and can be applied almost immediately and without significant technical effort – are ranked in the first 3 positions. This can easily be noticed by examining the detailed evaluations of the two actions ranked higher (i.e. BU_A1_4 and BU_A1_5 – see Table 5.8). Their performance is identical and on "positive side" on all criteria, except *effectiveness*. Clearly, BU_A1_4 is ranked higher than BU_A1_5 due to its greater potential for GHG reductions. On the other hand, the two actions ranked lower (BU_A2_1 and BU_A1_7) are the ones needing a greater commitment in financial, technical and time resources to yield benefits, which are, however, of a considerable level. This result does not mean that these actions should not be taken into account. It rather means that their overall advantageousness needs a more thorough analysis. For example, there are many European projects at the moment aiming at supporting EU members in the uptake of deep renovation (i.e. action BU_A1_7) and overcome the technical and financial barriers (European Commission, 2015d).

	BU_A1_1	BU_A1_2	BU_A1_3	BU_A1_4	BU_A1_5	BU_A1_6	BU_A1_7	BU_A2_1	BU_A2_2	BU_A3_1	BU_B1_1	BU_B1_2	BU_B1_3	BU_B2_1	BU_B3_1	BU_B3_2	BU_B3_3
BU_A1_1	1.00	0.86	0.86	0.57	0.57	0.57	1.00	1.00	1.00	0.86	0.43	0.57	0.57	0.71	0.43	0.71	0.57
BU_A1_2	0.86	1.00	1.00	0.71	0.71	0.71	1.00	0.86	0.86	0.71	0.57	0.57	0.71	0.71	0.57	0.71	0.71
BU_A1_3	0.86	1.00	1.00	0.71	0.71	0.71	1.00	0.86	0.86	0.71	0.57	0.57	0.71	0.71	0.57	0.71	0.71
BU_A1_4	0.86	0.86	0.86	1.00	0.86	1.00	1.00	1.00	0.86	0.86	0.86	0.57	1.00	1.00	0.86	0.71	1.00
BU_A1_5	0.71	0.71	0.71	0.86	1.00	1.00	0.86	0.86	0.71	0.71	0.86	0.71	1.00	0.86	0.86	0.71	1.00
BU_A1_6	0.71	0.71	0.71	0.86	0.86	1.00	0.86	0.86	0.71	0.71	0.86	0.57	1.00	0.86	0.86	0.57	1.00
BU_A1_7	0.57	0.57	0.57	0.57	0.44	0.57	1.00	0.86	0.57	0.71	0.38	0.44	0.57	0.57	0.38	0.71	0.57
BU_A2_1	0.57	0.43	0.43	0.43	0.25	0.43	0.86	1.00	0.57	0.71	0.27	0.25	0.43	0.71	0.27	0.44	0.43
BU_A2_2	1.00	0.86	0.86	0.57	0.57	0.57	1.00	1.00	1.00	0.86	0.43	0.57	0.57	0.71	0.43	0.71	0.57
BU_A3_1	0.71	0.57	0.57	0.57	0.44	0.57	1.00	1.00	0.71	1.00	0.57	0.71	0.57	0.71	0.57	0.86	0.57
BU_B1_1	0.71	0.71	0.71	0.71	0.71	0.86	0.71	0.71	0.71	0.71	1.00	0.71	0.86	0.71	1.00	0.71	0.86
BU_B1_2	0.71	0.57	0.57	0.00	0.00	0.00	0.71	0.71	0.71	0.71	0.00	1.00	0.00	0.57	0.00	0.86	0.00
BU_B1_3	0.71	0.71	0.71	0.86	0.86	1.00	0.86	0.86	0.71	0.71	0.86	0.57	1.00	0.86	0.86	0.57	1.00
BU_B2_1	0.71	0.71	0.71	0.71	0.57	0.71	0.86	1.00	0.71	0.71	0.57	0.43	0.71	1.00	0.57	0.57	0.71
BU_B3_1	0.71	0.71	0.71	0.71	0.71	0.86	0.71	0.71	0.71	0.71	1.00	0.71	0.86	0.71	1.00	0.71	0.86
BU_B3_2	0.71	0.71	0.71	0.57	0.57	0.57	0.86	0.71	0.71	0.71	0.71	0.86	0.57	0.57	0.71	1.00	0.57
BU_B3_3	0.71	0.71	0.71	0.86	0.86	1.00	0.86	0.86	0.71	0.71	0.86	0.57	1.00	0.86	0.86	0.57	1.00

Figure 5.2. The complete credibility table (Source: Present author).

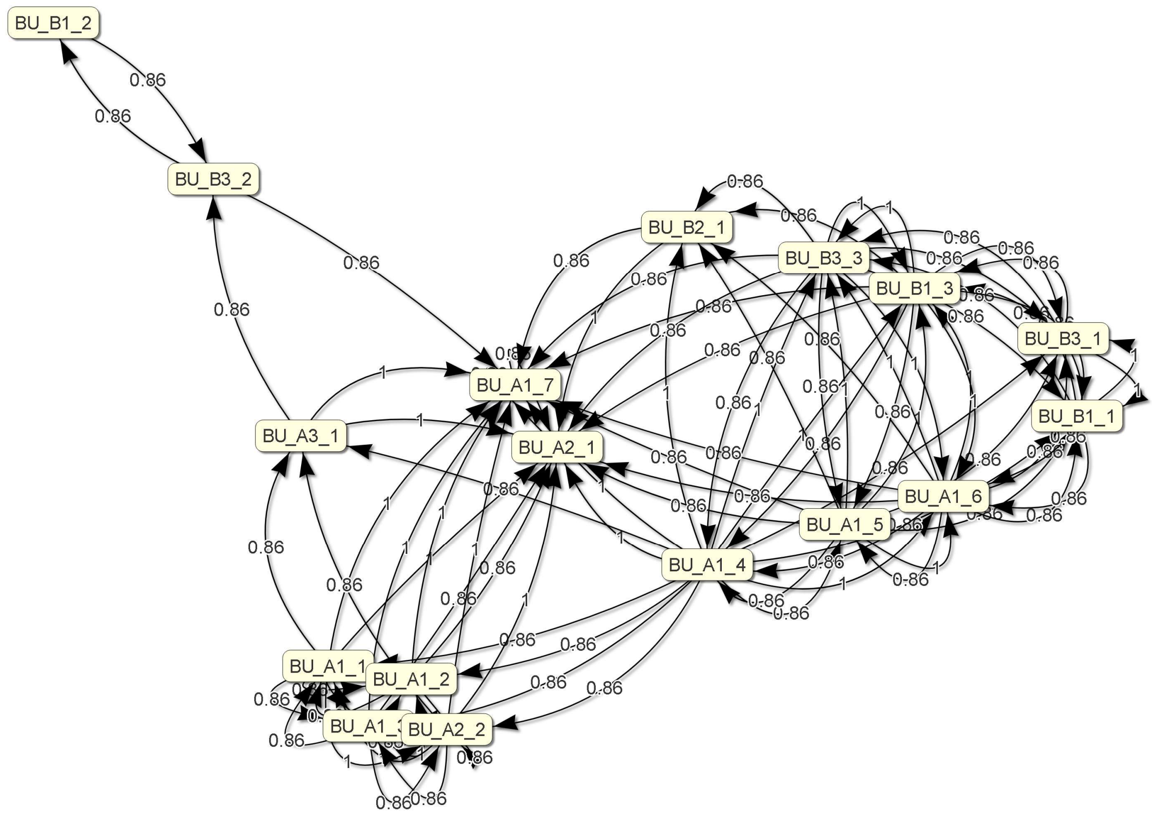


Figure 5.3. Visualisation of the complete credibility table with a cut-off of 0,80 for simplification (Source: Present author)

c) Dominance Matrix

	BU_A1_4	BU_A1_5	BU_A1_1	BU_A1_2	BU_A1_3	BU_A1_6	BU_A2_2	BU_A3_1	BU_B1_3	BU_B2_1	BU_B3_3	BU_B1_1	BU_B3_1	BU_B1_2	BU_B3_2	BU_A1_7	BU_A2_1
BU_A1_4	I	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
BU_A1_5	NP	I	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
BU_A1_1	NP	NP	I	NP	NP	NP	I	I	NP	P	NP	R	R	R	R	P	P
BU_A1_2	NP	NP	P	I	I	I	P	P	I	P	I	P	P	P	P	P	P
BU_A1_3	NP	NP	P	I	I	I	P	P	I	P	I	P	P	P	P	P	P
BU_A1_6	NP	NP	P	I	I	I	P	P	I	P	I	P	P	P	P	P	P
BU_A2_2	NP	NP	I	NP	NP	NP	I	I	NP	P	NP	R	R	R	R	P	P
BU_A3_1	NP	NP	I	NP	NP	NP	I	I	NP	P	NP	R	R	R	R	P	P
BU_B1_3	NP	NP	P	I	I	I	P	P	I	P	I	P	P	P	P	P	P
BU_B2_1	NP	NP	NP	NP	NP	NP	NP	NP	NP	I	NP	R	R	R	R	P	P
BU_B3_3	NP	NP	P	I	I	I	P	P	I	P	I	P	P	P	P	P	P
BU_B1_1	NP	NP	R	NP	NP	NP	R	R	NP	R	NP	I	I	P	P	P	P
BU_B3_1	NP	NP	R	NP	NP	NP	R	R	NP	R	NP	I	I	P	P	P	P
BU_B1_2	NP	NP	R	NP	NP	NP	R	R	NP	R	NP	NP	NP	I	R	P	P
BU_B3_2	NP	NP	R	NP	NP	NP	R	R	NP	R	NP	NP	NP	R	I	P	P
BU_A1_7	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	I	I
BU_A2_1	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	I	I

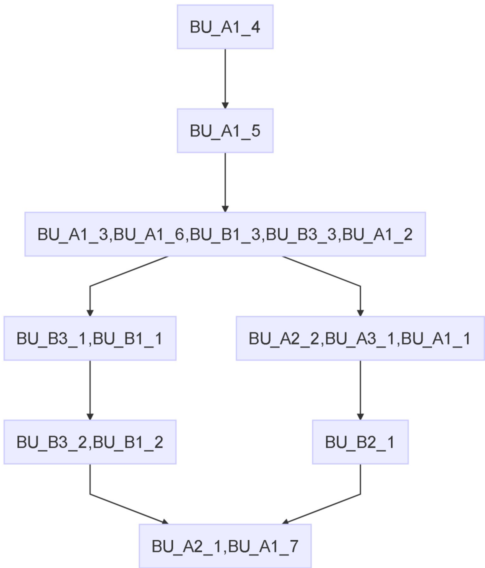
a) Descending pre-order

Action	Rank
BU_A1_4	1
BU_A1_5	2
BU_A1_1	3
BU_A1_2	3
BU_A1_3	3
BU_A1_6	3
BU_A2_2	3
BU_A3_1	3
BU_B1_3	3
BU_B2_1	3
BU_B3_3	3
BU_B1_1	4
BU_B3_1	4
BU_B1_2	5
BU_B3_2	6
BU_A1_7	7
BU_A2_1	7

b) Ascending pre-order

Action	Rank
BU_A1_7	5
BU_A2_1	5
BU_B2_1	4
BU_A1_1	3
BU_A2_2	3
BU_A3_1	3
BU_B1_2	2
BU_A1_2	1
BU_A1_3	1
BU_A1_4	1
BU_A1_5	1
BU_A1_6	1
BU_B1_1	1
BU_B1_3	1
BU_B3_1	1
BU_B3_2	1
BU_B3_3	1

d) Final ranking



alternative	ranking
BU_A1_4	1
BU_A1_5	2
BU_A1_2	3
BU_A1_3	3
BU_A1_6	3
BU_B1_3	3
BU_B3_3	3
BU_B1_1	4
BU_B3_1	4
BU_A1_1	5
BU_A2_2	5
BU_A3_1	5
BU_B1_2	6
BU_B3_2	6
BU_B2_1	7
BU_A1_7	8
BU_A2_1	8

Figure 5.4. Ranking-related results (according to the classical method), where: a) descending pre-order; b) ascending pre-order; c) dominance matrix; and d) final ranking derived from a), b) and c) (Source: Present author). Note: "P", "NP", "I" and "R" indicate "weakly or strictly preferred", "not preferred", "indifferent" and "incomparable", respectively.

Table 5.8. The performance evaluations of the two higher and two lower ranked actions resulted from the application of ELECTRE III (Source: Present author).

		Initial investment cost (scale 1-5)	Technical difficulty (scale 1-5)	Speed of implementation (scale 1-3)	Social compatibility (scale 1-3)	Effectiveness (scale 1-3)	Positive side effects (scale 1-5)	Negative side effects (scale 1-5)
Higher ranked actions	**BU_A1_4.** Lighting	L	L	H	H	**M**	H	L
	BU_A1_5. Appliances and electronics	L	**VL**	H	H	L	H	L
…	**…**	…	…	…	…	…	…	…
	…	…	…	…	…	…	…	…
Lower ranked actions	**BU_A2_1.** Energy management solutions and smart meters	M	H	M	**M**	M	H	L
	BU_A1_7. Integrated retrofit/renovation action	**H**	H	M	H	M	H	L

Note: Where "VL" = Very Low, "L" = Low, "M" = Moderate and "H" = High. Highlighted in red are the letters that indicate where the differences lie between the two higher ranked actions, as well as between the two lower ranked actions.

5.2.7 Stage VII: Sensitivity Analysis

In general, sensitivity analysis is a well-known technique used to investigate how changes in values of independent variables will affect a particular dependent variable under a given set of conditions. In the case of ELECTRE III, the ranking can be considered as being stable if the effect of any change is minor. Usually the first and simplest step is the variation of the weights of the different criteria. In the tool *ElectreIII_R*, this can be done in real time – weights can be changed directly in the tool, while showing the resulting ranking simultaneously. For the sensitivity analysis in the context of the hypothetical example, four “extreme” profiles of DMs – as they can typically be found in most neighbourhoods and municipalities – are defined and compared (Table 5.9). More specifically, it is assumed that each one of the “extreme” DMs highlights one single criterion more than the others by assigning to it a 40% weight, and therefore almost plus 25% of its original value (14,3% - that is, the scenario with the equalized weights). The other weights are decreased accordingly.

Table 5.9. Description of the five scenarios (Source: Present author).

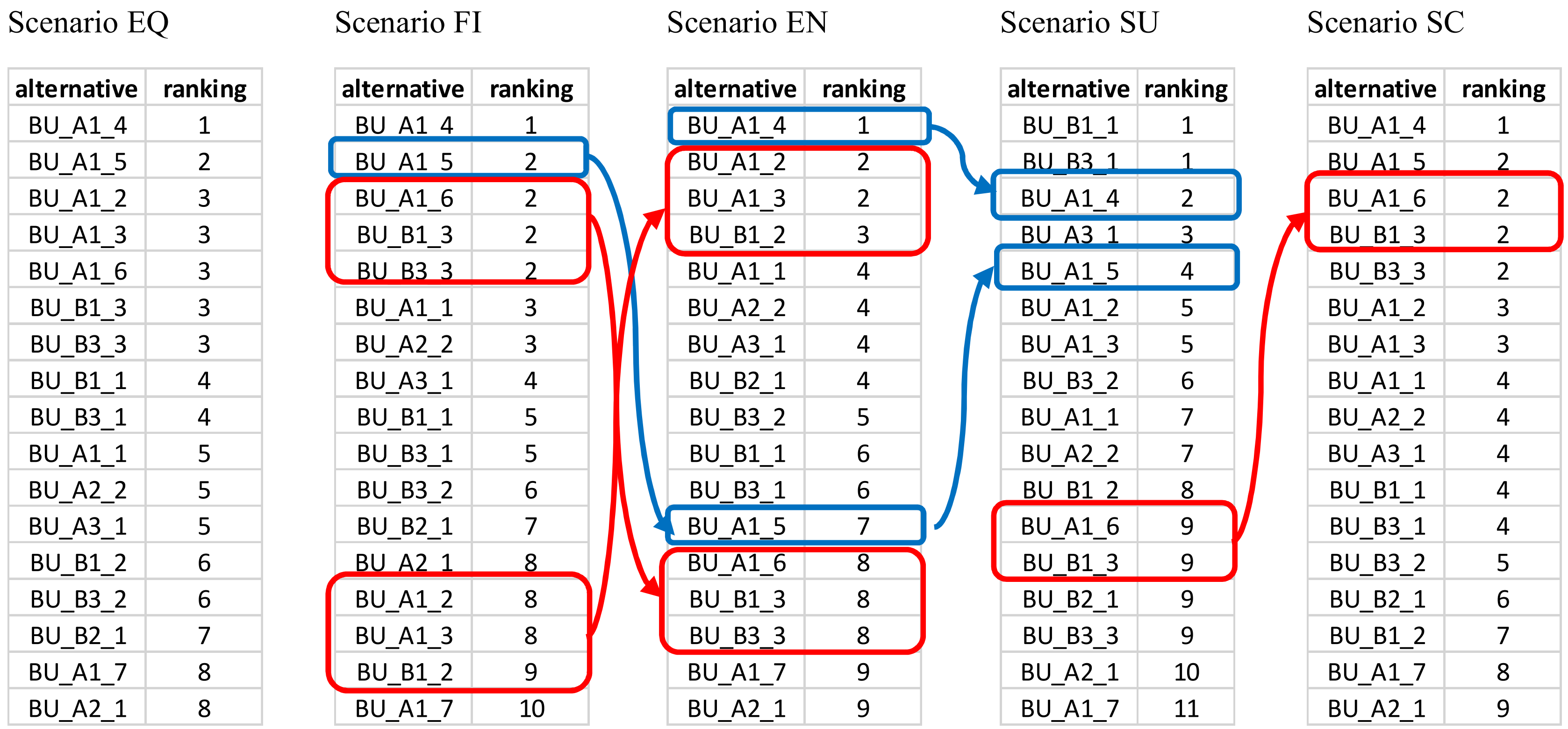
Scenarios	**Criteria weights**						
	C_1	C_2	C_3	C_4	C_5	C_6	C_7
Scenario EQ: Uniform criteria weights	0.143	0.143	0.143	0.143	0.143	0.143	0.143
Scenario FI: Priority to financial aspects (C_1)	0.40	0.10	0.10	0.10	0.10	0.10	0.10
Scenario SC: Priority to social compatibility (C_4)	0.10	0.10	0.10	0.40	0.10	0.10	0.10
Scenario EN: Priority to environmental aspects (C_4)	0.10	0.10	0.10	0.10	0.40	0.10	0.10
Scenario SU: Priority to sustainability as a whole (C_6)	0.10	0.10	0.10	0.10	0.10	0.40	0.10

For example, the DM concentrating on financial aspects may be a treasurer, the DM emphasizing GHG emission reductions may be an environmental activist, and the DM highlighting the overall positive side effects (that can be environmental, economic and social) may be a sustainability expert. Furthermore, the DM focusing on social compatibility may be a mayor seeking to safeguard or enhance his personal image or he/she may even the representative of a neighbourhood association. Figure 5.4 shows and compares the results of the sensitivity analysis on the different scenarios. Clearly, this experiment leads to changes in the ranking, and in some cases with significant differences being observed in the ranks.

However, Figure 5.5 reveals that the first action is stable; BU_A1_4 consistently ranks the highest, with the exception of Scenario SU, where it only moves one position. This confirms the domination of action BU_A1_4. Consistency in the ranking is also noticeable with respect to the lowest ranked actions, which nearly always stay at the very last two positions. With regard to BU_A1_5, relative stability can also be observed in the sense that it ranks at the same position (2) for three out of the five scenarios; yet, it slips as many as five positions in the case of Scenario EN. This is reasonable considering that its *effectiveness* relating to GHG reduction potential is on the low spectrum.

Nevertheless, the largest gaps appear in the comparison of the financial (FI) and environmental (EN) scenarios, where entire groups of actions move upwards and downwards in the rank as many as six positions. Therefore, for some actions, the criteria *initial investment cost* and *effectiveness* (i.e. GHG reduction potential) are potentially conflicting. Finally, the general conclusion that can be drawn from this analysis is that, although for some scenarios a high degree of stability can be observed (i.e. Scenarios EQ, FI and SC) with particular actions moving maximum one position upwards or downwards along the rank, the situation significantly changes when environmental aspects become the focus. In literature, more researchers observed this phenomenon in similar sensitivity analyses applied to ELECTRE III results (Pamučar et al., 2017); however, compared to other MCDA methods, the rankings produced by ELECTRE III are proved by several comparative studies as being among the most stable (Chitsaz & Banihabib, 2015).

However, the above-described approach is only one way of examining the stability of a problem with regard to changing weights. Another way is the analysis of stability intervals, which are intervals with a lower and upper bound indicating the range in which the weight of a criterion can be changed without affecting the ranking (Markl-Hummel & Geldermann, 2014). The purpose of such an analysis is to identify the most sensitive criterion – namely, the one that leads to changes in the ranking when its weight is modified the less. Additional sensitivity analysis could be performed on the other chosen preference functions, that is the indifference, preference and veto thresholds, or even on the performance values that specific criteria obtain, when these are subject to high levels of uncertainty.



Scenario EQ

alternative	ranking
BU_A1_4	1
BU_A1_5	2
BU_A1_2	3
BU_A1_3	3
BU_A1_6	3
BU_B1_3	3
BU_B3_3	3
BU_B1_1	4
BU_B3_1	4
BU_A1_1	5
BU_A2_2	5
BU_A3_1	5
BU_B1_2	6
BU_B3_2	6
BU_B2_1	7
BU_A1_7	8
BU_A2_1	8

Scenario FI

alternative	ranking
BU_A1_4	1
BU_A1_5	2
BU_A1_6	2
BU_B1_3	2
BU_B3_3	2
BU_A1_1	3
BU_A2_2	3
BU_A3_1	4
BU_B1_1	5
BU_B3_1	5
BU_B3_2	6
BU_B2_1	7
BU_A2_1	8
BU_A1_2	8
BU_A1_3	8
BU_B1_2	9
BU_A1_7	10

Scenario EN

alternative	ranking
BU_A1_4	1
BU_A1_2	2
BU_A1_3	2
BU_B1_2	3
BU_A1_1	4
BU_A2_2	4
BU_A3_1	4
BU_B2_1	4
BU_B3_2	5
BU_B1_1	6
BU_B3_1	6
BU_A1_5	7
BU_A1_6	8
BU_B1_3	8
BU_B3_3	8
BU_A1_7	9
BU_A2_1	9

Scenario SU

alternative	ranking
BU_B1_1	1
BU_B3_1	1
BU_A1_4	2
BU_A3_1	3
BU_A1_5	4
BU_A1_2	5
BU_A1_3	5
BU_B3_2	6
BU_A1_1	7
BU_A2_2	7
BU_B1_2	8
BU_A1_6	9
BU_B1_3	9
BU_B2_1	9
BU_B3_3	9
BU_A2_1	10
BU_A1_7	11

Scenario SC

alternative	ranking
BU_A1_4	1
BU_A1_5	2
BU_A1_6	2
BU_B1_3	2
BU_B3_3	2
BU_A1_2	3
BU_A1_3	3
BU_A1_1	4
BU_A2_2	4
BU_A3_1	4
BU_B1_1	4
BU_B3_1	4
BU_B3_2	5
BU_B2_1	6
BU_B1_2	7
BU_A1_7	8
BU_A2_1	9

Figure 5.5. Changes in the ranking according to the five different scenarios. The changes in the ranking of the first two actions is highlighted in “blue”, while the changes in the ranking highlighted in “red” indicate the most extreme changes observed in general (Source: Present author).

As the purpose of the hypothetical case study is to demonstrate the strength of MCDA methods to improve transparency and comprehensibility for the DMs, the application of systematic sensitivity analyses is out of scope. For a wide range of sensitivity analyses with ELECTRE III, one may refer to Chitsaz & Banihabib (2015), Matulaitis et al. (2016) and Spyridi et al. (2015).

5.3 Discussion and Summary

The analysis of the hypothetical case study by means of the ELECTRE III method showed that using MCDA as a decision-making tool can be an asset in handling the complexity of a multi-actor decision problem. Especially, in the case of ELECTRE III, the fact that it requires the definition of a whole set of preference parameters highlights the importance of a dialogue and to follow a continuous process-oriented approach through the whole SUD process. The application of the ELECTRE III model also showed that it can be a valuable tool not only to assess and evaluate the various possibilities of action but also to easily communicate the outcomes to the stakeholders involved. The application of the web-based tool ElectreIII_R developed by the present author allowed reducing the overall time of this exercise while providing sophisticated visualisations of the outcomes. This implies that such a tool would be well adapted to municipalities or local partnerships with a limited budget.

The possibility of ranking actions on the basis of various and often conflicting and incommensurable criteria provides the various stakeholders with useful information that combined with both expert and local knowledge can comprise a basis for action planning within the context of SUD. The ELECTRE III model provides a helpful decision-making platform for DMs to develop more effective and consensus-based action plans, without, however, giving a definitive answer to the action prioritisation problem. The role of MCDA methods is solely limited to decision aiding; judgment and critical interpretation of the results from the DMs would still be required. This can also be considered as one of the main conclusions of the outcomes of the sensitivity analysis on different weights performed in the context of the hypothetical case (on the basis of assuming four extreme DM profiles favouring specific criteria over others for all the BU alternatives). The comparative analysis of the resulting rankings suggests that there are neither optimal nor absolute solutions in multi-stakeholder settings, but only compromised solutions. MCDA methods and procedures as such offer a platform for further negotiations over the “strategic neighbourhood development plan” (see Step 3.4 in the process framework) for achieving SUD while maintaining equivocal participation of the multiple actors. Perhaps local leaders that truly embrace such approaches will not only be able to make better-informed decisions, but also enhance their reputation in the eyes of the community in which they operate.

6 Summary and Conclusions

This chapter, after reintroducing the main points with regard to research relevance (Section 6.1), summarizes the key contributions of this thesis (Section 6.2). Then the main conclusions are drawn and recommendations are formulated for the advancement of current SUD practices (Section 6.3). Finally, the limitations of the present research are explained (Section 6.4) and an outlook is provided (Section 6.5).

6.1 Research Relevance

Today, cities are challenged by a growing urbanization that goes hand-in-hand with a reinforcement of already existing environmental challenges. It is remarkable that although cities occupy a tiny proportion of Earth's land surface, their residents' environmental footprint is enormous, being responsible for more than two-thirds of GHG emissions (UN-Habitat, 2011). With challenges come opportunities. In this new urban age, the quest for sustainable urban development becomes a topic of crucial importance with several influential initiatives at the policy and practice level involved.

On the policy level, recent political international agreements determining sustainable development priorities for the years to come imply that no matter how ambitious the global goals for sustainable development are, without the consideration of cities they are predestined to fail (Koch & Ahmad, 2018). In the context of the 2030 Agenda, "sustainable cities and human settlements" (Goal 11) is one of its 17 Global Sustainable Development Goals (SDGs) and it paves the way for fully transformative urban commitments and principles.

Considering that population growth would predominantly occur in developing countries, urban sustainability efforts in Europe will need to be directed towards retrofitting actions. Indeed, Europe is an old continent with much retrofit to undergo. In this sense, for European cities the imperative is rather to decrease their environmental impact while maintaining their quality, and not to design sustainable urban areas from scratch.

In the science and practice arenas, an increasing recognition of neighbourhoods as a more manageable unit of analysis compared to cities with respect to investigating the possibilities of achieving SUD in a certain urban setting is clearly observed (Xia et al., 2015; Sharifi & Murayama, 2014; Berardi, 2013). The neighbourhood scale is considered as crucial with respect to testing new and innovative approaches and solutions to identify successes and failures, before moving to a full implementation at the city scale. Furthermore, local actors can identify themselves better with their neighbourhood than their city. In this sense, it is also considered a spatial scale where the encouragement and enablement of sustainable lifestyles of the residents is easier compared to a city, because the successes of SUD become tangible aspects of their daily life.

In the practice interface, recent years have also seen a proliferation of sustainability assessment systems for cities and neighbourhoods – with each one of them representing a different attempt to translate urban sustainability into a set of indicators and/or processes – which emerged in the light of the need to measure, and sometimes award or certify attainment of or progress towards sustainability outcomes. Although their contribution to advance SUD is undoubtedly significant, Chapter 2 of this thesis revealed that a large cluster of these systems are certification-centric in the sense that they place central emphasis on certification (sometimes alternatively referred to as “accreditation”, “labelling” or “endorsement”). as the final goal. This feature is often accompanied by fixed and predefined sets of indicators that lead to aggregated performance scores to form the basis for awarding certification without possibilities to adapt these sets to the local context.

Although rigid and certification-centric approaches relying on static assessments may be particularly attractive to private sector actors, there is some indication that they may not be welcomed by local authorities or leaders working towards transforming the urban area(s) in which they operate. The main reason is the fear of stigmatisation in case of a poor performance at the point in time the assessment takes place. An important disadvantage stigmatisation may bring is that potential investors interested in engaging in urban transformation processes may be discouraged by such results and focus on areas with more low hanging fruits to offer (Lützkendorf & Balouktsi, 2017).

The oversimplification of the city or the neighbourhood into a bundle of predictable and controllable factors and processes, cannot serve the complexities inherent in the improvement of existing neighbourhoods and should not be the approach to be strived for in such cases. SUD is a continuously evolving process and not a fixed endpoint. Existing systems can stimulate initiative but they cannot support the process itself. Rethinking SUD practices in neighbourhood projects is now an imperative that calls for more "process-based" approaches, where community participation plays a strong role in the planning process and in outcomes.

This thesis contributes to the ongoing discussion of the "paradigm shift" and fills the gap by proposing a conceptual "process-based" and "action-oriented" overall framework for planning SUD at neighbourhood scale in the European context. The individual contributions made to theory and practice in the effort to answer the research questions defined in Chapter 1 is discussed in the following in detail.

6.2 Main Results and Contributions

Already the analysis of NSASs currently used to support SUD and the development of a typology for their categorization can be considered as a first sub-result of this thesis. The extensive analysis and systematisation of the different NSASs to identify the gaps in the current approaches that go beyond the critical points typically discussed in literature can also be seen as a (secondary) contribution in itself.

The main result is the development of a new "process-based" and "action-oriented" approach presented in the form of a generic and comprehensive overall framework to support the SUD of neighbourhoods, and by extension cities. Given the dominance of certification-driven approaches of a prescriptive and static nature, and inspired by the clear statement of Elinor Ostrom, winner of the 2009 Nobel Prize in economics, "*Without a common framework to organize findings, isolated knowledge does not cumulate*.", the research carried out through this work developed a new integrative conceptual framework that combines a process-based and action-oriented approach to provide comprehensive and consistent guidance to decision making during the planning phase of a neighbourhood-scale SUD in the European context. Such a framework until now, has not been available, despite the related extensive discussions found in literature. This overall framework answered the first overarching question for this research:

"How can the current practice of sustainable urban development on a neighbourhood level be improved to overcome the weaknesses of certification-oriented concepts?"

The overall framework is comprised of three parts. The first part, referred to as the *process framework*, constitutes a comprehensively structured step-by-step workflow model representing a "good practice" process of SUD. In literature, it now well-acknowledged that SUD is a dynamic process that requires continual stakeholder engagement combined with continual monitoring, assessment and continuous improvement. However, the provision of concrete solutions and detailed frameworks to guide the process is still in its infancy. The process framework can be seen as a contribution to this direction of research.

The *process framework* answered the first three sub-questions as follows:

(1) *What specific quality requirements can ensure a high-quality SUD process (e.g. a more effective, co-creative and "open" process)?*

(2) *How can the SUD process be organised into distinct and interconnected steps?*

(3) *How can stakeholder involvement be addressed at each step of the SUD process?*

To answer the first sub-question, this thesis combined two streams of information and knowledge: the insights gained from literature on the most critical procedural/institutional aspects (i.e. aspects of the institutional pillar of sustainable development) of SUD overlooked by current practices were complemented and contrasted by perspectives gained by the present researcher through her participation in workshops and meetings of the collaborative project Urban Transition Lab 131 (R131), which aims to achieve SUD of the district of Karlsruhe Oststadt by means of a transdisciplinary process (Quartier Zukunft, 2017). On this basis, a list of nine generalisable process quality requirements was defined and described that ensure the integrity of the SUD process and alignment to the institutional principles of sustainable development. Because there is no universally accepted definition of what constitutes a high-quality SUD process, this set of QRs can be seen as an attempt to fill this gap and potentially stimulate further discussions on this topic.

The second and third sub-questions were explored simultaneously. To provide a comprehensive answer to both sub-questions, this thesis analysed the process of SUD into a logical sequence of distinct and interconnected phases and steps placing the main emphasis on the pre-implementation phase. Decisions taken at this phase lay the groundwork for the next phases. Decomposing the complex (planning) process of SUD into its constituent parts enabled the identification of specific tasks and challenges inherent in each step, so that to propose appropriate guidance. While this work-flow approach simplifies the analysis of the SUD process, it does not oversimplify the process itself viewing it as a single task. Looking at each step individually, it was possible to identify which steps of the process are purely technical and which ones could benefit from a wide stakeholder participation/involvement and in what way. In this thesis the use of the term participation is not used as a buzzword as often done in literature, but the model manifested varying degrees and types of participation for each step of the SUD process. Always pursuing the highest level of participation in the context of a good "culture of governance" is neither reasonable nor meaningful for some steps of a highly technical nature.

The second part of the overall framework, referred to as the *assessment framework*, mainly provides (1) a typology of indicators on the basis of their underlying function and (2) a model of "top-down" problem areas and themes, and partly indicators, identified, selected and systemised in a formal way to support monitoring and assessing progress towards SUD. Although a general description of a good practice can be provided for bottom-up processes, these cannot be easily (and maybe they should not be) generalised to their very core, since they are always dependent on the context of the individual cases. On the other hand, general frameworks describing key top-down processes can be constructed and be relevant across multiple contexts within one region (Europe in the case of this research), since they are grounded on pre-existing knowledge.

The *assessment framework* therefore deals with the framing of the "assessment part" of the SUD process and its main contribution lies in offering a ready-to-use guide on: (1) the identification of important problem areas and themes actionable at the neighbourhood level as well as the selection of appropriate indicators, while establishing connections to the global SDGs, and (2) the description of indicators in a way that clearly supports a process- and action-based approach by means of developing "advanced fact sheets".

The *assessment framework* answered the next two research sub-questions, as follows:

(4) *What specific goals, themes and indicators relevant to European context need to be considered for assessing and monitoring SUD on a neighbourhood level?*

(5) *How indicators can be linked with actual possibilities for actions?*

To answer the fourth sub-question, it was first necessary that a conceptual framework is developed to offer a formal way of thinking in the identification and selection of important topics and indicators. Two types of systematisation were considered necessary: a functional and a thematic one. The first focused on the development of a typology of indicators depending on their *underlying function* (i.e. purpose), what they actually *intend to measure* (i.e. baseline, outcome/impact, output or process), and finally whether they can be "*directly influenced*" by interventions of local actors inside the individual district. The latter distinction is considered particularly important in order to orient the focus and efforts in more actionable (or action-oriented) and empowering indicators. Indicators themselves do not guarantee the implementation of actions on the ground, but they can become the catalysts that stimulate and mobilise local actors to deliver the desired outcomes and outputs.

This led to the treatment of background and context-related characteristics as a separate category of indicators within the assessment framework, referred to as *background indicators*. While background indicators are not measures of progress, they can help decision-makers understand why a neighbourhood performs the way it does. They can therefore be also seen as early warning indicators. Additionally, they help better understanding the dynamic process and recognize constraints. This is a missing concept from current practices, except the results of the parallel (but independent to this research) standardization activities (ISO 37120) which also go towards this direction and therefore support the present researcher's approach. Although the functional systematisation did not provide a direct answer to the fourth sub-question, it constituted the starting point: The identification of problem areas, themes and eventually indicators depends on whether these are influenceable on a neighbourhood level or not.

For the thematic systematisation, first broad protection goals were defined on the basis of a modified set of Areas of Protection (adjusted from ISO 21929-1). This constituted a "top-level" approach to this type of systematisation and builds on the notion that there are "resources" and "values" that should be always protected even if they are not conceived as problems yet by the society (therefore in respect of intergenerational equity). To identity more specific problem areas, deep screening of the SDGs and related targets potentially relevant to European neighbourhoods was initially performed to check how they are connected and whether certain targets share common themes. This also involved an examination of the list of sustainable development indicators to understand how the targets will be monitored. This immediately led to a preliminary identification of a set of broad problem areas potentially relevant to the European context and influenceable/actionable at the neighbourhood level. Second, the preliminary set of problem areas was checked against the EU SDG indicator set, which reflects the EU's own policy priorities, to broadly confirm its importance for the European context and to identify additional pressing issues for the European region that are not explicitly addressed in the SDG targets.

Finally, wishing to narrow down to the most urgent problems, it was checked whether Europe is on track to meet its own targets in certain areas on the basis of official statistics or academic research. This made possible to determine the problem areas with an urgent need for problem solving or investigation at finer scales of analysis. The problem areas (in some cases they were broken down into themes to make them more specific) was used as a basis for the extracting a common performance indicator set presented for illustration-related purposes only. This performance indicator set represents an open and flexible group of indicators which aims at stimulating action and not at rating or certification on the basis of aggregated (using weights) results. Therefore, in the design of the proposed set, complete independence between the indicators was not striven for to avoid double-counting. Finally, a set of *background indicators* was provided, again for illustrative reasons only, as it constitutes an important source of contextual information.

To answer the fifth sub-question, a concept of "advanced factsheets" was conceived and developed for describing indicators. This was called advanced because along the typical information covered in such indicator fact sheets such as information on the calculation procedures and data requirements, this advanced fact sheet establishes an initial informational basis to orient the action-planning process through the analysis of strategies according to: (1) the implementing individuals or groups of stakeholders (also denoted as "active/acting" stakeholders); (2) their options/opportunities for action under each strategy; (3) the individuals or groups of stakeholders affected by decisions and/or actions of active stakeholders (also denoted as "passive/affected" stakeholders). This constitutes a new, enlarged approach to describing indicators and provides a way of linking indicators with actual possibilities for action.

The third part of the overall framework, referred to as the *action prioritisation framework*, provides a common interpretive frame to evaluate strategies and actions as part of the "action planning" task of the SUD process, while integrating MCDA as a decision support tool to this end. To better illustrate the potential contribution of this framework to practice, it was applied on a hypothetical case study with the help of a web-based tool developed by the author, named ElectreIII_R. This tool facilitates the computations of the ELECTRE III method and produces high-quality visualisations of the results. It is well-acknowledged that having software support to implement an MCDA method, manage the information and visualise the results in a clear and dynamic manner can make the overall MCDA process more transparent and comprehensible. This web-based tool is a practical result that contributes to an increased adoption of such methods.

The *action prioritisation framework* answered the next two research sub-questions, as follows:

(6) *How can specific SUD strategies be identified, evaluated and selected?*

(7) *How can multi criteria decision analysis be used as a decision support tool in this context?*

The development of fact sheets already covers the first component of the sixth sub-question. For the evaluation and selection component of the question, an extensive literature review was conducted to identify the broad range of criteria that are considered specifically for the evaluation and selection of actions for climate protection, assuming that the same criteria apply to SUD actions (climate protection is an integral objective of SUD). On the basis of the commonalities observed in the recommended criteria in all these sources, the most commonly identified ones were gathered in a non-exhaustive exemplary criteria tree. This can serve as a fundamental value system to be customised for the local circumstances.

To answer the seventh sub-question, a hypothetical case study was developed to which the action prioritisation framework by means of the web-based tool ElectreIII_R was applied. This allowed to gain a more in-depth understanding in particular of the capabilities of MCDA to support the selection process of SUD strategies and actions. The application of the ELECTRE III model showed that (at least) outranking methods can be a valuable tool not only to assess and evaluate the various possibilities of action but also to easily communicate the outcomes to the stakeholders involved. The application of the web-based tool ElectreIII_R developed by the present author allowed reducing the overall time of this exercise while providing sophisticated visualisations of the outcomes. This implies that such a tool would be well adapted to municipalities or local partnerships with a limited budget.

6.3 Conclusions and Recommendations for Action

Ultimately, this thesis has proven that multiple fields can contribute to achieving SUD on a neighbourhood level. The overall value of this research is that it can support the public decision process in a neighbourhood in its endeavour to transition towards sustainability and builds on an interdisciplinary bundle of allied methods from sustainability science, environmental science, decision-aid science[11], including also in part computer science and data analysis to serve the latter. Furthermore, the present author acknowledges that there is a unique opportunity to align local efforts to newly adopted SDG vision, and especially SDG 11.

More specifically, the overall conceptual framework provides a repeatable and transferable approach across Europe that can support local DMs in three major tasks: (1) organising the SUD process itself; (2) monitoring and assessing the progress towards SUD; (3) evaluating, prioritising and selecting strategies and actions. It is not meant to be prescriptive, but only as comprehensive as possible to provide a common framework for future discussion.

To further advance the existing practices the following recommendations can be drawn:

- Neighbourhoods are comparable only to a limited extent; closed sustainability assessment systems quickly reach their limits; it is necessary to shift to more flexible and context-sensitive indicator sets that supplement top-down topics with specific local problems (combination with bottom-up approach).

- Indicators themselves do not guarantee actions; a shift from assessment-centric approaches to more action-oriented approaches is necessary. As an initial advancement in this direction, the descriptions of indicators must be supplemented by information on actors and possibilities for action.

[11] A term first concretised by Roy (1993)

- Sustainable urban development is an ongoing process and not a fixed target. In this sense, also benchmarks (target values) and baselines need updating along the process to adapt to evolving local realities and needs.

- Integrating process-related guidance and opportunities for stakeholder participation in the visioning, selection of indicators and designing of the action plan itself, empowers DMs with local knowledge of the living conditions in the neighbourhood and assists in gaining people's acceptance regarding the project to be launched. The up-to-date indicator-based frameworks should start shifting to a more process-oriented approach where guidance is focused on the process-related elements of the SUD endeavour and recommendations on specific indicators only take second stage.

- There are many possibilities for actions at the beginning of the process to choose among – the utilization of tools for preselecting strategies and actions is necessary.

- Standardisation activities in the field of SUD should be extended to the process of SUD and not only focus on providing large lists of indicators with which adopters should comply with. Additionally, the fear of double-counting must be overcome.

6.4 Limitations

This scientific research encountered some limitations. The design of the three resulted frameworks as integral parts of the overall conceptual framework are primarily based on extensive literature surveys and the discussions taking place within a closed group of researchers. This implies that the author's interpretation of the literature sources played a major role, despite efforts to systematically define the interpretations that led to classifications. Therefore, perhaps the most significant limitation is the absence of an interview or questionnaire survey of actors – and therefore real DMs – of various backgrounds and locations (e.g. only DMs from German municipalities would not be a representative sample for the European context) to get a real feeling, for example, of: (1) what are the aspects they value as important (i.e. what the problem areas, themes and indicators are which are absolutely necessary for SUD, but also actionable on a neighbourhood level from the DMs' perspective); what processes are typically followed during the planning phase of a SUD project; (3) what evaluation criteria they typically consider when deciding on which actions to implement. Cross-checking and complementing where necessary the contents of the three frameworks with feedback from real DMs would potentially increase their practical usefulness.

In connection to this, also application under real conditions of use has been missing so far. Furthermore, the ease of use of the web-based tool developed to serve the purposes of the application of ELECTRE III method could have been tested with experts or responsible persons of such tasks in real municipalities that could provide feedback through a short online questionnaire connected directly to the tool. Finally, in connection to the set of common performance indicators that is provided for illustration purposes, filled in fact sheets could have been provided for all of the presented indicators in the common performance indicator set and not only for one (i.e. the indicator "energy-related GHG emissions expressed in CO_2 equivalents"). This was however not the objective of this research.

6.5 Outlook

This thesis supports the idea of an "open" indicator set that allows for multiple perspectives in order to take account of the specific information needs and the concrete options for action of individual actors. However, the ideology inherent in a commitment to openness and flexibility is fundamentally at odds with the current ideology of "systems" of indicators that have to follow specific weighting and aggregation rules to lead to certification. In this context, the following questions emerge:

- How can the current systems evolve into open indicator sets if still interested in staying marketable and provide some sort of accreditation to the adopters? Can these two approaches be combined?

Perhaps in future lessons can be drawn from the application of newly emergent process-based tools such as EcoDistricts (EcoDistricts, 2016) that provide accreditation for committing to a specific procedure and not for adopting a specific list of indicators. Until now, no observations are recorded in literature on how process-based certification works in praxis (also the exact contents of the prescribed procedures are not fully provided) and therefore future research can go towards this direction. Of course, creating open indicator sets presupposes the creation of mechanisms that foster collaboration between actors. But this is not the only precondition; community participation presupposes that certain willingness to participate is present. This leads to the next emergent question:

- What are the right engagement strategies per stakeholder group? And in this context, how to create effective communication messages that simplify complex concepts tailored to the mental model of each targeted stakeholder, especially lay persons with non-technical background?

Communication without technical jargon and powerful visualisation techniques are important for creating a sense of urgency and willingness to participate. Shome et al. (2009) specifically explored the psychology behind communicating the controversial topic of climate change. This study can form a starting point to expand research on how to more effectively communicate environment-related topics to a non-technical public. This is especially important in the action planning phase where the messages communicated from indicators can eventually define the willingness to act.

Finally, on the policy level, the introduction of subsidies that prioritise projects that can provide evidence of participatory and collaborative approaches and consideration of a multitude of stakeholders across various groups and sectors are necessary for a fast stimulation of the needed “shift” to new paradigms.

The present author hopes that these comments will encourage further research in this important field.

References

ADUPC. (2010, April). The Pearl Rating System for Estidama. Community, Building and Villa Rating System, Design & Construction, Version 1.0. Abu Dhabi, UAE: Abu Dhabi Urban Planning Council.

Ahvenniemi, H., Huovila, A., Pinto-Seppä, I., Airaksinen, M. (2017). What are the differences between sustainable and smart cities? *Cities, 60*, 234-245.

Almende, B.V., Thieurmel, B., & Robert, T. (2017). visNetwork: network visualization using 'vis.js' Library. 2017. Retrieved December 27, 2017, from https://CRAN.R-project.org/package=visNetwork

Al-Shalabi, M. A., Mansor, S. B., Ahmed, N. B., & Shiriff, R. (2006, October 8-13). GIS based multicriteria approaches to housing site suitability assessment. In *XXIII FIG Congress, Shaping the Change* (pp. 8-13). Munich, Germany.

Alvarenga, R. A. F., Lins, I. d. O., & Almeida Neto, J. A. d. (2016). Evaluation of abiotic resource LCIA methods. *Resources*, 5(1), 13.

Annema, J. A., Mouter, N., & Razaei, J. (2015). Cost-benefit analysis (CBA), or multi-criteria decision-making (MCDM) or both: politicians' perspective in transport policy appraisal. *Transportation Research Procedia, 10,* 788-797.

Arnstein, S. R. (1969). A ladder of citizen participation. *Journal of the American Institute of planners, 35*(4), 216-224.

Asadi, E., Da Silva, M. G., Antunes, C. H., & Dias, L. (2012). Multi-objective optimization for building retrofit strategies: A model and an application. *Energy and Buildings*, *44*, 81-87.

Assad, A. A., & Gass, S. I. (Eds.). (2011). *Profiles in operations research: pioneers and innovators* (Vol. 147). New York, NY: Springer Science & Business Media

Ayik, C., Ayatac, H., & Sertyesilisik, B. (2017). A Gap Analysis on Urban Sustainability Studies and Urban Sustainability Assessment Tools. *Architecture Research, 7*(1), 1-15.

Azevedo, I., Delarue, E., & Meeus, L. (2013). Mobilizing cities towards a low-carbon future: Tambourines, carrots and sticks. *Energy policy, 61*, 894-900.

Balouktsi, M., Lützkendorf, T., Kopfmüller, J. & Parodi, O. (2013). Sustainable neighbourhoods: Challenges for research, policy and planning. SB13. In: *Proceedings of the Sustainable Buildings: Implementing Sustainability - Barriers and Chance Conference*, *April 24-26, 2013* (pp.217-219). Munich: Fraunhofer IRB Verlag.

Balouktsi, M., Lützkendorf, T., Kopfmüller, J., & Stelzer, V. (2017). Creating Methods, Procedures and Tools for a More Sustainable Neighbourhood Development – Experiences from Germany. In: *Proceedings of the World Sustainable Built Environment Conference, June 5-7, 2017* (pp. 2272-2278). Hong Kong: Construction Industry Council (CIC) and the Hong Kong Green Building Council (HKGBC).

Batty, M. (2008). The size, scale, and shape of cities. *Science, 319*(5864), 769–771.

BBSR, & BBR. (2017). *CO2-neutral in cities and neighbourhoods – the European and international perspective.* BBSR-Online-Publikation 10/2017, Bonn. Retrieved March 20, 2018, from https://www.bbsr.bund.de/BBSR/EN/Publications/OnlinePublications/2017/bbsr-online-10-2017-dl.pdf?__blob=publicationFile&v=3

Behzadian, M., Kazemzadeh, R. B., Albadvi, A., & Aghdasi, M. (2010). PROMETHEE: A comprehensive literature review on methodologies and applications. *European journal of Operational research*, *200*(1), 198-215.

Belton, V., & Stewart, T. J. (2002). *Multiple Criteria Decision Analysis - An Integrated Approach*. Berlin, Germany: Springer Science & Business Media.

Berardi, U. (2013). Sustainability assessment of urban communities through rating systems. *Environment, Development and Sustainability, 15*(6), 1573–1591.

Berardi, U. (2015). Sustainability assessments of buildings, communities, and cities. In J.J. Klemeš(Ed.), *Assessing and Measuring Environmental Impact and Sustainability* (Chapter 15, pp. 497–545). Oxford, UK: Butterworth-Heinemann.

Beumer, C., & Martens, P. (2015). Biodiversity in my (back) yard: towards a framework for citizen engagement in exploring biodiversity and ecosystem services in residential gardens. *Sustainability Science, 10*(1), 87-100.

BMUB (Federal Ministry for the Environment, Nature Conservation, Buildings and Nuclear Safety). (2016). Climate Action Plan 2050. Principles and goals of the German government's climate policy. Retrieved May 20, 2017, from https://www.bmu.de/en/publication/climate-action-plan-2050-principles-and-goals-of-the-german-governments-climate-policy/

Bosch, P., Jongeneel, S., Rovers, V., Neumann, H., Airaksinen, M., & Huovila, A. (2017). CITYkeys Indicators for Smart City Projects and Smart Cities. CITYkeys. Retrieved June 24, 2017 from http://nws.eurocities.eu/MediaShell/media/CITYkeysD14Indicatorsforsmartcityprojectsandsmartcities.pdf

Bossel, H. (1996). Deriving indicators of sustainable development. *Environmental Modeling and Assessment*, *1*(4), 193-218.

Boyle, L., Michell, K. (2017). Urban facilities management: A systemic process for achieving urban sustainability. *International Journal of Sustainable Development and Planning, 12*, 446–456.

Brannigan, C., Biedka, M., Hitchcock, G., & Fiorello, D. (2017). *Study on urban mobility–Assessing and improving the accessibility of urban areas.* (Final report and policy proposals). Brussels: European Commission, Directorate-General for Mobility and Trasport & Directorate B – Investement, Innovation & Sustainable Transport.

Brans, J.P., Vincke, P., & Mareschal, B. (1986). How to Select and How to Rank Projects: The Method. *European Journal of Operational Research, 24*(2), 228–238.

Brenner, J. (Ed.). (2013). Anforderungen an energieeffiziente und klimaneutrale Quartiere (EQ): Ein Projekt des Forschungsprogramms Experimenteller Wohnungs- und Städtebau des Bundesministeriums für Verkehr, Bau und Stadtentwicklung (BMVBS) betreut vom Bundesinstistitut für Bau-, Stadt- und Raumforschung (BBSR), volume 81 of Werkstatt, stand: juni 2013 ed., Bonn, 2013. Retrieved July 18, 2017, from http://nbn-resolving.de/urn:nbn:de:101:1-2013111379.

Broc, J. S., Trauchessec, E., & Milin, C. (2015). Revisiting the KfW and Green Deal programmes: it's not all about finance! In: *Proceedings of the ECEEE Summer Study, 1-6 June 2015* (paper 2-150-15, pp. 321-331). Presqu'île de Giens, France: ECEEE (European Council for an Energy Efficient Economy).

Broto, V. C., & Bulkeley, H. (2013). A survey of urban climate change experiments in 100 cities. *Global Environmental Change*, *23*(1), 92-102.

Brown, D. (2009, October). *Good practice guidelines for indicator development and reporting*. Paper presented at the Third OECD World

Forum on “Statistics, Knowledge and Policy”: Charting Progress, Building Visions, Improving Life, Busan, South Korea (pp. 27-30).

Cailloux, O., Tervonen, T., Verhaegen, B., & Picalausa, F. (2014). A data model for algorithmic multiple criteria decision analysis. *Annals of Operations Research, 217*(1), 77-94.

CAT-MED. (2009, May). Proximity to basic services. Retrieved December 20, 2016, from http://www.catmed.eu/dic/en/61/proximity-to-basic-services

CBD Secretariat. (2010). The strategic plan for biodiversity 2011–2020 and the Aichi biodiversity targets. Document UNEP/CBD/COP/DEC/X/2. Nagoya, Japan: Secretariat of the Convention on Biological Diversity. Retrieved November 15, 2017, from https://www.cbd.int/doc/strategic-plan/2011-2020/Aichi-Targets-EN.pdf

Chang, W., & Borges Ribeiro, B. (2017). Shinydashboard: Create Dashboards with ‘Shiny’. Version 0.6.1. Retrieved August 11, 2017, from https://cran.r-project.org/package=shinydashboard

Chang, W., Cheng, J., Allaire, J., Xie, Y., & McPherson, J. (2017). Shiny: Web Application Framework for R. R package version 1.0.3. Retrieved August 11, 2017, from https://cran.r-project.org/package=shiny

Chapple, K. (2014). *Planning sustainable cities and regions: Towards more equitable development.* New York: Routledge.

Charlot-Valdieu, C., Outrequin, P., Robbins, C., & Symes, M. (2004). The HQE2R toolkit for sustainable neighborhood regeneration and European application overview. Paris: CSTB - Scientific and Technical Center for Building. Retrieved May 20, 2017, from https://www.scribd.com/document/10162836/HQE2R-English-Basics

Chitsaz, N., & Banihabib, M. E. (2015). Comparison of different multi criteria decision-making models in prioritizing flood management alternatives. *Water Resources Management*, *29*(8), 2503-2525.

Cinelli, M., Coles, S. R., & Kirwan, K. (2014). Analysis of the potentials of multi criteria decision analysis methods to conduct sustainability assessment. *Ecological Indicators*, *46*, 138-148.

Cities Alliance. (2015, November 23). Sustainable Development Goals and Habitat III: Opportunities for a Successful New Urban Agenda. Cities Alliance Discussion Paper No.3. Retrieved May 15, 2017, from http://www.citiesalliance.org/sites/citiesalliance.org/files/Opportunities%20for%20the%20New%20Urban%20Agenda.pdf

City of Berlin. (2014). Climate-Neutral Berlin 2050: Results of a Feasibility Study. Retrieved September 9, 2017, from https://www.berlin.de/senuvk/klimaschutz/studie_klimaneutrales_berlin/download/Machbarkeitsstudie_Berlin2050_EN.pdf

City of Copenhagen. (2012). CPH 2025 Climate Plan: A green, smart and carbon neutral city. Retrieved May 18, 2017, from http://kk.sites.itera.dk/apps/kk_pub2/pdf/983_jkP0ekKMyD.pdf

City Protocol Society. (2015, November 6). CPA-PR_002_Anatomy Indicators. City anatomy indicators. Retrieved May 18, 2017, from http://cityprotocol.org/publications/

Climate Action Tracker. (2017, November 6). Country Summary. EU. Retrieved May 29, 2017, from https://climateactiontracker.org/countries/eu/

ClimateTechWiki. (n.d.). Retrieved May 17, 2017, from http://www.climatetechwiki.org/

CLUE. (2015). CLUE - Climate Neutral Urban Districts in Europe. A project within the INTERREG IVC programme. Retrieved July 18, 2017, from http://www.clue-project.eu/

Coenen, F. (2009). Local Agenda 21: 'meaningful and effective'participation? In F. Coenen (Ed.), *Public participation and better environmental decisions* (pp. 165-182). Dordrecht, Netherlands: Springer.

Conticelli, E., Proli, S., & Tondelli, S. (2017). Integrating energy efficiency and urban densification policies: Two Italian case studies. *Energy and Buildings, 155*, 308-323.

Cooper, I. (2017). Sustainable Urban Development–Where Are You Now? In P. S. Brandon, P. Lombardi & G. Q. Shen (Eds.), *Future Challenges in Evaluating and Managing Sustainable Development in the Built Environment* (pp. 69-90). New Jersey, US: Wiley-Blackwell

Creighton, H. (2014, November 5). Europe's ageing demography. ILC-UK2014 EU Factpack. Retrieved February 10, 2017, from http://www.ilcuk.org.uk/images/uploads/publicationpdfs/Europes_Ageing_Demography.pdf

Crescenzo, M., Bottero, M., Berta, M., & Ferretti, V. (2018). Governance and Urban Development Processes: Evaluating the Influence of Stakeholders Through a Multi-criteria Approach—The Case Study of Trieste. In: *Proceedings of the International conference on Smart and Sustainable Planning for Cities and Regions: Results of SSPCR 2017, March 22-24, 2017* (pp. 503-522). Bolzano/Bozen, Italy: Springer International Publishing.

Curwell, S. (2017). Integrating Sustainable Urban Development. In P. S. Brandon, P. Lombardi & G. Q. Shen (Eds.), *Future Challenges in Evaluating and Managing Sustainable Development in the Built Environment* (Chapter 15). Chichester, UK: John Wiley & Sons, Ltd.

DEFRA. (2017). Emissions Factors Toolkit v8. User Guide. Retrieved March 20, 2018, from https://laqm.defra.gov.uk/review-and-assessment/tools/emissions-factors-toolkit.html

De Iuliis, M. (2017). Rethinking the Role of Time in Sustainable Urban Development. In P. S. Brandon, P. Lombardi & G. Q. Shen (Eds.), *Future Challenges in Evaluating and Managing Sustainable Development in the Built Environment* (Chapter 18). Chichester, UK: John Wiley & Sons, Ltd.

De Montis, A., De Toro, P., Droste-Franke, B., Omann, I., & Stagl, S. (2004). Assessing the quality of different MCDA methods. In *Alternatives for environmental valuation* (pp. 115-149). Routledge.

Decision Deck Consortium (2018). Diviz. Retrieved January 23, 2018, from https://www.diviz.org/

Dempsey, N., Bramley, G., Power, S., & Brown, C. (2011). The social dimension of sustainable development: Defining urban social sustainability. *Sustainable development, 19*(5), 289-300.

Dewulf, J., Benini, L., Mancini, L., Sala, S., Blengini, G. A., Ardente, F., ... & Pennington, D. (2015). Rethinking the area of protection "natural resources" in life cycle assessment. *Environmental science & technology, 49*(9), 5310-5317.

Dings, J., & Jensen, G. (2011). *Quiet Please: Better Health through Strong EU Regulation of Road and Rail Traffic Noise.* Brussels, Belgium: T&E – European Federation for Transport and Environment, & HEAL – Health and Environment Alliance. Retrieved January 23, 2017, from https://www.transportenvironment.org/publications/quiet-please-better-health-through-strong-eu-regulation-road-and-rail-traffic-noise

Dodgson, J., Spackman, M., Pearman, A., & Phillips, L. (2009). *Multi-Criteria Analysis: A Manual*. London: Department for Communities and Local Government. Retrieved May 15, 2017, from http://eprints.lse.ac.uk/12761/1/Multi-criteria_Analysis.pdf

EcoDistricts (2016). EcoDistricts Protocol. The New Standard for Community Development. Version 1.2 Retrieved March 14, 2017, from https://ecodistricts.org/get-started/the-ecodistricts-protocol/

Economist Intelligence Unit. (2011). *Liveanomics: Urban Liveability and Economic Growth* (A report from the Economist Intelligence Unit). Retrieved March 12, 2017, from The Economist website: https://www.eiuperspectives.economist.com/

Elgert, L. (2018). Rating the sustainable city: ‘Measurementality’, transparency, and unexpected outcomes at the knowledge-policy interface. *Environmental Science & Policy, 79*, 16–24.

Eltges, M., & Hamann, C. (2010). Leipzig Charta zur nachhaltigen europäischen Stadt: Wo steht Europa. *Informationen zur Raumentwicklung*, *4*, 303-311.

Energy-efficient urban redevelopment. (n.d.). Energy-efficient Urban Redevelopment Programme: Tapping the potential of neighbourhoods. Retrieved December 10, 2017, from https://www.energetische-stadtsanierung.info/

Erman, M. (2014). Climate neutral urban districts–the smartest form of a city’s districts? In: *Proceedings of the REAL CORP 2014–PLAN IT SMART! Clever Solutions for Smart Cities: 19th International Conference on Urban Planning, Regional Development and Information Society, 21-23 May 2014* (pp. 831-838). Vienna, Austria: CORP–Competence Center of Urban and Regional Planning.

European Commission (2008) Directive 2008/98/EC of the European Parliament and of the council of 19 November 2008 on waste. *Official Journal of the European Union*, L 312/13.

European Commission. (2010a, March 3). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. EUROPE 2020. A strategy for smart, sustainable and inclusive growth. COM (2010) 2020 final. Retrieved May 10, 2017, from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:2020:FIN:EN:PDF

European Commission. (2010b, July 20). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Towards a European road safety area: policy orientations on road safety

2011-2020. COM (2010) 389 final. Retrieved April 10, 2017, from https://www.eea.europa.eu/publications/noise-in-europe-2014

European Commission. (2011, May 3). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Our life insurance, our natural capital: an EU biodiversity strategy to 2020. COM (2011) 244 final. Retrieved April 10, 2017, from https://eur-lex.europa.eu/procedure/EN/200491

European Commission. (2014a). *Guide to Cost-Benefit Analysis of Investment Projects Economic Appraisal Tool for Cohesion Policy 2014-2020.* Brussels: European Union.

European Commission. (2014b, April 4). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. On effective, accessible and resilient health systems. COM (2014) 215 final. Retrieved April 10, 2017, from https://ec.europa.eu/health/sites/health/files/healthcare/docs/com2014_215_final_en.pdf

European Commission. (2015a). *The EU explained: Ten priorities for Europe.* Luxembourg: Publications Office of the European Union.

European Commission. (2015b, October 2). Report from the Commission to the European Parliament and the Council. The mid-term review of the EU Biodiversity Strategy to 2020. COM (2015) 478 final. Retrieved April 16, 2017, from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52015DC0478

European Commission. (2015c, December 2). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Closing the Loop – an EU Action Plan for the Circular Economy. COM

(2015) 0614 final. Retrieved April 20, 2017, from http://eur-lex.europa.eu/legal content/EN/TXT/?uri=CELEX:52015DC0614

European Commission. (2015d). Old meets green: New technologies to retrofit buildings in Europe. Retrieved November 15, 2017, from http://cordis.europa.eu/article/id/400003-retrofitting-buildings_en.html

European Commission. (2016). A new comprehensive Digital Skills Indicator. Retrieved November 15, 2017, from https://ec.europa.eu/digital-single-market/en/news/new-comprehensive-digital-skills-indicator

European Commission. (2017). *Noise, a hidden health threat*. Magazine Environment for Europeans. Retrieved April 10, 2018, from: https://ec.europa.eu/environment/efe/themes/urban-noise-and-health/noise-hidden-health-threat_en

European Commission. (2018). *Mobility and transport. Road safety. S*tatistics - accidents data. Retrieved April 19, 2018, from https://ec.europa.eu/transport/road_safety/specialist/statistics_en

European Commission & Eurostat (2017, May 31). EU SDG INDICATOR SET. Final version of 28 April 2017 as agreed with Commission Services, which received a favourable opinion by the European Statistical System Committee at its meeting of 17-18 May 2017. Retrieved April 10, 2018, from http://ec.europa.eu/eurostat/documents/276524/7736915/EU-SDG-indicator-set-with-cover-note-170531.pdf

European Council (2014, October 23-24) Conclusions on 2030 Climate and Energy Policy Framework. Retrieved April 10, 2017, from https://www.eea.europa.eu/policy-documents/european-council-23-24-10

European Environment Agency (EEA). (2014). *Noise in Europe 2014*. (EEA Report No 10/2014). Retrieved April 10, 2017, from https://www.eea.europa.eu/publications/noise-in-europe-2014

European Environment Agency (EEA). (2016). *Land recycling in Europe — Approaches to measuring state and impacts* (EEA Report No 31/2016). Retrieved April 10, 2017, from https://www.eea.europa.eu/publications/land-recycling-in-europe

European Environment Agency (EEA). (2017). *Air quality in Europe — 2017 report* (EEA Report No 13/2017). Retrieved February 10, 2018, from https://www.eea.europa.eu/publications/air-quality-in-europe-2017

European Parliament (2017, November 27). Renewable energy: setting ambitious targets for Europe. Retrieved April 10, 2018, from http://www.europarl.europa.eu/news/en/headlines/economy/20171124STO88813/renewable-energy-setting-ambitious-targets-for-europe

European Parliament and Council. (2002). Directive 2002/49/EC relating to the assessment and management of environmental noise. Brussels: Publications Office of the European Union.

Eurostat. (2017a). *Quality of life in Europe - facts and views - economic and physical safety.* Retrieved April 10, 2018, from http://ec.europa.eu/eurostat/statistics-explained/index.php/Quality_of_life_in_Europe_-_facts_and_views_-_economic_and_physical_safety

Eurostat. (2017b). *Sustainable Development in the European Union — Monitoring report on progress towards the SDGs in an EU context.* doi: 10.2785/237722

Eurostat. (2018). *Housing statistics*. Retrieved April 10, 2018, from http://ec.europa.eu/eurostat/

Fancello, G., Carta, M., & Fadda, P. (2014). A decision support system based on Electre III for safety analysis in a suburban road network. *Transportation Research Procedia, 3,* 175-184.

Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR) within the Federal Office for Building and

Regional Planning (BBR) (Ed.). (2017). *CO2-neutral in cities and neighbourhoods – the European and international perspective.* Bonn: BBSR-Online-Publikation 10/2017.Retrieved July 18, 2017, from https://www.bbsr.bund.de/BBSR/EN/Publications/OnlinePublications/2017/bbsr-online-10-2017-dl.pdf?__blob=publicationFile&v=3

Figueira, J., Greco, S., & Ehrgott, M. (2005). *Multiple criteria decision analysis state of the art surveys.* New York: Springer.

Figueira, J. R., Greco, S., Roy, B., & Słowiński, R. (2010). ELECTRE Methods: main features and recent developments. In C. Zopounidis & P. M. Pardalos (Eds.), *Handbook of Multicriteria Analysis* (pp. 51-89). Berlin-Heidelberg: Springer.

Figueira, J. R., Greco, S., Roy, B., & Słowiński, R. (2013). An overview of ELECTRE methods and their recent extensions. *Journal of Multi-Criteria Decision Analysis*, *20*(1-2), 61-85.

Figueira, J. R., Mousseau, V., & Roy, B. (2016). ELECTRE methods. In S. Greco, M. Ehrgott, & J.R. Figueira (Eds.), *Multiple Criteria Decision Analysis: State of the Art Surveys* (pp. 155-185). New York, NY: Springer.

Finnveden, G., Hauschild, M. Z., Ekvall, T., Guinée, J., Heijungs, R., Hellweg, S.,….Suh, S. (2009). Recent developments in Life Cycle Assessment. *Journal of Environmental Management, 91,* 1−21.

Fiorello, D., Martino, A., Zani, L., Christidis, P., & Navajas-Cawood, E. (2016). Mobility data across the EU 28 member states: results from an extensive CAWI survey. *Transportation Research Procedia, 14,* 1104-1113.

Fitzgerald, J., Tumber, T., & Corley, S. (2014). District-Scale Sustainability Scan. Boston, MA: Northeastern University Resilient Cities Lab. Retrieved April 10, 2017, from https://www.fundersnetwork.org/files/learn/

Gamboa, G., & Munda, G. (2007). The Problem of Windfarm Location: A Social Multi-Criteria Evaluation Framework. *Energy Policy, 35*(3), 1564–1583.

Garde, A. (2009). Sustainable by design: Insights from U.S. LEED-ND pilot projects. *Journal of the American Planning Association, 75*, 424–440.

Gasparatos, A., Doll, C. N., Esteban, M., Ahmed, A., & Olang, T. A. (2017). Renewable energy and biodiversity: Implications for transitioning to a Green Economy. *Renewable and Sustainable Energy Reviews, 70*, 161-184.

Genus, A., & Theobald, K. (2016). Creating low-carbon neighbourhoods: a critical discourse analysis. *European Urban and Regional Studies, 23*(4), 782-797.

Gerber, J. F. (2013). *Guide on multicriteria evaluation for Environmental Justice Organisations* (EJOLT Report No.: 08). Retrieved May 20, 2017, from http://www.ejolt.org/

Gesing, F. (2017, June 12). *The New Global Covenant of Mayors for Climate & Energy and the Politics of Municipal Climate Data* (ZenTra Working Paper in Transnational Studies No.: 71/2017). Retrieved January 22, 2018, from https://ssrn.com/abstract=2984761

Giannoulis, C., & Ishizaka, A. (2010). A Web-based decision support system with ELECTRE III for a personalised ranking of British universities. *Decision Support Systems, 48*(3), 488-497.

Gil, J., & Duarte, J. P. (2013). Tools for evaluating the sustainability of urban design: a review. In: *Proceedings of the ICE-Urban Design and Planning*, *December 2013* (Vol.166(6), pp. 311-325). ICE Publishing.

Global Commission on the Economy and Climate. (2014, September 23). Better growth, better climate: the new climate economy report. Washington, DC: World Resources Institute. Retrieved May 17, 2017, from www.newclimateeconomy.report

Global Taskforce of Local and Regional Governments, UNDP, & UN-Habitat. (2016). *Roadmap for Localising the SDGs: Implementing and Monitoring at Subnational Level.* New York, NY: Global Task-Force of Local and Regional Governments, UNDP, & UN-Habitat.

Gómez-Navarro, T., García-Melón, M., Díaz-Martín, D., & Acuna-Dutra, S. (2008). Evaluation of urban development proposals: An ANP approach. *World Academy of Science, Engineering and Technology, 44.*

Gouldson, A., Colenbrander, S., Sudmant, A., Papargyropoulou, E., Kerr, N., McAnulla, F., & Hall, S. (2016). Cities and climate change mitigation: economic opportunities and governance challenges in Asia. *Cities, 54*, 11-19.

Govindan, K., & Jepsen, M. B. (2016). ELECTRE: A comprehensive literature review on methodologies and applications. *European Journal of Operational Research*, *250*(1), 1-29.

Grau-Bové, J., & Strlič, M. (2013). Fine particulate matter in indoor cultural heritage: a literature review. *Heritage science, 1*(1), 8.

Greene, S., & Meixell, B. (2017, September 7). Hacking the Sustainable Development Goals. Can US cities measure up? Washington, DC: Urban Institute.

Griggs, D.J., Nilsson, M., Stevance, A-S., & McCollum, D. (Eds). (2017). *A Guide to SDG Interactions: from Science to Implementation.* Paris: International Council for Science.

Grimble, R., & Wellard, K. (1997). Stakeholder methodologies in natural resource management: a review of principles, contexts, experiences and opportunities. *Agricultural systems, 55*(2), 173-193.

Guitouni, A., & Martel, J.M. (1998). Tentative guidelines to help choosing an appropriate MCDA method. *European Journal of Operational Research, 109*, 501–521.

Gustavsson, E., & Elander, I. (2016). Sustainability potential of a redevelopment initiative in Swedish public housing: The ambiguous role of residents' participation and place identity. *Progress in Planning, 103*, 1-25.

Haapio, A. (2012). Towards sustainable urban communities. *Environmental Impact Assessment Review 32*(1), 165-169.

Haase, D., Kabisch, N., & Haase, A. (2013). Endless urban growth? On the mismatch of population, household and urban land area growth and its effects on the urban debate. *PLoS One*, *8*(6), e66531.

Habitat III. (2016, September 10). New Urban Agenda. Draft Outcome Document for Adoption in Quito, Ecuador.

Häkkinen, T., Antuna, C., Mäkeläinen, T., Lützkendorf, T., Balouktsi, M., Immendörfer, A.,….Van Dessel, J. (2012*). Sustainability and performance assessment and benchmarking of building.* (SuPerBuildings –Final report). Tarja Häkkinen (Ed.). Espoo VTT Technical Research Centre of Finland. Retrieved May 17, 2017, from https://www.oegut.at/downloads/pdf/bi_superbuildings-final-report.pdf

Hansen, W., Christopher, M., & Verbuecheln, M. (2002). *EU Waste Policy and Challenges for Regional and Local Authorities* (Background Paper for the Seminar on Household Waste Management "Capacity Building on European Community's Environmental Policy"). Berlin: Ecologic, Institute for International and European Environmental Policy.

Hardi, P., & Zdan, T. (Ed.). (1997). *Assessing Sustainable Development: Principles in Practice.* Winnipeg, Manitoba, Canada: International Institute for Sustainable Development.

Hickel, J. (2016). The true extent of global poverty and hunger: questioning the good news narrative of the Millennium Development Goals. *Third World Quarterly, 37*(5),749-767.

Hiremath, R.B., Balachandra, P., Kumar, B., Bansode, S.S., & Murali, J. (2013). Indicator-based urban sustainability—A review. *Energy for Sustainable Development, 17,* 555–563.

Hoornweg, D., Bhada-Tata, P., & Kennedy, C. (2013). Waste Production must peak this century. *Nature, 502*, 615-617.

Hwang, C. L., & Yoon, K. (1981). *Multiple Attributes Decision Making Methods and Applications*. New York: Springer-Verlag.

Iacobuta, G., & Höhne, N. (2017). Low-carbon transition under Agenda2030: Climate-development trade-offs and synergies. Contribution to 2017 Interconnections Conference, Bonn 12-13 May 2017. NewClimate Institute.

Institute for Housing and Urban Development Studies – IHS. (2014). Climact Prio - Climate Actions Prioritization Tool. Retrieved July 18, 2017, from http://www.ihs.nl/research/research_projects/climact_prio_tool/

IPCC. (2007). *Climate Change 2007: Synthesis Report. Contribution of working groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and A. Reisinger (eds.)] Geneva, Switzerland: IPCC

IPCC. (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.), pp.151]. Geneva, Switzerland: IPCC.

IPCC. (2018). EFDP. Main Page. Retrieved May 20, 2018, from https://www.ipcc-nggip.iges.or.jp/efdb/main.php

ISO. (1987). *ISO 1996-2:1987 – Acoustics: Description and measurement of environmental noise - Part 2: Acquisition of data pertinent to land use.* Geneva, Switzerland: International Organization for Standardization.

ISO. (2003). *ISO/TS 15666:2003 – Acoustics – Assessment of noise annoyance by means of social and socio-acoustic surveys*. Geneva, Switzerland: International Organization for Standardization.

ISO. (2011). *ISO 21929-1:2011 - Sustainability in Building Construction – Sustainability Indicators – Part 1: Framework for the Development of Indicators and a Core Set of Indicators for Buildings*. Geneva, Switzerland: International Organization for Standardization.

ISO (2014). *ISO 37120:2014 - Sustainable Development of Communities: Indicators for City Services and Quality of Life*. Geneva, Switzerland: International Organization for Standardization.

ISO. (2015). *ISO 21929-2:2015 - Sustainability in building construction – sustainability indicators – part 2: framework for the development of indicators for civil engineering works*. Geneva, Switzerland: International Organization for Standardization.

ISO. (2016). *ISO 37101:2016 - Sustainable development in communities — Management system for sustainable development — Requirements with guidance for use*. Geneva, Switzerland: International Organization for Standardization.

ISO (2017). *ISO/FDIS 37120:2017 - Sustainable Development of Communities: Indicators for City Services and Quality of Life* (Version of 20-11-2017). Geneva, Switzerland: International Organization for Standardization.

Janssens, A., Rebollar, J. V., Himpe, E., & Delghust, M. (2016). Transforming social housing neighbourhoods into sustainable carbon neutral districts. *Energy Procedia*, *132*, 549-554.

Jeffreys, I. (2004). The use of compensatory and non-compensatory multi-criteria analysis for small-scale forestry. Small-scale Forest Economics. *Management and Policy, 3*(1), 99-117.

Joss, S., Cowley, R., de Jong, M., Müller, B., Park, B. S., Rees, W., ... Rydin, Y. (2015). *Tomorrow's City Today: Prospects for Standardizing Sustainable Urban Development.* London: University of Westminster.

Joss, S., & Rydin, Y. (2018). Prospects for Standardizing Sustainable Urban Development. In S. Bell & S. Morse (Eds.), *Routledge Handbook of Sustainability Indicators* (pp.364-378). London, UK: Routledge.

Kain, J. H., & Söderberg, H. (2008). Management of complex knowledge in planning for sustainable development: the use of multi-criteria decision aids. *Environmental Impact Assessment Review, 28*(1), 7-21.

Keeney, R.L. (1992). *Value-focused thinking: a path to creative decisionmaking*. Cambridge, MA: Harvard University Press.

Keeney, R. L., & Raiffa, H. (1976). *Decision with multiple objectives: Preferences and value tradeoffs*. New York: John Wiley & Sons.

KEK, DFIU, IREES GmbH, P&C. (2011). Klimaneutrales Karlsruhe 2050: Machbarkeitsstudie zur Klimaneutralität im Stadtkreis Karlsruhe. Retrieved July 18, 2017, from http://www.kek-karlsruhe.de/de/pdf/Machbarkeitsstudie_KA_klimaneutral_end.pdf

Kennedy, C., Bristow, D., Derrible, S., Mohareb, E., Saneinejad, S., Stupka, R., ... & McIntyre, B. (2010). Getting to Carbon Neutral: A Review of Best Practices in Infrastructure Strategy. In R.K. Bose (Ed.) *Energy Efficient Cities: Assessment Tools and Benchmarking Practices* (pp. 165-184). Washington, DC: World Bank.

Kent, J. L., & Thompson, S. (2014). The three domains of urban planning for health and well-being. *Journal of planning literature, 29*(3), 239-256.

Koch, F., & Ahmad, S. (2018). How to Measure Progress Towards an Inclusive, Safe, Resilient and Sustainable City? Reflections on Applying the Indicators of Sustainable Development Goal 11 in Germany and India. In S. Kabisch, F. Koch, E. Gawel, A. Haase, S. Knapp, K. Krellenberg, J. Nivala & A. Zehnsdorf (Eds.), Urban transformations - Sustainable urban development through resource efficiency, quality of life and resilience, Future City 10 (pp. 77 – 90). Cham, Switzerland: Springer International Publishing.

Koffi, B., Cerutti, A.K., Duerr, M., Iancu, A., Kona, A., Janssens-Maenhout, G. (2017). CoM Default Emission Factors for the Member States of the European Union - Version 2017. European Commission, Joint Research Centre (JRC) [Dataset]. Retrieved Match 20, 2018, from http://data.europa.eu/89h/jrc-com-ef-comw-ef-2017

Komeily, A., & Srinivasan, R.S. (2015). A need for balanced approach to neighborhood sustainability assessments: A critical review and analysis. *Sustainable Cities and Society, 18,* 32-43.

Komeily, A., & Srinivasan, R. S. (2016). What is neighborhood context and why does it matter in sustainability assessment?. *Procedia Engineering, 145*, 876-883.

Kopfmüller, J., Brandl, V., Jörissen, J., Paetau, M., Banse, G., Coenen, R., & Grunwald, A. (2001). *Nachhaltige Entwicklung integrativ betrachtet: Konstitutive Elemente, Regeln, Indikatoren*. Berlin: edition sigma.

Krikke, T., Hensen, J. L. M., Blocken, B. J. E., & Willems, E. M. M. (2011). *Assessment tools for sustainable district development*. Eindhoven University of Technology, Department of Architecture, Building and Planning Unit Building Physics and Systems, in cooperation with: Cauberg-Huygen Raadgevende Ingenieurs BV.

Kumar, A., Sah, B., Singh, A. R., Deng, Y., He, X., Kumar, P., & Bansal, R. C. (2017). A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. *Renewable and Sustainable Energy Reviews, 69,* 596-609.

Kyrkou, D., & Karthaus, R. (2011). Urban sustainability standards: Predetermined checklists or adaptable frameworks? *Procedia Engineering, 21*, 204–211.

Lei, T. L., & Church, R. L. (2010). Mapping transit-based access: integrating GIS, routes and schedules. *International Journal of Geographical Information Science, 24*(2), 283-304.

Leyva-Lopez, J. C., & Fernandez-Gonzalez, E. (2003). A new method for group decision support based on ELECTRE III methodology. *European Journal of Operational Research*, *148*(1), 14-27.

Li, C., & Li, J. (2017). Assessing Urban Sustainability Using a Multi-Scale, Theme-Based Indicator Framework: A Case Study of the Yangtze River Delta Region, China. *Sustainability, 9*(11), 2072.

Liobikienė, G., & Butkus, M. (2017). The European Union possibilities to achieve targets of Europe 2020 and Paris agreement climate policy. *Renewable Energy, 106,* 298-309.

Luederitz, C., Lang, D.J., & von Wehrden, H. (2013). A systematic review of guiding principles for sustainable urban neighborhood development. *Landscape and Urban Planning 118*, 40-52.

Lützkendorf, T., Balouktsi, M., Kopfmüller, J. & Albiez, M. (2016). Supporting urban district development by accompanying sustainability assessment. In: *Proceedings of the Sustainable Built Environment Conference, 7-11 March 2016* (pp. 1104-1113). Hamburg, Germany: ZEBAU.

Lützkendorf, T., & Balouktsi, M. (2017). Assessing a Sustainable Urban Development: Typology of Indicators and Sources of Information. *Procedia Environmental Sciences, 38,* 546-553.

Maclaren, V. W. (1996). Urban sustainability reporting. *Journal of the American planning association, 62*(2), 184-202.

Markl-Hummel, L., & Geldermann, J. (2014). A local-level, multiple criteria decision aid for climate protection. *EURO Journal on Decision Processes, 2*(1-2), 121-152.

Masterton, G.G.T., Findlay, T., Wright, M. & Smith, S.D. (2017). Infrastructure performance indicators – a new approach based on the Sustainable Development Goals. In: *Proceedings of the International Symposium for Next Generation Infrastructure, 11-13 September 2017* (pp. 268-282). London: UK Collaboratorium for Research on Infrastructure and Cities (UKCRIC).

Matulaitis, V., Straukaitė, G., Azzopardi, B., & Martinez-Cesena, E. A. (2016). Multi-criteria decision making for PV deployment on a multinational level. *Solar Energy Materials and Solar Cells*, *156*, 122-127.

McCarney, P. (2017). 2.4 Measuring and Monitoring Metropolitan Governance. the Metropolis. In D. Gómez-Álvarez, R.M. Rajack, E. López-Moreno & G. Lanfranchi (Eds.) *Steering the metropolis: metropolitan governance for sustainable urban development* (p. 186). Washington: IDB.

McDonough, W., & Braungart, M. (2002). *Cradle to Cradle – Remaking the Way We Make Things.* New York: North Point Press.

Mendoza, G. A., & Martins, H. (2006). Multi-criteria decision analysis in natural resource management: a critical review of methods and new modelling paradigms. *Forest ecology and management, 230*(1-3), 1-22.

Meyer, P., & Bigaret, S. (2012). Diviz: A software for modeling, processing and sharing algorithmic workflows in MCDA. *Intelligent decision technologies*, *6*(4), 283-296.

Milner, J., Davies, M., & Wilkinson, P. (2012). Urban energy, carbon management (low carbon cities) and co-benefits for human health. *Current Opinion in Environmental Sustainability, 4*(4), 398-404.

Morency, C., Trépanier, M., & Demers, M. (2011). Walking to transit: An unexpected source of physical activity. *Transport Policy, 18*(6), 800–806.

Munda, G. (2005). Measuring sustainability: A multi-criterion framework. *Environment, Development and Sustainability, 7*, 117–134.

Murphy, E., & King, E. (2014). *Environmental noise pollution: Noise mapping, public health, and policy.* Amsterdam [The Netherlands]; Boston: Elsevier

Mustajoki, J., & Marttunen, M. (2017). Comparison of multi-criteria decision analytical software for supporting environmental planning processes. *Environmental Modelling & Software, 93*, 78-91.

Nakazawa, M. (2017). fmsb: functions for medical statistics book with some demographic data. R package version 0.6.1. CRAN Project Org Package Fmsb. Retrieved March 29, 2018, from https://rdrr.io/cran/fmsb/

Nathan, H. S. K., & Reddy, B. S. (2012). Towards a conceptual framework for development of sustainable development indicators for an urban setup. *International Journal of Sustainable Development, 15*(3), 187-205.

Neugebauer, S., Forin, S., & Finkbeiner, M. (2016). From life cycle costing to economic life cycle assessment—introducing an economic impact pathway. *Sustainability, 8*(5), 428.

Neves, A. R., Blondel, L., Brand, K., Hendel-Blackford, S., Calvete, S. R., Iancu, A., Melica, G., Koffi, B., Zancanella, P., & Kona, A.(2016). *The Covenant of Mayors for Climate and Energy Reporting Guidelines, EUR 28160.* Luxembourg: Publications Office of the European Union.

Nieboer, N., Tsenkova, S., Gruis, V., & van Hal, A. (Eds.). (2012). *Energy efficiency in housing management: policies and practice in eleven countries.* London: Routledge.

Niemeijer, D., De Groot, R.S. (2008). A conceptual framework for selecting environmental indicators sets. *Ecological Indicators,* 8*,* 14–25.

Nilsson, M., Griggs, D., & Visbeck, M. (2016). Map the interactions between Sustainable Development Goals. *Nature, 534,* 320-322.

Norman, J., MacLean, H. L., & Kennedy, C. A. (2006). Comparing high and low residential density: life-cycle analysis of energy use and greenhouse gas emissions. *Journal of urban planning and development, 132*(1), 10-21.

Norese, M. F. (2006). ELECTRE III as a support for participatory decision-making on the localization of waste-treatment plants. *Land Use Policy*, *23*(1), 76-85.

Norwegian Ministry of children and equality (2009). Norway universally designed by 2025: The Norwegian government's action plan for universal design and increased accessibility 2009-2013. Retrieved June 29, 2017, from https://www.regjeringen.no/globalassets/upload/bld/nedsatt-funksjonsevne/norway-universally-designed-by-2025-web.pdf

Oberschmidt, J. (2010). *Multikriterielle Bewertung von Technologien zur Bereitstellung von Strom und Wärme.* Stuttgart, Germany: Fraunhofer Verlag.

Olivotto, V. (2014). *CLIMACT Prio: A Decision Support Tool for CLIMate ACTions Prioritization*. Resilient Cities 2014, 5th Global Forum on Urban Resilience and Adaptation, 29-31 May, 2014 (Congress Report). Bonn, Germany.

OECD. (2006). *Cost-Benefit Analysis and the Environment: Recent Developments.* Paris: Organization for Economic Cooperation and Development.

Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. *Science, 325*(5939), 419-422.

Oteros-Rozas, E., Martín-López, B., Daw, T. M., Bohensky, E. L., Butler, J. R., Hill, R., ... & Thyresson, M. (2015). Participatory scenario planning in place-based social-ecological research: insights and experiences from 23 case studies. *Ecology and Society, 20*(4), 32.

Owen, J. (2018). Package 'rhandsontable'. Retrieved April 10, 2018, from https://github.com/jrowen/rhandsontable

Palich, N., & Edmonds, A. (2013). Social sustainability: creating places and participatory processes that perform well for people. *Environmental Design Guide*, *78*, 1-13.

Paloheimo, E., & Salmi, O. (2013). Evaluating the carbon emissions of the low carbon city: A novel approach for consumer based allocation. *Cities, 30,* 233-239.

Pamučar, D. S., Božanić, D., & Ranđelović, A. (2017). Multi-criteria decision making: An example of sensitivity analysis. *Serbian journal of management*, *12*(1), 1-27.

Park, A. (2014). *Equity in Sustainability: An Equity Scan of Local Government Sustainability Programs. The Urban Sustainability Directors Network (USDN).* Retrieved June 29, 2017, from Urban Sustainability Directors Network website: https://climateaccess.org/resource/equity-sustainability-equity-scan-local-government-sustainability-programs

Pingali, P. L. (2016). Opinion: The hunger metrics mirage: There's been less progress on hunger reduction than it appears. *Proceedings of the National Academy of Sciences of the United States of America*, *113*(18), 4880-4883.

Polatidis, H., Haralambopoulos, D. A., Munda, G., & Vreeker, R. (2006). Selecting an appropriate multi-criteria decision analysis technique for renewable energy planning. *Energy Sources, Part B, 1*(2), 181-193.

Pretty, J., Adams, B., Berkes, F., Athayde, S.F.d., Dudley, N., Hunn, E., ….. Pilgrim, S. (2008). How do biodiversity and culture intersect? In: *Proceedings of the Sustaining Cultural and Biological Diversity in a Rapidly Changing World: Lessons for Global Policy Conference*, *April 2–5, 2008* (Plenary paper). New York: American Museum of Natural History's Center for Biodiversity and Conservation, IUCN-The World Conservation Union/Theme on Culture and Conservation, and Terralingua.

Price, L., Zhou, N., Fridley, D., Ohshita, S., Khanna, N., Lu, H., ... & Hu, M. (2016). Low-Carbon City Policy Databook: 72 Policy Recommendations for Chinese Cities from the Benchmarking and Energy Savings Tool for Low Carbon Cities. Retrieved July 18, 2017, http://repository.usfca.edu/cgi/viewcontent.cgi?article=1023&context=envs

Prombo, M. (2014). Electre3_SimpleThresholds. ELECTRE III using non affine form of the thresholds. Retrieved December 21, 2017, from https://www.rdocumentation.org/packages/OutrankingTools/versions/1.0

Quartier Zukunft. (2017). Reallabor 131: KIT findet Stadt. Retrieved January 29, 2018, from http://www.quartierzukunft.de/quartier-zukunft/reallabor-131/

Reckien, D., Flacke, J., Olazabal, M., & Heidrich, O. (2015). The Influence of drivers and barriers on urban adaptation and mitigation plans: An empirical analysis of european cities. *PloS One, 10*(8), e0135597.

Reckien, D., Salvia, M., Heidrich, O., Church, J. M., Pietrapertosa, F., De Gregorio-Hurtado, S., ... & Orru, H. (2018). How are cities planning to respond to climate change? Assessment of local climate plans from 885 cities in the EU-28. *Journal of Cleaner Production, 191*, 207-219.

Reed, M.S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., …..Stringer, L.C. (2009). Who's in and why? A typology of stakeholder analysis methods for natural resource management. *Journal of Environmental Management, 90*(5), 1933-1949.

Reed, R., Bilos, A., Wilkinson, S., & Schulte, K-W. (2009). International comparison of sustainable rating tools. *Journal of Sustainable Real Estate*, 1(1), 1-22.

Reith, A., & Orova, M. (2015). Do green neighbourhood ratings cover sustainability? *Ecological Indicators, 48*, 660-672.

Ros, J. C. (2011). *Introduction to Decision Deck-Diviz: Examples User Guide*. (Technical report DEIM-RT11-001). Tarragona: Universitat Rovira i Virgili, Departament d'Enginyeria Informàtica i Matemàtiques.

Rosenzweig, C., Casassa, G., Karoly, D.J., Imeson, A., Liu, C., Menzel, A., ... Tryjanowski, P. (2007). *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* In M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden & C.E. Hanson (Eds.), (pp. 79-131). Cambridge, UK: Cambridge University Press.

Roy, B. (1968). Classement et choix en présence de critères multiples (la méthode ELECTRE), *RIRO*, *8*, 57-75.

Roy, B. (1985). *Methodologie Multicritere d'aide a la Decision.* Economica, Paris.

Roy, B. (1990). Decision-aid and decision-making. *European Journal of Operational Research*, *45* (2–3), 324-331.

Roy, B. (1991). The outranking approach and the foundation of ELECTRE methods. *Theory and Decision, 31*, 49-73.

Roy, B., & Bouyssou, D. (1993). *Aide Multicritère à la Décision: Méthodes et cas*. Economica, Paris.

RStudio Team (2015). RStudio: Integrated Development for R RStudio, Inc., Boston, MA URL

Saarikoski, H., Mustajoki, J., Barton, D. N., Geneletti, D., Langemeyer, J., Gomez-Baggethun, E., ... & Santos, R. (2016). Multi-Criteria Decision Analysis and Cost-Benefit Analysis: Comparing alternative frameworks for integrated valuation of ecosystem services. *Ecosystem services, 22*, 238-249.

Saaty, T. L. (1980). *The analytic hierarchy process*. New York: McGraw-Hill.

Saiu, V. (2017). The Three Pitfalls of Sustainable City: A Conceptual Framework for Evaluating the Theory-Practice Gap. *Sustainability, 9*(12), 2311.

Salminen, P., Hokkanen, J., & Lahdelma, R. (1998). Comparing multicriteria methods in the context of environmental problems. *European Journal of Operational Research, 104*(3), 485-496.

San Cristóbal, J. R. (2011). Multi-criteria decision-making in the selection of a renewable energy project in Spain: The Vikor method. *Renewable energy, 36*(2), 498-502.

Satterthwaite, D. (2008). Cities' contribution to global warming: notes on the allocation of greenhouse gas emissions. *Environment and urbanization*, *20*(2), 539-549.

Schmuck, P. (2012). Transdisciplinary evaluation of energy scenarios for a German village using multi-criteria decision analysis. *Sustainability, 4*(4), 604-629.

Schneidewind, U. (2014). Urbane Reallabore: ein Blick in die aktuelle Forschungswerkstatt. *Pnd/online (Planung Neu Denken), 3,* 1-7. Retrieved February 15, 2018 from http://www.planung-neu-denken.de/

Schnur, O. (2008). Quartiersforschung im Überblick - Konzepte, Definitionen und aktuelle Perspektiven. In O. Schnur (Hrsg.), *Quartiersforschung zwischen Theorie und Praxis* (pp. 19-52). Wiesbaden: VS Verlag für Sozialwissenschaften.

Scholes, R. J., Reyers, B., Biggs, R., Spierenburg, M. J., & Duriappah, A. (2013). Multi-scale and cross-scale assessments of social–ecological systems and their ecosystem services. *Current Opinion in Environmental Sustainability, 5*(1), 16-25.

Schomaker, M. (1997). Development of environmental indicators in UNEP. In: *Proceedings of the Land Quality Indicators and their Use in Sustainable Agriculture and Rural Development conference, 25–26*

January 1996 (pp. 35–36). Rome, Italy: FAO, UNDP, UNEP and World Bank.

Schremmer, C., & Stead, D. (2009). Restructuring cities for sustainability—A metabolism approach. In: *The Fifth Urban Research Symposium, Cities and Climate Change: Responding to an Urgent Agenda, Marseille, France, June 28-30 2009*. World Bank.

Science for Environment Policy. (2017). Noise abatement approaches. Future Brief 17. Produced for the European Commission DG Environment by the Science Communication Unit, UWE, Bristol. Retrieved January 15, 2018 from http://ec.europa.eu/science-environment-policy

Scrieciu, Ş., Bristow, S., & Puig, D. (Ed.) (2011). MCA4climate - A Practical Framework for Planning Pro-Development Climate Policy. United Nations Environment Programme.

Shanian, A., Milani, A. S., Carson, C., & Abeyaratne, R. C. (2008). A new application of ELECTRE III and revised Simos' procedure for group material selection under weighting uncertainty. *Knowledge-Based Systems*, *21*(7), 709-720.

Sharifi, A. (2016). A critical review of selected tools for assessing community resilience. *Ecological indicators, 69,* 629-647.

Sharifi, A., & Murayama, A. (2013). A critical review of seven selected neighborhood sustainability assessment tools. *Environmental Impact Assessment Review, 38*, 73-87.

Sharifi, A., & Murayama, A. (2014). Neighborhood sustainability assessment in action: Cross evaluation of assessment systems and their cases from the US, the UK, and Japan. *Building and Environment, 72*, 243–258.

Shmelev, S. E., & Rodríguez-Labajos, B. (2009). Dynamic multidimensional assessment of sustainability at the macro level: The case of Austria. *Ecological Economics, 68*(10), 2560-2573.

Shmelev, S. E. (2012). Economic Valuation and Decision Making: MCDA as a Tool for the Future. In S. E. Shmelev (Ed.), *Ecological Economics: Sustainability in Practice* (pp. 57-74). Dordrecht, Netherlands: Springer.

Shome, D., Marx, S., Appelt, K., Arora, P., Balstad, R., Broad, K., ... Weber, E. (2009). *The psychology of climate change communication: a guide for scientists, journalists, educators, political aides, and the interested public.* New York: Center for Research on Environmental Decisions.

Shukla, V., Auriol, G., & Hipel, K. W. (2016). Multicriteria decision-making methodology for systems engineering. *IEEE Systems Journal, 10*(1), 4-14.

Shyamsundar, P. (2002, January 01). Poverty-environment Indicators. Environmental economic series no. 84. Washington, DC: World Bank Environment Department. Retrieved June 29, 2017, from https://www.unpei.org/sites/default/files/PDF/PEMonitoring/PovertyEnvironment-Indicators.pdf

Singer-Brodowski, M., Beecroft, R., & Parodi, O. (2018). Learning in real-world laboratories: A systematic impulse for discussion. *GAIA-Ecological Perspectives for Science and Society, 27(*1), 23-27.

Spangenberg, J. H. (2004). Reconciling sustainability and growth: criteria, indicators, policies. *Sustainable Development, 12*(2), 74-86.

Spyridi, D., Vlachokostas, C., Michailidou, A. V., Sioutas, C., & Moussiopoulos, N. (2015). Strategic planning for climate change mitigation and adaptation: the case of Greece. *International Journal of Climate Change Strategies and Management*, *7*(3), 272-289.

Stelzle, B., & Noennig, J. R. (2017). A Database for Participation Methods in Urban Development. *Procedia Computer Science, 112*, 2416-2425.

Stirling, A. (2006). Analysis, participation and power: justification and closure in participatory multi-criteria analysis. *Land Use Policy, 23,* 95–107.

Sullivan, L. J., Rydin, Y., & Buchanan, C. (2014). *Neighbourhood sustainability frameworks-a literature review* (USAR Working Papers 001). London, UK: Centre for Urban Sustainability and Resilience (UCL).

Sustainability Solutions Group - SSG. (2017). Technical paper #4: Considerations of co-benefits and co-harms associated with low carbon actions for TransformTO. Retrieved May 18, 2018, from https://www.toronto.ca/wp-content/uploads/2017/10/8f26-TransformTO-Co-benefits-and-Co-harms-of-Climate-Action-Report-January-2017.pdf

Sveidqvist, K., Bostock, M., Pettitt, C., Daines, M., Kashcha, A., & Iannone, R. (2017). DiagrammeR: Create Graph Diagrams and Flowcharts Using R. R package version 0.9.0. Retrieved January 29, 2018, from https://CRAN.R-project.org/package=DiagrammeR.

Tanguay, G. A., Rajaonson, J., Lefebvre, J. F., & Lanoie, P. (2010). Measuring the sustainability of cities: An analysis of the use of local indicators. *Ecological Indicators, 10*(2), 407-418.

Tervonen, T., Figueira, J., Lahdelma, R., & Salminen, P. (2007). *Towards robust ELECTRE III with simulation: theory and software of SMAA-III* (Research report 1/2007 of CEG-IST). Lisbon, Portugal: Technical University of Lisbon.

Thunis, P., Degraeuwe, B., Peduzzi, E., Pisoni, E., Trombetti, M., Vignati, E.,…Pernigotti, E. (2017). *Urban PM2.5 Atlas: Air Quality in European cities.* Retrieved January 29, 2018, from https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/urban-pm25-atlas-air-quality-european-cities

Toolbox for localizing the sustainable development goals. (n.d.). Retrieved May 17, 2017, from http://localizingthesdgs.org/

UCLC. (2017, February 8). INSIGHT: German municipalities begin to localize the SDGs. Retrieved January 29, 2018, from https://www.uclg.org/en/media/news/insight-german-municipalities-begin localize-sdgs/

UCLG. (2015, September 25). The sustainable development goals: What local governments need to know. Retrieved January 29, 2017, from https://www.uclg.org/en/media/news/sustainable-development-goals-what-local-governments-need-know

Udo de Haes, H.A. (Ed.). (1996). *Towards a Methodology for Life Cycle Impact Assessment.* Brussels, Belgium: SETAC-Europe.

UN. (2009). Towards climate neutral cities: a regional perspective. ECE/HBP/2009/2. Geneva: United Nations Economic and Social Council.

UN. (2015, July 6). The Millennium Development Goals Report 2015. New York, NY: United Nations.

UN. (2018, March 9). SDG Indicators: Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development. (E/CN.3/2018/2, Annex II). Retrieved May 2, 2018, from https://unstats.un.org/sdgs/indicators/indicators-list/

UNFCCC. (2015, November 30). Adoption of the Paris Agreement. UN doc. FCCC/CP/2015/L.9/Rev.1. Bonn, Germany: United Nations Framework Convention on Climate Change (UNFCCC) Secretariat.

UN General Assembly. (2015, September 25). Transforming our world: the 2030 Agenda for Sustainable Development. A/RES/70/1. New York, NY: United Nations. Retrieved January 29, 2017, from http://www.un.org/en/ga/search/view_doc.asp?symbol=A/RES/70/1. 33

UN General Assembly. (2017, July 6). Work of the Statistical Commission pertaining to the 2030 Agenda for Sustainable Development.

A/RES/71/313. New York, NY: United Nations. Retrieved January 29, 2018, from https://undocs.org/A/RES/71/313

UN-Habitat. (2007). *Inclusive and Sustainable Urban Planning: A Guide for municipalities, Vol. 1.* Nairobi, Kenya: Un-Habitat.

UN-Habitat. (2011). *Cities and climate change: Global report on human settlements 2011.* London: Earthscan Ltd, UN-Habitat.

UN-Habitat. (2017). *Trends in Urban Resilience 2017*. Nairobi, Kenya: Un-Habitat.

UNSD. (2018a, March 6). Global indicator framework adopted by the General Assembly (A/RES/71/313) and annual refinements contained in E/CN.3/2018/2 (Annex II). New York, NY: United Nations Statistics Division. Retrieved May 9, 2018, from https://unstats.un.org/sdgs/indicators/indicators-list/

UNSD. (2018b, May 11). Tier classification for Global SDG indicators. New York, NY: United Nations Statistics Division. Retrieved May 9, 2018, from https://unstats.un.org/sdgs/iaeg-sdgs/tier-classification/

Valentin, A., & Spangenberg, J. H. (2000). A guide to community sustainability indicators. *Environmental Impact Assessment Review, 20(*3), 381-392.

Van den Dobbelsteen, A. (2008). Towards closed cycles – New strategy steps inspired by the Cradle to Cradle approach. In: *Proceedings PLEA 2008: 25th Conference on Passive and Low Energy Architecture, 22- 24 October 2008* (paper 655). Dublin, Ireland: UCD.

Van der Leer, J. G. G. (2016a). *Waste Solutions to use in Urban districts*. Booklet. TU Delft. doi: 10.13140/RG.2.2.33440.99842

Van der Leer, J. G. G. (2016b). *Zero Waste Buiksloterham: An Integrated Approach to Circular Cities* (Master Thesis). TU Delft. Retrieved January 29, 2017, from https://repository.tudelft.nl/

Van der Ven, H., Bernstein, S., & Hoffmann, M. (2017). Valuing the contributions of nonstate and subnational actors to climate governance. *Global Environmental Politics, 17*, 1-20.

Vandevyvere, H. (2013). Evaluating The Sustainable Performance Of An Urban District: Measured Score Or Reflexive Governance? *International Journal of Sustainable Development and Planning, 8(*1), 36-58.

Viles, H. A. (2002). Implications of future climate change for stone deterioration. *Geological Society London Special Publications, 205*(1), 407-418.

Vörösmarty, C. J., McIntyre, P. B., Gessner, M. O., Dudgeon, D., Prusevich, A., Green, P., ... Davies, P. M. (2010). Global threats to human water security and river biodiversity. *Nature, 467(*7315), 555.

Wal, M., De Kraker, J., Offermans, A., Kroeze, C., Kirschner, P. A., & Ittersum, M. (2014). Measuring social learning in participatory approaches to natural resource management. *Environmental policy and governance, 24*(1), 1-15.

Waldron, D., Cayuela, A., & Miller, D. (2013). Regenerative neighbourhoods–Scaling up from net positive buildings. *In Proceedings of the GaGBC National Conference*, *Stream- Pushing the Boundaries: Net Positive Buildings, June 4-6, 2013* (Vol. 5, pp. 80-93). Vancouver BC, Canada: University of British Columbia

Walsh, P. (2000). Targets and how to assess performance against them. *Benchmarking: An International Journal, 7*(3), 183-199.

Walton, J. S., El-Haram, M., Castillo, N. H., Horner, R. M. W., Price, A. D. F., & Hardcastle, C. (2005). Integrated assessment of urban sustainability. *In Proceedings of the Institution of Civil Engineers-Engineering Sustainability, June 1, 2005* (Vol. 158(2), pp. 57-65). Thomas Telford Ltd.

WBCSD. (2010). *Vision 2050: The new agenda for business* (Product Code: WBCSD0167). World Business Council on Sustainable Development. Retrieved January 29, 2017, from http://www.wbcsd.org/Overview/About-us/Vision2050/Resources/Vision-2050-The-new-agenda-for-business

WCCD. (2017). *WCCD City Data for the United Nations Sustainable Development Goal.* Retrieved January 29, 2018, from http://www.dataforcities.org/publications/

WCCD. (n.d.). Retrieved May 17, 2017, from http://www.dataforcities.org/

Westerhoff, L. M. (2016). Emerging Narratives of a Sustainable Urban Neighbourhood: The Case of Vancouver's Olympic Village. *Articulo-Journal of Urban Research*, *14* Ecourbanism Worldwide.

WHO. (2011). *Burden of disease from environmental noise. Quantification of healthy life years lost in Europe.* Retrieved January 29, 2017, from http://www.euro.who.int/en/health-topics/environment-and health/noise/publications

Wittmayer, J., Roorda, C., & van Steenbergen, F. (Eds.). (2014). Governing urban sustainability transitions–inspiring examples. *International Journal of Sustainable Development, 15*(1), 19-36.

World Bank Open Data. (n.d.). Retrieved August 7, 2017, from https://data.worldbank.org/

World Bank's CURB Tool (n.d.). Retrieved July 18, 2017, from http://www.worldbank.org/en/topic/urbandevelopment/brief/the-curb-tool-climate-action-for-urban-sustainability

WCED. (1987). *Our Common Future*. World Commission on Environment and Development. Oxford, UK: Oxford University Press.

World Economic Forum. (2015). *Global Risks 2015, 10th Edition* (Insight Report). Retrieved January 29, 2017, from http://www3.weforum.org/docs/WEF_Global_Risks_2015_Report15.pdf

WRI, C40, & ICLEI. (2014). Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) – An accounting and Reporting Standard for Cities. New York: World Resources Institute, C40 Cities Climate Leadership Group, and ICLEI Local Governments for Sustainability. Retrieved May 20, 2017, from http://ghgprotocol.org/city-accounting

Wright, L. A., Kemp, S., & Williams, I. (2011). 'Carbon footprinting': towards a universally accepted definition. *Carbon management, 2*(1), 61-72.

WWF. (2008). *Living Planet report 2008*. *World Wide Fund for Nature.* Gland, Switzerland: WWF, ZSL, & Global Footprint Network.

WWF. (2016). *Living Planet Report 2016. Risk and Resilience in a new era*. Gland, Switzerland: WWF, ZSL, & Global Footprint Network.

Xia, B., Chen, Q., Skitmore, M., Zuo, J., & Li, M. (2015). Comparison of sustainable community rating tools in Australia. *Journal of Cleaner Production, 109*,1–8.

Yang, R. J. (2014). An investigation of stakeholder analysis in urban development projects: Empirical or rationalistic perspectives. *International Journal of Project Management, 32*(5), 838-849.

Yavuz, M., & Altay, B. L. (2015). Reclamation project selection using fuzzy decision making methods. *Environmental Earth Sciences, 73*(10), 6167-6179.

Yetano Roche, M., Lechtenbohmer, S., Fischedick, M., Gröne, M-C., Xia, C., & Dienst, C. (2014). Concepts and Methodologies for Measuring the Sustainability of Cities. *Annual Review of Environment and Resources, 39*, 519–547.

Yatsalo, B., Gritsyuk, S., Sullivan, T., Trump, B., & Linkov, I. (2016). Multi-criteria risk management with the use of DecernsMCDA: methods and case studies. *Environment Systems and Decisions*, *36*(3), 266-276

Yigitcanlar, T., Dur, F., & Dizdaroglu, D. (2015). Towards prosperous sustainable cities: A multiscalar urban sustainability assessment approach. *Habitat International,* 45, 36-46.

Żak, J. (2016). The Methodology of Multiple Criteria Decision Making/Aiding in Transportation. In J. Żak, Y. Hadas & R. Rossi (Eds.), *Advanced Concepts, Methodologies and Technologies for Transportation and Logistics* (pp. 9-38). Cham: Springer.

Zamani-Sabzi, H., King, J. P., Gard, C. C., & Abudu, S. (2016). Statistical and analytical comparison of multi-criteria decision-making techniques under fuzzy environment. *Operations Research Perspectives, 3*, 92-117.

Zermoglio, M. F., Van Jaarsveld, A., Reid, W., Romm, J., Biggs, O., Tianxiang, Y., & Vicente, L. (2005). The multiscale approach. In D. Capistrano, C.K. Samper, M.J. Lee, & C. Raudsepp-Hearne (Eds), *Millennium Ecosystem Assessment, Ecosystems and human well-being* (vol. 4, pp. 61–83). Washington, DC: Island Press.

Zukowska, E. A., Romero, A., Egusquiza, A., Larrinaga, P., Mittermeier, P., Peyramale, V., ... & Wetzel, C., Camiruaga, I. (2014, July 10). FASUDIR Deliverable D2.4: IDST Key Performance Indicators. Retrieved April 10, 2017, from at http://fasudir.eu/

Appendix A: List of Analysed Neighbourhood Sustainability Assessment Systems

Table A.1 provides the list of NSASs for which the manuals where managed to be retrieved for a deeper look in their approaches. Table A.2 provides the actual information of interest for each NSAS. Two typologies have been employed:

- In relation to the type of organisation responsible for their development and provision, five broad categories are recognised: (1) Professional organizations; (2) Regional governmental agencies; (3) National/state governmental agencies; (4) NGOs/ social enterprises; (5) Private sector firms. The purpose of this categorization is to check the participation factor in the design of the tools – looking at the Table A.2 one can conclude that the development of NSAS are primarily driven by professional organisations.

- In relation to their dominant function, three broad categories are recognised: (1) Performance assessment; (2) Certification; (3) Planning toolkit - looking at the table A.2 one can conclude that the largest cluster of NSAS has certification as the dominant function.

Table A.1. List of analysed NSAS and the source of information (Source: Present author)

Tool	Information available at: (link)
EarthCraft Communities (ECC)	http://earthcraft.org/earthcraft-professionals/programs/earthcraft-communities/
Enviro-Development	http://www.envirodevelopment.com.au/
BREEAM Communities	https://www.breeam.com/discover/technical-standards/communities/
LEED-ND	https://www.usgbc.org/resources/leed-2009-neighborhood-development-current-version
SuBET	https://islandpress.org/resources/9781610913645_SuBET.pdf
Tool for Sustainable Urban Development	https://issuu.com/realdaniaby/docs/tool-for-sustainable-urban-developm
GBI Township Tool	https://dokumen.tips/documents/gbi-township-tool-v101.html
ESTIDAMA Pearls	https://www.upc.gov.ae/en/estidama/estidama-program/the-pearl-rating-system-for-estidama
IGBC Green Townships	https://igbc.in/igbc/redirectHtml.htm?redVal=showGreenTownshipsnosign
Global Sustainability Assessment System (QSAS) for Neighbohoods	http://www.gord.qa/trust-gsas-resource-center-overview
HQE for Urban Planning and Development	https://www.behqe.com/offers/sustainable-planning
DGNB-NSQ	https://www.dgnb-system.de/en/schemes/scheme-overview/neubau_stadtquartiere.php
Sustainable Project Appraisal Routine (SPeAR)	https://www.arup.com/Projects/SPeAR.aspx
BREEAM NL Gebiedsontwikkeling	https://www.breeam.nl/content/breeam-nl-english
Green Star Communities	https://new.gbca.org.au/green-star/rating-system/communities/
Green Mark for Districts	https://www.bca.gov.sg/GreenMark/others/GM_District_V2.pdf
BERDE for Clustered Residential Development	http://files.philgbc.org/download.php?id=199&token=MorqCYfbn2npnDF3ykSeLpwIVZdwgmCS&download
SBToolPT–UP	Castanheira & Bragança (2014)
BEAM Plus Neighborhoods	https://www.hkgbc.org.hk/eng/ND_Intro.aspx
HQE^2R	https://de.scribd.com/document/10162836/HQE2R-English-Basics
2030 Districts	https://www.2030districts.org/
CASBEE UD	http://www.ibec.or.jp/CASBEE/english/overviewE.htm

One Planet Living Communities	https://www.bioregional.com/oneplanetliving/
CCAP Precinct (PRECINX)	https://kinesis.org/ccap-precinct/
Neighborhood Sustainability Framework	http://www.beaconpathway.co.nz/further-research/article/neighbourhood_sustainability_framework_and_assessment_kit
EcoDistricts Protocol	https://ecodistricts.org/get-started/the-ecodistricts-protocol/
GPR-Stedenbouw	https://www.gprsoftware.nl/english-information/
SMEO-Quartiere	http://www.nachhaltige-quartiere.ch/de/
Living Community Challenge	https://living-future.org/lcc/
LEED for Communities	https://www.usgbc.org/articles/new-certification-now-available-leed-cities-and-leed-communities

Table A.2. Main information for each NSAS (Source: Present author).

Examples	Developer/ Provider	Type of organisation(s)	Country/ region	Latest year (Init. year)	Dominant function (other functions)	Themes/categories covered (in the latest version)
PLANNED NEIGHBOUHOODS						
EarthCraft Communities (ECC)	The Greater Atlanta Home Builders Association, the Atlanta Regional Commission, the Urban Land Institute, and others	Professional organisation (in collaboration with state govern. agencies and NGOs)	US	2013 (2005)	Certification – according to points earned (Performance assessment)	• Site selection • Water management • Planning and design • Preservation landscape • Community engagement • Green building • Innovation points
Enviro-Development	Urban Development Institute of Australia	Professional organisation	Australia	2006	Certification – it awards a "leaf" for the fulfillment of any of its six categories	• Ecosystems • Waste • Energy • Materials • Water • Community
BREEAM Communities	Building Research Establishment (BRE)	Professional organisation	UK	2012 (2009)	Certification – according to points earned (Performance assessment)	• Governance • Social & economic well-being • Resources & energy • Land-use & ecology • Transport & movement • Innovation
LEED-ND	USGBC, CNU (Congress for the New Urbanism), and NRDC (Natural Resources Defense Council)	Professional organisation (in collaboration with NGOs/Social Enterprises)	US	2014 (2009)	Certification – according to points earned (Performance assessment)	• Smart location & linkage • Neighborhood pattern & design • Green infrastructure & Buildings • Innovation & Design process • Regional Priority Credits

Examples	Developer/ Provider	Type of organisation(s)	Country/ region	Latest year (Init. year)	Dominant function (other functions)	Themes/categories covered (in the latest version)
PLANNED NEIGHBOURHOODS (continued)						
SuBET	HILSON MORAN, Dundee and Reading Universities	Private sector firm (in collaboration with NGOs/Social Enterprises)	UK	2011 (2009)	Performance assessment – it offers tiered ratings for achieving minimum requirements, good practice or best practice across 80 indicators.	• Land use & ecology • Mobility • Pollution • Water • Energy & climate change • Material, recycling & waste • Usability • Place making • Cultural and perceptual • Costs & economics
Tool for Sustainable Urban Development	Realdania By	NGO/Social Enterprise	Denmark	2013 (2009)	Performance assessment (Planning toolkit)	• Energy • Transportation • Water • Waste • Physical settings • Urban life • Health • Diversity • Overall economy
GBI Township Tool	Malaysian Institute of Architects (PAM), Association of Consulting Engineers Malaysia (ACEM)	Professional organisation	Malaysia	2010	Certification – according to points earned (Performance assessment)	• Climate, energy & water • Environment & ecology • Community planning & design • Transportation & connectivity • Building & resources • Business & innovation

Examples	Developer/ Provider	Type of organisation(s)	Country/ region	Latest year (Init. year)	Prominent function	Themes/categories covered (in the latest version)
PLANNED NEIGHBOURHOODS (continued)						
ESTIDAMA Pearls	Abu Dhabi Urban Planning Council	National/state governmental agency	Abu Dhabi	2010	Certification – according to points earned (Performance assessment)	• Integrated design process • Natural systems • Livable communities • Precious water • Resourceful energy • Stewarding materials • Innovating practice
IGBC Green Townships	Indian Green Building Council	Professional organisation	India	2010	Certification – according to points earned (Performance assessment)	• Site selection & planning • Land-use planning • Transportation planning, • Infrastructure resource management • Innovation in design & technology
Global Sustainability Assessment System (QSAS) for Neighbohoods	Gulf Organization for Research and Development	NGO/Social Enterprise	Qatar	2011	Certification – according to stars earned (Performance assessment)	• Urban connectivity • Site • Energy • Water • Materials • Outdoor environment • Cultural & economic value • Management & operations

Examples	Developer/ Provider	Type of organisation(s)	Country/ region	Latest year (Init. year)	Prominent function	Themes/categories covered (in the latest version)
PLANNED NEIGHBOURHOODS (continued)						
HQE for Urban Planning and Development	Cerway/Certivea	NGO/Social Enterprise	France	2011	Certification – according to stars earned (Performance assessment)	• Territory & local context • Density • Mobility & accessibility • Heritage, landscape & identity • Adaptability & ability to evolve • Water • Energy & climate • Material & equipment • Waste • Ecosystems & biodiversity • Natural & technological hazards • Health • Economics of the project • Social functioning & diversity • Atmosphere and public spaces • Integration, training & awareness • Appeal, economic dynamics & local branches
DGNB-NSQ	German Sustainable Building Council	Professional Organisation	Germany	2016 (2011)	Certification – according to a performance index (Performance assessment)	• Environmental quality • Economic quality • Sociocultural & functional quality • Technical quality • Process quality

Examples	Developer/ Provider	Type of organisation(s)	Country/ region	Latest year (Init. year)	Prominent function	Themes/categories covered (in the latest version)
PLANNED NEIGHBOURHOODS (continued)						
Sustainable Project Appraisal Routine (SPeAR)	ARUP	Private sector firm	UK	2011	Performance assessment (Planning toolkit)	• Community facilities • Culture • Form & space • Stakeholder engagement • Health & wellbeing • Transport • Soil & land • Biodiversity • Waste • Materials • Water • Energy • Climate change • Air quality • Facilities management • Governance & reporting • Economic effect • Employment & skills • Site selection • Procurement • Equality
BREEAM NL Gebiedsontwikkeling	Dutch Green Building Council (DGBC)	Professional Organisation	Nether-lands	2012	Certification – according to points earned (Performance assessment)	• Resources & climate • Spatial Development • Welfare & Prosperity • Management • Synergy

Examples	Developer/ Provider	Type of organisation(s)	Country/ region	Latest year (Init. year)	Prominent function	Themes/categories covered (in the latest version)
PLANNED NEIGHBOURHOODS (continued)						
Green Star Communities	Green Building Council of Australia	Professional Organisation	Australia	2016 (2012)	Certification – according to stars earned (Performance assessment)	• Governance • Liveability • Economic Prosperity • Environment • Innovation
Green Mark for Districts	Building and Construction Authority (BCA)	National/state governmental agency	Singapore	2013	Certification – according to points earned (Performance assessment)	• Energy efficiency • Water management • Materials & waste management • Environmental planning • Green buildings & transport • Community & innovation
BERDE for Clustered Residential Development	Green Building Council of Philippines	Professional Organisation	Philippines	2013	Certification – according to points earned (Performance assessment)	• Management • Land-use and ecology • Water • Energy • Transportation • Indoor environmental quality • Materials • Emissions • Waste • Heritage conservation • Innovation

Examples	Developer/ Provider	Type of organisation(s)	Country/ region	Latest year (Init. year)	Prominent function	Themes/categories covered (in the latest version)
PLANNED NEIGHBOURHOODS (continued)						
SBTool^{PT}–UP	The Building Physics and Construction Technology Laboratory (LFTC) of University of Minho and iiSBE	NGOs/Social enterprises	Portugal	2014	Performance assessment	• Urban form • Land use & infrastructure • Ecology & biodiversity • Energy • Water • Materials and wastes • Comfort and outdoor areas • Safety • Amenities • Mobility • Local and cultural identity • Employment promotion and investment • Extra (Sustainable buildings & ICT)
BEAM Plus Neigh-borhoods	Hong Kong Green Building Council	Professional Organisation	China	2015	Certification – according to points earned (Performance assessment)	• Community aspects • Site aspects • Materials and waste aspects • Energy aspects • Water aspects • Outdoor environmental quality • Innovation and additions

Examples	Developer/ Provider	Type of organisation(s)	Country/ region	Latest year (Init. year)	Prominent function	Themes/categories covered (in the latest version)
EXISTING NEIGHBOURHOODS						
HQE^{2}R	CSTB	NGO/Social enterprise	Europe	2001-2004	Planning toolkit	• Local environment • Heritage & resources • Social life • Integration • Diversity
2030 Districts	Architecture 2030	NGO/Social enterprise	US	2011	Planning toolkit/ Self-assessment system (Performance assessment)	• Building energy use • Water consumption • Transportation GHG emissions
ALL NEIGHBOURHOODS						
CASBEE-UD	Japan Sustainable Building Consortium (JSBC), and Japan Green Building Council (JaGBC)	Professional Association	Japan	2014 (2006)	Performance assessment	• Economy • Society • Environment • Load
One Planet Living Communities	BioRegional Development Group and WWF International	NGO/Social enterprise	UK	2008	Certification based on ecological footprint analysis (Planning toolkit)	• Zero carbon • Zero waste • Sustainable transport • Sustainable materials • Local and sustainable food • Sustainable water • Land use and wildlife • Culture and heritage • Equity and local economy • Health and happiness

Examples	Developer/ Provider	Type of organisation(s)	Country/ region	Latest year (Init. year)	Prominent function	Themes/categories covered (in the latest version)
ALL NEIGHBOURHOODS (continued)						
CCAP Precinct (PRECINX)	Kinesis	Private sector firm	Australia	2009	Performance assessment	• On-site energy • Embodied CO_2 • Potable water • Transport • Housing diversity • Storm water
Neighborhood Sustainability Framework	Beacon Pathway	NGO/Social enterprise	NZ	2010	Performance assessment	• Neighborhood satisfaction, • minimized costs, • maximized biophysical health, • appropriate resource use & climate protection, • effective governance & civic life, • functional flexibility
EcoDistricts Protocol*	EcoDistricts Organisation	NGO/Social enterprise	US	2016 (2010)	Planning toolkit (Certification)	Imperative topics, but no predefined indicators: • Equity • Resilience • Climate protection
GPR-Stedenbouw	City of Groningen, Municipality of Tilburg, W/E consultants	National/state governmental agency (in collaboration with private sector firm)	Denmark	2011	Performance assessment	• Energy • Spatial planning • Health • Practical value • Future value

Examples	Developer/ Provider	Type of organisation(s)	Country/ region	Latest year (Init. year)	Prominent function	Themes/categories covered (in the latest version)
ALL NEIGHBOURHOODS (continued)						
SMEO-Quartiere	BFE and ARE	National/state governmental agency	Switzer-land	2011	Performance assessment (Certification)	Criteria are organised according to life cycle categories: • Development • Materialisation • Use/Operation
Living Community Challenge	International Living Future Institute	NGO/Social enterprise	US	2014	Certification (Planning toolkit)	• Place • Water • Energy • Health & happiness • Materials • Equity • Beauty
LEED for Communities	USGBC, CNU (Congress for the New Urbanism), and NRDC (Natural Resources Defense Council)	Professional organisation (in collaboration with NGOs/Social Enterprises)	US	2016	Certification (Performance assessment)	• Energy • Water • Waste • Transportation • Human experience

Notes:
* Previously EcoDistricts Performance and Assessment Toolkit

Appendix B: The anatomy of a Shiny App

Every Shiny application consists of two main components/elements:

(1) the user interface script (UI): This element (script) sets the front-end design features like different types of input widgets and output formats. In other words, this element handles the the way the Shiny application looks like and, therefore, directly influences the user experience.

(2) the server script (SERVER): This element does all the back-end tasks like data retrieval, manipulation and wrangling. In other words, this element collects and analyses all the input calls and instructions given through the UI and returns the generated output objects (e.g. tables and graphs) back to the UI (browser).

Below the anatomy of a Shiny app is depicted (Figure B.1).

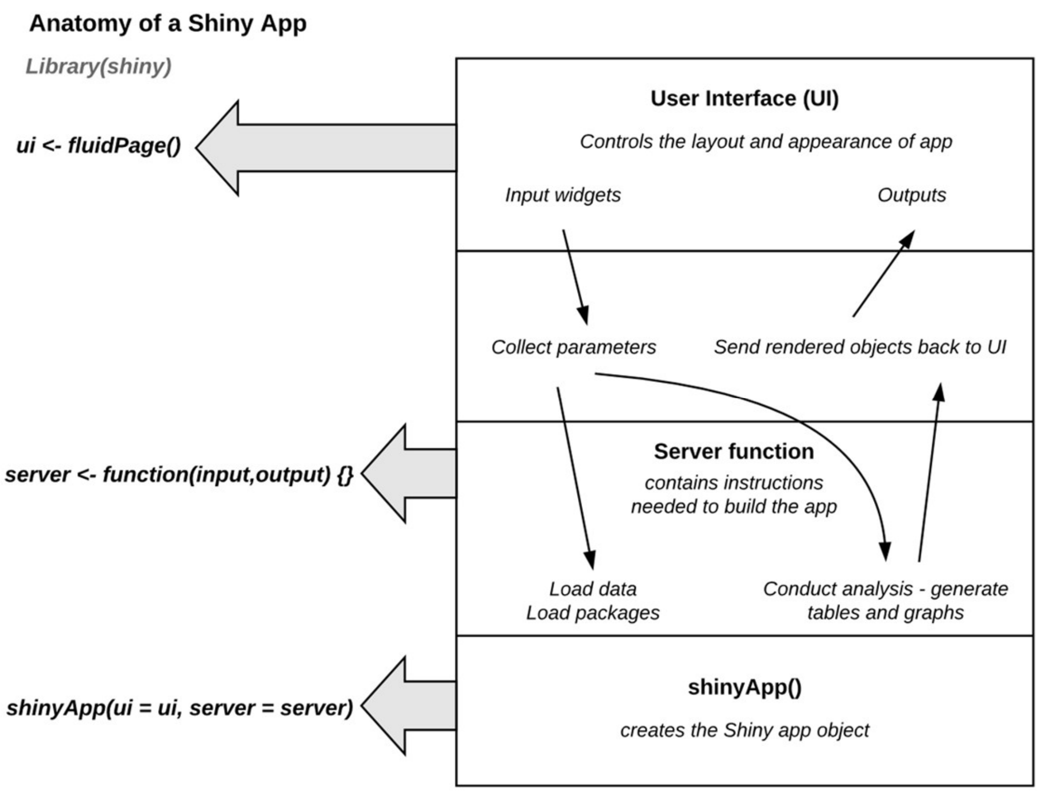


Figure B.1. Anatomy of a Shiny app (Source: Present author).

Shiny was paired with Shinydashboard, which is used to build dashboards with shiny. The UI for Shiny is built using the Bootstrap 3 web framework, while shinydashboard is based on the AdminLTE Bootstrap theme. The UI part of a shiny app built with Shinydashboard has three basic elements wrapped in the function *dashboardPage ()*.

1. dashboardHeader (),

2. dashboardSidebar (),

3. dashboardBody ()

Finally, the simplest Shiny app with Shinydashboard contains the following commands that if placed in an RStudio Shiny Web App file (RStudio Team, 2015), gives the the three parts of the dashboard:

Code:

```
library(shiny)
library(shinydashboard)
ui <- dashboardPage(
  dashboardHeader(),
  dashboardSidebar(),
  dashboardBody()
)
server <- function(input, output) { }
shinyApp(ui, server)
```

Appendix C: Listings of Actions

The listings developed for the neighbourhood-specific areas of intervention, public lighting (PL) and transport and mobility (TRM) are provided in Tables C.1-2. The listings developed for local energy production (LEP) and carbon sequestration (CS) as important for balancing out the remaining emissions in the context of a goal to reach a "nearly climate neutral" status are provided in Tables C.3-4.

Public lighting

Table C.1. Examples of mitigation actions with respect to Public Lighting (PL). "Direct" action categories are denoted as *A1, A2, …, An*, while "indirect" action categories are denoted as *B1, B2, …, Bn*.

Area of intervention	Action category	Actions
PL_ Public Lighting	**A1**. Energy-efficient street lighting	**PL_A3.1.** Substitution of inefficient streetlights with LED streetlights
		PL_A3.2. Installation of renewable energy powered streetlights
	A2. Energy-efficient traffic lighting	**PL_A3.3.** Substitution of inefficient traffic lights with LED traffic lights
		PL_A3.4. Installation of renewable energy powered traffic lights

Transport and mobility

Table C.2. Examples of mitigation actions with respect to Transport and Mobility (TRM). "Direct" action categories are denoted as *A1, A2, ..., An*, while "indirect" action categories are denoted as *B1, B2, ..., Bn*.

Area of intervention	Action category	Actions
TRM_ Transport & mobility	**A1.** Increase of the attractiveness of public transit systems	**TRM_A1_1.** Construction of dense stops – Public transport
		TRM_A1_2. Construction of enhanced stops (comfortable, barrier-free, weather protected and with dynamic passenger information)
	A2. Modal shift to walking and cycling	**TRM_A2_1.** Construction of bicycle paths or lanes
		TRM_A2_2. Installation of bicycle parking facilities
		TRM_A2_3. Shared bicycle system
	A3. Traffic management (structural)	**TRM_A3_1.** Application of highly visible crosswalks
		TRM_A3_2. Installation of speed limit signs
		TRM_A3_3. Roadside improvements
		TRM_A3_4. Car sharing or car pooling
	A4. Promotion of high fuel-economy or electric vehicles	**TRM_A4_1.** Installation of electric vehicle charging stations
	A5. Pedestrian-oriented urban design	**TRM_A5_1.** Compact, mixed-use and mixed-mode urban development
	B1. Information provision on public transit systems	**TRM_B1_1**. Provision of public education on transport options
	B2. Traffic management (non-structural)	**TRM_B3_1.** Application of congestion charging or access restrictions
	B4. Promotion of high fuel-economy or electric vehicles	**TRM_B4_1.** Application of low emission zones
		TRM_B4_2. Provision of free parking permit for eco or electric vehicle

Local energy production

Table C.3. Examples of mitigation actions with respect to Local Energy Production (LEP). "Direct" action categories are denoted as *A1, A2, …, An*, while "indirect" action categories are denoted as *B1, B2, …, Bn*.

Area of intervention	Action category	Actions
LEP_ Local Energy Production	**A1.** Exploitation of renewable energy technologies	**LEP_A1_1.** Installation of building-integrated photovoltaics
		LEP_A1_2. Installation of thermal solar panels for hot water
		LEP_A1_3. Installation of building-integrated wind turbines
		LEP_A1_4. Installation of ground source heat pumps
	A2. District heating and CHP schemes	**LEP_A2_1.** Installation of district heating/cooling
		LEP_A2_2. Combined heat and power (CHP)
	A3. Exploitation of smart grid technologies	**LEP_A3_1.** Smart grid demonstration project
	B1. Promotion of renewable energy technologies	**LEP_B1_1.** Consulting services for renewable energy technologies (incl. education campaigns)
		BU_B1_2. Grants and subsidies for renewable energy technologies
		BU_B1_3. Local workforce training on photovoltaics
	B2. Promotion of district heating and CHP schemes	**LEP_B2_1.** Consumer-owned cooperatives
		LEP_B2_2. Subsidies for condominiums connected to a district heating network

Carbon Sequestration

Table C.4. Examples of mitigation actions with respect to Carbon Sequestration (CS). “Direct” action categories are denoted as *A1, A2, …, An*, while “indirect” action categories are denoted as *B1, B2, …, Bn*.

Area of intervention	Action category	Actions
CS_ Carbon Sequestration	**A1.** Increase of urban green	**UDP_A1_1.** Greening/tree planting
	A2. Promotion of tree-planting	**UDP_B1_1.** Tree-planting campaign

Appendix D: Positive and Negative Side Effects of BU Actions

Table D.1 presents the positive and negative side effects of the BU actions:

Direct actions:

BU_A1_1. Improvement of building envelope

BU_A1_2. Substitution of inefficient space-heating and hot water

BU_A1_3. Substitution of inefficient cooling

BU_A1_4. Substitution of inefficient lighting

BU_A1_5. Substitution of inefficient appliances and electronics

BU_A1_6. Installation of occupancy sensors

BU_A1_7. Integrated retrofit/renovation action (all above)

BU_A2_1. Installation of energy management solutions and smart meters

BU_A2_2. Annual energy audits

BU_A3_1. Installation of green roofs

Indirect actions:

BU_B1_1. Provision of energy efficiency consulting services (incl. campaigns)

BU_B1_2. Provision of retrofit grants and subsidies

BU_B1_3. Provision of local workforce training on energy efficient retrofitting

BU_B2_1. Distribution of smart meters to businesses and residents

BU_B3_1. Provision of green roof consulting services (incl. education campaigns)

BU_B3_2. Provision of green roof grants and subsidies

BU_B3_3. Provision of local workforce training on green roof knowledge

Table D.1. Positive and negative side effects of the various BU actions with other sustainability objectives than climate protection. Where: +2: synergy, +1: enabling synergy, 0: uncertainty, -1: enabling trade-off, -2: trade-off, VH: Very high, H: High, N: None, L: Low, VL: Very low.

Actions	Common themes as identified in the assessment framework[a]														Additional important themes					POSITIVE SIDE EFFECTS	NEGATIVE SIDE EFFECTS
	Share of renewables	Reduced Water use	Reduced Land use	Biodiversity conservation	Improved air quality	Waste management	Noise pollution	Road safety	Feeling of safety	Accessibility	Public transport	Barrier-freeness	Affordable housing	Adequate housing	Aesthetic quality	Energy security	Adaptation to climate change	Local economy	Deferred infrastructure		
BU_A1_1	0	0	0	+2	+2	0	0	0	0	0	0	0	0	0	+1	+2	+1	+1	0	H	N
BU_A1_2	0	0	0	+2	+2	0	0	0	0	0	0	0	0	0	0	+2	0	+1	0	H	N
BU_A1_3	0	0	0	+2	+2	0	0	0	0	0	0	0	0	0	0	+2	0	+1	0	H	N
BU_A1_4	0	0	0	+2	+2	-1	0	0	0	0	0	0	0	0	0	+2	0	+1	0	H	L
BU_A1_5	0	0	0	+2	+2	-1	0	0	0	0	0	0	0	0	0	+2	0	+1	0	H	L
BU_A1_6	0	0	0	+2	+2	-1	0	0	0	0	0	0	0	0	0	+2	0	+1	0	H	L
BU_A1_7	0	0	0	+2	+2	-1	0	0	0	0	0	0	0	0	+1	+2	+1	+1	0	H	L
BU_A2_1	0	+2	0	+2	+2	-1	0	0	0	0	0	0	0	0	0	+2	0	+1	0	H	L
BU_A2_2	0	+2	0	+2	+2	0	0	0	0	0	0	0	0	0	0	+2	0	+1	0	H	N
BU_A3_1	0	-1	0	+2	+2	0	+2	0	0	0	0	0	0	0	+2	+1	+2	+1	0	VH	L

(Table D.1 continues)

Actions	Common themes as identified in the assessment framework[a]														Additional important themes					POSITIVE SIDE EFFECTS	NEGATIVE SIDE EFFECTS
	Share of renewables	Reduced Water use	Reduced Land use	Biodiversity conservation	Improved air quality	Waste management	Noise pollution	Road safety	Feeling of safety	Accessibility	Public transport	Barrier-freeness	Affordable housing	Adequate housing	Aesthetic quality	Energy security	Adaptation to climate change	Local economy	Deferred infrastructure		
BU_B1_1	0	0	0	+2	+2	0	0	0	0	0	0	0	-2	+2	0	+2	0	0	+2	**VH**	**M**
BU_B1_2	0	0	0	+2	+2	0	0	0	0	0	0	0	-2	+2	+1	+2	0	+1	+2	**VH**	**M**
BU_B1_3	0	0	0	+2	+2	0	0	0	0	0	0	0	0	0	0	+2	0	+2	0	**H**	**N**
BU_B2_1	0	0	0	+2	+2	0	0	0	0	0	0	0	0	0	0	+2	0	+2	0	**H**	**N**
BU_B3_1	0	-1	0	+2	+2	0	+2	0	0	0	0	0	-2	0	0	+1	+2	+2	0	**VH**	**M**
BU_B3_2	0	-1	0	+2	+2	0	+2	0	0	0	0	0	-2	0	+2	+1	+2	+1	0	**VH**	**M**
BU_B3_3	0	0	0	+2	+2	0	0	0	0	0	0	0	0	0	0	+2	0	+2	0	**H**	**N**

[a](some are reformulated)