INTERACTIVE MAP-BASED SUPPORT SYSTEMS: SUPPORTING SOCIAL LEARNING AND KNOWLEDGE CO-PRODUCTION ON ENVIRONMENTAL HEALTH ISSUES

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DISSERTATION

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the degree of doctor at the University of Twente,
on the authority of the rector magnificus,
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on account of the decision of the graduation committee,
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by

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born on 30 November 1984

in Kathmandu, Nepal

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Prof.dr.ir. M.F.A.M. van Maarseveen, supervisor
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Dedicated to my beloved parents, my loving husband, my family and also to those who made this study possible

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Chapter 1: Introduction

1.1 *Background*

As the world continues to urbanize health of people in urban areas is found to be declining worldwide (WHO & UN Habitat, 2010). In recent decades, the understanding of health evolved from being merely focused on the absence of illness and technology-based medical treatment to a perspective of a social phenomenon requiring strategies of prevention and health promotion (WHO, 1986). Such understanding of health acknowledges broad determinants of public health as described in the Rainbow model of Dahlgren and Whitehead (1991) that impinge on various spheres of social, economic and physical environment conditions impacting the health of individuals. Therefore, ensuring a high level of public health protection and a transformation of cities into a healthy urban living environment by addressing wider determinants of health is gaining attention as illustrated by many initiatives such as the European Healthy Cities Movement (Hancock, 1993), Health in All Policies (Rudolph et al., 2013) as well as in many national and municipal agendas.

In particular, attention is being paid to health inequity issues. Differences in health of people are found to exist at various geographic scales ranging from a global scale between countries to a local scale within cities in most countries (WHO & UN Habitat, 2010). There are mounting studies that provide evidence on the geographic variation in health status of people (Cummins et al., 2007; Curtis & Rees Jones, 1998; Macintyre et al., 2002). Moreover, health inequities are not confined to poor health of people in poor countries and good health of everyone else (Marmot et al., 2012). Ample evidence is brought together by the Commission on Social Determinants of Health (CSHD) on the existence of health inequities within cities of developed countries (Marmot et al., 2012). At the urban or intra city level, these inequities are usually found between neighbourhoods and are attributed to a complex interaction of social, economic and physical environment conditions (CSHD, 2008) giving rise to environmental health issues.

Environmental health issues comprise several characteristics of the environment that inherently affect or influence the health of people. These environmental characteristics not only include chemical, physical or biological agents, but also broad determinants of physical/built environment and social environment. Environmental factors influencing health equity issues are usually found to depict spatial inequalities in their distribution. For instance, the unequal distribution of environmental burdens such as air and noise pollution, as well as environmental resources such as parks and forests are found to evoke intra-urban spatial inequalities affecting certain SES (socio economic status) groups more than others (Diez Roux & Mair, 2010; Pearce et al., 2010; Schulz et al., 2005). To add to this complexity, it is now recognized that people are exposed to not just single environmental factors. Instead, the health of people is influenced by cumulative burdens of environmental hazards affecting certain social vulnerable groups more than others (Huang & London, 2012; Morello-Frosch et al., 2011; Sadd et al., 2011; Sexton, 2012). Therefore, health is inextricably linked with the environment and many environmental factors interplay in cities to shape the health of the urban population.

Addressing environmental health issues is now recognized as a concern of both the urban planning and public health sector. Crawford et al. (2010) advocate that 'health forms the heart of spatial planning'. The strong interface between health and planning can be traced back to the 19th century in Europe during which the concept of modern planning was borne in response to inhumane living conditions (Barton, 2009; Barton & Tsourou, 2000). Recently, many authors (Barton, 2005; Barton & Grant, 2006; Taylor et al., 2007; Taylor et al., 2006; Wernham, 2011) point to the fact that urban planning can influence the environment and thereby affect the health and wellbeing of people either positively or negatively. Consequently, it may contribute to an increase or reduction of spatial inequalities in health conditions between different socioeconomic groups.

Therefore, collaboration, deliberation and dialogue among sectors in urban planning and public health are being initiated to address environmental health issues (Northridge & Freeman, 2011; Rydin et al., 2012). Yet, researchers and practitioners still find collaboration challenging when it comes to integrating health into planning. Scholars have reported on sporadic engagement among the two professions (Northridge et al., 2003; Pilkington et al., 2008). Indications on a divide between the professions across Europe have also been reported (Barton & Tsourou, 2000; Cave & Molyneux, 2004; Crawford et al., 2010; Wanless, 2003). According to Crawford (2010) each sphere of public policy in health and planning is being pursued independently, adopting specific targets in order to deliver their objectives and hence failing to deal with the interdependencies of these two domains. In the same line Bond et al. (2012) argue that the planning profession is ill-equipped to consider health and well-being implications of its actions, while health professionals have limited understanding and aspirations when it comes to influencing planning.

Against these backdrops, point of departure of this study is that environmental health issues are 'wicked problems' (Rittel & Webber, 1973) and therefore, collaboration among various sectors needs to incorporate social learning and knowledge co-production of the involved stakeholders. To do so, the study aims at developing approaches supported by interactive map-based support systems—geo-information based technologies equipped with tangible user interfaces—and at exploring their usefulness in engendering social learning and knowledge co-production with regard to environmental health issues.

1.2 *Key concepts*

1.2.1 Environmental health issues

Environmental health issues are multidimensional and multifactorial phenomena defined as those aspects of human health that are determined or influenced by factors of the environment. The urban context inherently shapes the health of the urban population directly or indirectly (Galea et al., 2005; Galea & Vlahov, 2005). As such, environmental health issues are concerned with the determinants of health in urban areas and the urban context itself as the exposure of interest.

Several characteristics of the urban context are addressed to be important determinants of environmental health. These include not only direct pathological factors of chemical, physical or biological agents such as benzene, mercury, radiation etc. Also the physical and social environment which is affected by several spatial processes such as housing, urban development, land use and transportation, industry, shapes environmental health ((DHHS, 2010) in (Abernethy, 2014)). Galea & Vlahov (2005) have categorized these characteristics and contexts into three broad categories; the urban physical environment, the social environment, including economic conditions, and the availability of and access to health and social services.

The urban physical environment includes the entire built environment and their elements such as air, water and sanitation, indoor and outdoor noise, geological and climate conditions (Galea & Vlahov, 2005). Thus, the physical environment is referred to any man made entities such as roads, buildings, and open space. The physical environment either burdens the urban environment with pathogenic factors such as air pollution, noise pollution or provides environmental benefits to the population through salutogenetic factors such as green space, forest areas, and water bodies (Kruize, 2007). As such, these characteristics can affect the health of people either positively or negatively.

The social environment is also widely recognized to have its effect on the health of people (Galea & Vlahov, 2005). McNeill et al. (2006) have identified dimensions of social environment categorized into three broad categories. They are interpersonal relationships (e.g. social support and social networks), social inequalities (e.g. socioeconomic position, income inequality, racial discrimination)—these reflect one's place in the social hierarchy and are associated with differential access to social and material resources—and neighbourhood and community characteristics (e.g. social cohesion and social capital, neighbourhood factors).

Availability of and access to health and social services is the third category of factors affecting public health in an urban context. Many authors (Bambra et al., 2009; Galea et al., 2005; Galea & Vlahov, 2005; Whitehead & Dahlgren, 2006) advocate that cities face health inequities that are often associated with disparities in the availability and quality of health care. These health resources, for instance physicians, hospitals, health insurance, are found to be limited in numbers or limited in access for low-income and marginalized groups of people. Therefore, it is also an important aspect that tends to shape the public health within cities.

1.2.2 Linking planning and environmental health

Scholars emphasize that though individual factors such as lifestyle and individual behaviour also affect the health of people, significant effects are caused by the physical/built environment and the social environment. People in urban settings are exposed to a variety of environmental burdens, as well as environmental benefits that are interconnected with their health effects.

Interdependencies between urban planning and public health are gaining much attention for addressing spatial inequalities with respect to health, particularly in urban development and environmental planning policies. It is now recognized that planning interventions can affect health through impacts on the context in which individuals live. Several environmental justice studies are claiming the negative environmental externalities of planning and development decisions of siting locally unwanted land uses (LULUs) like industrial sites and hazardous waste sites being positively correlated with social inequality and health inequality (Brulle & Pellow, 2006; Evans & Kim, 2010; Kaswan, 2007; Pearce et al., 2010, 2011). Others have found the importance of planning open spaces and parks in neighbourhoods that can increase health-promoting activities (Durand et al., 2011; Wolch et al., 2014). Gelormino et al. (2015) report the built environment as an important policy domain that can impact on health inequalities. Bambra et al. (2009) found evidence that urban planning interventions, particularly in the housing and transport sectors such as traffic calming, promotion of walking and cycling and changes in housing infrastructure, can diminish social gradients in health. In this regard, planning decisions can potentially exacerbate as well as mitigate negative externalities of the physical/built and social environment, which ultimately affect the health of people (Barton, 2005; Taylor et al., 2007; Taylor et al., 2006).

1.2.3 Cross sectoral collaboration and 'wicked problem' characteristics of environmental health issues

With the renewed attention for the coherence of planning and environmental health, researchers have searched a close collaboration, deliberation and dialogue base between these fields of planning and health. The aim of this collaboration is to ascertain that any spatial planning intervention, plan or development decision influencing the environment does not lead to negative health impacts and health inequities, but produces positive effects on public health (Northridge & Freeman, 2011; Rydin et al., 2012; WHO & UN-HABITAT, 2010). In this context Lawrence (2004) has argued for transdisciplinary approaches by involving practitioners and researchers alike on equal footing to address environmental health issues. Several researchers are emphasizing the need for cross-sectoral collaborations among sectors such as health, environment, housing, transport as well as the private sector to address environmental health issues (Northridge & Freeman, 2011; Rydin et al., 2012; Marmot et al., 2008).

Yet, collaboration on the interface between planning and health is often reported to be challenging. Institutional and legal challenges with respect to narrow mandates and limited resources tend to get in the way (Abernethy, 2014; Baumgart, 2017), and difficulties seem to arise due to 'wicked problem' characteristics of environmental health. The term 'wicked problem' is generally used to characterize problems that are multifactorial, dynamic in nature and resistant to solution (Kreuter et al., 2004). Rittel and Webber (1973) offer the following characteristics of a 'wicked problem': a problem that is complex, difficult to define, with no immediate solution, and one where every problem can be considered a symptom of another problem. These characteristics are manifested in environmental health issues (Abernethy, 2014; Kreuter et al., 2004). For instance, the complex interdependencies and intertwining of causes and effects of multiple environmental factors in environmental health issues make it difficult to arrive at one single problem definition. The causes and symptoms are highly interrelated, do not follow linear pathways, and pass through many sectors such as health, housing, transport etc. Multi-stakeholder knowledge, interests, and understandings may remain contested. The nature of the problem is likely to be viewed differently depending on the perspectives, values and sectoral interests. Moreover, planning and health are observed to use different terminology and methodology. For instance, in the population-based approach of public health, location-related impacts are sometimes neglected, in contrast to the location-based approach of urban planning (Flacke et al., 2016). Therefore, it is hard to come to a consensus on what factors should be considered. It was noted by Negev (2012) during health impact assessment, where differences among professionals appeared with respect to their interests, and ways of knowing as well in usage of data. Stakeholders are observed to hold different perspectives or use a different language (e.g. tools, instruments, indicators) and they may lack common evidence base (Negev, 2012). This may lead to difficulties to reach an agreement about what the problem itself is, let alone the solution (Kreuter et al., 2004). Similarly, activities on health promotion and prevention are usually confronted with 'siloed problem solving attempts' from various organization forming rigid boundaries on development of knowledge between professions (Abernethy, 2014; Carmichael et al., 2013).

Addressing 'wicked problem' calls for deliberation among various stakeholders so that rather than trying to 'solve' such 'wicked problem' through standard science-based approaches, these problems are 'tackled, managed and dealt with' by sharing knowledge and engaging in learning process (Head & Xiang, 2016). In a similar line, Collins and Ison (2009) call for a paradigm shift in the thinking and practices of policy-making while dealing with a 'wicked problem'. The authors (Collins & Ison, 2009) emphasize the need to reconceptualise the roles, responsibilities and purpose of those involved, not along the lines of participation mediated in terms of power as suggested by Arnstein (1969), but also as a process of social learning about the nature of the issue itself and how it might be approached. Arguing the need of transdisciplinary approaches to address environmental health issues, Lawrence (2004) calls for social learning among practitioners and researchers. Corburn (2013) suggests social learning as one of the important components in adaptive urban health justice to achieve healthy city planning. Röling and Maarleveld (1999) point out that the social learning approaches allow to avoid the pitfall of understanding social processes only in terms of an aggregation of individual preferences by adopting a systemic view.

1.2.4 Social learning and knowledge co-production

Social learning is described as learning in and with social groups through interaction (Siebenhüner, 2005), which occurs when participants share their experiences, ideas and environment with others during a group activity (Armitage et al., 2008). It is a re-iterative process of assimilation through the interpretation of issues in terms of existing mental models and accommodation through changing of the mental models to make sense of the issues. When participants engage in deliberation within a collaborative dialogue, they learn as individuals and as a group about the problem, their goals, perspectives of other participants, and the context (Innes & Booher, 2016). As a result they engage in cooperative endeavours of knowledge co-production in which knowledge is said to be produced and used through interaction and learning among people with different perspectives (Fazey et al., 2013).

Various theories are available on learning reflecting different underlying assumptions about the nature of learning. For instance, learning can be instrumental according to Mezirow (1993) that is focussed on acquiring new knowledge or skills. 'Theories of communicative learning' describes the process by which a person constructs an inter-subjective understanding of a situation by exchanging and reinterpreting knowledge through communication with others (Van der Veen, 2000). Likewise transformative theories of learning describes a process where people gradually change their views on the subject (Muro & Jeffrey, 2008). Transformative learning is analogous to 'double loop learning' which is said to occur when the detected mismatch between expected and outcomes is corrected by revisiting the assumptions that underlie the actions (Argyris & Schön, 1997). On the other hand, single loop learning is categorised as incremental learning and is said to occur when a mismatch between expected and observed outcomes is corrected, leaving the underlying theories unchanged. The feedback loop from the actual experience does not change the basic assumptions or decision-making rules. Although not widely discussed in literature, another loop learning is the triple loop learning. The triple loop learning concept aims at a refinement of the influence of governing variables such as designing governance norms and protocols, institutional change etc. (Armitage et al., 2008; Pahl-Wostl, 2009). Similarly, Kolb (2014) describes experiential learning as a process where concrete experiences of people lead to reflection, and the generation of new ideas which they apply through active experimentation and therefore learn. These theories are acknowledged to be more complementary than competitive and provide an understanding of the processes upon which social learning is based (Muro & Jeffrey, 2008; Reed et al., 2010).

The intended outcome to which social learning contributes to in knowledge co-production can be seen manifested into four dimensions: the cognitive dimension, the moral dimension, the relational dimension and trust dimension (Romina, 2014). Webler et al. (1995) assumed that social learning is manifested in a cognitive enhancement and moral development of the participants. In the course of a participatory activity, participants acquire new information on the topic as well as exchange information in the groups that influence their cognitive dimension of knowledge acquisition. As a result, it may increase the knowledge about the issue as well as improve the ability of the participants to form a reasoned opinion about the issue, identify problems, opportunities and alternative actions. Likewise, when participants are enabled to appreciate the perspectives of others and understand others' concerns, it contributes to finding a common ground or a shared understanding about these issues. In other words, it leads to identifying areas of agreement and disagreement thus enhancing shared understanding among the participants (Garmendia & Stagl, 2010). Building a collaborative relationship and trust among participants are other social learning outcomes within a participatory activity. Enhanced relationships and increase in interpersonal trust provide a foundation for collective action and are thought to arise from social learning within a participatory activity (Garmendia & Stagl, 2010).

Various studies (Armitage et al., 2008; Dana & Nelson, 2012; Schusler et al., 2003) have explored the attributes that are necessary to engender social learning in a participatory activity as presented in Figure 1-1. The framework provides two categories of elements necessary to engender social learning in the process—process components and process attributes —and the intended outcomes on social learning and knowledge co-production.

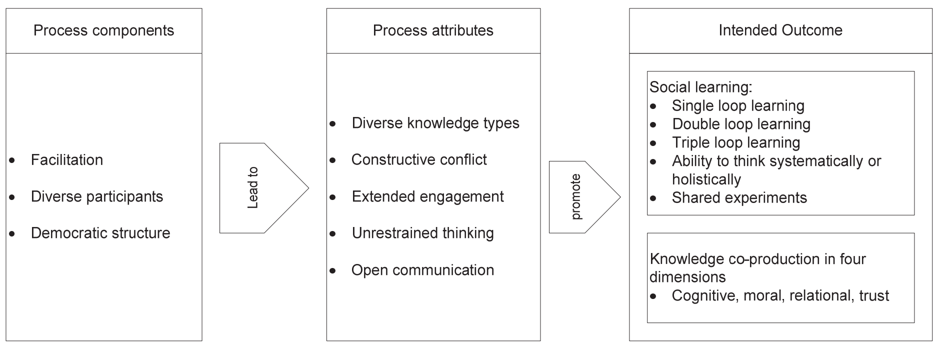

Figure 1-1 A framework on social learning and knowledge co-production modified from (Dana & Nelson, 2012; Schusler et al., 2003)

The key process components include: facilitation, diversity of participants and a democratic structure (Daniels & Walker, 2001; Mostert et al., 2007). Skilled facilitation is a pre-requisite of any participatory process as a facilitator ensures that all participants feel comfortable to share their ideas, remain focussed to the objective of the task and prevent domination of one participant (Daniels & Walker, 2001; Johnson et al., 2012). Having a diverse group of participants ensures that greater breadth of worldviews, mental models and experiences are included in the process (Jones et al., 2011; Rinner, 2001). A democratic structure ensures that all participants have opportunities to contribute and that their contribution is incorporated into the process (Dana & Nelson, 2012).

Approaches that incorporate these process components are viewed to generate process attributes that foster social learning. The process attributes included are: diversity of knowledge types, constructive conflicts, unrestrained thinking, open communication, extended engagement (Mostert et al., 2007; Schusler et al., 2003). Diversity of participants enhances the likelihood that the process will ensure a mixture of diverse knowledge types and by encouraging unrestrained thinking about different types of knowledge, the approach can lead to learning across traditional disciplinary or professional boundaries (Dana & Nelson, 2012). Open and effective communication is crucial for engagement to occur among various knowledge types and among those with differing opinions, and happens when participants feel comfortable asking questions and contributing knowledge, listen respectfully and are open-minded (Johnson et al., 2012). Yet, conflicts may arise about contested values and worldviews. If managed properly, constructive conflicts can foster a new understanding among diverse participants (Dana & Nelson, 2012; Johnson et al., 2012). Providing opportunities to express conflicting viewpoints without hampering the process allows the participants to identify areas that could be constructively focussed upon and other areas that need further deliberation (Schusler et al., 2003). Finally, an extended engagement refers to in-depth conversations and interactions among participants outside the formal exercise. If such engagement is enabled it may foster social learning.

The process components and process attributes together can promote social learning characteristics in the process. The extent to which the approach has supported in triggering the change can be assessed by exploring evidences in the following instances—single loop learning, double loop learning or triple loop learning (Armitage et al., 2008). Systemic thinking is crucial for learning as individuals adjust their mental models when they understand multiple facets of an issue (Dana & Nelson, 2012; Johnson et al., 2012). Participants begin to think systematically when they are enabled to envisage connections and feedback loops between various components (Pahl-Wostl & Hare, 2004; Rist et al., 2006). In order to do so, participants can be enabled to carry out 'shared experiments' (Armitage et al., 2008). Similarly, the contribution of social learning can also be seen as knowledge co-produced in four dimensions as explained above. Altered perspectives represent a measure of whether the approach has enabled change in people's perceptions or opinions upon learning new information (Armitage et al., 2008; Dana & Nelson, 2012; Johnson et al., 2012).

1.2.5 Interactive map-based support system

The complex nature of planning and decision making processes and the necessity for the accumulation, management and analysis of a variety of data sets make it necessary to use computer-based tools and models (Sugumaran & Degroote, 2010).

Particularly, Planning Support Systems (PSS) and Spatial Decision Support System (SDSS) have been developed, applied and tested in various fields to support stakeholders (Geertman & Stillwell, 2003, 2009). These tools, in particular PSS, are defined as a subset of geo-information technologies, many of them offering a 'visually attractive platform that structures the mutual exchange of knowledge among many actors' (Te Brömmelstroet, 2017, p.97). Vonk (2006) categorize these tools as information PSS, communication PSS and analysis PSS and argue that each of these focusses on improving informative, communicative and analytical aspects of stakeholder dialogue in the planning processes explicitly. Arciniegas et al. (2013) explored the effectiveness of collaborative map-based SDSS on three criteria: usefulness of the tool, clarity of the tool information and impact on decisions.

Geertman (2006, p.865) reported the obstacles related to PSS and has summarized these as being 'too generic, complex, inflexible, incompatible with the wicked nature of most planning tasks, oriented towards technology rather than problems, incompatible with the less formal and unstructured information needs and too focused on strict rationality'. Others (de Kok et al., 2009; McIntosh et al., 2011; Uran & Janssen, 2003; Vonk et al., 2007) have advised to avoid producing 'off-the-shelf' tools with high end design that are not responsive and flexible enough to respond to evolving needs of the task . Furthermore, Vonk et al. (2005) reported a number of bottlenecks with regard to using these tools in practice and concluded that it depends upon previous experience in planning practice, the user-friendliness of the systems and the user's awareness of the potential of PSS. Therefore, much of the research on PSS are being focused on understanding and improving the user-friendliness of the instrument (Te Brömmelstroet, 2017).

Researchers have now started to shift their focus from user-friendliness to the usefulness of such tools on improving the quality of the planning practice. Te Brommelstroet (2017) argues that user-friendly PSS are means rather than a goal and suggests to focus on the actual goal of improving the quality of planning practice. Traditionally, the added value of these tools was seen as improving the outcome of the process. However, in the last decades, the focus of most researchers have shifted towards improving the planning process and therefore, to study the value of such tools in improving the process itself. In this line, Pelzer et al. (2014) have explored perceived added values of such interactive PSS among practitioners and reported on their usefulness in initiating and strengthening interaction and collaboration. Others are paying attention to exploring such tools for encouraging social learning. Goodspeed (2013) has explored the extent to which the PSS can support social learning in land use planning workshops. Goodspeed (2013) reported positive evidence on instrumental learning and double loop learning among the participants in the planning workshops. Pelzer & Geertman (2014) on the other hand have explored interdisciplinary learning effects of PSS among various disciplines such as design, environment management, planning.

Previously, these tools used the traditional graphical user interface (GUIs) that did not provide the flexibility to interact with the system. Therefore, the concept of the tangible user interfaces (TUI) is developed providing flexibility of interaction with the system. A TUI is 'the combination of a table projection, a Geographic Information (GI) system, a new method to gather the input information necessary for the action to be performed by the GI system on the desired location of the table form' (Scotta et al., 2006). Arciniegas (2012) describes 'interactive' tools using a TUI as those that allow the user to provide input and generate output in real time through an easy-to-use user interface. Users interact with the system directly on the table surface with the use of hands or with drawing pens, and the system reacts on the movements on the table and responds to the user needs on information on the table surface. Currently, the progress in TUI related hardware and software is further contributing enormously on shaping the way technology can be used to engage stakeholders in collaborative activities. In this study, the term interactive map-based support system is used to describe our PSS that uses geo-information technologies and emphasizes the use of such TUIs to encourage interaction between the users and the system as well as among the users.

1.3 *Research gap*

Figure 1.2 shows the key concepts this study is built upon and their interlinkages.

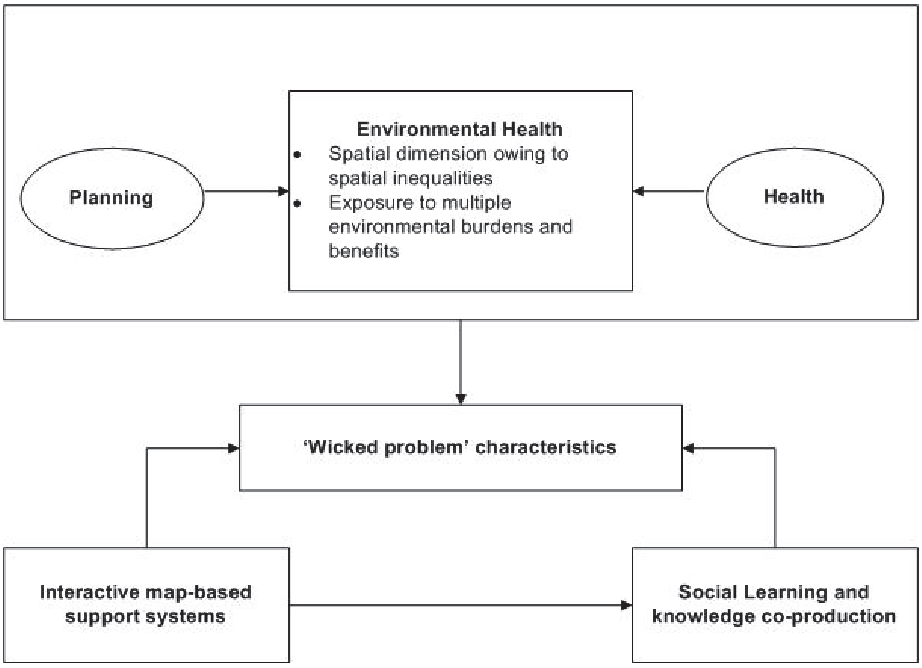

Figure 1-2 Key concepts used in this study and their interlinks

There is an increasing interest in researching environmental health issues and their implications on health across various groups. Significant rise in international initiatives could be seen on achieving healthy cities, such as the Ottawa Charter of the WHO (WHO, 1986), European Healthy Cities Movement (Hancock, 1993) and Health in All Policies Strategy (Rudolph et al., 2013). The main thrust of these movements is among others to build health into planning and decision-making processes within the local government, community organizations and businesses to develop strategies that address social, environmental and economic determinants of health. Some recommendations and guidance documents are available on how health and health inequities should be addressed in urban governance and planning (Marmot et al., 2010).

Health inequity issues are found to be closely intertwined with space or place where people live, work and age because 'where in a city you live and how that city is governed can determine whether or not one benefits from city living' (WHO & UN Habitat, 2010). Studies on the relationships between the built environment, contextual factors on neighbourhood level and health outcomes are particularly exploring spatial inequalities in terms of whether or not environmental benefits and burdens are spatially equally distributed over an area respectively among the groups of population (Diez Roux & Mair, 2010; Evans & Kim, 2010). In this vein, environmental health issues can be argued to have a strong spatial dimension. Corburn (2013) argues that most disease burden estimates tend to focus on the global scale or large geographic regions, which can potentially mask intra-city differences. Such, global data may not be relevant for informing national or municipal policy making at the local level. Therefore, consideration of spatial dimensions of environmental health issues at the local level becomes pertinent.

Concerns are being raised on the complex array of environmental factors that may shape health outcomes. People living in urban environments are increasingly exposed to a number of environmental factors such as air pollution, noise nuisance, and heat stress (Galea et al., 2005). On the other hand urban areas provide resources such as parks and green area that have the potential to positively influence the health of people (Brugge et al., 2015; Cohen et al., 2007). These pathogenic factors (chemical/physical stressors) and salutogenic factors (resources) exist simultaneously and are even interacting (Kühling, 2012; Mauderly & Samet, 2009). Therefore, a cumulative burden assessment, which considers multiple environmental factors together with social vulnerability of the population, is considered important. Social vulnerability describes the way in which various socio structural factors, such as race, ethnicity, SES, etc., create the social fabric in which individuals and groups are differentially susceptible to environmental hazards. Such an assessment provides significant opportunities for researchers and policy makers to understand the key mechanisms that underpin spatial inequalities in health outcomes (Evans & Kim, 2010; Jerrett, 2009; Pearce et al., 2011). It can be concluded that it is pertinent to explore how multiple environmental burdens combine to produce cumulative effects and how those effects generate spatial inequalities in health across population with varying social vulnerability.

With the growing recognition of the link between planning and health, interest has originated on cross-sectoral collaboration between urban planning and health sector, in order to address environmental health issues. Nonetheless, collaboration is often reported challenging with respect to environmental health issues. Among others, one of the challenges that has been put forward is the 'wicked problem' characteristics of environmental health issues as discussed in section 1.2.3. In order to manage and tackle 'wicked problems', collaborative endeavours need to draw on broad range of knowledge, develop a common base of knowledge to address the complexities of the 'wicked problem' and serve as a premise for cooperation (Head & Alford, 2008). Therefore, scholars now call to examine such 'wicked problem' using a 'panoramic social lens rather than a scientific microscope, and working on it in an open and heuristic process of collective learning, exploration and experimentation' (Xiang, 2013, p.2).

Engaging stakeholders in social learning and knowledge co-production is, therefore, gaining much attention as a way to deal with 'wicked problems' thereby integrate different ways of knowing, understandings and interests of broad sectors.

Literature on social learning has provided attributes that need to be promoted in participatory activities to engender social learning and knowledge co-production among participants. Nonetheless, scholars have also concluded that social learning does not emerge with every group interaction (Johnson et al., 2012). Similarly, social learning cannot be forced upon actors (Rist et al., 2006). Instead, actors have to be positively influenced. To do so, participatory activities need to be attuned enough to create and nurture learning opportunities that make it possible to involve different actors (Muro & Jeffrey, 2008). In this regard, the development of PSSs shows that these tools have potential to support learning among stakeholders. Moreover, owing to spatial dimension of environmental health, these tools seem valuable to engage stakeholders in social learning and knowledge co-production with regard to understanding spatial inequalities; thereby integrating both the spatial dimensions of environmental health issues and the knowledge, values and perspectives of stakeholders in the process. However, most of the research surrounding these types of tools is limited to supporting strategic planning in the fields of land use planning, transport planning, and environmental planning (Arciniegas, 2012; Pelzer et al., 2013; Te Brómmelstroet & Schrijnen, 2010). Therefore, the usefulness of such tools in an environmental health context is yet to be explored. This gives rise to a research question: How can an interactive map-based support system engage stakeholders in a social learning and knowledge co-production process in environmental health context, taking into account spatial dimensions of environmental health at a local level and cumulative effects of multiple environment burdens?

Four methodological and application aspects drive the development of research objectives in the next section. First, owing to the 'wicked problem' characteristics of environmental health issues, in particular, the importance of shared understanding about problem situation and knowing 'what is really going on and why before actually looking for a solution' (Trainor & Parnell, 2010), we explored the literature that have used map-based support systems during the problem understanding phase. Only a few studies (Couclelis & Monmonier, 1995; Horita, 2000) have attempted to use GIS-based support systems here, but without explicitly focussing on social learning and knowledge co-production aspects at locally specific issues of environmental health. Second, emphasizing the importance of cumulative burden assessment in understanding environmental health issues, only few studies were found that have included simultaneous exposure to both burdens and benefits along with social vulnerability of the population (Lakes et al., 2014; Pearce et al., 2010, 2011). All these methods are specifically being used to assess geographical areas at a regional and national level where the unit of analysis is an administrative boundary. Therefore, fine-scaled assessment of multiple burdens and benefits across the social vulnerability of the population at the local level is lacking. Third, although ‘wicked problems’ of cumulative burden assessment are nowadays realized (Huang & London, 2016), requirements to engage stakeholders in social learning and knowledge co-production processes are largely ignored. Fourth, while the necessary attributes to engender social learning and knowledge co-production are available, there is limited research on how these attributes can be mediated into the participatory activities using interactive map-based support systems. So far only a study by Kaiser et al. (2017) attempted to develop a conceptual approach of platform that can engender social learning and knowledge co-production among stakeholders. Nonetheless, the authors (Kaiser et al., 2017) acknowledge that the platform lacks GIS components and therefore may not be promoted as a PSS in the conventional sense.

1.4 *Research objectives and research questions*

This research aims to explore the usefulness of interactive map-based support systems to engage stakeholders in the process of social learning and knowledge co-production in environmental health context.

Research objectives

Objective 1:
To develop and implement a methodological approach, named Interactive Spatial Understanding Support System (ISUSS), for facilitating knowledge co-production and social learning in order to achieve a shared understanding during the early phase of problem understanding within a planning process.

- How can knowledge co-production and integration among practitioners and researchers be supported by means of the ISUSS approach?

- What insights can be obtained with respect to interaction, social learning, and shared understanding during the implementation of the ISUSS approach in an environmental health context?

Objective 2:
To develop an approach to assess cumulative burdens including both burdens and benefits across a population with varying levels of vulnerability at a local scale.

- How can multiple environmental features, including both burdens and benefits, and social vulnerability be combined into an index?

- What methods can be used to disaggregate the indicators at a local scale?

- What are the potential applications, complexities and the usability of the method for identifying 'hotspots' of environmental health related spatial inequalities?

Objective 3:
To develop an interactive stakeholder-based cumulative burden assessment approach (Interactive-CuBA) that facilitates social learning and knowledge co-production during a science based stakeholder dialogue.

- How can our interactive stakeholder-based approach support a science-based stakeholder dialogue for cumulative burden assessment?

- What insights on a stakeholder-based cumulative burden assessment can be obtained from the implementation of this approach?

Objective 4:
To develop a conceptual framework on supporting social learning and knowledge co-production mediated through approaches using interactive map-based support systems.

- What are the lessons learnt from the two approaches on interactive map-based support system with respect to existing frameworks of social learning?

- How can approaches of interactive map-based support systems support social learning and knowledge co-production processes?

1.5 *Research methodology*

In this study a sociotechnical view has been adopted to explore the usefulness of interactive map-based support systems for engendering social learning and knowledge co-production. A sociotechnical view draws on design research literature in fields like information systems, education, management as well as in the field of science, technology and society (Edwards, 2003). This view seeks to integrate social and technical dimensions and therefore considers technology not as a freestanding tool to be studied in a laboratory stetting, but something that needs to be studied as it is applied in specific projects (Goodspeed, 2013). As such, this study has used the context of the Jufo-Salus project (described in section 1.6) and has carried out evaluation of the approaches by involving stakeholders from a real-world context.

Figure 1-3 shows the general methodology that was applied in the development and evaluation of the approaches of interactive map-based support systems. We have used a System Development Life Cycle (SDLC) (Zhang et al., 2005) that consists of a process of conceptualizing, developing and implementing an information system in sequential steps. Carugati (2008) has summarized the SDLC process into five basic steps as: identification & conceptualization, requirement definition, system design, implementation, and testing & refinement. In this study, these steps are generalized as development of a conceptual framework, system design and development with prototyping and pretesting, implementation and evaluation with a feedback loop to the conceptual framework.

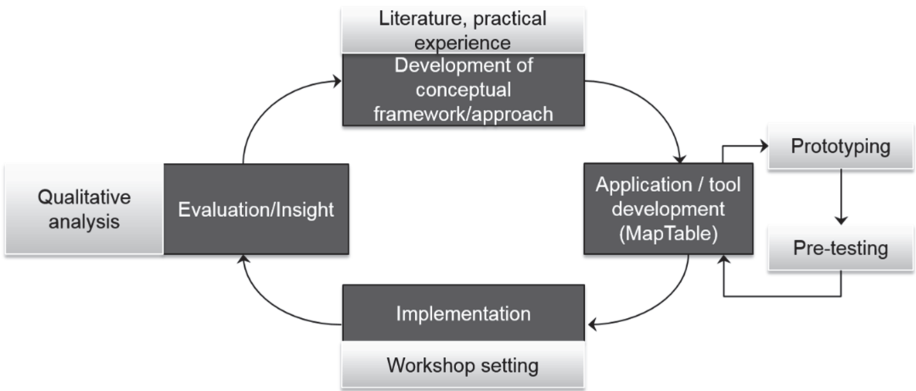

Figure 1-3 General methodology used in this study to develop and evaluate the approaches on interactive map-based support systems

Accordingly, the conceptual framework was defined for the two approaches of interactive map-based support systems in this study. The conceptual frameworks for both depict the way these approaches facilitate the process of social learning and knowledge co-production in the context of environmental health issues.

Operationalization of the framework in both approaches involved selecting the platform and user interface, designing the tool/model specific to the context and defining the facilitation task. In both approaches a MapTable was used as an interactive medium for user engagement. A MapTable is a large-scale, horizontal interactive display that shows digital contents in terms of maps. It allows users to interact with the content through touching and gestures. In the ISUSS approach, Phoenix 1.1 software (Geodan) was used in the development of the tool and the Interactive-CuBA approach uses CommunityViz Scenario 360 (CommunityViz Scenario 360) to develop the CuBA model. These approaches were first prototyped and tested with researchers from Jufo-Salus research group (section 1.6) and MSc students from TU Dortmund University before being used with the stakeholders.

Implementation of both approaches was carried out in a face-to-face workshop settings. All the workshops with the stakeholders were held in German language. Given the preparation needed to set up the workshops and the required harmonization with the other workshops of the Jufo-Salus research group, the ISUSS workshop was conducted only in Dortmund, Germany on 26 October 2014. The two workshops for Interactive-CuBA were conducted in Dortmund on 29 October 2015 and in Munich, Germany on 7 November 2015. The selection of stakeholders for both workshops was based on their professional roles, expertise and knowledge of environmental health issues in Dortmund/Munich. Prior Jufo-Salus workshops were used to identify participants. For the ISUSS workshop, a total of six individuals participated in the workshop—two municipal staffs (one each from the health and urban planning departments), three practitioners with backgrounds as NGOs/social entrepreneurs (one in a neighbourhood association, one in childcare and one from Local Agenda 21), and one researcher in urban planning. For the Interactive-CuBA workshops, five individuals participated in Dortmund and seven individuals in Munich. Participants in the Dortmund workshop included one municipal staff member from the urban planning department, three practitioners associated with NGOs/social entrepreneurs (one each from Local Agenda 21, a tenant association and a youth organization) and one researcher in public health. The Munich workshop included three municipal staff members (one from the social planning department, environmental department and the health department), one practitioner associated with an environmental NGO, one representative from a health insurance company, and one representative from a social housing company, and one researcher in urban planning.

Evaluation of the workshops included the collection of data obtained by using screen capture of the MapTable during the mapping sessions, voice recordings, observers' notes, a post-session questionnaire, and the maps produced on the MapTable. In the ISUSS workshop, a short debriefing of each participant and a rich picture drawings produced additional data. Screen recording voice were later transcribed with time coding and translated from German into English. Analysis of the data done using an exploratory methodology during which micro-analysis of the workshop transcripts were carried out. The use of micro-level analysis of conversations by the participants have been advocated as appropriate for understanding interactions mediated by technological artefacts (Tavella & Franco, 2015; Tsoukas, 2009)

1.6 *Jufo-Salus Context and Case Study*

This research has been developed in the context of the junior research group Jufo Salus (Jufo-Salus, 2013a). The group started the project on 'Cities as healthy place to live, regardless of social inequality' in 2013. The central aim of the project is to address the goal of healthy cities by integrating the concepts of health and health promotion in the planning process of urban areas in German municipalities. This research project focussed on exploring and understanding spatial inequalities in the urban area with regard to both salutogenic (green parks, forests) and pathogenic factors (air pollution, noise pollution) of the environment and their unequal distribution across various social vulnerability factors. Two German cities, Dortmund and Munich, were chosen as case study cities in the project. Both cities are among the ten largest cities in Germany in terms of population, Dortmund being the eighth and Munich being the third largest city. They are also the members of the WHO Healthy Cities Network and differ significantly in spatial structure and socio-demographic factors.

The city of Dortmund is located in the western part of Germany. It is situated in the highly urbanized region of the Ruhr in the federal state of North-Rhine Westphalia. It covers an area of 280 square kilometres with a population of around 600,000 inhabitants. The city has a long history of coal mining, steel-production and beer brewing, which produced a booming economy for the city from the early 19th century to the mid-20th century. Its history of industrialization and subsequent deindustrialization has, leading to long-lasting economic transformation, has had a great impact on the city: unemployment rates are high compared to German averages (Stadt Dortmund, 2015). In addition to strong social and ethnic segregation, Dortmund is characterized by a spatial structure that is typical for many other cities in the Ruhr, with better-off neighbourhoods in the south and disadvantaged neighbourhoods in the north (Flacke et al., 2016; Reuschke & Weck, 2013; Wehling, 2014). There is also a significant difference in health outcomes in the northern and southern neighbourhoods. The average life expectancy in 2011 ranged from 66.3 years in the Nordstadt district of Nordstadt to 76.3 years in one of the southern districts of Dortmund (Jufo-Salus, 2012).

The city of Munich, located in the south of Germany, is the capital and the most populated city in the German state of Bavaria. Munich is the third largest city in Germany with a population of around 1.5 million inhabitants. It covers an area of around 311 square kilometres. The city is a major centre for industrial production, services, and education in Germany and enjoys a very high standard and quality of living. However social integration remains a challenge in the city and affordable housing is its most pressing issue (Cucca & Ranci, 2016). Studies have also shown that environmental inequalities exist with respect to neighbourhood socio-economic position and negative environmental exposure in the city (Schüle et al., 2016; Schüle et al., 2017).

1.7 *Thesis Outline*

Chapter 1 sets the ground of this study. It provides a brief research background, describes key concepts this study builds upon, identifies the research gap and outlines the overall aim followed by the research objectives and research questions. It further describes the methodology applied in this study and briefly describes the Jufo-Salus project within which this study is embedded followed by a short description of the case study cities.

Chapter 2 addresses the first research objective of this study. The chapter sets the ground for involving stakeholders in a transdisciplinary research practice as is deemed necessary to tackle environmental health. This is rather challenging due to differences in understanding about these issues, contested nature of interests, knowledge that may persist among various stakeholders. In this regard, the chapter presents a methodological approach, named Interactive Spatial Understanding Support System (ISUSS) that facilitates stakeholders into a process of joint and mutual learning through co-production and integration of knowledge in an early planning phase of problem understanding. The usefulness of the approach is tested with a group of stakeholders in Dortmund, Germany.

Chapter 3 addresses the second research objective. The chapter presents a methodological approach to assess multiple environmental features including both pathogenic and salutogenic factors across a population with varying level of social vulnerability at a local level. It describes the application of the method to the city of Dortmund in Germany and illustrates its potential applications, complexities and the usability of the method for identifying 'hotspots' of spatial inequalities.

Chapter 4 addresses the third research objective. The point of departure is that a science-based stakeholder dialogue needs to be facilitated in cumulative based assessment with a particular focus on enabling social learning and knowledge co-production among stakeholders. Therefore, the chapter presents an interactive stakeholder based cumulative burden assessment approach (Interactive-CuBA) to support the science-based stakeholder dialogue. Following the methodological approach developed in chapter 3, two separate models are developed for the case studies of Dortmund and Munich. The usefulness of the approach is tested in two workshops, one in Dortmund and another one in Munich.

Chapter 5 addresses the fourth and final research objective. First the chapter presents the conclusions and main findings of the development and testing of the two approaches presented in chapters 2, 3 and 4. Based on the findings and lessons learned with respect to the social learning framework derived from literature in chapter 1, it provides a conceptual framework to support social learning and knowledge co-production mediated through the approaches of interactive map-based support systems. Finally, the main contributions and recommendations for further research are discussed.

Chapter 2: Interactive knowledge co-production and integration for healthy urban development *

* *This chapter is based on the article:*
Shrestha, R., Köckler, H., Flacke, J., Martinez, J., & Van Maarseveen, M. (2017). Interactive knowledge co-production and integration for healthy urban development. *Sustainability*, *9*(11), 1945.

Abstract

The transformation of cities towards healthy urban living environments for all is a challenge that needs to be addressed through collaboration of all relevant sectors in a transdisciplinary research processes. This paper reports on the design and showcase implementation of a methodological approach, named Interactive Spatial Understanding Support System (ISUSS), that is intended to support interactive knowledge co-production and integration among practitioners and researcher in a specific local context. The approach involves the combined use of interactive maps on a MapTable and a rich picture. The goal is to stimulate, articulate and map stakeholders' knowledge on environmental health issues to come to a shared problem understanding. Drawing on the rich seam of data gathered over the reflexive engagement with the participants in Dortmund, Germany, we explored incidences of a transdisciplinary process. Findings suggest that the approach has the potential to encourage communication and social learning geared towards a shared understanding of the holistic problem situation. Whilst locally embedded spatial knowledge was shared using interactive maps on the MapTable, the rich picture elicited issues linked to wider geographical scale as well as non-spatial drivers. The paper concludes discussing research needs to further explore the approach among various other groups, including citizens.

2.1 *Introduction*

The transformation of cities towards healthy urban living environments for all has received considerable attention in many international initiatives, such as the Ottawa Charter of the WHO (WHO, 1986), European Healthy Cities Movement (Hancock, 1993) and the Health in All Policies Strategy (Rudolph et al., 2013; Ståhl et al., 2006). Recognizing that urban planning processes fundamentally affect human health by influencing environmental determinants of health, scholars are now studying to integrate health promotion into urban planning at the local level (Barton, 2009; Barton & Grant, 2013; Corburn, 2004; Corburn & Bhatia, 2007). Environmental health herein comprises those aspects of human health that are determined or influenced by factors in the environment including both physical and social determinants of health (CSHD, 2008; Schulz & Northridge, 2004) in a specific local context, e.g. at the place of residence. Considering the multifactorial aspects of environmental health there is consensus that this subject is not structured within traditional disciplinary or sectoral boundaries. Owing to the strong linkages of environmental health issues to broader sectors in societies such as public health, social and private sectors, housing etc., researchers have endorsed collaboration by involving stakeholders from all relevant disciplines and sectors (Abernethy, 2014; Jackson, 2003). This understanding has brought attention to transdisciplinary research processes in the field of environmental health (Holmes et al., 2008; Khreis et al., 2016; Rosenfield, 1992).

Transdisciplinarity implies knowledge production which is based not only on the integration of knowledge from different disciplines, but also on the inclusion of values, knowledge, know-how and expertise from non-academics (Klein et al., 2001; Scholz, 2017; Scholz et al., 2000). As such, scientists and practitioners need to work on equal footing both taking co-leadership and requiring knowledge production and integration to be a collaboration and reciprocity among and between three main agents a) a legitimized decision-makers from practice; b) researcher from a university or public science institution; and c) those concerned with or affected by the problem addressed or by the decision made by the legitimized decision make (Scholz et al., 2014, p.85). Nevertheless, involving such a diverse group of stakeholders entails that people may have different values as well as interpretations of the problem itself, not only on the solution. Multi-stakeholder knowledge, interests, and understandings are confronted with each other and are to be integrated into a shared understanding. Therefore, Scholz (2017, p.5) formulates consensus building during the problem definition phase as one goal of transdisciplinary research. This is relevant in environmental health as health and health related problems are commonly understood in different ways by different people. The comprehensive understanding of health in the sense of the Ottawa Charter (WHO, 1986) goes beyond the absence of illness and medical treatment and follows setting oriented strategies of prevention and health promotion. A setting oriented approach seeks to include lifeworld oriented views of health. Activities to follow health promotion and prevention are confronted with 'siloed' problem-solving attempts among organizations and professions. The challenge in environmental health may not be the disagreement about how to address a given situation but what the issues to be solved are (Abernethy, 2014). Furthermore, overall knowledge on determinants of health has to be transferred into locally specific contexts.

Transdisciplinarity is not an automated process that arises by bringing together people from different disciplines or professions (Lawrence, 2004). In order to encourage transdisciplinarity, it requires an ingredient that has been referred to as 'transcendence' (Lawrence, 2004). This implies giving up sovereignty over knowledge, minimizing power differences among researchers and practitioners, generating new insights and knowledge by collaboration, developing capacities to jointly consider the know-how of professionals and therefore enabling all participants to become co-creators of knowledge (Boylorn, 2008; Lawrence, 2004). Thus, in transdisciplinary research, science is understood as a 'public good that serves all stakeholder groups' equally (Klein et al., 2001; Scholz, 2017). Collectively, transdisciplinary processes need to stimulate mutual and joint learning between science and society in order to enable a shared understanding of a subject (Scholz, 2000).

The motivation and justification to mobilize stakeholders into a process of joint and mutual learning through co-production and integration of knowledge have called for innovative approaches to transdisciplinary research. In general, these approaches need to encourage an open dialogue between participants in order to incorporate diverse perspectives and knowledge into the research process. Increasing research on health disparities and variation across geographic units advocates that health has a clear spatial connotation (Diez Roux & Mair, 2010; Northridge et al., 2003; Schulz et al., 2005), particularly the relationships between the built environment, contextual factors on neighbourhood level and health outcomes (Jackson, 2003; Voigtländer et al., 2010). This calls for an integration of the spatial dimension in the transdisciplinary dialogue in order to incorporate locally spatialized knowledge into health-related planning processes. Consistent with such recognition, we contend that a methodological approach to facilitate the co-production of knowledge by integrating knowledge and perspectives of various professionals with explicit spatial connotation can provide a useful tool for mutual and joint learning processes. For this we advocate a multi-method approach we named Interactive Spatial Understanding Support System (ISUSS), which is applicable in transdisciplinary research, following the goals of transdisciplinarity being capacity building between science and practice as well as consensus building (Scholz, 2017). We assume that the ISUSS approach enables knowledge co-production and integration by involving stakeholders from different sectors and that it encourages interaction, social learning and shared understanding on the locally specific problem situation.

In this paper, we provide the theoretical and conceptual basis of the ISUSS approach followed by a showcase implementation of the approach in the field of healthy urban development. The article pursues the following research questions: 1) how can knowledge co-production and integration among practitioners and researcher be supported by means of the ISUSS approach? 2) what are insights obtained with respect to interaction, social learning and shared understanding during the showcase implementation of the ISUSS approach in an environmental health context in Dortmund, Germany and 3) how does the ISUSS approach support a transdisciplinary research process?

Accordingly, the paper is structured as follows: In section 2, we describe the theoretical basis of knowledge co-production and integration model and methods; section 3 describes the conceptual framework of the ISUSS approach and section 4 explains the implementation of the ISUSS approach in a workshop in the city of Dortmund. Section 5 reports and discusses the findings gained during the showcase implementation. Finally, we reflect on the approach to facilitate a transdisciplinary dialogue, including its strengths and limitations.

2.2 *Knowledge co-production and integration in an environmental health context*

Knowledge co-production and integration implies a process where knowledge is produced and used through interaction among people with different perspectives and background through cooperative endeavours and mutual learning (Fazey et al., 2013). Various approaches have been used in participatory research to involve stakeholders in the process of knowledge co-production, such as World-Café, Delphi discussion, forecasting, backcasting (Preller et al., 2017). Similarly, various tools and methods are proposed for eliciting and capturing knowledge and perspectives such as sketch mapping, mental modelling, web-based mapping, mind mapping, photo mapping, interactive mapping (Andrienko et al., 2007; Cadag & Gaillard, 2012; Dennis et al., 2009). In situations where problems need to be explicated holistically at an early stage by incorporating multiple perspectives of the stakeholders related to a wider social, political, cultural context, problem structuring research provides various approaches and methods such as rich picture in Soft System Methodology (SSM) and cognitive mapping in Strategic Option Development and Analysis (SODA) (Ackermann, 2012). Likewise, with regards to knowledge integration, five types of integration are discussed in transdisciplinary research practice. These are interdisciplinarity integration, integrated system analysis, integrating different modes of thought, integrating interests and worldviews from different stakeholders, and integration relating to different cultures (Scholz & Steiner, 2015). In order to facilitate these types of knowledge integration in transdisciplinary processes, several methods and methodology have been presented for representation, evaluation and transition of real world cases (Scholz & Tietje, 2002; Vilsmaier et al., 2015).

Different concepts of knowledge have been advocated by various scholars (Pfeffer et al., 2013; Polanyi, 1966; Te Brömmelstroet & Bertolini, 2010). Knowledge co-production and integration in this study considers two dimensions of knowledge: explicit knowledge, which is formal and codable such as data, indicators; and tacit knowledge, which is personal, experiential, sectoral, and rooted in individuals' actions, experience, ideas, values, beliefs, and emotions. Confronting and combining tacit and explicit knowledge helps to make the explicit knowledge understandable for the stakeholders and increases the relevance of tacit knowledge in planning and decision making (Te Brómmelstroet & Schrijnen, 2010). In order to link tacit and explicit knowledge, Nonaka & Takeuchi (1995) have proposed a 'spiral' model of knowledge creation (SECI model). Describing knowledge co-production and integration as a learning and social process, the authors suggest that knowledge can be elicited and shared interactively through four key modes: socialization (tacit with tacit), externalization (tacit with explicit), combination (explicit with explicit), and internalization (explicit with tacit).

Recognizing that most real world problems are complex and need to be addressed in its complexity rather than in parts, scholars have argued for the combined use of two or more methods within a single intervention known as 'multi-method' or 'multi-methodology' (Franco & Lord, 2011; Mingers et al., 2010). Although a prescribed 'best way of combining methods is unlikely to exist', Franco & Lord (2011) advocate that choice of methods also depends on the nature of the task to be supported. Environmental health is being recognized as such complex, multi-dimensional problem that need to be understood holistically by incorporating knowledge and perspectives from various stakeholders. Additionally, determinants of environmental health are found to have a strong spatial connotation at the local scale and are influenced by various regional and supra-regional drivers (Voigtländer et al., 2012). In this regard, a multi-method approach is pertinent in the context of environmental health. Thus, a multi-method that deems appropriate in our approach is the combination of interactive maps to depict the spatial dimension of stakeholders' knowledge on environmental health at the local scale and a rich picture to depict knowledge and perspectives of stakeholders that may cover wider geographic scale and include spatial as well as non-spatial factors.

Interactive maps, are understood as dynamic maps supported by interactive interfaces. Owing to its dynamic features, interactive maps permit the users to browse, navigate, retrieve, filter large amount of spatial information in a gradual manner and in the same time support sketching as the users' goals are continually reformulated. Therefore, interactive maps can be effective organizers of geospatial data and can facilitate the exploration of problems and solutions in geographic space, support the integration of spatial information during reasoning, deliberation and communication among stakeholders (Andrienko & Andrienko, 2006).

A rich picture, is a graphical, 'cartoon-like' representation of a problem situation that is particularly used during early phases to record stakeholders' perspective and knowledge of a situation. Using roughly sketched symbols such as stick figures with short text rather than a linear prose structured in long text, a rich picture provides a strong visual expression about features of interest and the interactions among those features (Bell & Morse, 2013). It allows individuals to communicate their story of the relevant conditions affecting a situation and act as a tool for conversation and learning (Ackermann, 2012). Therefore, the rich picture can be a strong tool to incorporate knowledge and perspectives from various stakeholders in the same picture when used in participatory setting.

2.3 *Conceptual framework of the ISUSS approach*

Figure 1 presents the conceptual framework of the ISUSS approach and its interrelation with the SECI model and SSM. The intended outcome of the ISUSS approach is to enable communication and social learning throughout a process and to develop a shared understanding about the problem situation in a specific local context. The framework acts as a platform to enable integration of explicit knowledge and stakeholders' tacit knowledge during a collaborative stakeholder workshop. The framework distinguishes three phases: preparation, process and intended outcome. The preparation phase includes setting up the spatial data and determining facilitation interventions. The process phase is divided into iterative steps that the stakeholders are asked to carry out. Whilst the stakeholders are engaged in these steps, they follow the cyclical process of the SECI model implicitly (top horizontal). In doing so, the stakeholders move from a situation where they view the problem from their own frames to a situation where they share their views to others, following the first two stages of SSM (bottom horizontal). Each of the steps in the process framework is supported by either interactive maps or rich picture.

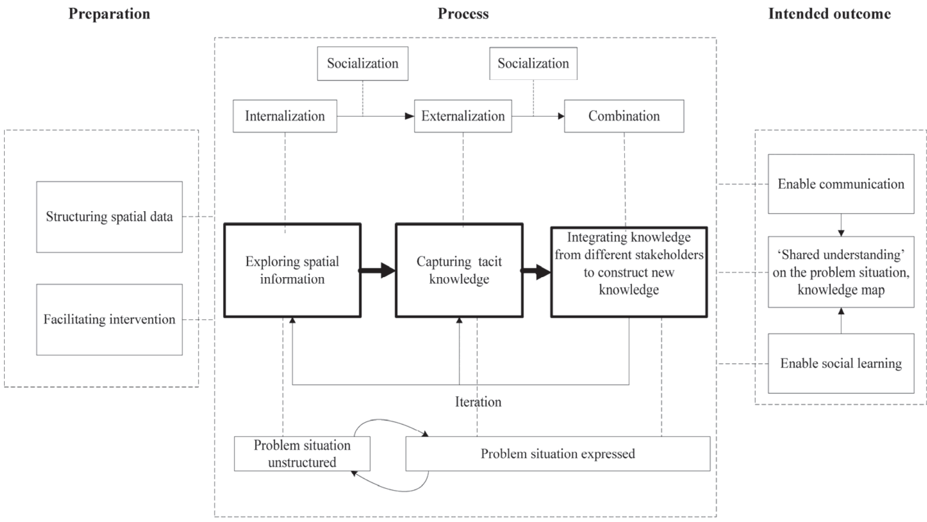

Figure 2-1 Conceptual framework of the ISUSS approach

2.3.1 Preparation phase

- Structuring spatial data

Structuring spatial data entails organizing spatial data in such a way that it provides relevant spatial information about the context under discussion. Essentially this means, collecting, processing, arranging and visualizing spatial information in the form of meaningful indicators at an appropriate scale and resolution to create maps ready for interactive use.

We use a MapTable—a horizontal table surface with a touch sensitive screen — in combination with Phoenix 1.1 software (at the time of the research, Phoenix 1.1 from Geodan was found best suited for our concept of the ISUSS. However, we customized some of the functionalities of the software to fit our purpose). The MapTable provides a platform for spatial discussion with a shared map interface to facilitate interaction among users and between users and the system through its touch-enabled interface during face-to-face group collaboration (Arciniegas, 2012). The table allows to use GIS (Geographical Information System) functions for navigation, map structuring, visualization as well as to produce and store spatial content interactively during the discussion.

For the ISUSS approach the following GIS functions are provided: map layer management and visualization, navigating tools, 3D visualization tool, multiple map overlaying, annotating, sketching and iconography.

- Facilitation of the workshop

The collaborative dialogue includes listening to each other, treating each other's interests with respect, looking for common interests rather than differences, and challenging assumptions ((Innes & Booher, 2003) in (Beukers et al., 2014)). In such a collaborative dialogue, group facilitation plays a critical role to ensure group performance and effectiveness. A facilitator can enable such a collaborative dialogue by ensuring that all participants feel comfortable to share their ideas and thoughts, to show empathy and critical judgement, and to analyse issues deeply. Furthermore, the participants need to be stimulated to think beyond their disciplinary boundaries as well as be willing to put their 'half baked' ideas forward ((Innes & Booher, 2003, p.46) in (Beukers et al., 2014)).

Hirokawa & Gouran (1989) divide the activities of facilitators into three areas: substantive, i.e. related to topics discussed; procedural, i.e. drawing attention to process elements like the agenda; and relational, i.e. attending to social or emotional issues (Pelzer et al., 2015). In the ISUSS approach the facilitator stimulates the stakeholders to share their perspectives, asking them for clarifications by encouraging them to make spatial references of their claims on the same. Moreover, the facilitator asks guiding questions in each step of the process helping to sharpen the arguments and to focus the discussion. Additionally, the ISUSS approach also requires tool-related facilitation. The use of technology during a collaborative dialogue could be a barrier due to participant's anxiety to the technology, the system's inflexibility, low reliability and learning time needed for participants to use the technology (Niederman et al., 1996). Therefore, the facilitator, also known as chauffeur, ensures that the discussion is not hampered while using the interactive maps on the MapTable. Similarly, while using the rich picture, the facilitator ensures that each stakeholder is encouraged to draw and to explain what is drawn to the other participants.

2.3.2 Process

- Exploring spatial information

The ISUSS process asks the stakeholders to explore and understand the spatial information provided in order to get insights into the context. While doing so, explicit knowledge is internalized into the individual's tacit knowledge bases in the form of mental models or technical know-how. Such effects have been observed by Te Brömmelstroet & Bertolini (2010) in a planning context.

Furthermore, when the stakeholders are engaged in exploring the information spatially, we assume that their tacit knowledge is triggered and they are encouraged to make it explicit. Thus, the ISUSS approach assists the discussion on a spatial context by providing interactive maps integrated into the MapTable. The stakeholders can explore the spatial information in the form of indicators individually or in combination, can compare them or evoke contrasts between various scales – such as neighbourhood to citywide.

- Capturing tacit knowledge

The second step allows the stakeholders to articulate their views, experiences, issues and concerns as a part of defining the problem situation. In doing so, they are presumed to undergo a process of externalization, i.e. articulating tacit knowledge. Several ways of expressing tacit knowledge have been acknowledged, for instance through metaphors, analogies, or models (Te Brómmelstroet & Schrijnen, 2010; Tee & Lee, 2013). Individuals express their perspectives, experiences or stories which they tend to relate to certain geographical locations. When the individuals are facilitated to link those experiences explicitly with related geographic objects on maps it can improve the discussion on a spatial context (Rémy & Mougenot, 2002; Rinner, 2006). Annotation and sketching tools help individuals to illustrate spatial relationships among objects of interest and to mark specific locations of issues that are retrievable and reviewable later (Tversky, 2000). Such sketching tools enable the stakeholders to make their understanding and their knowledge of the situation explicit while interacting with others.

- Integrating knowledge from different stakeholders to construct new knowledge

As part of expressing the problem situation in total, different knowledge from the stakeholders is combined collaboratively to construct a more holistic picture of the problematic situation. It includes systematizing, sorting, adding (Tee & Lee, 2013) and thus interrelating the issues and concerns of the stakeholders by applying the rich picture method.

2.3.3 Intended outcome

- Communication

Planning has become an argumentative process rather than purely instrumental and technocratic rationality (Healey, 1993). Such an argumentative process allows to 'appreciate different ways in which practitioners formulate and construct what the problem should practically be – before they can provide plausible alternatives or recommendations' (Fischer & Forester, 1993, p. 5). Communication is an important element in a transdisciplinary process to construct a shared understanding, for which acceptance of a degree of collaboration and reciprocity is needed (Healey, 1999). This includes accepting the opinions of others and that truth and values are the outcomes of social interaction within specific contexts (Beukers et al., 2014). In the same line, Innes (1998) argues that for a communicative and collaborative process to succeed, the process needs to encourage participants to address both explicit knowledge and tacit knowledge. In this line of reasoning, the ISUSS approach should encourage communication among the stakeholders.

- Social learning

Stimulating social learning among different stakeholders in a planning process is both an end and a means to achieve a better-informed outcome and shared understanding (Beukers et al., 2014; Innes, 1998). Social learning may occur through imitation and under the influence of norms and social context (Bandura, 1962). In order to encourage social learning 'a process must demonstrate that a change in understanding has taken place in the individuals involved, that this change goes beyond the individual and becomes situated within wider social units or communities of practice and occur through social interactions and processes between actors within a social network' (Reed et al., 2010, p.1).

To observe this change in understanding, a mental model has been advocated as a bridging concept (Scholz et al., 2015). A mental model is a 'schemata of interpretation' (Goffman, 1974) of external reality that people form in their minds to make sense of specific issues, to consider certain aspects of the problem more important, to select and highlight certain facets of the issues, and to promote a particular perspective of problem definition or interpretation (Jones et al., 2011; van Lieshout et al., 2011). Therefore, changing mental models with the support of social interaction is considered an indicator of social learning.

Mental models are determined to a great extent by the disciplinary background of the stakeholders in ways that reflect their training and techniques. Stakeholders may gain from making their frames more explicit and using them for generating different perceptions about the central issues (De Boer et al., 2010). Explicit mental models help to encourage an interdisciplinary communication, which may lead to forming a holistic understanding of the problem beyond the boundaries of single disciplines. Making mental models explicit, however, is not an easy task, since they tend to be rooted in the different rationalities of the stakeholders involved (Carton, 2007): 'from systematized accounts and analyses, and practical manuals, to stories exchanged in the flow of life, and skills exercised in doing practical work'

(Healey, 2007). As such, appropriate elicitation techniques are needed to explicate the mental model of each participant. In this regard, the ISUSS approach should support the stakeholders to articulate their frames on the problem situation as well as local context and communicate them to other stakeholders from different sectors in a common language shared by all.

- Shared understanding

Shared understanding refers to a degree of similarity between the mental models of the participants. The process of reaching a shared understanding has been viewed as an outcome of a social learning process where individuals interact with each other, take into account each other's perspectives, try to change their own mental models, negotiate and therefore identify common ground (Mulder, 2004). In doing so, the group members are engaged in 'divergent' and 'convergent' thinking processes and take into account different stakeholders and viewpoints to produce a representation that conveys a 'shared social reality' (Kaner, 2014).

While going through the ISUSS process phase, participants have the opportunity to engage in divergent thinking and share their knowledge, perspectives and initial interpretation of issues of concern on the locally specific problem situation. While engaging in convergent thinking, participants identify commonalities in views, learn about different issues and perspectives and therefore form a consolidated perspective of the issues. In doing so, in the ISUSS approach knowledge and perspectives at neighbourhood scale are captured as spatial knowledge map and at a wider geographic scale in the rich picture.

2.4 *Implementation of the ISUSS approach in Dortmund, Germany*

2.4.1 Context

The ISUSS approach has been developed in the context of the junior research group Jufo-Salus 'Cities as a healthy place to live, regardless of social inequality' (Jufo-Salus, 2013a). The project started in 2013 with the aim of integrating the concepts of sustainability and health for planning in urban areas for two German municipalities, Dortmund and Munich. The main focus of the project is on addressing health inequalities in the urban area including both salutogenic and pathogenic factors of the environment and their unequal distribution across various socio-economic groups. The city that is considered in this study is Dortmund.

The city of Dortmund is located in the western part of Germany in the former coal mining and steel-producing, highly urbanized region of the Ruhr. Influenced by historical industrialization and more current deindustrialization processes the city is undergoing a long-lasting economic transformation, resulting in high unemployment rates compared to German averages. The highly fragmented city shows large socio-economic disparities with significant differences in environmental quality. The persistent spatial inequalities in relation to unequal distribution of environmental burdens (air pollution, noise pollution) and benefits (green areas, forest areas) in the city of Dortmund have been highlighted in recent research (Shrestha et al., 2016). In addition to strong social and ethnic segregation in Dortmund, the city is characterized by a spatial structure with better-off neighbourhoods in the south and disadvantaged neighbourhoods in the north which is typical for the Ruhr (Flacke et al., 2016). Moreover, the city reveals significant differences in health outcomes. The average life expectancy in 2011 ranges from 66.3 years in the Nordstadt district in the north to 76.3 years in a southern district of Dortmund (Jufo-Salus, 2012).

One central element of the Jufo-Salus project is a transdisciplinary dialogue amongst scientists from urban planning and public health as well as practitioners from relevant fields with regard to environmental health. In this dialogue neither citizens nor politicians have been actively involved. For the transdisciplinary dialogue, other than the ISUSS approach, different methods, e.g. World-Café and planning game have been applied. (Köckler et al., 2014). The whole research process of the Jufo-Salus was structured around stakeholder workshops, directing the focus of the content on mixed land use and migration. This has influenced the preparation phase of the ISUSS workshop described below with respect to the selection of stakeholders, indicators and the study area of Nordstadt.

The ISUSS approach was first tested in a number of workshops with the researchers in the Jufo-Salus project, MSc students and academics from the TU Dortmund University. All participants were familiar with environmental health issues in Dortmund and had various disciplinary backgrounds, such as spatial planning, public health, transport planning. Based on the feedback from the participants and our observations from these test workshops, we refined the ISUSS approach with regard to the structuring of spatial data, facilitation intervention and workshop design. The ISUSS workshop itself was one three-hour stakeholders' session. The workshop took place on 26 October 2014 in Nordstadt in the office of a local NGO named Borsig 11 e.V. It was conducted in German language.

2.4.2 Stakeholder selection

The selection process of stakeholder was focused on involving practitioners representing different sectors and interests. In this regards, they were selected based on their professional roles, expertise and knowledge on environmental health issues in Dortmund. Potential participants were identified based on the contacts from prior workshops in Jufo-Salus. A total of six individuals participated in the workshop session. Participants included two municipal staffs from health and urban planning departments respectively and three practitioners having a background as NGO/social entrepreneur in neighbourhood association, childcare and Local Agenda 21 respectively. The second author acted as a participant from research. All the participants were closely related to the Nordstadt. Two authors of this paper facilitated the workshop, the first author carried out the role of a chauffeur, and the third author provided facilitation. One person observed the whole workshop.

2.4.3 Workshop design

Figure 2-2 provides the timeline for the workshop session, which was divided into three main steps. Spatial data used in the workshop were provided by the city of Dortmund (Table A1 provided in Appendix A). Indicator maps were prepared based on the issues discussed during earlier workshops and as requested by the participants during the test workshops. Data was provided at the smallest scale available.

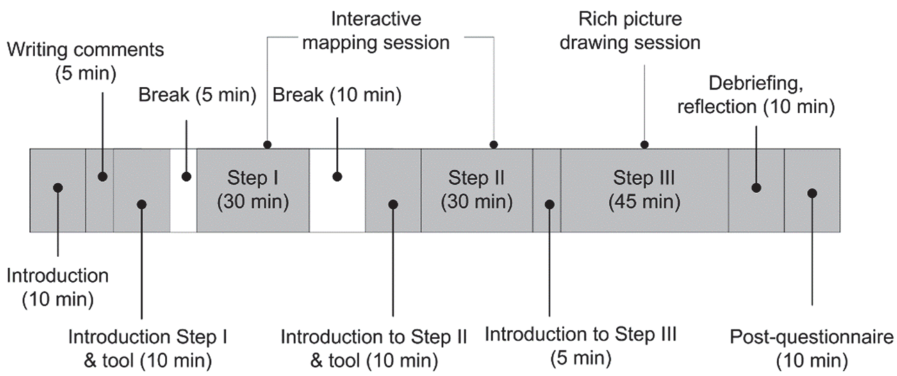

Figure 2-2 Timeline for the workshop session

The session began with an introduction to the objective of the workshop and to the study area. Next, the individual participants' perceptions of the most important issues in the case study area with respect to environmental health were collected. A short explanation of the steps and relevant tools was provided. At the end of the session each participant was asked to reflect on the issues collected at the beginning, their experiences with the ISUSS approach and to complete an evaluation questionnaire.

The interactive mapping session was carried out using interactive maps integrated into the MapTable (Figure 2-3 a, b). This session was divided into two steps as reflected in Figure 2-2—exploring spatial information (Step I) and capturing tacit knowledge (Step II). The purpose of the first step was to explore spatial information about the area and to evoke the initial concerns of the participants. To do so each participant was encouraged to choose spatial indicators on the MapTable that he/she perceived to be important and to explore the case study area with respect to these. The second step included eliciting and sharing each other's knowledge on environmental health issues relevant to the case study area and add their tacit knowledge on the MapTable. The initial framing question was focused on resources, opportunities or the lack thereof in terms of environmental and social factors.

(**a**) (**b**)

Figure 2-3 (a,b) Stakeholders working with the MapTable

Figure 2-4 shows the participant drawing a rich picture in Step III of the process. The aim of this step was to form a holistic view on the problem situation by integrating concerns and knowledge from each stakeholder. The participants were asked to make a pictorial representation of the most important issues relevant to environmental health, to show how they are interrelated to each other and to identify vulnerable groups to issues perceived as problematic in relation to environmental health.

Figure 2-4 Stakeholders drawing the rich picture

2.4.4 Workshop analysis

Data for analysing the workshop were collected using seven sources, namely screen capture of the interactive mapping session, voice recording, observer's notes, short debriefing on the overall workshop approach by each participant immediately after the session, a post-session questionnaire, the knowledge map produced on the MapTable and the rich picture. The screen capture and voice recording of the workshop and debriefing session were intended to capture complex interactions between the participants, the participants and the facilitators, and the participants and the tools. After the workshop, the recordings were transcribed and translated in English with time coding and were used to augment the questionnaire and observational results with illustrative examples of the participants' interactions and responses. The post-session questionnaire consisted of two parts: the first part on the usefulness of the interactive maps and the second part on the usefulness of the ISUSS approach to achieve the intended outcomes – communication, social learning and shared understanding. Participants were asked to use five-point Likert scales to express their level of agreement and provide a short answer on each question. The observer's notes were used to consolidate the findings from the workshop transcript and participants responses.

The analysis of the workshop was based on the reflexive engagement of three of the authors with the stakeholders from Dortmund during the workshop session. Reflexive engagement means 'making visible, paying attention to, negotiating and discovering at the various arenas' (Pihkala & Karasti, 2013, p.90). The adoption of this approach was motivated by the objective to understand the subjective meaning participants attributed to their experience using the ISUSS approach. The evidences were gathered and categorized by the first author which were re-examined by the second and the third author independently.

2.5 Insights from the ISUSS workshop

Throughout the entire ISUSS workshop all 6 participants were engaged in exploring data, mapping issues, discussing their own perspectives and knowledge in relation to environmental health in the case study area and later elaborating it into a pictorial form. One participant from urban planning was active immediately after introducing the methods whereas others required to be facilitated more, particularly in using the tools on the MapTable. The participants studied the indicators either individually or in combination and made use of 3D visualization when needed especially to identify specific locations. More stimulation and tool support was needed during the second step when they needed to sketch and annotate on the MapTable to explicate their knowledge. Drawing the rich picture needed initial activation before the participants drew actively. In general, the ratings given by the participants on the usefulness of interactive maps ranges between very useful to moderately useful (Table 2-1, questions 1-2). The ratings on the usefulness of the ISUSS approach to achieve the intended outcome also ranges between very useful to moderately useful except for one participants who gave lower responses for learning about new issues during the workshop (Table 2-1, questions 3-6).

Table 2-1 Questions and participants responses on the usefulness of method and ISUSS approach using five point Likert scale

	very useful	**useful**	**moderately useful**	**not so useful**	**not useful at all**
1. To what extent is the MapTable useful for you to explore the data and understand the information in relation to environmental health related spatial inequalities?					
Spatial information exploration	3	0	3	0	0
Understand spatial inequalities	4	0	2	0	0
2. To what extent is the MapTable useful to elicit your own knowledge and shared them to others?					
Own knowledge elicitation	1	2	3	0	0
Share knowledge to others	2	3	1	0	0
3. To what extent is the workshop approach useful to communicate your points of view to others?					
Communication	3	2	1	0	0
4. To what extent is the workshop approach useful to learn new aspects on the problem situation?					
Learn new aspects	0	4	1	0	1
5. To what extent is the workshop approach useful to understand and learn about other participant's perceptions and concerns?					
Learn about others' perspectives	2	2	2	0	0
6. To what extent is the workshop approach useful to find common among participants on the important issues?					
Find common ground	0	6	0	0	0

Note: usefulness of rich picture was derived from participants' debrief, observation from facilitator and observer

2.5.1 Workshop process: enabling active stakeholder participation

The use of interactive maps on the MapTable acted as a platform for the participants to support the internalization process of the existing spatial information. The ratings given by the participants were corroborated by their comments on the questionnaire. Three participants referred to spatial visualization of indicators as particularly relevant to see the connection between the places they know and the respective spatial information as well as to visualize various driving factors together. In doing so, information and knowledge are communicated in an interactive and dynamic way, the dialogue becomes energetic, and content in the form of map layers and stakeholders' knowledge is shared easily, as observed also by Pelzer and Geertman (2014). The screen capture showed that user-friendly interfaces together with the possibility to zoom in, pan and overlay different layers supported the participants to explore the environmental and social indicators together in multiple combinations instantly. For instance, by combining the indicators "Share of children under 6 years" with "Noise level from the street", the participants were able to explore their concern regarding the share of children being exposed to high noise levels. Structuring data to visualize indicators at a disaggregate level and enabling comparison of the Nordstadt with the entire district and even across different districts of Dortmund was particularly relevant to understand spatial inequalities as stated by the participants while working on the MapTable. This supports the fact that spatial inequalities are a relative phenomenon rather than an absolute phenomenon and the existence of spatial inequalities in an area can only be ascertained after knowing what is going on in other parts of the city (Baden et al., 2007; Whitehead, 1991). However, some tensions and resistances were also surfaced as one participant stated that the lack of small-scaled data at block level limited their analysis.

Figure 2-5 Spatial knowledge map: M1- inequality in accessibility and possibility to extend cycling routes between the northern and southern part of the city, M2- safety concerns, M3- good accessibility to parks inside the Nordstadt

In relation to the use of interactive maps to externalize and capture tacit knowledge, one participant stated as being a good platform to 'trigger discussions'. Referring to the spatial visualization of indicators, annotation and sketching functionality, one participant stated in the questionnaire that they were able to draw their 'ideas and scenarios quickly and further discuss them with others'. This resonates with Forester (1999) acknowledging that when the sketch of a plan was used to mark the boundary of the topic to be discussed, it helped the participants to clarify what they meant, to share and sharpen their arguments and to focus the discussion. Supported with the sketching tools and by using different colours and icons, they added knowledge at the scale of neighbourhood area as shown in Figure 2-5.

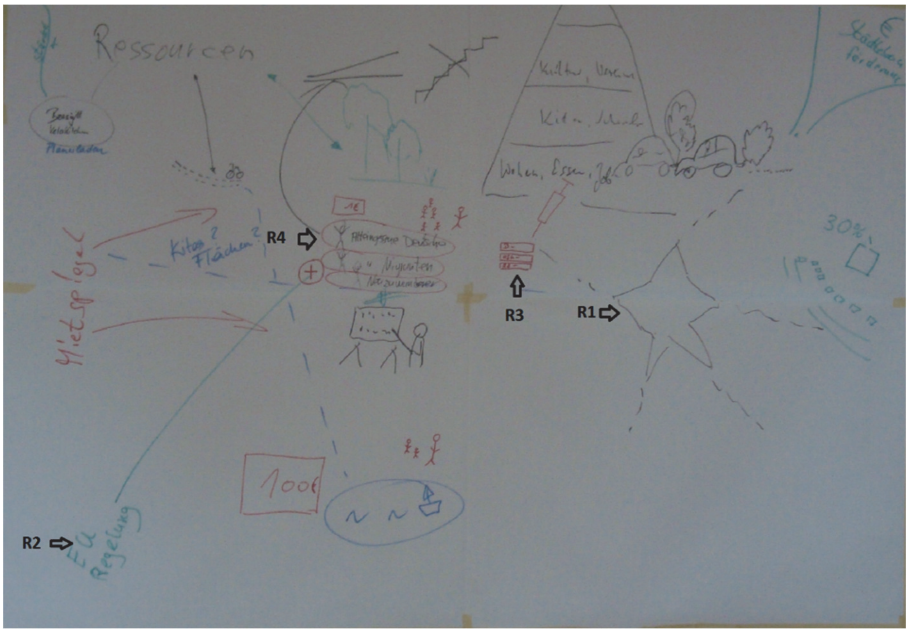

Figure 2-6 Rich picture: R1- the central square in Nordstadt being linked with different environmental burdens and benefits (e.g. cars causing pollution, green areas as resources), R2 - local and supra-regional drivers such as EU directives, rent index, EU health insurance policy not being able to provide proper health insurance to non-German inhabitants coming from other EU-Countries, R3- vehicles coming from other cities for various and even illegal activities, including buying drugs, R4- different vulnerable groups

The elaboration of the issues and concerns through the rich picture (Figure 2-6) supported the stakeholders in constructing an integrated picture of the environmental health situation in the study area. Furthermore, we observed the complementary use of the two methods. Visualizing spatial inequalities and communicating the views having localized spatial connotation was well supported by the interactive maps on the MapTable. For example, while discussing the topic of accessibility and transport safety the participants used the interactive map to develop a bicycle route that connects Nordstadt to the city-wide cycling infrastructure. When the discussions incorporated the reference to wider geographical contexts and non-spatial knowledge of the participants, such as health insurances of non-German inhabitants or the rent index, the joint elaboration of discussion through a rich picture enabled the participants to articulate, share and thus integrate such non-spatial or yet to spatialize knowledge into the holistic view.

2.5.2 Workshop outcomes: incidences of transdisciplinary aspects

The ISUSS workshop conducted in Dortmund contained various outcomes that are characteristic for a transdisciplinary research process. Particularly the elements of communication and interactions among the participants and social learning were observed during several occasions throughout the workshop. As one workshop participant phrased it:

> The system has produced discussions that wouldn't have taken place without it. In contrast to other workshops where presentations are using slides followed by the discussion, the approach was different as you stand in front of the screen [the MapTable] and you can really do something and discuss it.

By guiding the participants through a structured facilitation and enabling them to work actively with the interactive maps on the MapTable, the participants engaged with and questioned the existing spatial information. Additionally, the MapTable appeared to be a useful medium to bring the people together, encourage them to 'show what they meant'. This corroborates with findings from Hopkins et al. (2004) who found increased interaction among groups working with horizontal compared to vertical displays. In the sense of a transdisciplinary approach, in which the participants are the active agents and co-creators of knowledge, the ISUSS approach appeared to support such process of co-creation by providing a 'dialogue space' where evidence-based discussion is encouraged. This view was also reflected in the statements from two participants:

> […] because you get together in a different setting [bring different knowledge] and talk about specific issues [that the individual perceive as important], it is something completely different compared to just presenting some statistics on a screen […].

> […] when you use the indicators shown in the maps for discussions in the city council, you discuss based on fact and not about what you believe.

In this regard, the interactive maps allowed the participants to raise and register their views and further discuss them in more depth. Raising and registering views was also continued during the rich picture drawing session where the use of pictograms instead of texts and the linking of their views to others was stated by the participants as salient features to support communication. Whilst perceived improved communication is not different from the one claimed when the methods are deployed in isolation (Pelzer et al., 2014), it can be argued that the enhanced communication and enriched insights about the problem situation in the ISUSS approach was facilitated by the combined use of the interactive maps and the rich picture. This was clearly indicated in one participant's comment:

> Concerning the topics of noise and air pollution it may be sufficient [showing them on the MapTable]. But I see another field, i.e. the field of health insurance. I had the feeling that in the beginning this doesn't fit into the map. But it is relevant when talking about city as a healthy living space. So, I mention it here at the end [showing the rich picture].

Successful communication leads to enriched insights and social learning. The interactive maps and the rich picture enabled the participants to convey their thoughts to others and as such social learning was evidenced at different points in the workshop. For example, the participants overlaid multiple environmental and social indicators (e.g. share of children under 6 years overlaid with noise level (L_{den}) from streets) on the MapTable and discussed the same further, learning that children's routes to school are partly highly affected by noise and air pollution. The counterintuitive nature of the results from the interactive maps elicited the existing mental models of the participants. Through reasoning and interaction the participants sought to change their existing knowledge. For instance, after observing a striking high share of unemployment aid recipients (SGB II) along a certain street (Brunnenstraße), the participants were forced to think in-depth and discussed potential underlying reasons for the same. In the same way, the participants realized that the situation according to PM_{10} concentration on a specific street (Brackeler Straβe) is still problematic, but better than assumed. This street has been a symbol for high levels of air pollution in Dortmund and has been in the media quite often. One participant explained different initiatives being undertaken to improve the situation in that street. Learning was also ensured during the rich picture drawing session where the participants emphasized that by drawing a holistic view of the problem situation 'linkages became obvious and complex relations were represented clearly'. Nonetheless, one participant perceived less learning. He stated of being aware of the topics that were discussed and resonates with what Goodspeed (2013) found that participants who attended planning workshops more frequently (self) report less learning.

Operationalizing and assessing the concept of shared understanding has been reported difficult as it includes individual cognitive processes that often remain implicit (Mulder, 2004). However, construction of shared meanings were evidenced during the workshop. For instance, while discussing the accessibility of green areas from residential areas, part of the discussion was on whether the focus should be in terms of time and distance or in terms of safety of the access route. Consensus was reached about assessing the quality of the access from a safety point of view. Likewise, improving accessibility to green areas was identified as important in the case study area to promote the health of people. In general, the participants also rated the approach being helpful to find common ground. Nonetheless, the presence of consensus in the group as acknowledged in observer's notes depict that participants' opinions were mainly confirmed.

2.6 *Discussion and conclusion*

The ISUSS approach is a particular approach that seeks to stimulate knowledge co-production and integration on the problem situation by involving practitioners and researcher in a transdisciplinary process. Using an exploratory methodology and involving in reflexive engagement with the participants, we provided preliminary insights on the use of the ISUSS approach with respect to enabling communication, encouraging social learning and developing shared understanding for consensus building in the context of environmental health in Dortmund. Similarly, we were able to map knowledge and perspectives of various participants on the problem situation in environmental health context in Dortmund. In doing so, various underlying drivers and causes for the detected inequalities in the area were identified jointly, including both constraints and potentials as shown in Figure 2-5 and 2-6.

Various participatory methods and approaches have been designed with the aim of knowledge co-production and integration (Preller et al., 2017). The ISUSS approach shares similar epistemologies with these approaches regarding enabling communication, encouraging social learning and developing shared understanding. Nonetheless, our approach differs from others in the following aspects. The approach is designed explicitly to support a transdisciplinary dialogue among and between practitioners and researchers. In doing so, it aims to enable confrontation and combination of the explicit knowledge with the tacit knowledge of participants actively in a dialogue. In particular, the ISUSS approach support two types of knowledge integration as discussed for transdisciplinary research processes (Scholz et al., 2014; Scholz & Steiner, 2015): integrating different modes of thought and integrating interests and worldviews from different stakeholders. A potential benefit of using the ISUSS approach is that it allows the participants to explore multiple indicators in various combinations, to switch between various scales and levels (neighbourhood to city), and to integrate both spatial and non-spatial factors interactively.

Nevertheless, the approach entails two main challenges: completeness and comprehensiveness of indicators and proper tool-related facilitation. It was noted that during the interactive mapping session, particularly while exploring existing spatial information, the discussion was somewhat constrained either by limited number of indicators or unavailability of small scaled data. Similarly, while proper facilitation is needed to ensure the quality of any participatory approach, the importance of tool related facilitation becomes particularly important in the ISUSS approach. The risk of participants being distracted while using the interactive maps was mitigated by the chauffeur who supported the participants to use the tool where needed. Likewise, the risk of meaningless scribbles on the rich picture as concerned by others (Berg & Pooley, 2013) was mitigated in the ISUSS workshop by the facilitator who ensured that the participants describe the picture as they draw so that other participants understand the meaning associated to it. Therefore, skills of the facilitator and chauffeur in the ISUSS approach are essential to the process.

The ISUSS workshop in this study was conducted with six participants. Our intention was to construct a comprehensive workshop process and to provide initial information about the use of the ISUSS approach. This has led us to adopt exploratory methodology and to report insights on the use of the ISUSS approach rather than a controlled experimental settings with quantitative analysis like ANOVA-based design (Njoroge et al., 2015). This is worth being explored in further application studies of the ISUSS approach.

We hardly touch upon the evaluation of the ISUSS approach on the basis of its outputs – spatial knowledge map and rich picture – and their uptake in actual decision making process. The participants during the ISUSS workshop brought diverse knowledge and perspectives from various sectors on environmental health issues in Dortmund, but the small number of participants in this study has limited the representativeness of the spatial knowledge map and the rich picture generated. Nonetheless the participants represent a diverse group needed for a transdisciplinary approach (Scholz & Le, 2014). In the Jufo-Salus public health and urban planning work together in an interdisciplinary manner and the stakeholder groups were selected systematically to represent relevant topics of environmental health in Dortmund. Due to the design of the Jufo-Salus research group neither citizens nor politicians have been involved. The knowledge and values of these stakeholders who have not participated in the

ISUSS workshop might be different but equally relevant. Similarly, the ISUSS workshop with its interactive maps and rich picture allow to reflect on existing models of determinants of health (Bolte et al., 2012), however, this is beyond the scope of this paper. Therefore, further empirical studies can shed light on the ISUSS approach based on the outputs and their actual use in decision process by extending the approach to various groups in real-world context.

The ISUSS approach, as with other participatory methods, also depends on several other factors such as group dynamics, the knowledge base of the participants on the topic. Having a group with contrasting norms, values and competing knowledge together with a constructive conflict among the group can improve understanding of a situation with new insights (Cuppen, 2012). However, we found that the participants in the ISUSS workshop were partly like-minded. As such, the group appeared to have comparable norms, values and lack of challenging assumptions; at least they did not become obvious. This might have been caused by having the stakeholders who volunteer to participate in the research context of Jufo-Salus. Nonetheless, the participants brought various knowledge and perspectives about the problem situation. The ISUSS approach with a group of 'different-minded' would have resulted into increased confrontation of contrasting and even competing knowledge claims, which would have enriched the discussion.

Transdisciplinary research practice requires to facilitate process of mutual learning between science and society, enable co-production and integration of knowledge from science and practice through co-leadership among all the relevant stakeholders (Scholz & Steiner, 2015). In this regards, only getting stakeholders to participate is not enough to break hierarchical relationships as in the traditional form of knowledge production. In the ISUSS workshop we noted that the participants remained active, stimulated and engaged throughout the workshop and the knowledge production evolved from a one-directional information provision or unidirectional knowledge transfer to interactive knowledge co-production. Visual artefacts used in the ISUSS in the form of interactive maps on the MapTable and rich picture offered a 'dialogue space' and 'shared language' to engage in a dialogue process. Moreover, the methods encouraged a 'learning by doing' and 'knowing-in-action' (Schön, 1987) attitude among the participants and enabled the stakeholders to be co-creators in the process of knowledge co-production and integration. Similarly, transforming the conditions that influence health requires broad-based collaborative partnerships between practitioners, researchers, beneficiaries. In this sense, the approach has laid foundations for 'transformative reflexivity' in transdisciplinary research as described by Kindon (2010, p.264) 'in which both researcher and researched reflect on their (mis)understandings and negotiated the meanings of information generated together' (Preller et al., 2017). During the workshop, construction and negotiation of meaning became evident such as defining accessibility in terms of safety rather than in terms of distance by the participants before exploring the issues further.

We gained insights about the ISUSS approach both on a conceptual as well as on an operational level. The method is applicable for projects that deal with complex spatial problems and are required to include diverse knowledge and perspectives, both spatial and non-spatial, In the future the method might be applied within transdisciplinary processes as shared problem understanding and co-production of knowledge is a crucial point. In addition, with the ISUSS approach various frames can be brought to the fore and may increase the awareness among stakeholders and researcher that multiple frames or even competing claims exist. The ISUSS approach as presented here is designed for involving practitioners in early phase of problem understanding in transdisciplinary research practice. In the future, it is interesting to study its applicability to involve citizens with their knowledge and perspectives in the process or real-world decision problem. Nonetheless, the approach might require modifications in several aspects such as achieving representativeness of the group, combining knowledge maps from different groups together.

Chapter 3: Environmental health related socio-spatial inequalities: Identifying 'hotspots' of environmental burdens and social vulnerability*

* *This chapter is based on the article:*
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Abstract

Differential exposure to multiple environmental burdens and benefits and their distribution across a population with varying vulnerability can contribute heavily to health inequalities. Particularly relevant are areas with high cumulative burdens and high social vulnerability termed as "hotspots". This paper develops an index-based approach to assess these multiple burdens and benefits in combination with vulnerability factors at detailed intra-urban level. The method is applied to the city of Dortmund, Germany. Using non-spatial and spatial methods we assessed inequalities and identified "hotspot" areas in the city. We found modest inequalities burdening higher vulnerable groups in Dortmund (CI = −0.020 at p <0.05). At the detailed intra-urban level, however, inequalities showed strong geographical patterns. Large numbers of "hotspots" exist in the northern part of the city compared to the southern part. A holistic assessment, particularly at a detailed local level, considering both environmental burdens and benefits and their distribution across the population with the different vulnerability, is essential to inform environmental justice debates and to mobilize local stakeholders. Locating 'hotspot' areas at this detailed spatial level can serve as a basis to develop interventions that target vulnerable groups to ensure a health conducive equal environment.

3.1 *Introduction*

People living in urban environments are increasingly exposed to severe conditions of air pollution, noise nuisance, and heat stress which critically influence their health and wellbeing (Galea et al., 2005). On the other hand urban areas also provide resources such as parks and green areas that have the potential to attenuate noise levels (Lakes et al., 2014), absorb air pollution concentration (Brugge et al., 2015), regulate microclimate ecosystem services (Harlan et al., 2006) or provide opportunities for health promoting physical activities of their inhabitants (Cohen et al., 2007). These pathogenic factors (chemical/physical stressors) and salutogenic factors (resources) exist simultaneously and even interact with each other (Kühling, 2012; Mauderly & Samet, 2009).

In addition to the co-occurrences of pathogenic and salutogenic factors, urban environments have populations with varying social vulnerability. Social vulnerability describes the way in which various structural factors create the social fabric in which individuals and groups are differentially susceptible to environmental hazards, thereby shaping their ability to cope, adapt or resist differently when exposed to the same environmental hazard (Bolte et al., 2011; Cutter et al., 2003). Various studies are uncovering the heightened vulnerability among population who belong to racial or ethnic minorities or are of low socio-economic status (SES) (Gee & Payne-Sturges, 2004; Morello-Frosch & Shenassa, 2006; Morello-Frosch et al., 2011). These socio structural factors, such as race, ethnicity, SES, etc., are found to be determinants of social vulnerability and to be directly related to health effects (Galobardes et al., 2003; Richter & Hurrelmann, 2009) or to act as "effect modifiers" (Cushing et al., 2015; Kohlhuber et al., 2006). Given a certain level of environmental hazard, groups of a lower SES may bear more health effects than their counterparts. Several reasons have been proposed for widespread environment-related health inequalities among various social structural groups. As noted by Hermans (2004), people with a higher SES have more opportunities to adapt to the actual environmental situation; they have more choice about where they live, are able to influence decision making about their locality, and are able to get more involved in planning decisions affecting their living environment (Kruize, 2007 p. 106) (p. 106). On the other hand, the poor and minorities tend to possess less political power to fight the location of environmental hazards in their proximity ((Hamilton, 1995) in (Raddatz & Mennis, 2013)); their residential choices are strongly constrained by limited economic resources (Mennis & Jordan, 2005); they might experience discrimination in the housing market, which increases residential segregation. Studies have reported residential segregation as one such critical link between social structural factors and environment related health inequalities (Gee & Payne-Sturges, 2004; Morello-Frosch & Jesdale, 2006). Hence, differential exposure to multiple environmental burdens and benefits and varying levels of social vulnerability across the population may cause serious health inequalities (WHO, 2015).

A holistic assessment, which considers environmental burdens and benefits as well as their distribution across population with different vulnerability, is essential to inform environmental justice debates, to mobilize local stakeholders, and to develop interventions at local level that target vulnerable groups to ensure a health-conducive equal environment (Koeckler, 2014; Morello-Frosch et al., 2011). Environmental justice-framed studies have explicitly approached the multidimensional relationship between environmental inequalities and social disparities in their distribution (Huang & London, 2012; Pearce et al., 2010; Walker, 2010).+ These studies have a long tradition in the U.S. and the UK and have focused mostly on race, ethnicity and SES, largely ignoring the role of migration. The need to address these environmentally related health inequalities has recently been put on the agenda in many other European cities, focusing predominantly on single environmental variables and their social disparities (Hornberg & Pauli, 2007; Lakes et al., 2014). Along with the efforts to extend the environmental justice investigation to other European cities, there is now a growing recognition that a background of migration can be a social determinant of health and poor SES might itself be a result of migrant status and ethnic origin because of various processes of social exclusion, residential segregation as well as employment segregation (Rechel et al., 2013). Koeckler (2005) included, while exploring the role of social vulnerability and household coping strategies for Kassel in Germany, the percentage of foreigners in an index of SES in addition to the proportion of children and teenagers and unemployment rate. In the environmental justice study for Kassel, the socio-economic variables were measured as income, educational attainment, migration background, and number of children (Köckler, 2008). The author concluded that the households with lower SES and a background of migration to Germany live disproportionately in districts with lower environmental quality. Considering foreigners and welfare recipients as disempowered segments of population with minority status and poverty, Raddatz and Mennis (2013) found that industries and toxic release facilities are disproportionately located within and closer to neighborhoods with a relatively higher proportion of foreigners and poor people in Hamburg, Germany. Following the historical influx of working class immigrants, the authors (Raddatz & Mennis, 2013) speculated that persistent labor segregation, in combination with discrimination in housing, and lack of political empowerment to prevent the siting of environmental burdens, have reinforced residential segregation to produce patterns of environmental inequalities. In the German context, it is however to be noted that the status of foreigners or the background of migration is different from the characteristics of race or ethnicity as they are used in the U.S. context. Although the immigrants from the 1950s and 1960s who have resided in Germany for many years have acquired German citizenship through naturalization, and many children of those immigrants born in Germany have been granted German citizenship, they still bear the status of having a migration background (Raddatz & Mennis, 2013). Besides, existing studies have used administrative boundaries such as census tracts and districts that are often large and aggregated, in demonstrating inequalities with respect to environmental factors across various SES groups. However, there is growing evidence that substantial inequalities also exist on smaller and local scales (Roy et al., 2014). Therefore, an uneven distribution of multiple environmental burdens and benefits across areas with different social vulnerabilities remains to be investigated on a small, local scale.

This paper presents an approach to assess multiple environmental features including both pathogenic and salutogenic factors across a population with different vulnerabilities at a local scale. The method includes the construction of an integrated index using a number of environmental indicators that define residential exposure to various environmental aspects, as well as social vulnerability indicators of the residential population at a local scale. The paper describes an application of the method to the city of Dortmund, Germany to illustrate potential applications, complexities and the usability of the method for identifying "hotspots" of inequalities. It is a new approach to assess an uneven distribution of multiple environmental burdens and benefits taking into account the vulnerability of the population at a detailed intra-urban scale. The indices rely on data from the city administration and facilitate stakeholders to monitor the magnitude of these inequalities locally.

3.2 *Cumulative Assessment of Multiple Environmental Burdens and Social Vulnerability*

Spatial assessment and visualization of geographical areas with different environmental burdens and benefits across social vulnerable groups provide a strong tool in environmental planning and policy formulation and in informing environmental justice debates (Maantay, 2002). Such an assessment when conducted at a detailed scale helps to identify "hotspots" of groups and areas within the city that are most susceptible to harm due to the exposure to multiple environmental factors that might cause health inequalities considering the vulnerability of these groups and areas. While most environmental regulations and strategies in Germany are developed at the regional or national level, municipalities are responsible and have the freedom to implement those plans and strategies at local level (Strelau & Köckler, 2015). Therefore, easily comprehensible assessment methods should enable local agencies to design, implement and prioritize remedial activities as targeted interventions are particularly visible at this scale.

Various tools and methods have been proposed for the assessment of multiple stressors. While single or multiple environmental factors (especially burdens) are increasingly being considered in these studies, approaches including simultaneous exposure to both burdens and benefits along with social vulnerability of the population are rare. Lakes et al. (2014) included noise exposure and vegetation as an indicator of burden and benefit respectively to assess environmental justice issues using a social development index at planning unit level for Berlin. The authors (Pearce et al., 2010, 2011) calculated a multiple environmental deprivation index (MEDIx) at ward level on a nation-wide scale and showed "triple jeopardy" of environmental burdens and benefits deprivation, socio-economic disparities, and health outcome. Su et al. (2009) advocate that their CEHII index is able to aggregate multiple environmental factors and demonstrate its application by assessing inequality across non-white population and poverty (income). Their index focused on air pollution hazards whereas Wheeler (2004) focused on air quality, air pollution inventory, landfills, and major accident sites in England and Wales using a deprivation index.

All these methods are specifically being used to assess geographical areas at a regional and national level where the unit of analysis is a strict administrative boundary, except for the work of Sadd et al. (2011), who used the neighborhood scale unit, and Vlachokostas et al. (2014), who used the activity space of people as a unit of analysis. We argue that these methods are insufficient to provide a small-scaled assessment of multiple burdens and benefits across the social vulnerability of the population. The term "multiple burden and benefit" and "cumulative burdens" is used interchangeably in this paper and indicates the simultaneous occurrence of a number of environmental features at the same time in the same place.

3.3 *Study Area*

With 570,000 inhabitants, Dortmund is one of the ten biggest cities in Germany and the biggest in the Ruhr District (situated in the federal state of North-Rhine Westphalia). The city's economy boomed and flourished from the early 19th century to the mid-20th century from coal mining, steel industries, and beer brewing. In the mid-20th century, deindustrialization started, causing radical structural changes in most of the cities in the Ruhr District, including Dortmund.

Industrialization and deindustrialization had their impact not only on the employment sector, but also on the spatial structure of the city. During the industrial era the city grew from a moderate size to one of the largest cities in the Ruhr District. Growing industrial production in the city demanded a large number of workers. As a result the city opened its doors to migrant workers from other countries. In order to accommodate these workers within walking distance of these industries, housing was developed in close proximity to the industry locations. Later, deindustrialization brought another structural change to the city. The closing down of many industries led to job losses of the many industrial workers on the one hand and several abandoned and derelict spaces on the other.

At present, the spatial effects of these structural changes are different in the southern and northern part of Dortmund as in many other cities in the Ruhr District with a similar history. While the southern outskirts overall have a lower population density, dominated by single family houses with high average income households, the northern part of the inner city, specifically the districts of Nordstadt and Union, have the highest population density, the highest density of people with a migration background, dominated with houses of five storeys or more, and lower average income households with the highest percentage of people receiving social welfare (Stadt Dortmund, 2010). These spatial effects are strongly related to the historic development of the region as an industrial region and the particular geological structure of the Ruhr coalfield. In the south, industrialization began in the 1850s, the northern part was industrialized at the end of the 19th century. As such the southern outskirts and central part of the city have undergone extensive urban renewal processes during the course of structural change and are less burdened. In the northern part of the city, which was the working-class area of the 1980s and early 1990s, problems have accumulated: demographic, social and ethnic segregation, and multiple deprivation (Reuschke & Weck, 2013; Wehling, 2014).

3.4 *Materials and Methods*

Generally two arguments can be discerned in the construction of an index: (i) a deductive one, based on existing theories and frameworks (Pearce et al., 2011; Su et al., 2012); and (ii) an inductive one, that is data driven without an a priori model where a statistical model explains the observed outcome (Benmarhnia et al., 2013; Lalloué et al., 2014). According to Hinkel (2011) there exists a third argument which is based on individual or collective value judgements known as a normative argument. Existing frameworks and scientific knowledge in deductive arguments on multiple environmental burdens and benefits are immature. These frameworks and theories provide guidance on selecting potential environmental factors but not for aggregating. An inductive approach, on the other hand, requires sufficient data which may not always be available at the required scale. In this respect we prefer to use a normative argument. In this approach stakeholder-driven knowledge on the local context is incorporated while pre-selecting a suite of indicators for the city and also aggregating the indicators. For instance, environmental stressors prevalent in urban areas such as PM_{10} and NO_2 are often correlated as these can share the same sources of pollution (e.g., road traffic), which yield multicollinearity issues in an inductive approach (Lalloué et al., 2014). However, these stressors might lead to different health outcomes (Honold et al., 2012) and therefore need to be included. The methodological procedure for constructing an integrated index of multiple environmental burdens and benefits with social vulnerability is given in Figure 3-1.

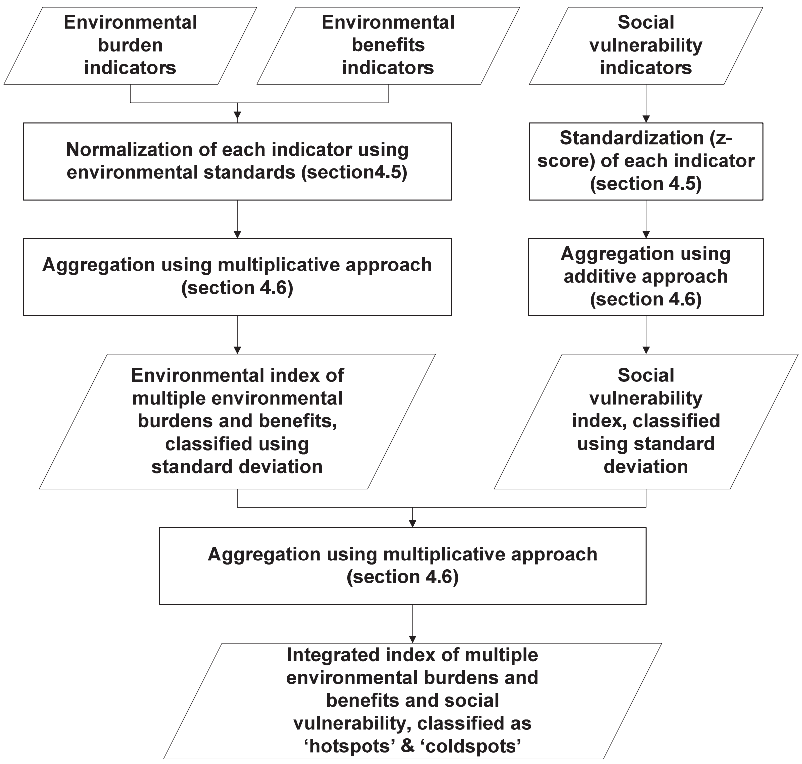


Figure 3-1 Methodological procedure to develop integrated index of multiple environmental burdens and benefits with social vulnerability of population

3.4.1 Environmental Indicators and Data Characteristics

The selection of environmental factors and respective indicators to be included is based on the following criteria:

(1) factors plausibly associated with health;
(2) relevance of the factors specific to Dortmund;
(3) comprehensive data for the entire city at adequate spatial resolution;
(4) representative state variables according to Driving, Pressure, State, Exposure, Effect, Action (DPSEEA) framework (WHO, 1999).

A broad scoping of literature was conducted to identify environmental factors potentially having health impacts (Benmarhnia et al., 2013; Brainard et al., 2004; Honold et al., 2012; Lakes et al., 2014; Pearce et al., 2011; Su et al., 2009). Only those environmental variables that represent external physical, chemical or biological characteristics of the environment were considered, such as air pollution in the neighborhood rather than indoor air quality (Pearce et al., 2010). These environmental factors and their indicators were then further screened based on the stakeholders' local knowledge of the relevance of the indicators for Dortmund collected during a workshop (in September 2013, within the project of Jufo-Salus, a stakeholder workshop was conducted. The main objective of the workshop was to identify key environmental indicators that affect the health of people in Dortmund and are relevant for the city. Stakeholders that participated in the workshop were from the municipality of Dortmund, health department, planning department, local NGO. Around 20 stakeholders participated in the one-day workshop (Jufo-Salus, 2013b)). Only those environmental factors having data available at neighborhood level were included in the index of multiple environmental burdens and benefits as presented in Table 1. For example, air quality indicators might include many pollutants such as PM_{10}, SO_2, NO_2, and CO, but we included only PM_{10} and NO_2 in accordance with relevancy for the city as stated by the stakeholders. Other factors, such as, heat stress, accessibility to health services (general practitioner other than hospitals), though acknowledged as relevant indicators for the city, were excluded due to the absence of fine-scaled data. We further sought to minimize the potential overlap between the indicators in order to prevent double counting (Blanc et al., 2008). As such the indicators for each environmental factor were chosen to correspond to the state level according to the DPSEEA framework. For example, instead of taking into account traffic density, or urban development, which are driving forces that push the environmental process or put pressure on the environment and may also be an indicator of air quality, we included the air pollutant concentrations that represent the state of the environment as indicators of air pollution.

Table 3-1 Environmental indicators included in the index of multiple environmental burdens and benefits

Dimension	Domain	Description of Indicators
Environmental burdens	Air quality	Annual average concentration of PM_{10} (μg/m^3)
		Annual average concentration of NO_2 (μg/m^3)
	Noise nuisance	Noise level from individual sources (industries, street and tram) measured in decibel (dB)
		Logarithmic aggregation of noise level from all sources (dB)
Environmental benefits	Green spaces	Accessibility to green areas >0.5 ha in size within walking distance
		Accessibility to forest areas of >0.5 ha in size within walking distance
		Accessibility to green areas in general (forests, parks, cemeteries) >0.5 ha in size within walking distance

For each of the environmental indicators as presented in Table 3-1 the datasets were obtained from the City of Dortmund. Table 3-2 presents the data sources used to capture each environmental indicator and its detail description.

Table 3-2 Data characteristics and sources for environmental factors

Domain	Data	Data Source	Areal Unit
Air Quality	Average concentration of air pollutants (PM10, NO2) in a year	City of Dortmund, 2013	Grid (125 × 125 m)
Noise nuisance	Noise level from individual sources (industry, traffic, tram)	City of Dortmund, 2013	Point data at 10 m interval
Green spaces	Land use	Current land use map from City of Dortmund 2013	Parcel level

Air quality includes annual averages of nitrogen dioxide (NO_2) and particulate matter (PM_{10}) concentration (expressed in μg/m^3) which was modelled on a 125 × 125 m resolution using the LASAT dispersion model. The modelling included emission data from individual sources: traffic (cars, trains, air, and ships), industry, and households (domestic heating and small firing, in and outside Dortmund); having a resolution of 1 km × 1 km resulting from different time frames between 2004 and 2012 (for more details on modelling, see (SimuPlan, 2013)).

Noise nuisance from a single source was modelled for the entire city using the noise dispersion model following the Noise Mapping Decree (Federal Emission Protection Decree and Federal Emission Control Act) and the Noise Mapping Directive 2002/49/EC (Environmental Noise Directive). The following noise level data were acquired: road traffic, industries, above-ground subway, and tram. The noise model data provide a weighted noise pressure level (topography, building footprints, and height were included in the model) for each point location at a 10-m interval (for more details, see (Ministry for Climate Protection)). The metric that was used to characterize noise at each point location from an individual source is the European standard L_{den} indicator (day-evening-night level, measured in decibels, dB), an assessment of daily exposure over a 24-hour period taking into account residents' increased sensitivity to noise during the evening (1800 hours till 2200 hours) and at night (2200 hours till 0600 hours) (Ministry for Climate Protection).

Green spaces were extracted from a land-use data set on existing land-use from the City of Dortmund. The land-use data were prepared using 1:5000 scale aerial photographs from 2013. The data contained detailed land-use categories at parcel level. For green spaces we took public green spaces where access is unrestricted (e.g., parks, cemeteries, green areas, and forest areas). We excluded backyard gardens and urban gardens from green areas as they are private and not accessible to the general public. For the forest we considered areas that are designated as deciduous, coniferous or mixed forest from the land use dataset.

3.4.2 Social Vulnerability Indicators and Data Characteristics

Table 3-3 shows the list and description of the social indicators that represent the social vulnerability of people in Dortmund. The selection of the social vulnerability indicators was primarily based on the studies specific to the context of Germany (Köckler, 2005, 2008; Lakes et al., 2014; Raddatz & Mennis, 2013). The initial list for SES variables included income, unemployment, education attainment, and migration background. Instead of measured income and unemployment rate we used population receiving public assistance (social welfare known as SGB II—working age population receiving assistance—and SGB XII—basic security for old age, disability, assistance for livelihood share) as an indicator of unemployment and those living below the poverty line respectively specific to the context of Germany. Based on the inputs from stakeholders during the workshop and other studies (Cushing et al., 2015; Meehan August et al., 2012), we further included indicators for sensitive population such as children aged between 6 to 11 (prenatal and neonatal were excluded as we considered the ages between 6 to 11 to be more exposed to the outside environment) and the elderly above 65 years. Moreover, we only included those indicators that could be obtained from census data at neighborhood level. As such, we could not include the indicator on educational attainment after higher school though it was acknowledged as important for Dortmund.

Table 3-3 Social indicators included in the index of social vulnerabiltiy

Dimension	Domain	Description of Indicators
Social vulnerability	Sensitive population	Number of people aged between 6 and 11 (persons/625 m^2) Number of older adults aged 65 years and over (persons/625 m^2)
	Social and economic	Number of people with migration background (persons/625 m^2) Number of people receiving SGB II (persons/625 m^2) Number of people receiving SGB XII (persons/625 m^2)

The data characteristics for each indicator of social vulnerablity from the 2014 survey are presented in Table 3-4.

Table 3-4 Data characteristics and sources for social factors

Domain	Data	Data Source	Areal Unit
Sensitive population	Population aged between 6 and 11 years Population aged 65 years and older	Social structure Atlas from City of Dortmund, department of Statistic	Neighborhood level
Social and economic	Proportion of population having migration background Proportion of population receiving SGB II Proportion of population receiving SGB XII		

3.4.3 Data Conditioning and Spatial Resolution

The descriptive statistics for each environmental indicator on a 125 × 125 m grid cell for the entire city are presented in Table 3-5.

Table 3-5 Descriptive statistics for environmental indicators

Indicators	Min	Max	Mean	Standard Deviation (Std. Dev.)
Annual average concentration of PM_{10} (μg/m^3)	22.08	394.40	24.90	5.45
Annual average concentration of NO_2 (μg/m^3)	21.79	116.76	32.06	8.12
Noise level from individual sources (industries, street and tram) measured in decibel (dB)	0^a, 0^b, 0^c	76.16^a, 89.05^b, 69.31^c	2.66^a , 55.7^b, 5.6^c	10.89^a, 8.6^b, 15.19^c
Logarithmic aggregation of noise level from all sources (dB)	14.7	89.05	56	8.44
Accessibility to green areas >0.5 ha in size within walking distance (m)	1	2053	452.5	388.6
Accessibility to forest areas of >0.5 ha in size within walking distance (m)	1	2011.09	301.00	337.27
Accessibility to green areas in general (forests, parks, cemeteries) >0.5 ha in size within walking distance (m)	1	1344.83	152.80	188.64

a – refers to value for industries, b – refers to value for street, c – refers to value for tram

The air pollution data were acquired on a 125 m raster level for the entire city. For the environmental indicators we chose a 125 × 125 m^2 grid cell as spatial resolution. This resolution provides enough variation within the sub-district level. The point data on noise level for each source were also interpolated at 125 × 125 m^2 resolution using Inverse Distance Weighted function in Geographic Information System (GIS) (Farcaş & Sivertun, 2010) in order to match the spatial resolution of the air quality indicator. In addition, noise levels from single sources were integrated using a logarithmic scale (Brainard et al., 2004).

All green and forest areas with unrestricted accessibility, above 0.5 ha in size and provide areas for recreation and physical activity were included in the analysis (Honold et al., 2012). Before excluding areas less than 0.5 ha in size, areas that are adjacent to large areas were merged together as we observed that these small patches are in reality part of the large areas and are only separated by pathways or water bodies inside parks or forests. We calculated "crow flight" distance for each 125 m grid cell to any nearest green area separately for parks and forests, and green areas in total (including both parks and forests) using GIS.

The descriptive statistics for each social vulnerability indicators on the level of neighborhoods are presented in Table 3-6.

Table 3-6 Descriptive statistics for indicators of social vulnerability at statistical sub-districts level

Indicators	Min	Max	Mean	Std. Dev
Number of people aged between (persons/km^2)	0	2806.3	166.07	263.97
Number of older adults aged 65 years and over (persons/km^2)	5.2	2943.63	620.97	515.29
Number of people with migration background (persons/km^2)	1.05	23,884.80	1142.79	2410.75
Number of people receiving SGB II (persons/km^2)	0	13711	626.68	1373.31
Number of people receiving SGB XII (persons/km^2)	0	1243.04	68.11	138.44

We divided each neighborhood into 25 m × 25 m grid cells (hereafter referred to as social units) in order to show intra-urban variations of social vulnerability indicators. The choice of a 25 m spatial resolution for social units was made after a visual inspection to avoid underrepresentation and overrepresentation of residential areas at neighborhood level. The residential areas were extracted from the land-use dataset that shows detailed categories of existing land use in the city at parcel level. We reproduced each social indicator at 25 m resolution using the polycategorical three-class dasymetric method to distribute population from each census zone (Eicher & Brewer, 2001; Moon & Farmer, 2001). Initially, each land use with specific housing characteristics was assigned a fixed proportion of the population. The proportion was subsequently adjusted considering actual land use areas with specific housing characteristics within each source zone (here in neighborhood) (Langford, 2006; Mennis, 2003). As such the total population, accounted for on each neighborhood level, is maintained and distributed to residential areas with specific housing characteristics belonging to the same neighborhood. We used equation (1) as proposed by Langford (2006) for the:

$$d_{cs} = \frac{P_s}{\acute{P}_s} . d_c \qquad (1)$$

where c = land cover class or urban density class; s = source zone; d_{cs} = specific density estimate for class c in zone s; Ps = actual population of source zone s; $\acute{P}_s$ = estimated population of source zones given by:

$$\acute{P}_s = \sum_{c=1}^{C} d_c n_{cs} \quad (2)$$

with d_c = initial global density estimate of class c; n_{cs} = number of pixels of class c in source zone s; C = total number of populated land cover classes or urban development classes.

We used physical housing characteristics based on the categories in the land use dataset in terms of number of storeys (two, three, more than five) and land use classes (residential and mixed land use). Occupancy rates and population density in an area varies with socio-economic factors such as wealth, age groups, and cultural differences, and are assumed to be related to physical housing characteristics (Langford, 2006). The initial global density (d_c) for each class C was estimated, based on the stakeholders' opinions regarding residential land use with two-storied (15%), three-storied (30%), more than five-storied buildings (40%), and residential mixed land-use (15%). The descriptive statistics for each social vulnerability indicators on the level of 25 × 25 m^2 resolution are presented in Table 3-7.

Table 3-7 Descriptive statistics for indicators of social vulnerability at the level of social units

Indicators	Min	Max	Mean	Std. Dev
Number of people aged 6–11 (persons/625 m^2)	0	4.8	0.42	0.37
Number of older adults aged 65 and over years (persons/625 m^2)	0.4	24.4	1.71	0.96
Number of people with migration background (persons/625 m^2)	0.08	41.5	2.62	3.59
Number of people receiving SGB II (persons/625 m^2)	0	23.8	1.44	2.06
Number of people receiving SGB XII (persons/625 m^2)	0	2.81	0.15	0.23

3.4.4 Normalization or Standardization of Indicators

The steps that are generally addressed before aggregating the indicators are normalization or standardization of each indicator to overcome the incommensurability of the units in which single indicators are measured, followed by weighting of indicators to assign preference of one indicator over the other. We used environmental standards as thresholds for normalizing each environmental indicator. Environmental standards are used in planning and policy making as an acceptable limit that no intervention should exceed. Normalizing the indicator in such a way helps stakeholders to identify areas that have high exceedance of environmental standards. We calculated the ratio value for each grid cell (125 m × 125 m) by dividing the indicator value by the corresponding environmental standard (Table 8). All environmental burdens and resources are transformed in such a way that values less than 1 refer to low burden or good access to resources with respect to the threshold standard, and values higher than 1 to higher burden or poor access to resources. For social vulnerability indicators we used standardization (z-score) to avoid the score being influenced by a high or low value for one variable and to put each variable on the same scale, centred around the city's mean (Morgan & Baker, 2006). Social units (25 m × 25 m) with a positive standardized score show higher level of vulnerability. On the contrary, a negative score shows less vulnerability.

Table 3-8 Environmental standards used to normalize each environmental indicators

Environmental Indicators	Threshold Values	Source
Annual average PM_{10} concentration Annual average NO_2 concentration	40 µg/m^3 40 µg/m^3	Deutscher Bundestag (2010)
Annual average noise level	55 dB	EU (2002)
Distance to green spaces >0.5 ha	500 m	Honold et.al. (2012)

3.4.5 Aggregation of Indicators into Index

The final step of constructing the index is the aggregation of indicators into one composite score. The most commonly used method is the additive or weighted arithmetic mean (Cushing et al., 2015; Huang & London, 2012; Lakes et al., 2014; Meehan August et al., 2012) and the multiplicative or geometric mean method (Su et al., 2009; Zhou et al., 2006). Both methods produce meaningful results in the case indicators are normalized before aggregation as these become dimensionless (Zhou et al., 2006). Nonetheless, aggregating indicators arithmetically based on equal weights implies that variables are perfect substitutes, which means that a low value in one variable can be compensated by a sufficiently high value in another (Nardo et al., 2005; Vlachokostas et al., 2014). An implicit assumption of the additive approach is that variables are preferentially independent and non-interactive. Alternatively, the multiplicative approach suggests that a low value in one dimension cannot be fully substituted by a high value in another dimension. This approach is better when it is known that the aggregated entities influence each other (Nardo et al., 2005; Villa & McLeod, 2002). Therefore, even if the exact interaction of the environmental indicators are not known and not within the scope of this study, we argue that neighborhoods having higher burdens should not be fully compensated by higher benefits. We therefore used a multiplicative approach to aggregate environmental variables (Equation (3)). The index score for the cumulated multiple burdens and benefits ranges between 0.13 to 1.41. The additive method was used to construct the social vulnerability index (Equation (4)), implying that there can be a compensation between a high and low value. For instance, a neighborhood with a higher number of migrants may not be vulnerable given that they have sufficient resources to escape from environmental burdens. In both indices equal weighting was considered for all the indicators. The score for social vulnerability index ranged between −4.17 to 45.54. We used the standard deviation based visualization for both the environmental and the social vulnerability index to identify areas that have the highest deviation from the city's mean.

$$EI_j = \prod_{i=1}^{n} \left(w_i r_{ij}\right)^{\frac{1}{n}} \tag{3}$$

where, EI = Environmental Index of multiple environmental burdens and benefits; j = spatial unit, here 125 m × 125 m grid cell; i = environmental indicators under consideration (i = 1, 2, 3,……,n); r_{ij} = ratio value with respect to indicator i at spatial unit j; w_i = weight assigned for each indicator; here it is equal to 1 as equal weight

$$SVI_{\hat{j}} = \sum_{k=1}^{m} w_k p_{k\hat{j}} \tag{4}$$

where, $SVI_{\hat{j}}$ = Social Vulnerability Index; ĵ = Social units, here 25 m × 25 m grid cells, which fall into j; k = social vulnerability indicators under consideration (k = 1, 2, 3,……,m); $p_{k\hat{j}}$ = standardized score with respect to indicator k at social unit ĵ; w_k = weight assigned for each indicator; here it is equal to 1 as equal weight.

An integrated index score of multiple environmental burdens and benefits with social vulnerability was calculated for each social unit (25 m × 25 m). The score was obtained using a multiplicative function (Equation (5)) considering social vulnerability as "effect modifier".

$$IESVI = EI \times SVI \tag{5}$$

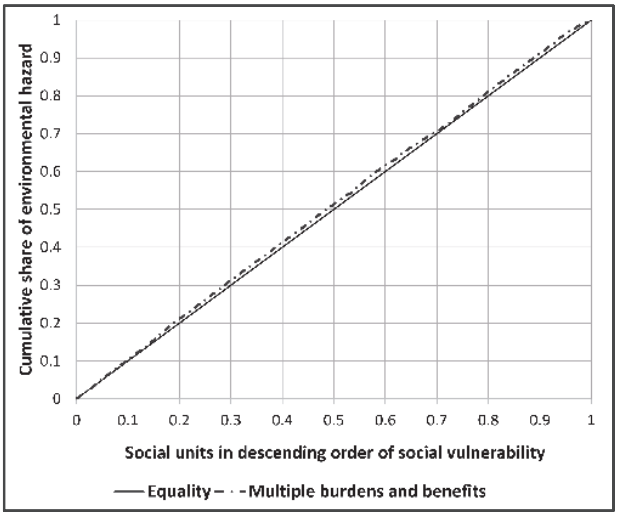
where, IESVI = Integrated environmental and social vulnerability index; EI = Environmental Index of multiple environmental burdens and benefits; SVI = Social Vulnerability Index.

Given a similar environmental quality, areas with higher vulnerability suffer greater impact than those with lower vulnerability. The score for integrated environmental and social vulnerability index ranges between −3.8 to 38. In order to visualize the “hotspots” (having high cumulative burdens and high social vulnerability) and “coldspots” (having low cumulative burdens and low social vulnerability) the index value was categorized based on the standard deviation value. Areas with a score of more than 2.5 standard deviation from the city’s mean in the positive direction are termed “hotspots” whereas areas with a score of less than 0.5 standard deviation in the other direction are considered as “coldspots”.

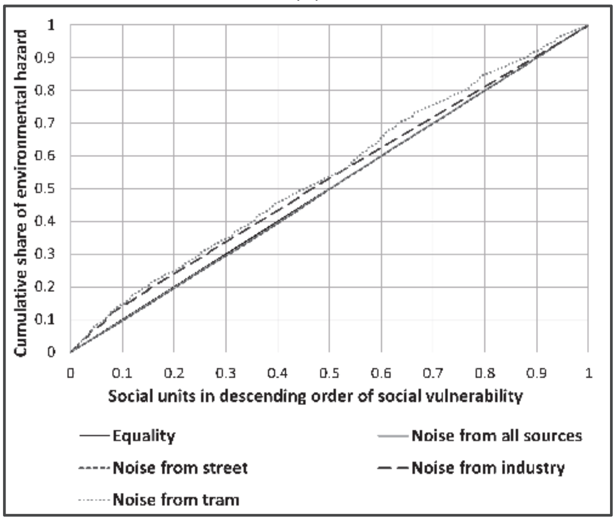
3.5 *Results*

Concentration curves illustrating the distribution of single and multiple environmental burdens and benefits with regard to social vulnerability scores in social units across the entire city are presented in Figure 3-2. We constructed the concentration curve by ordering each social unit across the x-axis from highest to lowest in terms of social vulnerability (Cushing et al., 2015; Su et al., 2009). If there is perfect equality in the distribution of environmental burdens and benefits across social vulnerable groups, the graph will be a straight diagonal crossing the origin at 45°. Curves above this equality line indicate an unequal distribution with social units of higher vulnerability bearing disproportionately higher environmental burdens; for curves below the equality line it is the other way around. The farther the curve is above the line of equality, the more concentrated environmental burdens are among social units with higher vulnerability and vice versa.

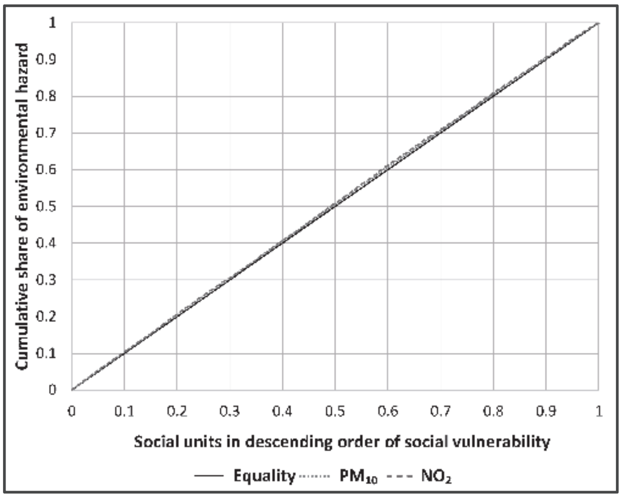
The concentration curve for multiple burdens and benefits with respect to social vulnerability (Figure 3-2a) lies almost on top of the equality line. Based on this observation we can assume that there is no pronounced inequality. Exploring the concentration curves for every single environmental factor separately in Figure 3-2b–d, we observe that all the concentration curves lie rather close to the line of equality, except for access to green areas and access to forest areas, indicating an only limited inequality with respect to individual environmental factors as well. Among all the environmental factors lying above the equality line, access to forest areas shows relatively large deviations followed by noise exposure from tram and industry. On the other hand, among those lying below the equality line, access to green areas affects the social units having lower social vulnerability stronger.



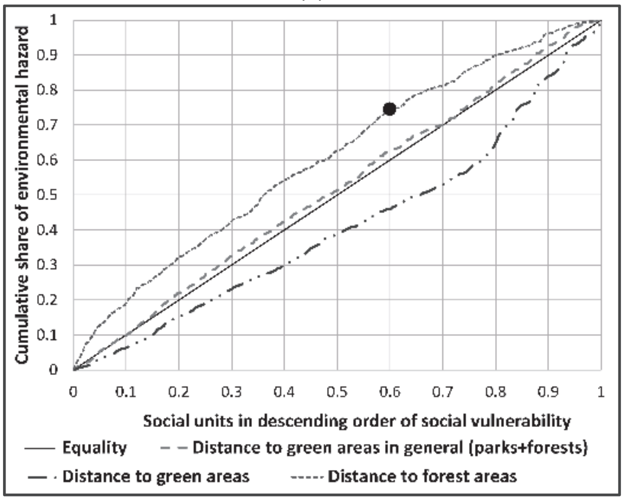
(**a**)



(**b**)



(**c**)



(**d**)

Figure 3-2 **(a)** Concentration curves illustrating the distribution of indicators for combination of factors with regard to social units having varying social vulnerability; **(b)** Concentration curves illustrating the distribution of noise indicators from individual sources and combined noise exposure (logarithmic addition of noise level from all sources) with regard to social units having varying social vulnerability; **(c)** Concentration curves illustrating the distribution of air pollution indicators with regard to social units having varying social vulnerability; **(d)** Concentration curves illustrating the distribution of green areas (public parks, cemeteries) and forests separately and green areas in general (parks, cemeteries, forests) with regard to social units having varying social vulnerability. For example the point in **(d)** illustrates that when the cumulative share of social units is 60%, those social units with higher social vulnerability bear the disproportionate share of distance to forest areas of 75%.

The concentration indices (CI) provided in Table 9, calculated after Kakwani et al. (Kakwani et al., 1997), depict both the strength of the relationship between social vulnerability and environmental hazards and the degree of variability in the environmental factors. The CI values range from −1 to 1, with zero indicating equality, negative values indicating environmental burdens disproportionally affecting social units that have a higher vulnerability, and positive values the opposite. We tested the null hypothesis CI = 0 and the significance of the CI index by calculating the standard error, and 95% confidence intervals (Kakwani et al., 1997).

Concentration indices and their 95% confidence intervals in Table 3-9 show that although the degree of inequality with respect to multiple burdens and benefits is very modest, there is a significant relationship between social vulnerability and cumulative burdens and benefits and that social units with higher vulnerability are affected.

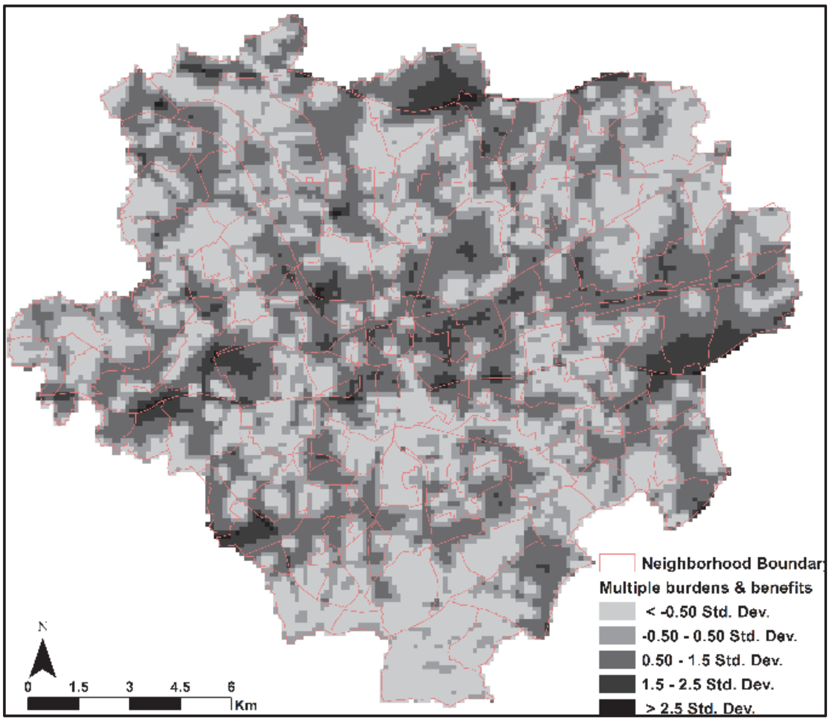
Table 3-9 Concentration indices (CI), standard errors (SE) and 95% confidence intervals for individual environmental factors and multiple environmental burdens and benefits with respect to social vulnerability

S.N	Environmental Factors	CI	SE(C)	Low	High
a	PM_{10}	−0.009	0.000	−0.009	−0.010
b	NO_2	−0.014	0.000	−0.013	−0.015
c	Distance to green areas in general (green areas, forests)	−0.032	0.002	−0.028	−0.036
c-1	Distance to green areas	0.178	0.002	0.175	0.182
c-2	Distance to forest areas	−0.208	0.002	−0.204	−0.211
d	Noise from all sources (logarithmic addition)	0.004	0.000	0.003	0.004
d-1	Noise from street	0.006	0.000	0.005	0.006
d-2	Noise from industry	−0.049	0.001	−0.046	−0.051
d-3	Noise from tram	−0.084	0.002	−0.081	−0.088
	Multiple environmental burdens and benefits (a, b, c, d)	−0.020	0.001	−0.019	−0.022

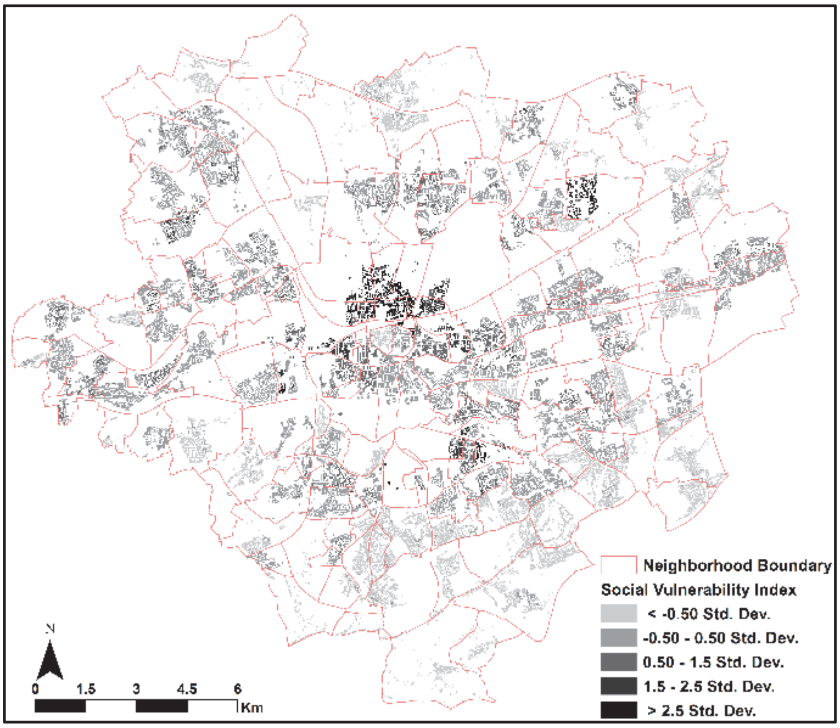
Note: All the value is significant at 95% confidence interval (p <0.05).

Among the single environmental factors with negative CI values (Table 3-9), access to forest areas is the highest followed by tram and industry noise exposure and NO_2, all values being statistically significant (p <0.05, see Table 3-9) i.e., social units with a higher social vulnerability have lower accessibility with respect to forest areas and are also more exposed to tram and industry noise exposure and NO_2 concentration. Similarly, the relationship between access to green areas (including both forests and parks) and social vulnerability is also significant (p <0.05, see Table 3-9) suggesting that social units with higher social vulnerability have a lower level of accessibility to resources. On the other hand noise exposure from street and noise exposure irrespective of the source (logarithmic addition) have the least CI value which is positive and significant (*p* <0.05, see Table 3-9), suggesting that social units with lower social vulnerability are to some extent exposed to noise pollution. Thus, though less pronounced, there is some degree of inequality that is burdening social units with a higher social vulnerability and it is generally greater with respect to environmental resources than to environmental burdens.

Spatial patterns of cumulated multiple burdens and benefits as illustrated in Figure 3-3a show a perforated and scattered pattern throughout the city. Smaller clusters with a higher cumulative score compared to the city's mean (>1.5 Std. Dev.) are found predominantly around the inner city, but in the central eastern and western part of the city too. Similarly, large clusters with a higher cumulative score can be found in the northern and southernmost part of the city, and near the airport region on the eastern city boundary.



(a)



(**b**)

Figure 3-3 (**a**) Spatial patterns of index score for multiple environmental burdens and benefits in Dortmund; (**b**) Spatial patterns of social vulnerability index score in Dortmund. The positive value of Std. Dev. represents higher cumulated environmental burdens in (**a**) and higher social vulnerability score in (**b**) as compared to the city's mean. The more negative value of Std. Dev. representing the area has lower cumulated environmental burdens in (**a**) and a lower social vulnerability score in (**b**) as compared to the city's mean. Finally, the social vulnerability based index of multiple burdens and benefits presented in Figure 4 allows us to identify the spatial pattern of inequalities across the city and enable us to locate "hotspots" (>2.5 Std. Dev.) and "coldspots" (<−0.5 Std. Dev.) of inequalities, i.e., social units with double burdens of low environmental quality and higher social vulnerability or vice versa.

Unlike the environmental index, the social vulnerability index in Figure 3-3b shows only a few distinct geographic concentrations of higher vulnerability scores (>2.5 Std. Dev.). The visual inspection of the spatial distribution of vulnerability scores shows that social units with higher vulnerability (>2.5 Std. Dev.) are concentrated within the city core, mostly in the district of Nordstadt. Nevertheless, we observe relatively higher vulnerability scores in the north eastern part of the city. Additionally, there are a few smaller clusters with medium vulnerability levels (1.5–2.5 Std. Dev.) in the southern urban core of the city. High scores are typical in areas with population characterized by a high density of migration background and receiving unemployment benefits.

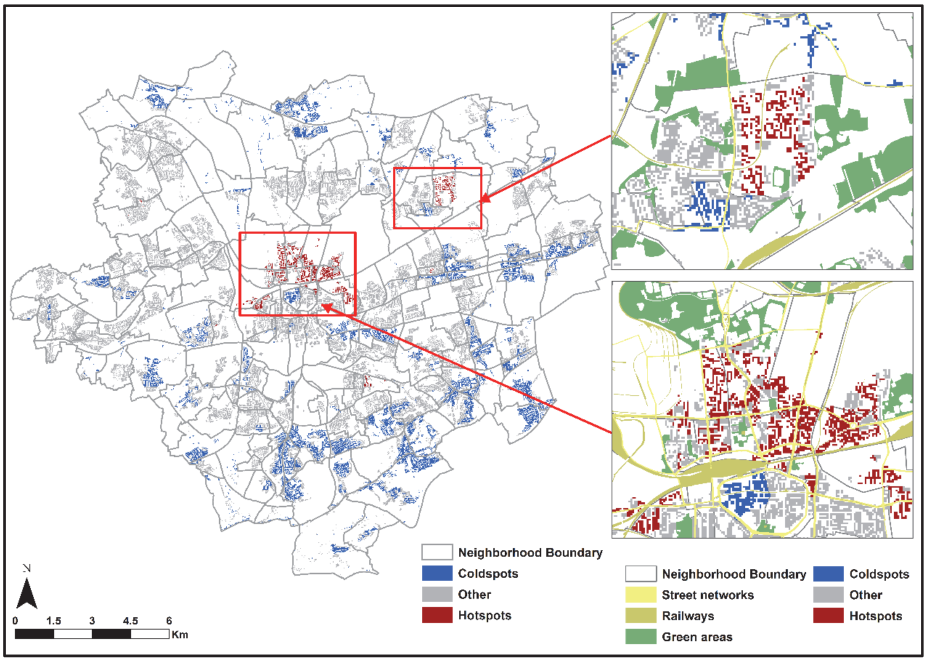


Figure 3-4 Spatial distribution of "hotspots" and "coldspots" of integrated index of multiple environmental burdens and benefits with social vulnerability

Large clusters of "hotspots" appear in the northern part of the city center in the district of Nordstadt and in the north-eastern part of the city as shown in Figure 3-4. Only a few small clusters appear in the southern part of the city. Without exception, the "coldspots" or the social units with both favorable environmental quality and lower social vulnerability are found in the outskirts of the city. We observe that such clusters are located prominently in the urban fringe, mostly in the southern part of the city. Nevertheless, one large "coldspot" can be found in the southern part of the urban core in the downtown area and another one near to the 'hotspot' in the north east part of the city. These results can be explained by the fact that these areas have a relatively lower population density. Overall most social units across the entire city have both environmental quality and social vulnerability marked as medium to low or low environmental quality with low social vulnerability. It explains the lower degree of inequalities.

3.6 *Discussion*

3.6.1 Spatial Inequalities and "hotspots" of Multiple Burdens and Benefits with Respect to Social Vulnerability in Dortmund

Our findings suggest that there is only a limited degree of inequality with respect to social vulnerability in Dortmund for both single and multiple environmental burdens and benefits. However, the inequality is statistically significant, demonstrated by CI values at 95% confidence intervals, and is burdening communities with a higher vulnerability. The modest environmental inequality in Dortmund is comparable to European cities found in other studies that also detected a small degree of inequality burdening lower SES groups (Kruize, 2007; Lakes et al., 2014). Consistent with these findings Figure 3-4 shows some geographical pattern that confirms results of other studies (Wheeler, 2004): a relatively high value for environmental burdens in urban core areas coincides with higher social vulnerability index scores producing "hotspots" in the urban core rather than in suburban areas where low to medium value for environmental burdens coincide with lower social vulnerability scores thus producing "coldspots".

The concentration indices from the single environmental factors reveal that certain environmental burdens and benefits are more unequally distributed with regard to social vulnerability than others. Inequality with respect to green areas (including both parks and forests) is the highest compared to air pollutants and aggregated noise exposure. However, the CI value (–0.032, *$p < 0.05$,* see Table 3-9) suggests that the strength of inequality is rather small. Findings from other studies with respect to this issue reveal divergent results; while some studies found more open spaces in affluent communities than in SES communities (Estabrooks et al., 2003), other studies showed a more equitable distribution across neighborhoods (Timperio et al., 2007). In Dortmund, such a low degree of inequality can be attributed to the spatial distribution of green areas and forest areas. As depicted in the spatial distribution maps of access to green areas and forests (Figure S1 provided in Appendix B) the urban core tends to have better accessibility to green areas due to the presence of some of the largest parks such as Fredenbaumpark, Hoeschpark, and Nordmarkt near to the areas where communities with a higher vulnerability are resided. On the other hand suburban areas are closer to forest areas.

Amongst the environmental burdens, the study shows that inequality with respect to the noise exposure from individual sources (tram and industry) is the highest and is disproportionately burdening communities with a higher vulnerability. The CI values for tram noise exposure (–0.084, $p < 0.05$, see Table 3-9) and industry noise exposure (–0.049, $p < 0.05$, see Table3-9) depict a relatively greater strength as compared to other environmental burdens and are burdening communities with higher social vulnerability. The reason can be attributed to spatial patterns of tram lines following radial patterns and location of industries, both dominating the urban core (Figure S2a and Figure S2b provided in the Appendix B). Street noise, however, is found ubiquitous and shows a scattered pattern across the entire city with a higher concentration along the major roads and highways (Figure S2c provided in the Appendix B). It is consistent with the findings in other studies where people living in advantaged areas exposed to higher levels of road traffic noise than in disadvantaged areas (Havard et al., 2011; Lakes et al., 2014), which explains the low positive CI values (0.006, $p < 0.05$, see Table 3-9) for exposure to street noise. CI value (0.004, $p < 0.05$, see Table 3-9) with respect to aggregated noise exposure from all the sources was found to be least and affects social units with lower vulnerability indicated by its positive value. However, for Dortmund we need to make the reservation that the noise indicators in this study do not include noise exposure from long distance trains that pass through the city in the east west direction close to the district of Nordstadt in the north and downtown area in the south and noise exposure from the airport on the eastern border of the city. Including these would have implications on the total noise levels and consequently the inequality results. Regarding air pollutants (PM_{10} and NO_2), they are also disproportionately burdening communities with a higher vulnerability, and inequalities with respect to these pollutants are also significant. This finding confirms results of many other studies showing that communities with lower SES are generally exposed to higher levels of air pollutants more than affluent communities (Raddatz & Mennis, 2013). Nevertheless, the degree of inequality in Dortmund is rather small (CI for PM_{10}= –0.009, $p < 0.05$; CI for NO_2= –0.014, $p < 0.05$; see Table 3-9) that can be attributed to spatial patterns of these air pollutants similar to street noise exposure (Figure S3 provided in the Appendix B). Whilst higher values of pollutants exist in urban core areas where communities with a higher social vulnerability tend to live, it also follows a linear pattern along major roads and highways in the urban fringe where communities with lower vulnerability live.

Our integrated index of multiple burdens and benefits and social vulnerability demonstrates a strong geographical pattern of inequalities with small scaled variations (Figure 3-4). Relatively high index scores are located predominantly in the northern part of the urban core particularly in the neighborhoods of Nordstadt and north-eastern part of the city termed as “hotspots”, and areas with lower index values appear in the urban fringe, but also in small clusters in the southern part of the urban core in the neighborhoods of City-West. Why some urban residents benefit from the geographical distribution of environmental burdens and benefits while many others do not has been discussed extensively in literature (Walker, 2009). The studies emphasized the role of past and present structural processes through which the political economy of different places can act to create local environments and influence the distribution of people, which ultimately result in the observed inequalities (Morello-Frosch, 2002). Such processes include historical patterns of industrial development, labor markets, suburbanization and segregation, and economic restructuring. The long history of industrialization and coal mining activity in Dortmund is the most plausible explanation for such a pattern as in other cities with a coal mining history (Reuschke & Weck, 2013; Wehling, 2014).

3.6.2 Strengths, Limitations and Sensitivity of Integrated Index of Multiple Environmental Burdens and Benefits and Social Vulnerability

Spatial information of multiple burdens and benefits combined with information on social vulnerability at small scales provide a strong tool to identify “hotspots” of population with a higher level of vulnerability suffering from a lower environmental quality. Such identification of “hotspots” enables targeted interventions and measures in order to reduce health inequalities and allows the prioritization of resource allocation from a need benefit perspective (Fann et al., 2011). Detailed information on intra-urban variations could support municipalities in deciding how and where to apply scarce resources to reduce exposure for certain subpopulations at risk and to minimize health inequalities. Development of a comprehensive index is challenging because of the need to make scientific and policy-related choices in the design process (Sadd et al., 2011). As such, our integrated index of multiple burdens and benefits and social vulnerability has a number of limitations. Foremost, the choice of indicators is subjective and open to discussion. The selection of indices includes those environmental factors that have potential health effects as well as social vulnerability factors that can alter people’s ability to cope with environmental burdens as evidenced from literature, acknowledged by local stakeholders, and enabled by available databases. We recognize that other health-related environmental characteristics exist as well as other social vulnerability factors relevant in the context of Germany, for which we were unable to obtain adequate small-scaled data. Similarly, we derived access/egress from residential locations to nearest park locations based on assumptions that reasonably qualify for providing recreation. Our method considers “crow flight distance” and ignores street network, connectivity, and barriers that have an effect on actual accessibility (Kaczynski et al., 2014). In addition to accessibility, the quality of green areas (e.g., attractiveness, cleanliness, safety, environmental quality) affects the actual usage of green areas and therefore needs to be considered (Williams & Green, 2001). In particular in the case of Dortmund this aspect is important as Bajracharya et al. (2016) found that some parks with good access in the neighborhood of Nordstadt are not considered attractive due to several issues of drugs, crimes, and safety.

Most existing approaches for the assessment of cumulative burdens in combination with social deprivation are based on administrative units/boundaries for identifying "hotspots" and inequalities. These studies overlook detailed spatial variations of environmental factors and social characteristics and suffer from the modifiable areal unit problem (Roy & Blaschke, 2011). We overcome this issue using a grid based approach to construct our indices. Whilst environmental data were readily available for Dortmund in the form of a grid, the smallest spatial unit of social vulnerability data was only available at statistical sub-district level. Using the three class dasymetric method the efficacy of our index was improved by designating where people actually live rather than assuming an even distribution of residents throughout the statistical sub-district. As a result our index was able to show small scaled variations of "hotspots" of double burdens which we consider a strength of our approach. Nonetheless, we acknowledge the criticality of allocating a proportion of population for each land use class based on housing type. Intuitively, urban and rural areas might have a different proportion of people living in various housing types. Similarly, the same proportion that has been used in our analysis for each indicator may not hold true. An empirical survey in each district, both in urban and rural areas, and for each indicator separately, could provide statistical data to derive the proportional density fraction for each land use category (Mennis, 2003).

One of the critical points in the development process of indices is the type of aggregation used. The choice of multiplicative approach while combining environmental indicators was guided by the normative argument—multiplicative approach suggests that a low value in one indicator cannot be fully substituted by a high value in another indicator in contrast to the additive approach that allows full compensation. Nonetheless, given the uncertainty of the aggregation approach we conducted a sensitivity analysis using an additive approach and henceforth derived a concentration index for the cumulated environmental burdens. Similar to the result found in using the multiplicative approach, we found inequality with respect to cumulated environmental burdens using the additive approach and it is burdening social units with higher vulnerability as suggested by the CI value (−0.009, see Table 3-9) significant at

95% confidence interval (−0.009, −0.008, see Table 3-9). However, the strength of inequality produced using the additive approach is lesser when compared to the multiplicative approach (CI = −0.020, see Table 3-9). It is generally expected that the multiplicative approach produces a greater difference than the additive approach and aligns with the finding from Su et al. (Su et al., 2009).

The choice of standardization and the use of standard deviation as the basis to yield rank for each spatial unit are other critical points in the development process of indices for multiple burdens and benefits with social vulnerability (Lakes et al., 2014; Sadd et al., 2011). The use of EU standards supports agencies to identify areas exceeding the threshold and to develop targeted interventions. The aggregation of indicators into one index entails loss of information and creates the risk of equalization of different distinct spatial patterns (Vlachokostas et al., 2014). The multiplicative approach minimizes such compensation to some extent. Different weighting schemes for individual indicators could help to mitigate the effect (Su et al., 2009) but due to limited knowledge about the impact of the selected environmental and social vulnerability variables on health outcome, we applied equal weighting. However, the index is flexible enough to accommodate such weighting schemes in the near future through a deliberative process with experts (Morello-Frosch & Shenassa, 2006).

3.7 *Conclusions*

We presented an approach for assessing multiple environmental burdens and benefits with social vulnerability at a spatially disaggregated level. In an application we assessed single and cumulative environmental inequalities with respect to social vulnerability of residents across the entire city of Dortmund, Germany, using concentration curves and a concentration index. “hotspots” of inequalities were identified spatially.

We found only modest but nevertheless significant inequalities regarding multiple environmental burdens and benefits with respect to social vulnerability in Dortmund. The integrated index allows us to locate large clusters in the northern part of the city with relatively high scores termed as “hotspots” indicating that these areas have a higher social vulnerability with a low to medium environmental quality, whereas the southern part of the city generally has a lower index score. More useful and interesting is the fact that the integrated index revealed small-scale variations and patterns of “hotspots” that may be concealed at higher spatial levels.

Despite some methodological and data related limitations, our approach enables us to combine environmental burdens and benefits and to investigate intra-urban spatial inequalities with respect to social vulnerability for the first time. Where spatial inequalities are apparent, causality cannot be determined with our analyses. It might be possible that environmental burdens and limited environmental resources in deprived areas have been directed deliberately or that such observed inequalities could be random due to historical industrial development, operation of housing markets, labor markets and subsequent differential migration of those people that can afford to move away from environmental burdens. Nonetheless, "whatever the root causes, if inequality exists, and policies and programs do not act to reduce it, then they act to perpetuate and reinforce environmental injustices" (Wheeler, 2004). In this regard an analysis of distributional aspects of environmental injustice could be informative and useful to target remedial activities and to allocate scarce resources to such areas.

Our approach focused on combining multiple environmental burdens and benefits with respect to social vulnerability and did not consider associations with different health outcomes. In this respect further validation of identified "hotspots" with health-related data is needed as in other studies (Pearce et al., 2011). As Lakes et al. (Lakes et al., 2014) have advocated, the challenge for such analyses is inherent due to data restrictions on morbidity and mortality and this holds true for the city of Dortmund. Moreover, the challenge is further accentuated when analyses require health-related data at finer scales as in our approach largely due to data privacy. A data envelope technique such as geomasking could be useful and needs to be explored further to include health data in such small-scaled analyses while preserving data privacy (Hampton et al., 2010).

Underlying complexity and scientific evidence on whether different environmental factors have synergistic, additive or interactive effects and different pathways, through which multiple environmental factors together with social vulnerability may affect human health, still remain incomplete and in a formative stage (Su et al., 2009; Vlachokostas et al., 2014). Therefore, our approach assumes a simplistic viewpoint of the existence of multiple environmental factors simultaneously at the same place and the same time with social vulnerability as an "effect modifier". Furthermore, where composite scores can be useful in many situations, a major limitation is that it leads to loss of information about how the different factors that make up the integrated index interact with each other and contribute to the index score (Vlachokostas et al., 2014). In this regard we want to emphasize on what is referred to as the "danger of simplistic policy conclusions" (Commission, 2008) in (Lakes et al., 2014). Nevertheless, having more information is intrinsically good to enable an informed and reasoned debate on the situation (Walker, 2010) and such information, when developed in close cooperation with stakeholders, could promote "action-oriented responses to the research findings" (Lakes et al., 2014). With a number of calls from the scientific community for the need to involve stakeholders from different disciplines to tackle environment related health inequalities (Corburn, 2002; Galea et al., 2005; Payne-Sturges et al., 2006) it is warranted that assessment of multiple burdens and benefits including social vulnerability should be able to incorporate both expert and local knowledge. Involving stakeholders in each phase of development and assessment could strengthen the partnership between practice and research and enable the utility of the information in policy and decision-making. However, involving stakeholders from various disciplines is not without challenge as they might have a diverse knowledge and different understandings of cartographic representations as found by Lakes et.al (Lakes et al., 2014). The challenge is then to facilitate stakeholder participation from various disciplines, to support them in a joint assessment of multiple environmental burdens and benefits with social vulnerability, to provide useful insights on the utility of the information on existing inequalities and "hotspots" in the city, and to discuss how this information can be incorporated in actual planning practice and policy.

Chapter 4: Interactive cumulative burden assessment: Engaging stakeholders in an adaptive, participatory and transdisciplinary approach*

* *This chapter is based on the article:*
Shrestha, R., Flacke, J., Martinez, J., & van Maarseveen, M. (2018). Interactive Cumulative Burden Assessment: Engaging Stakeholders in an Adaptive, Participatory and Transdisciplinary Approach. *International journal of environmental research and public health*, *15*(2), 260.

Abstract

Cumulative burden assessment (CuBA) has the potential to inform planning and decision-making on health disparities related to multiple environmental burdens. However, scholars have raised concerns about the social complexity to be dealt with while conducting CuBA, suggesting that it should be addressed in an adaptive, participatory and transdisciplinary (APT) approach. APT calls for deliberation among stakeholders by engaging them in a process of social learning and knowledge co-production. We propose an interactive stakeholder-based approach that facilitates a science-based stakeholder dialogue as an interface for combining different knowledge domains and engendering social learning in CuBA processes. Our approach allows participants to interact with each other using a flexible and auditable CuBA model implemented within a shared workspace. In two workshops we explored the usefulness and practicality of the approach. Results show that stakeholders were enabled to deliberate on cumulative burdens collaboratively, to learn about the technical uncertainties and social challenges associated with CuBA, and to co-produce knowledge in a realm of both technical and societal challenges. The paper identifies potential benefits relevant for responding to social complexity in the CuBA and further recommends exploration of how our approach can enable or constraint social learning and knowledge co-production in CuBA processes under various institutional, social and political contexts.

4.1 *Introduction*

Environmental health issues are receiving attention in many international initiatives such as the Ottawa Charter (WHO, 1986) and the Health in all policies discourse (Rudolph et al., 2013; Ståhl et al., 2006). Environmental legislation and regulations for individual environmental pollutants such as the Clean Air Act (Wolff & Perry, 2010) for air quality or Noise Action Plans (King et al., 2011) for noise nuisance have attracted considerable attention in Europe, particularly in relation to reducing pollution levels. However, scholars have pointed out the need to identify and address health disparities with regard to multiple environmental burdens and benefits across population having varying social vulnerability (Honold et al., 2012). Framing the disproportional distribution of environmental burdens and resources as an issue of distributional environmental justice (Walker, 2012), both academic scholarship and public policy initiatives have advocated use of cumulative burden assessment (CuBA) to inform planning and decision making (Alexeeff et al., 2012; Faust, 2010; Huang & London, 2012; Morello-Frosch et al., 2011).

A full spectrum of CuBA may include the complex dynamics of compounding, aggregating and interaction of various benefits/burdens This includes driving forces such as urban development, zoning decisions, and economic and social processes that put pressure on the environment, such as increases in traffic density, emissions and waste release (Hambling et al., 2011). Both driving forces and pressures contribute to the state whereby the environment is often degraded through increases in air pollution and noise nuisance, facilitating population exposures that might produce health disparities among populations of varying social vulnerability. However, CuBA, as the term used in this study, indicates the simultaneous occurrence of a number of environmental features at the same time and in the same place. It integrates a range of environmental burden and benefits that represent the state of the environment (e.g air pollution, noise pollution, green areas, forest areas) with a range of social vulnerability factors, such as the socio-economic status of the population, into one or more indices. Such an indicator-based CuBA can be used to identify populations and places that are subjected to both elevated environmental exposures and lack economic, political and social resources for either avoiding or adapting to the actual environmental situation. In contrast to a health impact assessment, which quantifies potential health impacts of a given plan or development project (Harris-Roxas & Harris, 2011), a CuBA serves as a screening tool to identify 'hotspots' that require additional study, investments, or other precautionary actions (Alexeeff et al., 2012; Faust, 2010; Huang & London, 2016). Therefore, conducting a CuBA offers opportunities for addressing environmental health related socio-spatial inequalities in planning and policy processes.

Various indicator-based approaches to CuBA are being developed at regional to local scales (Lakes et al., 2014; Pearce et al., 2010; Shrestha et al., 2016; Vlachokostas et al., 2014). The shift from burden assessment of single environmental factors to assessment of cumulative burdens is considered important for understanding the socio-spatial characteristics of health inequalities (Pearce et al., 2010). Nonetheless, it has brought new challenges that are both technical and social in nature (Huang & London, 2016). The technical challenges comprise limited data availability for various factors, uncertainty of interaction among various environmental factors, and uncertainty regarding combined health effects of multiple environmental stressors (Huang & London, 2012; Sadd et al., 2011). In particular, concerns have been raised about dealing with 'social complexity' while conducting CuBA. As Huang and London (Huang & London, 2016) have noted, the 'social complexity' associated with CuBA shares the basic characteristics of a 'wicked problem' (Rittel & Webber, 1973). Similarly to a 'wicked problem', a clear problem definition in CuBA is controversial as it is driven by a number of individual, institutional, behavioural and structural factors. Identifying and analyzing significant factors in CuBA amidst multiple perspectives of stakeholders do not follow linear, easily-standardized or agreed formulas. CuBA could not, therefore, be supported only by providing better data and expert-based assessment ((Balint et al., 2011) in (Huang & London, 2016)). CuBA needs to be place-specific to consider unique characteristics and at the same time consistent with accepted standards of scientific rigor and regulatory frameworks (Huang & London, 2016). Although the knowledge of multiple stakeholders from both science and practice is required to address cumulative burdens, multi-stakeholder knowledge and interest may remain contested and the approach to address cumulative burdens can have inherently unintended consequences.

Several researchers have called for an adaptive, participatory and transdisciplinary approach (APT) to address such 'wicked problems' (Head & Xiang, 2016; Xiang, 2013). Huang and London (Huang & London, 2016) argue that if CuBA is conducted in an APT manner it may address some of the 'wickedness'. In particular, APT calls for deliberation among various stakeholders so that rather than trying to 'solve the wicked problem through standard science-based approaches, these problems are tackled, managed and dealt with' by sharing knowledge and engaging in a social learning process (Head & Xiang, 2016; Xiang, 2013). In this regard, enabling an active dialogue, encouraging a culture of social learning and the explicit co-production of knowledge by linking ‘domains of discourse’ of various stakeholders are pivotal to APT. To link ‘domains of discourse’—i.e. contexts for a reasonably coherent exchange of arguments and ways of knowing (Jaeger, 2003)—among various actors with their specialized knowledge requires a science-based stakeholder dialogue as an interface for the combination of different knowledge domains. There is a long-standing tradition of facilitating stakeholder dialogues in decision-making processes regarding complex environmental problems (Reed, 2008; Stoll-Kleemann & Welp, 2007). However, the practice of a science-based stakeholder dialogue—unlike ‘public engagement’, ‘policy dialogues’, and ‘multi-stakeholder dialogues for governance’—is seen as a structured communicative process for linking different types of knowledge (Welp et al., 2006).

To induce a science-based stakeholder dialogue in CuBA with the aim of enabling social learning and knowledge co-production, the approach must communicate information in the right way and enable deliberation that incorporates exchange of arguments, values and knowledge within the realm of both social and technical challenges related to CuBA. The approach needs to avoid merely producing optimal technical solutions and instead emphasize the establishment of shared goals and interests among a multitude of stakeholders through an open process. As such, the process of establishing indicators and assessing cumulative burdens needs to be an exercise embedded in a culture of active dialogue and social learning that allows for rapid adjustments and feedback loops in a participatory environment that focuses on explicit knowledge co-production among stakeholders. Moreover, CuBA needs to be situated at the interface between science and practice so that it can incorporate the production and the use of knowledge from both academia and practice alike (van Asselt Marjolein & Rijkens-Klomp, 2002). This calls for an innovative stakeholder-based CuBA approach that enables an iterative, multi-faceted process and focuses explicitly on encouraging social learning and knowledge co-production.

Following this reasoning, we describe in this paper an interactive approach for facilitating science-based stakeholder dialogue in CuBA. In two workshops organized in German cities, one in Dortmund and another in Munich, we explored the usefulness and practicality of this approach for engaging stakeholders in collaborative work of CuBA. Our research questions were: 1) how can our interactive stakeholder-based approach support science-based stakeholder dialogue for cumulative burden assessment? 2) what insights on stakeholder-based cumulative burden assessment can be obtained from the implementation of our approach in Dortmund and Munich?

4.2 *A framework for supporting social learning and knowledge co-production in cumulative burden assessment*

Social learning can be described as learning in and with social groups through interaction (Siebenhüner, 2005). Participants, when engaging in deliberation within a collaborative dialogue, learn as individuals and as a group about their problems, their goals, the perspectives of other participants and their shared context (Innes & Booher, 2016). In doing so, they are engaged in cooperative endeavours of knowledge production in which knowledge is produced through interaction and mutual learning among people with different perspectives and backgrounds (Fazey et al., 2013).

In addition to political, institutional and social contexts, the nature and structure of the participatory process—i.e. the participatory methods used to engage stakeholders and the processes and techniques to help stakeholders understand their own and others' implicit frames—is equally important for fostering social learning (Tippett et al., 2005). Figure 4-1 outlines the specific attributes necessary for our interactive stakeholder-based approach that supports knowledge co-production and social learning in cumulative burden assessment. Our assumption is that by providing two types of process-support—communication support and information support—our approach will contribute to the intended outcomes of knowledge co-production and social learning among stakeholders in relation to various issues on cumulative burdens amidst their 'social complexity'. We synthesized the necessary attributes of our approach from recent studies that have used interactive tools during the participatory workshops. The process-support characteristics and intended outcomes were also synthesized from studies on social learning and knowledge co-production during participatory activities. Process-support and intended outcomes were later used to gather evidence for the evaluation of our approach.

4.2.1 Approach attributes

Numerous references can be found in the literature to interactive tools that have been designed under the notion of Planning Support Systems (PSS) for supporting the informative, communicative, analytical side of spatial planning (Vonk & Geertman, 2008; p.79). These tools have been applied in a variety of research initiatives—urban planning (Goodspeed, 2013; Pelzer & Geertman, 2014), environmental health (Shrestha et al., 2017) and renewable energy (Flacke & de Boer, 2017)—with a focus on strengthening collaboration among and between domain experts and stakeholders, as well as citizens in general.

Drawing on existing PSS tools, three main attributes are considered to be appropriate when designing an interactive stakeholder-based CuBA: a flexible and auditable model; an interactive interface-driven shared workspace; and skilled facilitation.

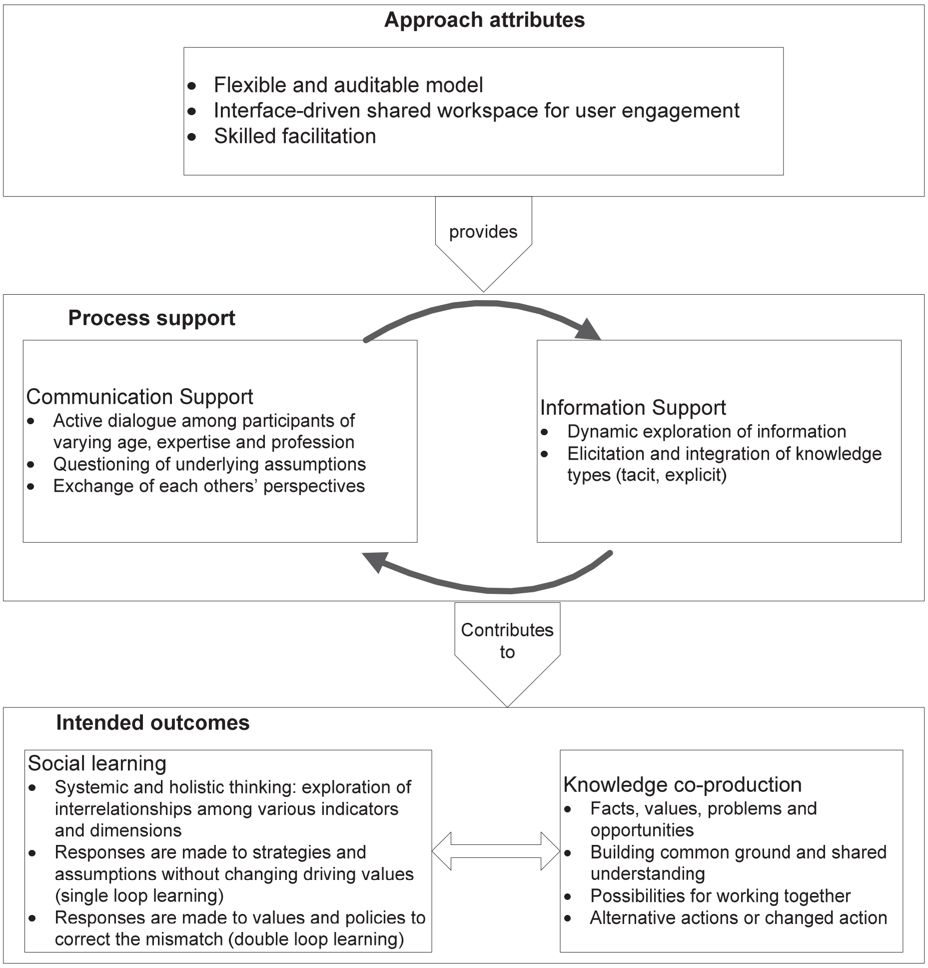


Figure 4-1 A conceptual framework for supporting social learning and knowledge co-production in cumulative burden assessment

A flexible and auditable model allows stakeholders to freely select indicators or change assumptions relevant for their CuBA. It has been generally argued that participants may not use the indicators and indices the way assumed by the scientist as in many cases the topics are characterized by different legitimate interpretations of the same indicators/index (Lyytimäki et al., 2011; Rametsteiner et al., 2011). Therefore, in CuBA process by explicitly giving users an opportunity to work with a flexible and auditable model, this may enable them to perform calculations in a way that is transparent, relevant and easy for them to comprehend. In doing so, the participants may also come to understand how assessment results are connected to choices they have made during the process, as well as enable them to explore relevant topics in varying degrees of detail or depth (Salter et al., 2010).

4.2.2 Process-support

In order to achieve the goals of social learning and co-production of knowledge, our interactive stakeholder-based approach needs to provide two kinds of support during the assessment process: communication support and information support. The communication support aims at supporting elements that are important for engendering social learning and co-production of knowledge in CuBA: active dialogue, questioning of underlying assumptions, and an exchange of each other's perspectives. An active dialogue, or what Tsoukas (2009) calls a 'productive dialogue', is crucial for engagement to occur among people of varying age, expertise and knowledge, and among those with differing opinions. Such dialogue occurs when participants feel comfortable in contributing their knowledge and are prepared to listen to others respectfully and with an open mind (Johnson et al., 2012). Questioning the underlying assumptions made in the model cultivates transparency in the process and supports social learning and a shared understanding of the issues under investigation (Salter et al., 2010). By providing opportunities for participants to understand the underlying assumptions, as well for expressing their viewpoints without hampering the process, participants may be enabled to identify areas that could be focused upon constructively and to identify other areas that need further deliberation and improvement (Schusler et al., 2003). Along with explicit knowledge, insights into normative aspects and each other's assumptions underlying the different viewpoints are needed so that stakeholders can work through discrepancies and differences among knowledge sources to produce meaningful information (Van de Kerkhof, 2006). Therefore, participants should also be enabled to share perspectives among each other through clarification and mutual evaluation while taking part in an active dialogue.

Our approach should provide information support throughout the process by allowing dynamic exploration of information, i.e. eliciting and integrating both tacit and explicit knowledge. Participants exploring spatial information dynamically and analyzing impacts using a shared spatial language may lead to learning through improving the quality of dialogue (Pelzer & Geertman, 2014). Furthermore, Friedmann (1984) argues that in order to support social learning the process needs to integrate the two kinds of knowledge—explicit knowledge and stakeholders' tacit knowledge—to yield an understanding greater than either could have produced individually. Therefore, elicitation of stakeholders' tacit knowledge and continuous integration of factual and empirical knowledge with stakeholders' knowledge and any assumptions underlying the different viewpoints can enrich cumulative burden assessment.

4.2.3 Intended outcomes

The intended outcomes to which process-support contributes are related to the characteristics of social learning process and co-production of knowledge. Various theories are available on learning that reflect on how people learn as individuals and within a group. Nonetheless, these theories have been acknowledged to be complementary rather than competitive; they provide an understanding of the processes upon which social learning is based (Muro & Jeffrey, 2008; Reed et al., 2010). For instance, learning can be instrumental according to Mezirow (1993), i.e. focused on acquiring new knowledge or skills. 'Theories of communicative learning' describes the process by which a person constructs an inter-subjective understanding of a situation by exchanging and reinterpreting knowledge through communication with others (Van der Veen, 2000). Likewise, transformative theories of learning describe a process whereby people gradually change their views on a subject (Muro & Jeffrey, 2008). Transformative learning is analogous to 'double-loop learning' which is said to occur when the detected mismatch between expected and observed outcomes is corrected by revisiting the assumptions, policies and values that underlie the actions (Argyris & Schön, 1997). On the other hand, single-loop learning is categorized as incremental learning and is said to occur when a mismatch between expected and observed outcomes is corrected, leaving the underlying theories for the action unchanged. A feedback loop from actual experience does not change the basic assumptions or decision-making rules. Similarly, experiential learning as proposed by Kolb (2014) describes a process in which concrete experiences of people lead to reflection, and the generation of new ideas, which they apply in turn through active experimentation and, therefore, learn.

In general, altered perspectives with changes in people's perceptions or opinions represent a measure of social learning (Armitage et al., 2008; Dana & Nelson, 2012; Johnson et al., 2012). However, a large shift in opinions or belief could not be expected within one intervention, and changes may be detected where participants lack knowledge beforehand or have not yet formed opinion (Dana & Nelson, 2012). Such a change occurs in response to an external 'trigger' that leads to critical reflection and a transformation in perspective (Hovlid et al., 2012; Muro & Jeffrey, 2008). The extent to which the approach has supported 'triggering' of the change in this study was assessed by exploring evidence in the following three instances: i) single-loop learning is encouraged when participants are enabled to change a detected mismatch by changing their strategies or the assumptions underlying those strategies, ii) double loop learning is enabled to respond to underlying values and policies (Armitage et al., 2008), and iii) systemic thinking is crucial for learning as individuals adjust their mental models when they understand multiple facets of an issue (Dana & Nelson, 2012; Johnson et al., 2012). Participants begin to think systematically when they are enabled to envisage connections and feedback loops between various components. Along this line, the participants should also be enabled to explore interrelations among various dimensions of cumulative burdens.

In the course of social learning, the knowledge co-produced in the process manifests itself in three dimensions: cognitive dimensions, a moral dimension, and relational dimension (Romina, 2014). Participants acquire new information, learn facts and values on the issue, identify problems and opportunities, and form a reasoned opinion that lead to cognitive enhancement (Webler et al., 1995). Likewise, when participants are enabled to understand concerns of others and areas of agreement and disagreement, this contributes to building common ground or a shared understanding of the issues (Garmendia & Stagl, 2010; Schusler et al., 2003). This in turn lays the foundations of collaborative relationships or contributes to relational dimension by offering prospects to work together and for collective or even alternative action within a participatory activity (Garmendia & Stagl, 2010).

4.3 *An interactive stakeholder-based cumulative burden assessment*

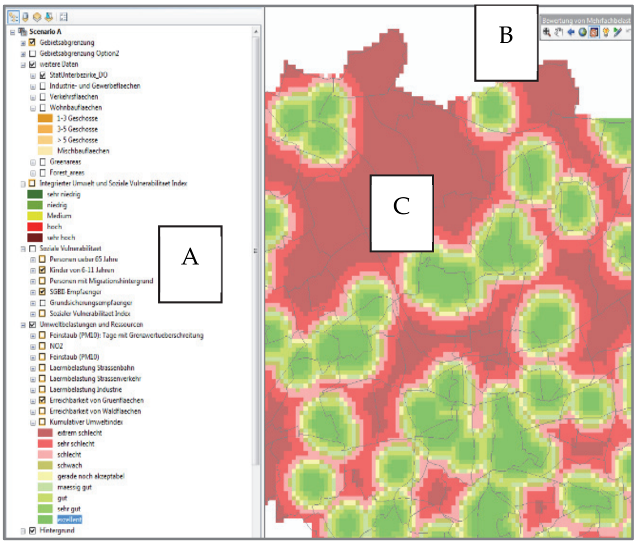
Based on the approach attributes described in the previous section, our approach on interactive stakeholder-based CuBA comprises three components—a flexible and auditable model, an interface-driven shared workspace, and skilled facilitation—which will be described in the following subsections.

4.3.1 Flexible and auditable model

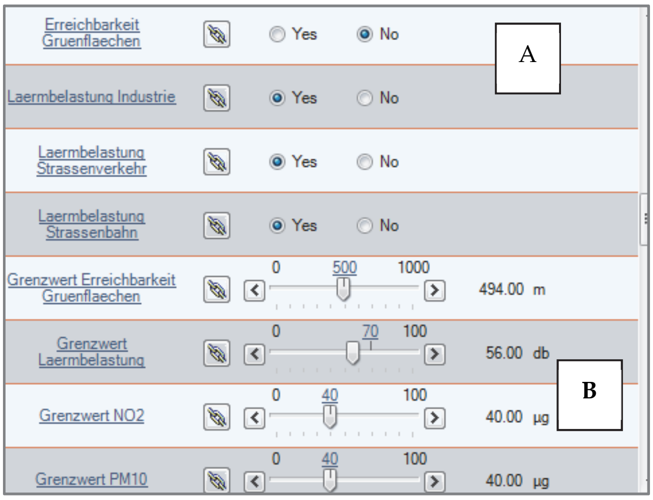
The indicator-based CuBA method adopted in our model has been discussed in detail by Shrestha et al. (Shrestha et al., 2016). Firstly, the method uses a grid to represent information in a fine spatial resolution for both environmental and social vulnerability indicators and indices. Secondly, stakeholders can deliberate on the cumulative burdens at a local level, unrestricted by administrative boundaries. Using information at small scales is particularly relevant for identifying intra-urban spatial inequalities and 'hotspots' of cumulative burdens.

Thirdly, the method uses a relative procedure for normalization/standardization of indicators by using environmental standards and city-wide averages. In doing so, the method supports the stakeholder to understand the assessment result in a relative manner that is easy to comprehend, understand and communicate. Lastly, the method allows the integration of environmental burdens and benefits together with social vulnerability using a simple aggregation method.

Community Viz Scenario 360 (CommunityViz Scenario 360), a GIS based PSS, is used to adapt the CuBA method into a flexible and auditable model that features interactive tools and dynamic visualization. Using the interactive tool, stakeholders can choose to overlap individual social vulnerability indicators on various environmental indicators, create either a separate indices for environmental burdens and social vulnerability, or an integrated index that combines an index/indicator of environmental burdens with a social vulnerability index/indicator (Figure 4-2a). The tool also allows the stakeholders to select/deselect the indicators to be combined in the index and this functionality is available for constructing both environmental burdens indices and social vulnerability indices (Figure 4-2b). For environmental burden indicators, stakeholders can change the threshold value of environmental standards (Figure 4-2b). The effect of these changes and their variation with respect to the distribution of 'hotspots' can then be viewed dynamically in real-time and spatially in the form of 2D spatial maps (Figure 4-2a).



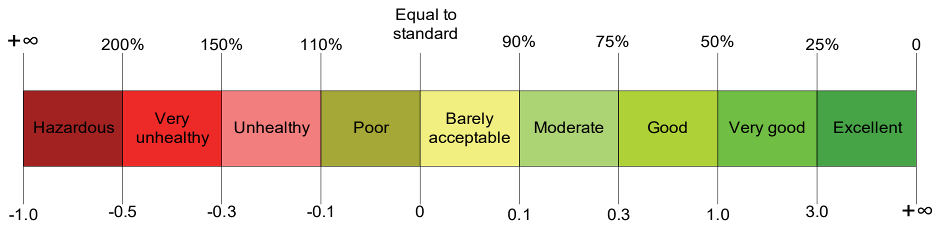
(a)



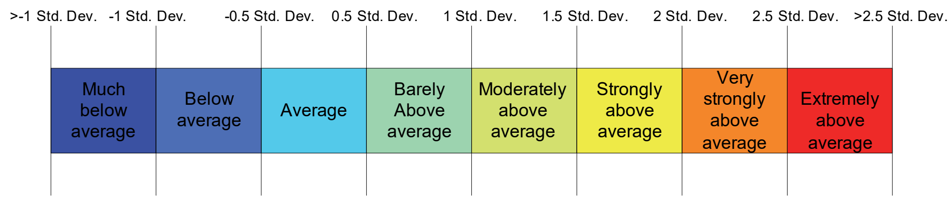
(**b**)

Figure 4-2 (**a**) User interface for A-overlaying indicators/index, B-manoeuvring on the maps, C-dynamic visualization of 2D maps; (**b**) Interactive tools for A-selecting indicators to construct index, B- changing thresholds

To characterize and visualize the area being exposed to various levels of environmental burdens and social vulnerability the tool uses relative scale visualization. Such visualization is derived by comparing the indicator value with a set of standards or a city-wide average value and then represented by a qualitative colour-coded legend. For instance, Figure 3a shows a relative scale visualization to characterize an area with environmental burdens as developed by Vlachokostas (2014). In this scale, an approximate zero-indicator value characterizes a poor to barely acceptable exposure, which means the area has an indicator value approximately the same as the threshold value of the environmental standard. Negative values characterize a problematic situation, and the higher the environmental burden in the area the closer to -1 the indicator value will be. An indicator value greater than 1 can be considered as a very good as the value is 50% below the threshold value set by the environmental standard. Likewise, Figure 3b shows a vulnerability scale that uses the standard-deviation classification method to characterize the area compared to the city-wide average. An indicator value between 0.5 to -0.5 of the standard deviation characterizes a vulnerability score close to the city-wide average. More negative or positive values on the scale characterize lower or higher vulnerability scores, respectively, as compared to the city-wide average. In a similar manner, Figure 3c shows a qualitative scale visualization of a range of integrated environmental and social vulnerability indices. Using a matrix of environmental indices and social vulnerability indices the scale allows user to visualize the area having both environmental burdens and social vulnerability.



(**a**)



(**b**)

	Cumulative Environmental Index					
Social Vulnerability Index		Very low (1 - Infinity)	Low (0.1 - 1)	Medium (-0.1 – 0.1)	High (-0.1 - -0.5)	Very high (-0.5 - -1.0)
	Very Low (-1 Above Std Dev)	Very low	Very low	Low	Medium	Medium
	Low (-0.5 - -1 Std Dev)	Very low	Very low	Low	Medium	High
	Medium (-0.5 – 0.5 Std Dev)	Low	Low	Medium	High	High
	High (0.5 – 2 Std Dev)	Medium	Medium	High	Very high	Very high
	Very High (Above 2 Std Dev)	Medium	High	High	Very high	Very high

(**c**)

Figure 4-3 Relative scale representation for (**a**) an environmental indicator/index; (**b**) a social vulnerability indicator/index, and (**c**) an integrated environment and social vulnerability index

4.3.2 Interface-driven shared workspace for user engagement

The advancement of technological development has opened up new ways for supporting a collaborative dialogue among stakeholders. Advanced hardware solutions, such as a touch-enabled horizontal screen, have made the user interface of the model more interactive and suitable for supporting group work (Figure 4-4).

Figure 4-4 The MapTable as a shared workspace for supporting group work

Our approach uses a similar sort of hardware, referred to as the MapTable: a large-scale horizontal table surface with a touch-sensitive screen that shows the content as a common map interface and supports user interaction with the map via touching and gesture.

4.3.3 Skilled facilitation

Hirokawa and Gouran (1989) divide activities of facilitators into three areas: substantive, i.e. related to topics discussed; procedural, i.e. drawing attention to process elements such as the agenda; and relational, i.e. attending to social or emotional issues. Additionally, the use of models in participatory activity requires tool-related facilitation. Niederman et al. (1996) argue that knowledge of a tool is a critical factor in such meetings, pointing out that the use of technology could be a barrier due to participants' anxiety about the technology, distractions caused by the technology and the learning time needed for participants to use it. Therefore, the facilitator (referred to as the chauffeur) in our approach also supports the participants on technical issues while using the MapTable and other interactive tools.

4.4 *Implementation of the interactive stakeholder-based CuBA in Dortmund and Munich*

4.4.1 Context and case-study areas

The junior research group Jufo-Salus, entitled as 'Cities as a healthy place to live, regardless of social inequality' (Jufo-Salus, 2013a), was started in 2013 with the aim of integrating the concepts of sustainability and health for planning in urban areas. To achieve this the project focuses on addressing health inequalities in the urban area by highlighting both pathogenic (environmental burden) and salutogenic (environmental benefits) factors and their unequal distribution across a population that exhibits varying social vulnerability. Two German cities, Dortmund and Munich, were chosen as case-study areas for the project. Studies have shown the existence of spatial inequalities in these cities in relation to cumulative environmental burdens and their unequal distribution across various social vulnerability factors (Flacke et al., 2016; Schüle et al., 2017) .

One central aspect of the Jufo-Salus research group's approach is to facilitate a transdisciplinary dialogue amongst researchers from urban planning and public health disciplines, as well as practitioners from relevant fields, with regard to environmental health. Various participatory methods and approaches have been applied by the group in workshop settings at different phases of the project, such as World Café (Jufo-Salus, 2012) and ISUSS (Shrestha et al., 2017) during the problem scoping and problem understanding phases. In a later stage of the project, a planning game was designed as a one-day workshop in both cities. The design of the planning-game workshop was embedded in the context of Social City Programme (Federal Ministry for the Environment), which is an assistance programme being conducted as part of federal urban development policy in Germany. The aim of the programme is to upgrade and revitalize economically and socially deprived districts, neighbourhoods and communities. To do so, the programme intends to develop interdepartmental coordination, improve linkage between the various policy areas (e.g. employment, housing development, social integration, health promotion) and find synergies for efficient project funding schemes. Therefore, one of the tasks in the planning-game workshop was to identify the so-called programme areas, in which all stakeholders decide collaboratively to invest in during a workshop session (herein refers to one particular session where we implemented our approach during the planning game workshop). In doing so, the participants in the session were directed to consider health promotion and spatial inequalities in relation to environmental burdens as central topics and to integrate a cumulative burden assessment, mediated by our approach, as a screening tool in their discussions.

4.4.2 Participants

Intentionally, the participant selection aimed to involve both researchers and practitioners representing diverse sectors and interests in environmental health issues. In this regard, contacts from previous Jufo-Salus workshops were used to identify potential participants based on their professional roles, expertise and knowledge on environmental health issues in Dortmund and Munich, respectively. Five individuals participated in the Dortmund workshop session and seven individuals in the Munich workshop session. Participants in Dortmund included one staff member from the municipality's urban planning department, three practitioners associated with a NGO/social entrepreneur—the local agenda21 group, a tenant association and a youth organization—and one researcher in public health. The Munich workshop session included three municipal staff members from the social planning department, environmental department and the health departments, three practitioners respectively associated with an environmental NGO, a health insurance company, and a social housing organization, and one researcher in urban planning. Two authors of this paper facilitated the workshop, the first author carried the role of a chauffeur and the second author generally facilitated the process in both workshops. Two other persons observed each workshop in its entirety and made notes of their observations.

4.4.3 Model specification

Two separate models were prepared for Dortmund and Munich, respectively. Both models followed the general design characteristics described in Section 3. The environmental and social vulnerability indicators used in both cases are listed in the Table A1 provided in the Appendix C. The preparation of the model had been very selective so as to include only those environmental variables that represent external characteristics of the environment. The inclusion of indicators in the model were also influenced by the relevance of these indicators for the cities as based on previous stakeholder workshops run by Jufo-Salus and the availability of data at neighbourhood level.

The models used a 125x125 m grid as spatial resolution for both individual environmental indicators and the cumulative environmental index. While city-wide modelled data on air quality were acquired for this resolution, available point-data for noise nuisance in Dortmund had to be interpolated for the 125x125 m grid. For Munich, modelled data at the 125x125 m resolution were available for noise nuisance, but measured air quality data were only available along its roads. For this reason the indicators and the index of air quality for Munich were prepared as line data. Indicators on access to green areas (parks and forests) for both cities were prepared as described by Shrestha et al. (2016). In the workshops, we considered 1 ha as the minimum area required for providing recreation and opportunities for physical activity. Both social vulnerability indicators/indices and integrated socio-environment indices used a spatial resolution of 25x25 m, chosen after visual inspection to avoid under/over-representation of residential areas at the neighbourhood level.

Social vulnerability indicators were prepared using a poly-categorical three-class dasymetric mapping of population distribution (Shrestha et al., 2016).

Environmental standards shown in Table A2 in the Appendix C were used to normalize the environmental data, whereas social vulnerability indicators were standardized using the city-wide average. Although the assessment of cumulative burdens resulting from a number of environmental factors and their impacts on health requires an understanding of complex interactions among these factors, we decided to use a simple aggregation method that is easy to comprehend by the stakeholders. Additive aggregation was used to combine individual indicators into an index for both environmental factors and social vulnerability factors. For environmental factors, additive aggregation as proposed by Vlachokostas (2014) was applied, whereas simple additive aggregation as described by Shrestha et al. (2016) was adopted for constructing the social vulnerability index. Multiplicative aggregation was used to combine the environmental index and the social vulnerability index in order to create an integrated socio-environment index. Both models were adopted into CommunityViz for the addition of flexibility and auditability into the model and integrated into the MapTable to provide shared-user interface (described in Section 3). As such, the participants could deliberate on the impact of environmental standards or indicators by changing the threshold values of the provided indicators or selecting which indicators to combine into index. Deliberation was, however, limited to only indicators provided in the models.

4.4.4 Workshop session design and analysis

The planning game workshop in Dortmund took place on 29 October 2015 and in Munich on 7 November 2015; they were conducted in the German language. While the planning game was conducted as a one-day workshop, the workshop session on stakeholder-based cumulative burden assessment took 1.5 – 2 hours. The workshop session began with an introduction by the facilitator on the objectives of the session followed by a description of the task on delineating programme areas. A short explanation of the CuBA model was provided, together with a demonstration of how to use the MapTable tools and hands-on experience for the participants.

Data for analyzing the workshop session were collected from four sources: screen capture of the interactive MapTable; voice recordings; observers' notes; and a post-session questionnaire. Screen capture and the voice recording of the workshop session were carried out to capture complex interactions between the participants, between the participants and the model, and between the participants and facilitators. The recordings were later transcribed, translated into English and provided with time coding. The post-session questionnaire focused on the usefulness of the tool and on model specifications instrumental in identifying 'hotspots' of cumulative burdens. Participants were asked to use a five-point Likert scale to express their level of agreement with questions/statements and provide a short comment on each. The observers' notes consisted of general observations on the participants' interactions and their experiences while using the approach.

The analysis of the workshop sessions was based on reflexive engagement (Pihkala & Karasti, 2013) of the two authors of this paper with participants during the workshop session. The use of the reflective engagement was motivated by our interest in examining each element of the framework in depth and the participants' experience with our approach. We used exploratory analysis, especially focusing on micro-analysis of the workshop transcripts. In particular, focus on a single workshop and the use of micro-level analysis of conversations by the participants have been advocated as appropriate for understanding interactions mediated by technological artefacts, such as a model (Tavella & Franco, 2015; Thomas et al., 2011; Tsoukas, 2009). Nonetheless, we used transcripts from the two workshop sessions to broaden our empirical base. The screen captures, observers' notes and post-session questionnaire were used to supplement and consolidate the findings from the workshop transcript.

To assess and report on communication and information support as mediated by our approach, we looked for operational treatments of each element of these two process-support in the theoretical description of the framework and the data. By simultaneously examining the theoretical descriptions and the data, the first author identified a number of activities associated with each element in the communication and process support and the evidence related to these activities. These were then re-examined by the second author independently and revised if needed. Using these identified activities to structure the evidences, we present the findings and examples of evidence that manifest these activities in Section 5. Although the elements of communication support and information support are presented separately, it is to be noted that they are interrelated and therefore influence each other. Likewise, some items of evidence exhibit the influence of more than one of these activities and elements. Evidence for social learning and co-production of knowledge was collected using the theoretical descriptions in the analytical framework. Any discrepancies discovered while collecting and analyzing the evidence were resolved through discussion between the authors.

4.5 *Insights from the workshops*

4.5.1 General observations and participants' evaluation

In general, the flexible and auditable model augmented with the MapTable enabled the participants to explore the effect of individual indicators/indices in a shared workspace. Using relative scale visualization, and based on their selection of indicators, participants were able to visualize the spatial distribution of 'hotspots' with respect to single indicators/indices in real-time on maps. As such, the process evolved from one-way communication of information on cumulative burden assessment to a two-way process in which participants' suggestions and knowledge were also considered during the assessment.

Nonetheless, the discussions that took place during the workshop sessions did not always flow smoothly. The use of an interactive tool and characteristics of the MapTable hardware were observed to constrain the process to some extent. We observed some anxiety and distractions related to the MapTable and the interactive tools—also reported by Niederman et al. (1996)—as a limiting factor in using the tool. However, the facilitator provided guidance for participants, helping to maintain focus on the objectives and task of the workshop, as well as clarifying underlying assumptions in the model, communicating the uncertainty associated with scientific analysis, and providing participants with equal opportunities to ask questions or respond to the others' perspectives. Likewise, the chauffeur assisted the participants to execute the moves using the tool as intended by the participants and encouraged them to embrace the dynamism. In both workshop sessions, it was observed that participants used individual indicators or overlaid single indicators on each other more often than they did for cumulative indices.

These observations also resonate with participants' evaluations on the usefulness of the tool and model specifications for identifying 'hotspots' of cumulative burdens and thereby identify programme areas for investing resources from Social City (see Table 4-1). Overall, participants rated the use of the model augmented with the MapTable as being useful. Individual indicators were considered to be more useful than the integrated index for cumulative burden assessment. The added value of an integrated environmental and social vulnerability index was found to be limited in the Dortmund workshop, so it was not included in the Munich workshop. The majority of participants rated the social vulnerability index as more useful than the cumulative environmental index. They considered information on both environmental and social vulnerability factors to be useful in the delineation of programme areas for the funding of the Social City programme.

Table 4-1 Evaluation of participants' responses on usefulness of the tool and model specifications

Tool and model specification	Very much agree	Agree	Somewhat agree	Disagree	Very much disagree
The model integrated into the MapTable was useful for identifying 'hotspots' relevant to cumulative burden assessment across social vulnerability					
	2	4	2	0	1
The following information provided during workshop was useful for cumulative burden assessment					
Individual indicators (air quality, noise, migration background, etc.)	3	4	2	0	0
Cumulative environmental index	2	1	3	2	1
Social vulnerability index	2	5	1	1	0
Integrated indicator on environment and social vulnerability (only for Dortmund)	0	0	1	2	1
The following information was useful to delineate area for resource allocation					
Information on environmental factors	2	0	7	0	0
Information on social factors	1	6	1	1	0

Note: This evaluation is based on only four participants in Dortmund and five participants in Munich

4.5.2 Communication support and information support

To provide communication support for stakeholder-based CuBA we identified three main elements that our approach needs to facilitate: active dialogue among participants having varying levels of expertise and professional backgrounds; critical questioning of underlying assumptions incorporated in the model; and open exchange of each other's perspectives. In both workshops it was observed that there was an active dialogue among the participants on various issues related to CuBA. Activities that encourage an active dialogue, such as openness and the freedom to share points of view (Rouwette, 2011), thus building on meanings proposed by others to produce alternative meanings (Tavella & Franco, 2015), were evident as presented in Table 4-2. The MapTable was observed to support such active dialogue by providing a shared workspace in which indicator maps functioned as a common language. This corroborates the findings of Hopkins et al. (2004), who found increased interaction among groups working with horizontal instead of vertical displays. The active dialogue was further supported by the facilitator, as indicated in Table 4-2. Critical questioning of underlying assumptions of the model was also observed during the workshops. By providing opportunities to interact with the model, for example by changing threshold values of environmental indicators and viewing the result of the change in real-time, the participants were prompted to first understand the assumptions and methods used in preparing the indicators, indices and data used for deriving each indicator. In doing so, the participants were triggered to raise their concerns about various aspects of the model and to critically discuss the relevance of each indicator and index for the identification of 'hotspots' of cumulative burdens. Furthermore, they were stimulated to seek more information to allow them to fully understand the model. Moreover, they provided feedback related to the information used in the model (Table 4-2). As a result, underlying assumptions in the model became transparent and thus open to scrutiny. Mostly exchange of perspectives among participants centred around the indicator maps and on information that was acknowledged to be important but had not been included in the model used during the workshops. Further, the exchange of various perspectives on the same topic from different participants was also evident (Table 4-2). To conclude, the model in the MapTable provided supporting material to stimulate participants to talk with each other and was not just a source of information (Borowski & Hare, 2007).

Table 4-2 Evidence of communication support provided by our interactive stakeholder-based CuBA approach

Elements	Activities	Descriptions and examples of evidence
Active dialogue among participants with a variety of expertise and profession experience	Openness and freedom to share ideas, opinions	Several subjects were raised for discussion, as well as new ideas and opinions being introduced openly.
	Building on meanings proposed by others to produce alternative meanings	Discussions raised on 'what is more risky, dangerous PM_{10} or noise'. Affirming this, another participant added: 'PM_{10} is defined stricter in law but noise is subjective […]'. To this argument an alternative perspective was proposed by another participant, who stated: 'most of the noise is produced by road traffic and most of the fine dust particles too. This means it should be the same point, actually' (00:05:12 – 00:06:04 Dortmund)

Elements	Activities	Descriptions and examples of evidence
	Support of the discussion by the facilitator	In both workshops, in several instances the facilitator kept the group focused on the task (observer notes)
Questioning an underlying assumption in the model	Openly agreeing and disagreeing on various aspects of model	40 µg as threshold value for air pollution was acknowledged to be relevant as it is set by law (00:18:41 Dortmund) Disagreement on the use of 70 dbA, which is acknowledged as the remediation value rather than precautionary value, and agreement reached on 55 dbA (00:18:41 Dortmund; 00:02:16 – 00:03:38 Munich)
	Raising concerns and critical discussions related to the model	Concerns raised on averaging out of noise levels from three sources (industry, tram, street) in cumulative index (00:28:33 Dortmund), on balancing one factor by another in the aggregated index (00:24:26 Dortmund), on absence of indicator on quality of green areas (00:19:11 Munich) Critical discussion on the implication of using Euclidean distance (distance as crow flies) to measure accessibility to green areas (00:07:46 – 00:09:12 Dortmund)
	Seeking explanation from the facilitator to better understand the model	Facilitator explained the use of absolute vs. relative population data in social vulnerability indicator to emphasize the number of vulnerable populations (00: 38: 24 Munich)
	Providing feedback to improve the model	Acknowledge the need for other data to deliberate on cumulative burdens such as location of hospitals, schools, other social vulnerability indicators, quality of green areas, traffic volumes, health status (open-ended questionnaire)
Exchange of each other's perspectives	Different viewpoints shared on same topic	One participant explained the benefit of including areas of at least 1 ha as used in the model so that people can experience the natural environment; another stated quality of green areas to be important, with small green areas and also non-green areas being relevant for children (00:12:07 – 00:14:39 Dortmund); and yet another explained the quality of green areas in general (00:19:09; 00:20:49 Munich)

Elements	Activities	Descriptions and examples of evidence
	Explaining one's viewpoint in relation to what is visualized in the MapTable	Changing the threshold noise value from 70 dbA to 55 dbA based on own experience (17:54 – 18:41 Dortmund)
	Explaining one's viewpoint in relation to what is not yet visualized in the MapTable	Explaining differences in peoples' subjective perception of noise (00:04:34 – 00:05:31 Munich)

There are two main elements needed for the provision of information support in the process of stakeholder-based CuBA. These are a dynamic exploration of information, and elicitation and integration of both tacit and explicit knowledge. The findings presented in Table 4-3 demonstrate that dynamic exploration of spatial indicators and indices was well supported by our approach. Often participants were focused on exploring indicators on a particular segment of a street or neighbourhood, as well as comparing the area with the rest of the city. Such dynamic exploration of information at various scales was found to be supported by the interactive features of the tool, such as zooming in and out. The flexibility of the model augmented with the MapTable and supported by the chauffeur also stimulated participants to explore the distribution of 'hotspots' with various combinations of indicators—e.g. individually or in multiple combinations to form an index, overlaying one indicator with another, and the effect of changing threshold values. In addition, the use of fine-scaled spatial units to derive indicators/indices further supported deliberation about cumulative burdens at local levels in order to identify programme areas requiring resources from the Social City programme other than those areas predefined using administrative boundaries. Elicitation of participants' tacit knowledge and combining it with explicit knowledge seemed to emerge in multiple ways. While the participants were engaged in exploring the model using the MapTable, they used their tacit knowledge to either help others to understand the information being presented through the indicators/indices or even to highlight relevant information that was not captured in the data and indicators (see Table 4-3). Further, evidence indicated that the participants combined both explicit and tacit forms of knowledge and that in doing so they tended to contextualize meaning to information, to highlight relevant personal experience and to elicit their responses.

Table 4-3 Evidence of communication support provided by our interactive stakeholder-based CuBA approach

Elements	Activities	Description and examples of evidence
Dynamic exploration of information	Viewing of information at various scales – street, neighbourhood, through to city-wide	One participant remarked that the tool can display values of indicators per street and that it is exciting to see other sub-zones besides Nordstadt, which has always been a broad-funding area (00:31:50 Dortmund) Spatial resolution of environmental indicators could be refined more (observer notes) Tool enabled to get an overview of differences within a neighbourhood (observer notes)
	Seeking information via various combinations of indicators and indices	Assessment of indicators individually or in combination to produce an index and by overlaying one indicator with another (screen capture)
	Changing assumptions in the model and visualizing those changes in real-time	Participants changed threshold of noise level from 70 dBA to 55 dBA to see the difference (screen capture)
	Seeking guidance on using the tool	Participant asked for guidance, such as: 'could we make it smaller so that we can have an overview again?' (00:06:19 Munich)
Elicitation and combination of various knowledge types	Drawing on own knowledge to explain or understand the existing information	One participant explained to another the concept of threshold values in planning (00:03:01 Munich)
	Highlighting information not included in the model	Participants remarked that important parks known to them were missing (1:00:38 – 1:01:50 Dortmund); importance of quality of green parks for the city (00:19:09 Munich)
	Supplementing the information provided by indicators/indices to further contextualize the information	A participant noticed an area that had above-average values for all social vulnerability indicators (SGBII, migrant background, number of kids, older adults). This was further elaborated upon by another participant working in the area stating that the area itself is being considered in the Social City programme (00:52:02 – 00:52:12 Munich)

4.5.3 Intended outcomes

4.5.3.1 Social learning

The communication and information support provided by our approach helped to 'trigger' social learning to a certain degree. During the workshop sessions, participants were encouraged to think systematically and holistically while assessing cumulative burdens and finding 'hotspots' of cumulative burdens. By offering them the possibility of using the tool in ways they think to be appropriate, participants were stimulated to think critically about each indicator/index. In doing so, they reasoned about the relevancy of each indicator/index in CuBA to identify areas with cumulative burdens and attempted to conceive the underlying interrelations among them. As a result, instead of creating a single index for both environmental and social vulnerability indicators, the participants in Dortmund overlaid the social vulnerability index with the single environmental indicator of access to green areas and noise from street to delineate programme areas there. In the Munich workshop, the participants created a vulnerability index based on indicators relating to older adults, people with a migration background and children aged between 6 and 14 years. By overlaying this onto the noise index they assessed cumulative burdens and delineated a programme area there. The current practice of undertaking cumulative burden assessments using quantitative indicators only was challenged during the workshops. For instance, the participants concluded that the tool lacks information on the quality of green areas, which cannot be derived from quantitative data alone. Input based on experiences and perceptions is needed, demonstrating that it is hard to delineate areas exclusively from quantitative indicators. Likewise, perceptions of people in the neighbourhood regarding noise pollution and their needs were also acknowledged to be necessary inputs in such an assessment.

Evident instances of single-loop learning in the workshops were mainly related to improving the existing CuBA model. For instance, the use of 70 dBA as a threshold for acceptable noise pollution was decided to be very high. By observing the distribution of 70 dBA noise levels participants confirmed that the areas they are aware of having high noise levels did not become visible with 70 dBA assumption. As a result, indicators for noise pollution were reduced to 55 dBA before continuing with the assessment in Dortmund. Similarly, the use of noise level indicators from various sources (train, road, industry) as separate indicators in the index was realized to have a compensatory effect in Dortmund. Therefore, the use of a logarithmic scale for combining noise levels from different sources was considered necessary in the CuBA model; this measure was confirmed during the Munich workshop. The use of 1 ha as a minimum size for green areas that was initially approved by the participants was later reconsidered as smaller parks in the city centre were filtered out using the 1 ha threshold. General shortcomings and difficulties in combining environmental indicators into an index were discussed extensively, in particular the loss of information using an aggregated index and the fact that single indicators having very high or low values are possibly averaged out in an index. For instance, one participant stated that certain indices are more useful than others. In the case of CuBA positive and negative environmental indicators need to be combined, i.e. one would still need to look at these indicators individually. In this respect a conceptual mismatch was detected while aggregating environmental factors. Areas showing high values with respect to one environmental indicator were assessed to be only moderately affected due to compensation by lower values of another indicator. For instance, areas with high exposure for noise levels were not identified as having high cumulative burdens if their accessibility to parks was considered to be good or if they had lower levels of air pollution. On the other hand, the social vulnerability index was found to emphasize areas that are vulnerable with regard to all individual indicators and is, therefore, aligned with how participants perceive social vulnerability in their city. A need to combine the knowledge and experience of participants from the area was also found to be necessary in CuBA. This was evident when a participant acknowledged that although they found one area where noise burden, problem of accessibility and social vulnerability overlap, there could be other areas depending on the indicators they have chosen. Nonetheless, they agreed on the area they have delineated as it was verified through their knowledge and experience. Likewise, the aggregated indices was found useful particularly as a screening tool to compare one area of a city, e.g. the Nordstadt, to other parts of the city, as acknowledged by a participant in the Dortmund workshop session.

Double-loop learning was observed in only a few instances. Instances of double-loop learning occurred when the participants discussed the procedure for conducting CuBA and the challenges associated with CuBA in the context of on-going policies. For instance, in relation noise levels, participants in Munich agreed on the importance of including the level of satisfaction of people, particularly in relation to noise pollution. It was suggested to assess noise pollution at two levels, one based on the data and another based on subjective experiences, and then to integrate these to identify areas with stronger impacts. The participants in Munich concluded that areas with cumulative burdens are not confined to a fixed administrative boundaries—meaning that different administrative units and boards are responsible—which ultimately makes it difficult to assess and plan interventions. Similarly, the issue of the weighting of each indicator—either based on its impact on health or on the objective of the assessment—was raised and at a later stage dismissed, suggesting that weighting often includes political decisions.

4.5.3.2 Knowledge co-production

The presence of attributes of social learning process in the participatory activity lead to co-creation of knowledge among the groups. The co-creation of knowledge has been identified to be manifested in three aspects: a) a cognitive dimension or acquiring knowledge about facts, values, problems and opportunities; b) a moral dimension or building common ground; and c) a relational dimension, such as establishing a collaborative relationship, for undertaking collective action. Cognitive enhancement was evident during workshops as participants clearly opted to acquire knowledge other than that previously held. For instance, the transport planner told the facilitator that although he is not a social expert he found the social vulnerability index useful. Another participant who had been living in Dortmund already for 40 years claimed to have knowledge about the green areas and therefore wanted to know about the impact of road traffic on these areas. In the Munich workshop one participant from the health department observed that there was much more social data available than she had known about before. Discussions also sprang up in which participants shared their perspectives on values such as 'what is more risky: noise or PM_{10}?' Problems and opportunities for assessing cumulative burdens and thus identifying programme areas were identified jointly. For instance, the interactive properties of the model, relative scale normalization and real-time visualization were useful in supporting stakeholders in their deliberations about cumulative burdens, whereas challenges were related to aggregation of environmental indicators into indices without compensating the effects of each other.

Building common ground in participatory activities refers to identifying areas of agreement upon which to focus constructively and, similarly, areas of disagreement that need further deliberation. The participants discovered common linkages between various interests. For instance, in the process of exploring the distribution of children as an issue of interest of one participant, another participant shared an interest in knowing the distance children at various locations have to travel to visit parks. The participants therefore combined the indicator of distribution of children with that of accessibility to green areas. In this way, the participants were able to work through their interests linking these with others, so that later they were able to agree on a set of indicators/indices for assessing cumulative burdens so as to delineate programme areas. Collaborative relationships were also evident in the form of opportunities for different departments to work together. In the Munich workshop, participants remarked that the model and the MapTable could be used to integrate data from various departments, e.g. health, environment, social, education, and to overlay these to generate new, meaningful information. Finally, the approach lead to collective action by the group: new programme areas were delineated that integrated cumulative burdens and their impact on social vulnerability, as well as knowledge of multiple stakeholders.

4.6 *Discussion and Conclusions*

The 'social complexity' with respect to CuBA has generated a growing need to focus on engaging stakeholders in social learning and the knowledge co-production process through the practice of a science-based stakeholder dialogue as an interface for combining different domains of knowledge. Although social learning may occur whenever stakeholders come together to discuss their differences, the learning opportunities that arise require careful nurturing (Muro & Jeffrey, 2008). Individuals learn and knowledge is co-produced when explicit knowledge (e.g. scientific information, data) is taken up in their cycle of knowledge acquisition, so that such explicit knowledge is made sense of through their own tacit knowledge base (experiential knowledge, know-how) in an open and collaborative process (Snowden, 2002). In this regard, the approach presented here clearly supports such a science-based stakeholder dialogue in CuBA. The insights from the two workshops demonstrate that the approach has been able to position the CuBA process in the interface between the production and use of knowledge from both research and practical points of view. By opening a window of opportunity for interaction with a flexible, auditable model in a shared workspace provided by the MapTable and supported by a facilitator, the stakeholders were enabled to deliberate collaboratively on cumulative burdens, to learn about the technical uncertainties and social challenges associated with cumulative burdens, and to co-produce knowledge in a realm of both technical and social challenges.

A number of potential benefits from the approach can be identified that are relevant for addressing 'social complexity' in CuBA. Firstly, it is acknowledged that in addition to expert-based scientific reasoning and knowledge from a broad range of stakeholders, CuBA requires the incorporation of ethical considerations, multiple perspectives and value judgements. To meet such requirements our approach enabled a group of stakeholders to actively and collaboratively engage in the process of cumulative burden assessment. In doing so, stakeholders tended to exchange their perspectives and integrate their tacit knowledge, values and reasoning in the process, as was evident from the workshops. Secondly, in CuBA it is difficult, if not impossible, to identify and analyze significant factors amidst multiple perspectives as this does not follow a linear, easily-standardized and agreed upon formula. There is thus a risk of imposing simplified models and expert-based assessment over the complex realities of CuBA (Huang & London, 2016). In our approach we addressed this risk by providing stakeholders the opportunity to critically reflect on any underlying assumptions used in the model and on the indicators/indices included in it and to decide on their relevancy in the CuBA process. Moreover, the approach stimulated the participants to use the tool as they thought appropriate for CuBA; it was not necessary to arrive at a single index. This lines up with what Payne-Sturges & Lawrence(2014: p.3) stated: 'perhaps the assessment or evaluation of cumulative burdens do not necessarily mean we must arrive at one number'. Thirdly, a CuBA needs to reflect the specific characteristics of a specific geographic area or population, but at the same time it must conform to scientific rigour and regulatory frameworks. This calls for 'a mutual and recursive relationship between analysis and deliberation' (Calow & Martin, 2013) in the CuBA process. The approach supported an analytic-deliberative process in CuBA by reconciling both analytic components (e.g. technical data, methods, environmental standards) and the deliberation components from the users (e.g. discursive arguments, logics, reasoning, perspectives, understanding of the issues) that are socially and contextually relevant. Fourthly, the impacts of cumulative burdens often cannot be fully predicted for the areas due to interlinking between issues, making it difficult to follow one course of action. Nonetheless, the resulting assessment, enriched with the knowledge and perspectives of many, as well as inputs of shared interest and informed choice, is considered to contribute to better informed decision-making (Bautista et al., 2017). Moreover, integration of knowledge and learning, together with increased trust, ownership and support for the assessment product, are considered to be important outcomes of the participatory process (Measham, 2009; Raymond et al., 2010). In this regard, our approach was set up to improve assessment outcomes by supporting stakeholders in an experimental process of step-wise inquiry into cumulative burdens. In doing so, it allowed different ways of knowing by researchers and practitioners to be integrated in an open, flexible and transparent manner, thereby engendering social learning and knowledge co-production in CuBA processes. Consequently, the approach enabled access to data and knowledge on the sectoral specificities of the participants, laid a foundation for developing common linkages among various sectors, and provided a platform for stakeholders to interact in a complementary manner, thus contributing with their respective strengths to the CuBA process.

In spite of having essential values in engaging stakeholders from both research and practice in a CuBA process, it is necessary to stress challenges pertinent to our approach. Direct interactivity with models and tools demands a high level of engagement by participants. Such levels gives users more control of the model with which to follow through on ideas about what is visualized and discussed among groups, to revisit observations, and to receive and give feedback on their interpretations and choices (Vervoort et al., 2010). For instance, participants could select their own set of indictors/indices and visualize these in the MapTable. It may, however, make stakeholders anxious about understanding the model structure and the groups may even get distracted by using the tool, which was evident in a few instances during the workshops. Therefore, one of the challenges in the use of our approach is to maintain a balance between the experiences of users in attempting to understand the model's structure or applying the tools and to put these to use when deliberating on CuBA. The use of a relative scale for coherent representations of indicators/indices and a colour coded legend was found useful to communicate the information generated by the model to the participants. Likewise, while the role of facilitator is noted to be important in most participatory activity (Muro & Jeffrey, 2008; Schusler et al., 2003), assigning the role of facilitator to one person and the role of chauffeur to another distinctly benefitted the process. Therefore, careful design of the model and tools and the harnessing of the skills of the facilitator and chauffeur are essential for our approach. Another challenge relevant to the approach is the explicit inclusion of qualitative information—in addition to quantitative information—in CuBA. This challenge is recognized as being present in many domains, particularly where scientific or technical information interfaces with human values (Salter et al., 2010). Although through our approach the engagement of multiple stakeholders increased the representation of qualitative information in the assessment of cumulative burdens, a qualitative/quantitative tension was found to remain. For instance, this tension became apparent when participants were discussing the perception of residents on noise pollution, the quality of green areas and the traffic situation in a particular street. We noted that our approach could be extended to include the qualitative information as other layers of information in the model, although such qualitative information would have to be elicited and captured beforehand. Perhaps it is relevant to explore the integration of other approaches for capturing qualitative information for stakeholder-based CuBA, such as the one developed by Shrestha et al. (2017). Likewise, in order to fully support stakeholder dialogue in cumulative burden assessment, the approach would need to extend the CuBA model to include health-related indicators/indices. Dealing with the conceptual mismatch related to a cumulative index of environmental burdens is another challenge that needs to be addressed. To do so, it might be necessary to understand interactions among various environmental factors and the influence these may have on each other when those factors occur simultaneously.

In this study, we sought to develop an approach to facilitate science-based stakeholder dialogue while assessing cumulative burdens. Given our intention to construct and test a comprehensive approach and provide initial insights about its applicability, we conducted workshops in Dortmund and Munich with five and seven participants, respectively. To this end, we adopted an exploratory methodology and conducted a micro-analysis of the workshop data. In doing so, we examined the interactions in depth as mediated by our approach and found some outcomes on social learning and co-production of knowledge. Yet, looking at research into science-policy interfaces and other literature on social learning and knowledge co-production, we consider that other factors, for example prior knowledge of the topic and study area by stakeholders, the social and institutional context in which the participants' experience are embedded, and the group dynamics during the workshop, might have influenced the way participants access and use the models and the tool. Therefore, further research may be worthwhile on how such an approach enables or constrains participants in CuBA in various institutional, social and political contexts. Other methodologies, such as a more controlled experiment with a larger number of participants, would also be worthwhile to derive more quantitative results on various elements of the framework that may be generalized.

Chapter 5: Synthesis[*]

[*] *This chapter is partly based on the book chapter:*
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5.1 Introduction

The point of departure of this study is that in order to support collaboration with regard to environmental health issues, both the urban planning sector and the public health sector need to be engaged in the process of social learning and knowledge co-production. In doing so, interactive map-based support systems provide a platform to engender social learning and knowledge co-production. Two approaches of interactive map-based support systems have been developed and tested: the Interactive Spatial Understanding Support System (ISUSS) and the interactive stakeholder-based cumulative burden assessment approach (Interactive-CuBA).

The ISUSS approach aims at supporting knowledge co-production and integration by engaging stakeholders from different sectors. It intends to engender communication and social learning in order to develop a shared understanding of a locally specific problem situation. Typically, the approach is designed to support workshop activities during an early phase of health-related planning processes. The ISUSS framework acted as a platform to enable the integration of explicit knowledge (e.g. data, indicators) and stakeholders' tacit knowledge (i.e. experiences, expertise) during a collaborative workshop by combining two specific methods, namely interactive mapping and 'rich picture' drawing. Spatial visualizations of indicators supported in linking the places stakeholders know and the respective spatial information as well as various driving factors. User-friendly interfaces with functionalities to zoom in, pan and overlay different layers supported the stakeholders while exploring environmental and social indicators simultaneously in multiple combinations. Additionally, structuring data to visualize indicators at a disaggregated level was noted to be important for understanding spatial inequalities by comparing areas of the case study city. Likewise, it provided a good platform to 'trigger' discussions and capture stakeholders' tacit knowledge. With the support of spatial visualization, annotation and sketching functionalities on interactive maps the participants were able to draw their ideas, discuss them further with others and add their knowledge at the neighbourhood scale. They were further supported in elaborating their issues and concerns by using pictograms on the 'rich picture' and making links to other views, which enabled them to construct an integrated picture of the environmental health situation in the study area.

Communication among the participants was observed throughout the entire ISUSS workshop in Dortmund. Interactive maps on the MapTable appeared to support communication of information and knowledge in an interactive and dynamic way. The MapTable appeared a useful medium to bring people together. By guiding them through structured facilitation, the participants were enabled to work actively and encouraged to ‘show what they meant’. Combined use of the interactive maps and the ‘rich picture’ drawing supported the articulation, sharing and integration of both locally spatialized knowledge and non-spatial or yet to be spatialized knowledge respectively in the discussion. As such, social learning was evidenced at different moments in the workshop. For instance, by overlaying multiple environmental and social indicators (e.g. share of children under 6 years overlaid with noise level from streets) on the MapTable, the participants commented that the children’s routes are in some parts highly affected by noise and air pollution. They also sought to change their existing knowledge through reasoning and interaction. For instance, a strikingly high share of unemployment aid recipients (SGBII) along a street forced the participants to think in depth about the potential underlying reasons; elsewhere, the participants realized that the situation according to PM_{10} on a specific street is still problematic, but better than assumed. Likewise, the development of a shared understanding was observed during a few instances while the participants were engaged in constructing shared meanings and identifying shared interests. For instance, while discussing the accessibility to green areas, participants discussed whether the focus should be in terms of time and distance or in terms of safety of the access route. Consensus was reached on assessing the quality of the access from a safety point of view. Similarly, improving accessibility to green areas was identified as important in the case study area to promote health.

Some limitations and challenges were also observed during the implementation of the ISUSS approach. While exploring existing spatial information, the discussion was somewhat constrained either by the limited number of indicators or the unavailability of small scaled data. The facilitation was found to be important to ensure the focussing of participants while using the tool as well as during the ‘rich picture’ drawing session. Group dynamics and the knowledge base of the participants were found to influence social learning and development of a shared understanding. One participant perceived less learning as he had been aware of the topics that were discussed already. Likewise, it was observed that participants were mostly ‘like-minded’ and therefore, appeared to have comparable norms, values and lack of challenging assumptions. The use of the MapTable poses challenges on supporting a large number of participants. The number of participants that can be supported around a table is limited to 6 or 7 people. As such, the knowledge and values of a large number of stakeholders is difficult to accommodate in one knowledge map and ‘rich picture’ during a workshop. Nonetheless, the participants remained active, stimulated and engaged throughout the workshop, the knowledge production evolved from one-directional information provision to interactive knowledge co-production.

The interactive stakeholder-based CuBA approach aims at facilitating a stakeholder dialogue in order to collaboratively assess cumulative burdens and thereby engender social learning and knowledge co-production among stakeholders. The Interactive-CuBA approach adopts an indicator based cumulative burden assessment method. It uses a grid-based, fine spatial resolution to represent indicators on both environmental and social vulnerability factors. A relative procedure for normalization and standardization of indicators using environmental standards and city-wide averages are adopted in order to integrate both environmental burdens/benefits into an index together with social vulnerability factors. The approach included three main attributes. Firstly, a flexible and auditable model that allows the stakeholders to freely select indicators or change certain assumptions relevant for their CuBA. As such, stakeholders can overlay individual social vulnerability indicators on various environmental indicators, and create either a separate index for environmental burdens and social vulnerability or an integrated index combining both indices. The interactive tool allows stakeholders to (de)select indicators to be combined into an index or change the threshold value of environmental standards in the case of environmental indicators. The effect of these changes with regard to the distribution of cumulative burdens can be viewed dynamically and spatially in the form of 2D maps. Secondly, the interactive interface-driven shared workspace, which is MapTable in the approach, provides an opportunity to allow the interactive use of the model, which is necessary to maintain user engagement. Thirdly, skilled facilitation, including both process and tool facilitations, supports in achieving the outcomes of the participatory activity. The approach aimed at providing communication support by enabling active dialogue among the stakeholders, allowing them to question the underlying assumptions made in the model and encouraging them to exchange their perspectives. Likewise, the approach aimed at providing information support by allowing the stakeholders to explore the information dynamically and spatially using a shared spatial language. Finally, the integration of both tacit and explicit knowledge yields a more comprehensive understanding than each of these could have produced separately.

In general, the findings show that the Interactive-CuBA was able to provide communication support in both workshops in Dortmund and Munich. An active dialogue was observed, mediated by the use of the MapTable that provided a shared workspace on which indicator maps were shown as a common language. The use of this flexible and auditable model provided opportunities for the participants to interact with the model, such as changing the threshold value of environmental indicators, selecting the set of indicators and viewing the results of a change at the same time, which prompted the participants to question the underlying assumptions used in the model. The model appeared transparent as well as open to scrutiny. The model and the MapTable acted as a supporting material for the participants to talk with each other and thereby exchange various perspectives on the same topic from different participants as well as on the information that was acknowledged important but was not included in the model. The approach offered information support in the CuBA process by enabling the participants to explore the indicators dynamically using interactive tools such as zoom in and out, selecting or deselecting. They explored the indicators at various scales—street level to city-wide scale—and in various ways, combining indicators to form an index, overlapping one indicator with another, changing indicator thresholds, etc. The use of fine-scaled spatial units further supported deliberation about cumulative burdens at the local level. As the participants engaged in exploring the model using the MapTable, participants' tacit knowledge seemed to be elicited, which they used to make others understand the information presented through the indicators or even highlighted the relevant information that were not captured in the model and thereby contextualizing the meaning to the information provided.

Instances of social learning and co-production of knowledge were observed during the workshops. For instance, the use of 70 dBA as the threshold for acceptable noise levels was decided to be too high, and the use of logarithmic scales when mapping the same was acknowledged necessary to avoid compensatory effects of various noise indicators. The use of one hectare as the smallest size for parks was identified to filter out important parks in the city centre. Shortcomings and difficulties in combining environmental indicators into an index were also jointly discussed. The importance of including the subjective perception of residents in relation to noise pollution and the quality of green areas to promote healthy environment were concluded. In addition, several problems and opportunities to assess cumulative burdens for resource allocation were jointly identified. For instance, cumulative burdens are not confined within fixed administrative boundaries. Therefore, different administrative units and boards being responsible for the same ultimately make it difficult to assess and plan interventions. On the other hand, the participants identified opportunities for different departments to work together using the model on the MapTable. They would be able to integrate data from various departments such as health, environment, social, education etc. and consequently generate meaningful information.

Certain challenges and shortcomings were observed with respect to the Interactive-CuBA approach. Similar to the ISUSS approach, one of the challenges in the use of the Interactive-CuBA is to keep balance between the experiences of users in attempting to understand the model's structure or applying the tools and put it to use when deliberating on CuBA. Therefore, a careful design of the models and tools and definition of the facilitation task becomes apparent. The explicit inclusion of qualitative information, in addition to quantitative information, would need to be further improved in the approach. In order to fully support the stakeholder dialogue in CuBA, the approach would need to extend the CuBA model to include other indicators on health outcome and services. Nonetheless, the approach has been able to position the CuBA process in the interface between the production and use of knowledge by involving stakeholders to deliberate collaboratively on cumulative burdens.

5.2 *Supporting social learning and knowledge co-production strengthened by an interactive map-based support system: a conceptual framework*

The following section starts with presenting the lessons learned, particularly with respect to the generic framework of social learning and knowledge co-production described in chapter 1. The lessons have been synthesized based on the design and implementation of the two approaches of interactive map-based support systems. Thereafter, a conceptual framework of social learning and knowledge co-production strengthened with interactive map-based support systems is presented.

5.2.1 Lessons learned

Figure 1-1 in Chapter 1 provides a generic framework of social learning derived from existing literature. The framework entails three process components—facilitation, diverse participants, democratic structure—that are necessary in any participatory activity. Assuming these are present, they may generate process attributes of a participatory activity, which are inclusion of diverse knowledge types, constructive conflict, extended engagement, unrestrained thinking and open communication. Having these process components and process attributes together in a participatory activity, social learning might be promoted among the participants and thereby co-production of knowledge during the process. In this respect, the following paragraphs shed light on how the two approaches of interactive map-based support systems developed in this study have addressed the process components and process attributes of the social learning framework.

One of the key elements in both the ISUSS approach and the Interactive-CuBA approach is the role of facilitation and the facilitator. The process facilitator ensured that all participants feel comfortable to share their ideas and thoughts, stimulated the participants to contribute in the process, and drew attention of the participants to the process elements such as agenda, objectives and task of the session whenever necessary. In addition to process facilitation, the approaches also included tool facilitation. The tool related facilitation was meant to ensure that the discussion is not hampered using the tool in the process, for instance while using the interactive maps on the MapTable in the ISUSS approach and the CuBA models in the Interactive-CuBA approach. Therefore, different roles were assigned to two facilitators, one being the process facilitator and another being the chauffeur or tool facilitator. In doing so, it benefitted the process for supporting stakeholders to carry out workshop activities and at the same time embracing the dynamism of the interactive tools and models.

With respect to supporting diverse participants, the design of the approaches was found to be supportive as well as to pose some limitations. The interactive maps in the ISUSS approach and the CuBA model in the Interactive-CuBA approach integrated on the MapTable acted as a common language with a shared workspace for participants that potentially helped in engaging individuals from a variety of professions. In this way, they were able to contribute a range of personal interests and experiences. Nonetheless, the number of participants that could be hosted around the MapTable in one session is limited to 6 or 7 people. A larger numbers of MapTables could of course be used to support larger numbers of participants, but that would require more facilitation, technical support and may even require some changes in the design of the approaches.

Similarly, a democratic structure was in both approaches supported as the participants were given the opportunity to ask questions, to give feedback on the data and methods and were encouraged to respond to others' perspectives. Possibilities to explore indicators individually or in combination, to add their own area-specific knowledge to the interactive maps or knowledge related to wider geographic areas on the rich picture supported the democratic structure in the ISUSS approach. In the Interactive-CuBA approach, a democratic structure was ensured by allowing the participants to use the model as they felt it appropriate while exploring the indicators or constructing the index. However, some tensions were also evidenced with regard to the approaches, in particular, due to unavailability of data as asked by the participants and sometimes distractions caused due to focus on using the technology. These can be seen as aspects that pose challenges to assuring a democratic structure in the process while using the approaches of this study.

The approaches developed in this study supported the process attributes of open communication and the inclusion of diverse knowledge better than the other attributes, namely unrestrained thinking, constructive conflict and extended engagement. Sharing of knowledge and experiences in an active dialogue among the participants was observed in both workshops. Working together in a small group around the table, and viewing the same information acted as a 'dialogue space' for the people to actively engage and talk with each other. In the ISUSS approach, one participant remarked that 'the system (MapTable) has produced a dialogue that would not have been possible without it'. In the Interactive-CuBA workshops, stakeholders were given opportunities to explore and understand the underlying assumptions of the model dynamically and with various combinations of the indicators/index that also supported the dialogue thereby stimulated them to share their perspectives and knowledge. Inclusion of diverse knowledge types, in the form of tacit knowledge and explicit knowledge, is another attribute that was observed to be well supported with the approaches developed in this study. Explicit knowledge was included in the form of interactive maps as in the ISUSS or as indicator maps, or environmental standards as in the CuBA model. Tacit knowledge, on the other hand, needed to be elicited and articulated. This was supported by allowing stakeholders to interact with the flexible and dynamic tools/methods and at various scales—such as city wide to neighbourhood—during which participants tend to relate their knowledge and experience specific to geographic reference. Moreover, when the stakeholders were encouraged to mark and annotate the areas while adding their knowledge as in the ISUSS approach or drawing a 'rich picture', it helped to explicate and thereby capture their tacit knowledge.

Unrestrained thinking about different types of knowledge and epistemologies among the participants is said to be stimulated by avoiding a priori presumptions on what information would be relevant to the participants nor what options, ideas would be discovered. Deciding on a fixed set of indicators shown in the interactive maps or in the CuBA model beforehand is necessary in the approaches of interactive map-based support systems. However, it was found to restrain the thinking among the participants as they were implicitly forced to discuss around the indicators that have been provided. Nonetheless, the use of the 'rich picture' in the ISUSS approach seems to support the unrestrained thinking. One participant explained on how he was able to bring the topic of health insurance only during 'rich picture' session as the data was not provided during the interactive mapping session. Similarly, the limitations also seem to affect the stimulation of a constructive conflict. The notion of a constructive conflict refers to an open exploration and evaluation of competing ideas and knowledge claims in order to achieve new ideas, insights and options. However, constructive conflicts need to be stimulated. The approaches tested here were less effective at stimulating constructive conflicts in the workshops. When conflicting viewpoints were uncovered in the Interactive-CuBA workshops, they were muted or lead to affective reactions in the process because the model lacked relevant information. In the view of Cuppen (2012) stimulating cognitive conflicts that ‘pertain to conflict about ideas in the group and disagreement about the contexts and issues of the task’ and subduing affective conflict as seen in affective reactions such as annoyance and animosity is necessary to generate constructive conflicts. Not only the design of the approach, but also the selection of participants influences potential constructive conflicts as argued by Cuppen (2012). This could be observed as the participants were somewhat ‘like-minded’ in the ISUSS workshop and conflicting viewpoints did not surface. In order to sustain social learning and knowledge co-production these kind of activities would have to be extended beyond a single participatory activity. This would demand additional resources in form of a series of participatory activities mediated through such approaches. In doing so, extended engagement could have been supported and potentially more opportunities to foster social learning and knowledge co-production could have been offered.

Next to these process attributes, two other new attributes—building of visual artefact and reflexivity—were observed during the workshops. Visual artefacts are visual representations of objects or entities that take form through constant negotiation of meaning among participants during participatory work (Singh, 2011). Working on interactive maps and drawing of the ‘rich picture’ acted as visual artefacts during the ISUSS approach. In the Interactive-CuBA approach, constructing an index provided opportunities to build visual artefacts. These visual artefacts were found to support the participants to engage in dialogue with a ‘shared language’. It also supported in engendering reflexivity that is ‘the process by which people learn from and even change behaviour based on information they receive’ (Fiorino, 1999, p.3). Visual artefacts were observed as a way to provoke participants’ reflections in a shared setting. For instance, in the ISUSS workshop, when the participants saw a strikingly high proportion of unemployment aid recipients along a certain street, or when a street that was known having high PM_{10} was observed to have relatively less value on PM_{10}, they were drawn to discuss the potential causes of the situation. Deciding on the noise threshold standard after observing the variation with respect to two threshold values, and acknowledging the usefulness of the social data by a transport planner could be seen as instances of reflexivity in the CuBA workshops.

5.2.2 A conceptual framework of an interactive map-based support systems approach for social learning and knowledge co-production

Figure 5-1 provides a conceptual framework of an approach of interactive map-based support system for supporting social learning and knowledge co-production. The framework is based on the general framework on social learning as given in Chapter 1 and integrates the lessons learned through the development and testing of the two approaches on interactive map-based support systems as described in section 5.2.1. The framework presents a conceptual basis for an approach with an interactive map-based support system for promoting social learning and knowledge co-production. It shows the attributes of the existing framework on social learning as well as provides additional attributes that could be strengthened with an approach of interactive map-based support systems to support social learning and knowledge co-production.

The first part of the framework (A) describes the approach attributes that are necessary for such interactive map-based support systems. It constitutes of three main attributes: flexibility and dynamics in tools/models; interface-driven shared workspace for user engagement; and skilled facilitation. These three elements are considered generic for the development of approaches using interactive map-based support systems. Depending on the context and the task to be supported, the specifications of the tools and models, the type of the hardware and software to augment the tools and models with flexibility and dynamics, the shared workspace, and the detail of facilitation tasks all need to be decided. In the ISUSS approach, the use of the interactive maps of varying levels of detail, combined with rich picture drawings, provided flexibility and dynamism. In the case of Interactive-CuBA, the opportunities to explore the indicators/index individually, or in combination, and to select the indicators and subsequently construct an index preferred by the participants ensured flexibility and dynamism in the process. In both approaches, the MapTable acted as the shared workspace and skilled facilitation was provided by appointing a facilitator to stimulate interaction and commitment among stakeholders and chauffeur to provide guidance on the use of the tools.

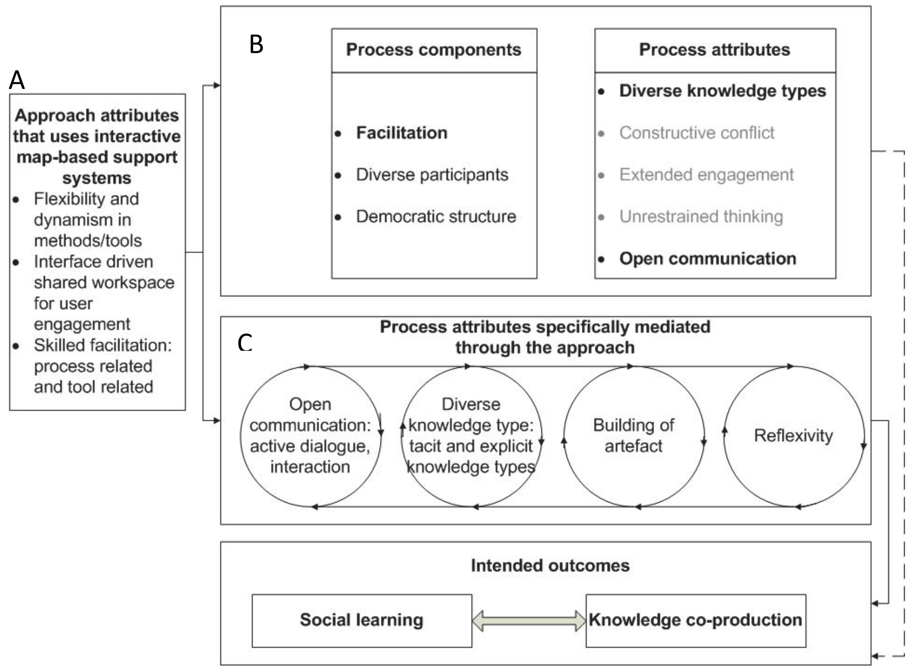

Figure 5-1 A conceptual framework of an approach of interactive map-based support system for social learning and knowledge co-production

The second part of the framework (B) shows the process components and process attributes as described in the social learning literature. The normative argument taken is that these are in general necessary for any kind of formal participatory activity to engender social learning and knowledge co-production, including the approaches supported by interactive map based support systems. With these approaches, some of the process components and process attributes are supported as discussed in 5.2.1. For instance, the approaches supported the facilitation whereas they posed some challenges on fully supporting two components—in particular diverse participants and democratic structure. Similarly, the approaches were able to support open communication and integration of diverse knowledge types in the process using interactive map-based support systems. However, the use of interactive map-based support systems restricted other attributes—unrestrained thinking and stimulating constructive conflict. Moreover, other factors such as availability of data, preparation of tools and model beforehand and whether the participants have similar or different perspectives influenced in the generation of unrestrained thinking and a constructive conflict in the process. However, extended engagement, understood as in-depth conversation and interactions among participants outside the formal exercise, although important to sustain social learning, cannot be achieved in a short duration, which also holds true with the approaches on interactive map-based support systems.

The third part of the framework (C) presents the four attributes—open communication, inclusion of diverse knowledge, building of visual artefact and engendering reflexivity—that could be strengthened effectively through the approaches on interactive map-based support systems. Open communication with an active dialogue is acknowledged to activate an exploratory learning behaviour. Using tools/models that are flexible and dynamic in the sense that participants can explore the information in the participatory activity as they want and having them on a shared workspace for all to look in could potentially trigger the dialogue. Together with skilled facilitation, participants could be encouraged to 'show what they meant' or share their perspectives with respect to what is being visualized or even not yet into the system. In doing so, they could be enabled to incorporate explicit knowledge provided through the tools and models such as indicators, environmental standards into their discussions. Tacit knowledge, on the other hand, need to be elicited and articulated since such knowledge may tend to exist in stakeholders' pre-existing viewpoints and experiences. In this regard, enabling participants to relate their tacit knowledge with specific places or geographic objects could support in explicating their tacit knowledge. Moreover, supporting such activity with an interactive shared workspace provides opportunities to communicate participants' tacit knowledge effectively among the groups. The approaches support participants in building of visual artefact during the process. When the participants are enabled to build a visual artefact it provides them with an opportunity to get 'hands on' experience (i.e. learning-by-doing) that is also reported to benefit learning, particularly in a shared setting (Seitamaa-Hakkarainen et al., 2010). Providing opportunities for reflexive communication among each other or opportunity to investigate their own experiences and knowledge could potentially support in learning. Focussing on concrete experiences and locally relevant information could be seen as a way of encouraging experiential learning (Kolb & Kolb, 2009) and therefore, as a basis for reflecting, thinking and acting (Wibeck, 2014). In this regard, allowing participants to visualize information at various scales, in multiple combinations could further draw them into a deeper exploration of the issues based on what is visualized as well as on their own knowledge and experiences. As such, it can promote learning among individuals by enabling them to 'reflect on new information or even reassess their taken-for-granted knowledge and experience of the world' (Dyke, 2009) in a participatory setting. This also enables explicit knowledge to enter into a cycle of knowing, which is made sense of through the tacit knowledge of the participants. Moreover, both explicit knowledge and stakeholders' tacit knowledge could be confronted with each other or even challenged mutually. Therefore, the process emerges as interactive and these attributes are implanted dynamically rather than linearly.

5.3 *Reflections*

This section reflects on the main contributions of this research and provides some recommendations for further research.

5.3.1 Main contributions

The main contributions of this study can be distinguished into three aspects: methodological contributions, application related contributions and conceptual contributions.

From a methodological perspective, this study provides innovative approaches of interactive map-based support systems to engage stakeholders focussing on two aspects: the development of a shared problem understanding and cumulative burden assessment

- To support stakeholders in an early planning phase of developing a shared problem understanding, this study tested a novel methodological approach, namely the Interactive Spatial Understanding Support System (ISUSS). The ISUSS approach combines two methods—interactive maps integrated on the MapTable and a 'rich picture' drawing. Previous studies have used these two methods separately. Hence, the innovation of the ISUSS approach is the combination of these two methods. The ISUSS approach showed an added value of the combination of these methods for integrating and capturing both spatial and non-spatial or yet to spatialize knowledge of stakeholders into the discussions.

- With respect to the cumulative burdens assessment, the study provides a method that integrates both environmental burdens and benefits across the population with varying levels of social vulnerability. Studies that have considered multiple environmental burdens and benefits together with social vulnerability factors are limited. Moreover, studies on cumulative burden assessment have considered administrative boundaries at a regional or district level (Alexeeff et al., 2012; Pearce et al., 2010, 2011). Such assessment at an aggregate level is not sufficient to inform health-related planning at a local level. In this respect, the major contribution of this study is the fine-scaled and interactive assessment of multiple environmental burdens and benefits across a population with varying social vulnerability. The study showed the utility of population disaggregation methods to investigate social vulnerability indicators at a small-scaled grid. Secondly, this study extended the use of cumulative burden assessment methods towards facilitating science-based stakeholder dialogues, namely interactive stakeholders-based cumulative burden assessment (Interactive-CuBA). The approach highlighted the benefits of adapting the method into a flexible and auditable model integrated on a MapTable so that stakeholders could use the model as they think is appropriate, integrate both explicit and their own knowledge into the discussions.

From an application perspective, this study shows the usefulness of the approaches to stimulate social learning and co-production of knowledge among a group of stakeholders.

- With respect to the ISUSS approach, the study shows the applicability of the approach in an early stage of problem understanding, in particular, to support transdisciplinary research practice. Transdisciplinary research practice calls for mutual learning through co-leadership among all relevant stakeholders during an early stage in the process and thereby supporting knowledge co-production and integration from both science and society (Scholz & Steiner, 2015). In this vein, the ISUSS approach contributes by providing a platform where stakeholders from various sectors and researcher with their own knowledge and perspective interact, learn and develop a shared understanding and produce insights on the problem situation jointly. As such it is an important contribution to facilitate health-oriented urban planning for which different sectors need to collaborate in a transdisciplinary research.

- The interactive stakeholder-based cumulative burdens assessment (Interactive-CuBA) approach has been applied to engender social learning and support knowledge co-production while assessing cumulative burden to delineate certain areas as a planning task. Cumulative burden assessment is generally acknowledged as a screening tool to identify areas that need additional investments. However, there is limited research that reports on engaging stakeholders in the assessment of cumulative burdens. In this vein, this study shows the usefulness of the Interactive-CuBA approach to support science-based stakeholder dialogues. In this approach stakeholders can deliberate collaboratively on cumulative burdens, access data and knowledge on sectoral specificities of the participants, learn about technical challenges and social complexities associated with cumulative burdens, interact in a complementary manner, and thus contribute with their respective strengths in the process.

From a conceptual perspective, this study provides a framework that can be used to design an approach of interactive map-based support system to engender social learning and knowledge co-production. Participatory activities require elements to engender social learning and knowledge co-production. However, these elements have not been explored with respect to interactive map-based support systems in a broader sense. Therefore, based on the two applications, this study provides a conceptual framework to engender social learning and knowledge co-production when developing an interactive map-based support system.

5.3.2 Implications on cross-sectoral collaboration and 'wicked problem' characteristics of environmental health issues

Environmental health issues are a typical example for a necessary collaboration between the urban planning and public health sector because of the influence these sectors can exert on the physical, social and economic environment and consequently on health of people. Nonetheless, cross-sectoral collaboration can be a challenging endeavour in an environmental health context, due to the 'wicked problems' characteristics of environmental health, as discussed in chapter 1. These are characterized in this study as differences in understandings among stakeholders on the topic, the existence of 'silo' mentalities with rigid boundaries in the development of knowledge across professions, differences in usage of data, terminology, methodology thereby lacking a common evidence base, and the existence of competing points of views on problems, let alone solutions. The findings in this study shows that the approach of using an interactive map-based support system has provided certain advantages to address these 'wicked problem' characteristics. For instance, opportunities to map knowledge and perspectives enabled the stakeholders to make different understandings on the topics explicit and thereby helped developing a shared understanding and meaning, which is considered essential for coherent action (Conklin, 2005). Similarly, stimulating learning about others' perspectives and sectoral specificities and sharing and co-producing knowledge may help in breaking down 'silos' in the development of knowledge among sectors as reported by others (Bundred, 2006). Differences in usage of data and language (e.g. indicators) and lack of a common evidence base are described as another challenge that is addressed by using interactive maps on the MapTable. The Maptable can potentially provide a common evidence base by integrating data from various sectors for joint working as acknowledged during the Interactive-CuBA workshop. Therefore, cross-sectoral collaborations grounded on engaging stakeholders in mutual learning, sharing and co-production of knowledge might promote opportunity to address some of the 'wicked problem' characteristics.

Nonetheless, such collaboration requires broad based partnership among the various sectors that constantly needs to be practiced and in the long run institutionalized.

5.3.3 Recommendations for further research

After developing the interactive map-based support systems in the context of environmental health and exploring the usefulness to engender social learning and knowledge co-production, several topics have evolved that could be considered by further research.

- This study has considered the physical environment defined by the external characteristics of a residential neighbourhood, and the social environmental defined by social vulnerability factors of the population as determinants of environmental health. Owing to the broad determinants of environmental health, what has not been covered within this study are other dimensions of social environmental such as social support, social cohesion, social capital as well as availability and access to health and social services such as physicians, health insurance, etc. These have been mentioned by the stakeholders as additional important factors influencing the health of people in a German context. Therefore, further research could explore the integration of these aspects into the interactive map-based support systems.

- In this study, only objective data on environmental factors were used to derive indicators on environmental burdens and benefits. Additional data, in particular the perception of resident with respect to noise level and quality of green areas, are acknowledged important to include in both the ISUSS and the Interactive-CuBA approach. Such additional data may further improve the approaches as also pointed out by the stakeholders. Moreover, this study has not yet included health outcome-related data. Acquiring data on mortality and morbidity is however, not without challenge due to data restrictions, also recognized by others (Lakes et al., 2014). It is even more challenging when data is required at finer scales, mainly due to data privacy issues. Possible ways to overcome this challenge would be to explore data envelope techniques while preserving data privacy (Hampton et al., 2010).

- Cumulative burden assessment methods developed in this study have considered the co-occurrence of environmental benefits and burdens across population with varying social vulnerability. In reality, these environmental benefits and burdens exist simultaneously or are even interacting with each other. Moreover, compensatory effects among the factors were found to exist while aggregating indicators into an index. In this respect, further research needs to explore non-compensatory methods capable of integrating interacting effects of various environmental factors.

- A three class dasymetric method was used in this study to disaggregate social vulnerability data from statistical sub-district level to small-scaled grid based spatial resolution. The efficacy of the indicator was improved by designating where people actually live instead of assuming an even distribution of residents throughout the statistical sub-district. However, the study assumed the same proportion of people living in various housing types in both urban and rural areas for each indicator, which may not hold true. Therefore, further studies might take an empirical survey into account in each district, both in urban and rural areas, and for each indicator separately, to acquire statistical data to derive the proportional density fraction for each land use category (Mennis, 2003).

- The usefulness of the approaches has been evaluated with a low number of participants in a one-day workshop. Given the few number of participants and the intention to provide first insights on the application of these approaches in an environmental health related context, an exploratory analysis was adopted in this study. Other methods such as controlled, comparative experiments, with or without using the approaches, are worth being explored in further research with a larger number of participants.

- The study has shown the usefulness of the approaches with practitioners and researchers. Recent studies on collaborative planning, however, call for exploring the usefulness of such tools in involving citizens in the process. In this regard, a recent study has shown some positive findings on the usefulness of PSS tools to engage citizens (Flacke & de Boer, 2017). With recognition that health-related planning also requires involvement of residents (Rydin et al., 2012), it is interesting to explore the applicability of the approaches involving citizens with their experiences, perception and knowledge on various aspects of environmental health issues in their neighbourhood. It might address procedural injustice as one dimension of environmental justice that demands citizen involvement in the planning process (Walker, 2009).

- This study provided initial insights on the usefulness of the approaches to engage stakeholders in an environmental context thereby engender social learning and co-produce knowledge. However, these approaches have been developed and tested in the Jufo-Salus research context. PSS scholars are emphasizing the need to bridge the gap between the technology and practice so that such tools can be taken into practice (Silva et al., 2017). Similarly, studies on social learning and co-production of knowledge acknowledge the extended engagement of stakeholders spanning over a longer duration. The general assumption is that the uptake of the technology in practice as well as stimulating social learning and knowledge co-production using such technology is influenced by institutional and political contexts. In this vein, the approaches developed in this study still needs to be explored in practice in a real context. Further research could provide insights on the question whether such approaches could foster or constraint social learning and knowledge co-production during collaborative endeavours among stakeholders under various institutional, social and political contexts.

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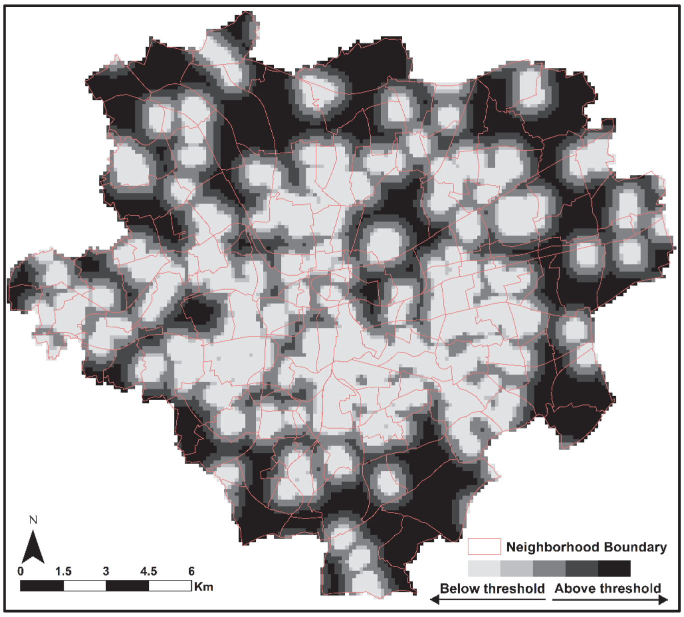
Appendix

Appendix A

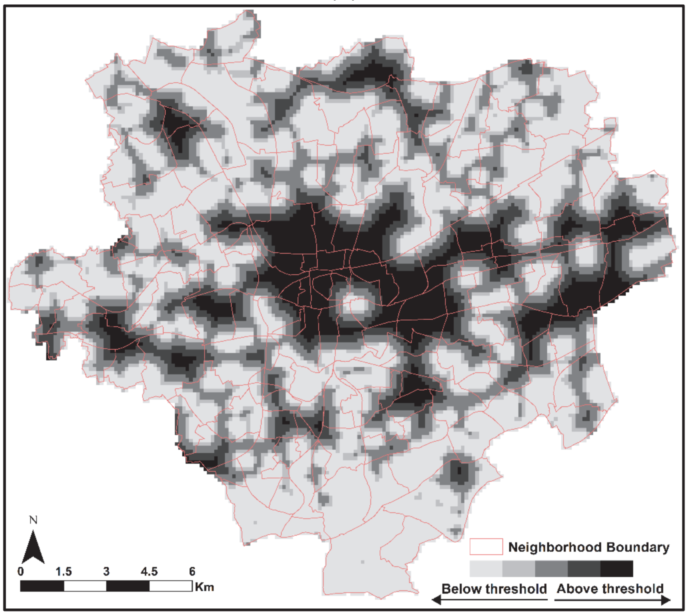
Table A 1 List of Indicator Maps with the description

Factors	Indicators Green and Water Areas	Description According to RVR Mapping
Environmental factors	Noise level from industries; Noise level from rail transport: railway, tram; Noise level from road traffic	24 h level in dB (A), 2007
	Total Particulate Matter (PM_{10}) and from street; Total Nitrogen Dioxide (NO_2) and from street	Annual average in g/m^3, 2000–2012, modeled in 2013
	Average Daily Traffic	Volume DTV in veh/24 h, 2007
Social factors	Social benefits: SGB II	Percentage of working age population (15–65 years) receiving SGB II at statistical sub-district, 2012
	Basic security in old age, disability, assistance for livelihood share: SGB XII	Percentage of basic security receiver per statistical district 2011
	Children up to 6 years; Children and adolescents (>6–14 years)	Percentage of children per statistical district, 2012
	People with migration background	Percentage of people with a migration background per statistical sub-district, 2012
Other factors	Administrative boundary	Dortmund city districts (12), statistical districts (62), statistical sub-districts (170)
	Land use plan	Existing/planned land use zoning, 2004
	Real land use: Commercial and industry use, Residential and mixed use	According to RVR mapping
	Point locations: schools, kindergartens, playgrounds, hospitals, nursing homes	According to RVR mapping, 2003–2008
	Power line distribution	In KV, 2004

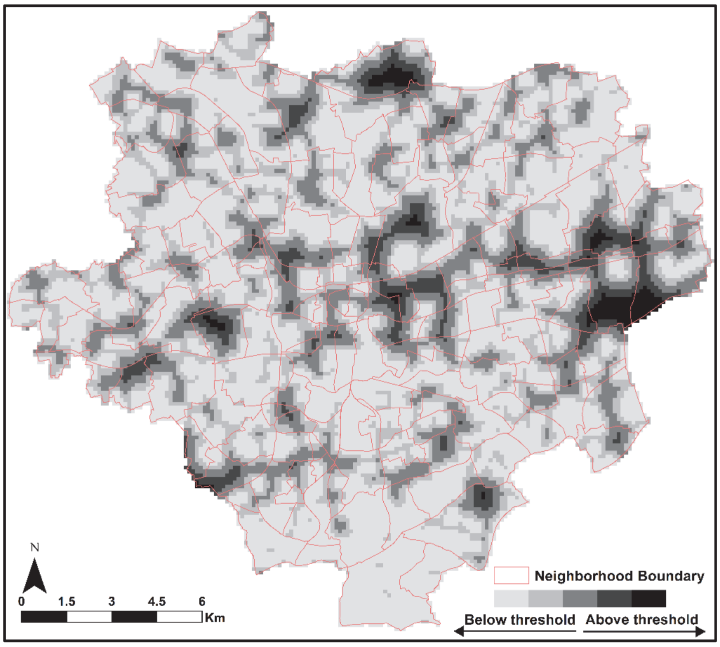
Appendix B



(a)

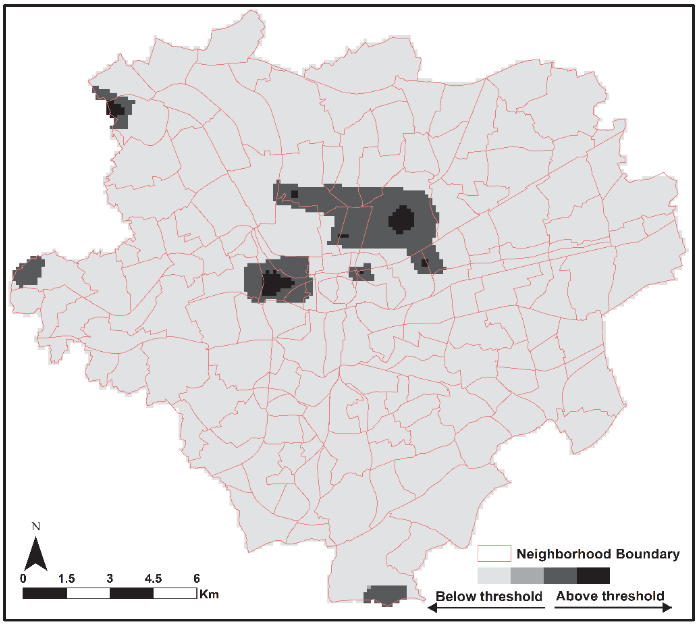


(b)

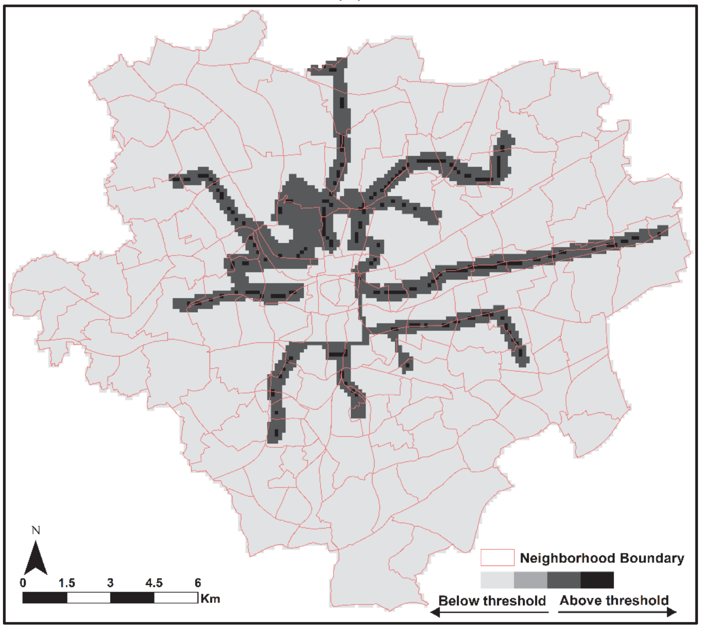


(**c**)

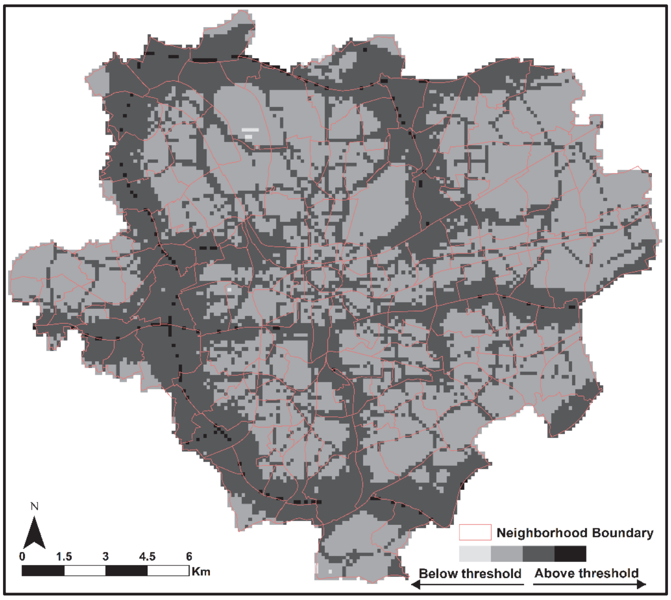
Figure S1 Spatial patterns of individual indicator on environmental benefits normalized with respect to environmental standards (legend shows deviation above and below given threshold value), (**a**) Accessibility to green areas (parks, cemeteries) (**b**) Accessibility to forests (**c**) Accessibility to green areas in general (including parks, cemeteries and forests)


N
0 1.5 3 4.5 6
Km
Neighborhood Boundary
Below threshold
Above threshold

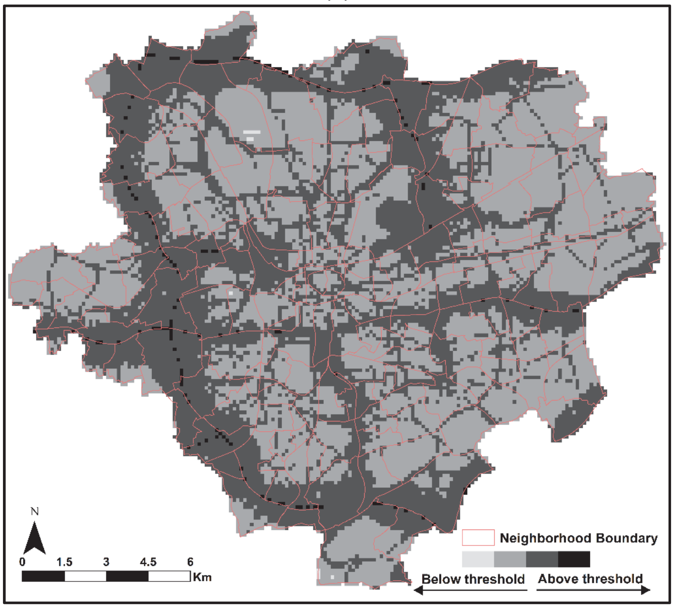
(**a**)


N
0 1.5 3 4.5 6
Km
Neighborhood Boundary
Below threshold
Above threshold

(**b**)

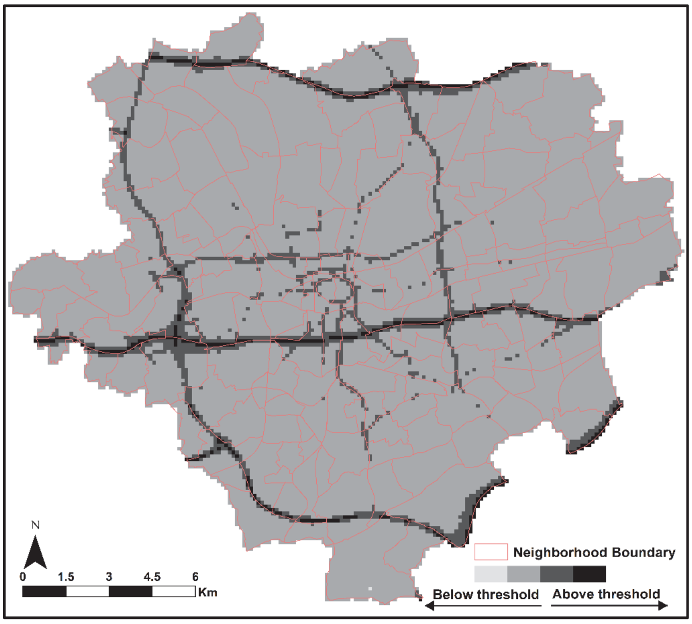


(**c**)

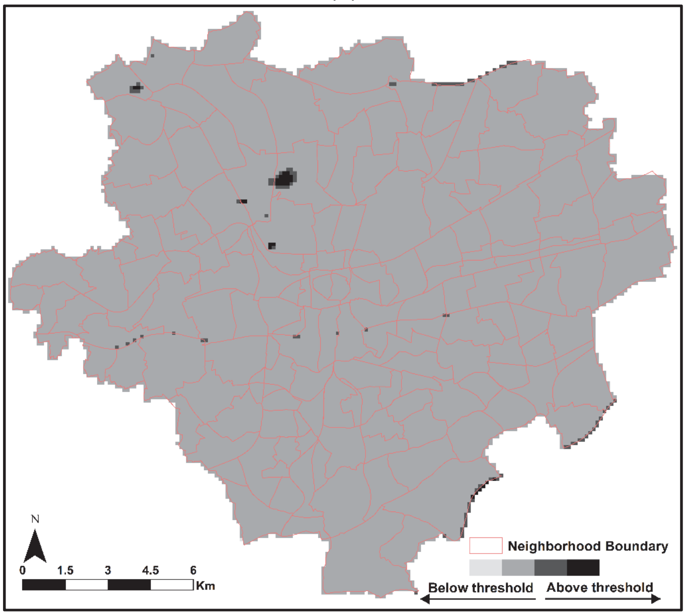


(**d**)

Figure S 2 Spatial patterns of individual indicators on noise exposure from each source normalized with respect to environmental standards (legend shows deviation above and below given threshold value), (**a**) Noise exposure from industry (**b**) Noise exposure from trams (**c**) Noise exposure from traffics on major streets and highways (**d**) Combined noise exposure including all three sources (street, tram, industry) using logarithmic addition method.



(**a**)



(**b**)

Figure S 3 Spatial patterns of individual indicators on air pollutants normalized with respect to environmental standards (legend shows deviation above and below given threshold value), (a) Annual average NO2 concentration (b) Annual average PM10 concentration

Calculating concentration index, standard error and t-test for each indicator across social vulnerability

Concentration Index

The concentration index (CI) for individual observations is computed using the following formula by Kakwani et al. (Kakwani et al., 1997)

$$\text{CI}= \frac{2}{n \times \mu} \sum_{i=1}^{n} x_i R_i - 1$$

where, n is the sample size, x_i is the indicator of environmental burden for each social unit *i,* μ is the mean of environmental burden indicator, and R_i is the fractional rank in percentage.

Standard Error

A standard error of the estimator of concentration index (CI) can be computed using a formula given in Kakwani et al. (Kakwani et al., 1997). The variance of the estimator of C is given by

$$var(\widehat{CI}) = \frac{1}{n} \left[\frac{1}{n} \sum_{i=1}^{n} a_i^2 - (1 + CI)^2 \right]$$

Where *n* is the sample size and

$$a_i = \frac{y_i}{\mu}(2R_i - 1 - CI) + 2 - q_{i-1} - q_i$$

$$q_i = \frac{1}{\mu n} \sum_{\gamma=1}^{i} y_i$$

is the ordinate of the concentration curve L(*p*), and q_0=0.
Calculating *t* for t-test

In the construction of a concentration index in this paper, the whole social units was taken into consideration, *t* could then be calculated by

$$t = \frac{CI}{\sqrt{var(\widehat{CI})}}$$

Appendix C

Table A1 List of indicator maps used during the workshops.

Dimension	Domain	Description of Indicators
Environmental burdens	Air Quality	Annual average concentration of PM_{10} (μg/m^3)
		Annual average concentration of NO_2 (μg/m^3)
		Number of days PM_{10} exceed the limit of 40 μg/m^3 (d/a)
	Noise Nuisance	Noise level from individual sources (industries, street and tram) in decibels (dBA)
		Logarithmic aggregation of noise levels (industries, street and tram) in decibels (dBA) (for Munich)
Environmental benefits	Green spaces	Accessibility to green areas >1 ha within walking distance
		Accessibility to forest areas >1 ha within walking distance
Social vulnerability	Sensitive population	Number of children aged 6–11 years (persons/625 m^2)
		Number of adults aged 65 years and over (persons/625 m^2)
	Social and economic	Number of people with migration background (persons/625 m^2)
		Number of people receiving SGB II[1] (persons/625 m^2)
		Number of people receiving SGB XII[2] (persons/625 m^2)

[1, 2] Social welfare recipients: SGB II for working age population receiving assistance, an indicator of unemployment; SGBXII to provide basic security covering old age, disability, living assistance, an indicator of those living below the poverty line.

Table A2 Environmental standards used during the workshops

Environmental Indicators	Threshold Values
Annual average PM_{10} concentration	40 μg/m^3
Annual average NO_2 concentration	40 μg/m^3
Annual average noise level	70 dBA
Distance to green spaces >1 ha	500 m

Summary

Declining health of people living in cities worldwide is raising concerns to many international organizations as well as to national and municipal governments. In particular, health inequity issues are gaining attention. Health inequities defined as differences in health outcomes among the population are found globally between countries, but also locally within cities, including cities in developed countries. At intra-city level, these inequities are attributed to complex interaction between social, economic and physical environment conditions, captured in the concept of environmental health. Environmental health issues comprise those aspects of human health that are determined or influenced by factors of the environment. These environmental factors are usually found to depict inequalities in their spatial distribution. The general question with respect to these inequalities is whether or not environmental benefits and burdens influencing the health of people are spatially equally distributed over an area or among groups of population. Furthermore, it is recognized that these environmental burdens and benefits exist simultaneously, interact and thereby influence the health of people in a complex way.

Addressing these inequities in health outcomes should be a concern of both urban planning and public health sector. Planning can affect the health and wellbeing of people through influencing the physical environment either positively or negatively. The public health sector is showing an increasing awareness of the importance of social determinants of health and can provide valuable expertise and resources for improving the health conditions of people. Therefore, collaboration, deliberation and a dialogue between urban planning and public health are needed to address these environmental health issues. Yet, scholars report on sporadic engagement at the interface between urban planning and public health. Besides institutional and legal challenges, this finding could be explained by the ‘wicked problem’ characteristics of these environmental health issues. In this vein, scholars now call for new forms of collaboration that can constructively integrate different ways of thinking of stakeholders from various sectors of society. Deliberation by stakeholders in social learning and knowledge co-production is called for so that such problems are explored from various perspectives, awareness of mutual expectations is raised, insights into the causes are gained, as well as the means required to transform. However, scholars are advocating that social learning does not emerge with every arbitrary group interaction. Learning opportunities need to be nurtured in participatory activities thereby involving different actors in knowledge co-production.

The development of Planning Support Systems (PSSs) show that these tools have the potential to support stakeholders in social learning and knowledge co-production processes. Such tools might be valuable to integrate both the spatial dimensions of environmental health issues and the knowledge, values and perspectives of stakeholders in the process. However, the usefulness of such tools have not been explored in an environmental health context. It generates the research question: How can an interactive map-based support system engage stakeholders in a social learning and knowledge co-production process in an environmental health context, taking into account spatial dimensions of environmental health at local level and cumulative effects of multiple environment burdens? To address this question the study aimed to explore the usefulness of interactive map-based support systems in this context. Four sub-objectives have been formulated for which the main findings are summarized below.

To support stakeholders in an early planning phase of developing a shared problem understanding, a methodological approach namely Interactive Spatial Understanding Support System (ISUSS) is developed in chapter 2. The approach that has been tested with a group of stakeholders in Dortmund combined two methods—interactive maps integrated on a MapTable and the construction of a 'rich picture' drawing. Findings show that the approach supported communication of explicit and tacit knowledge among participants in an interactive and dynamic manner. The MapTable appeared to be a useful medium to bring people together. By facilitating them in a structured manner the participants were engaged actively. Social learning was evidenced at different instances where participants sought to change their existing knowledge through reasoning and interaction. Construction of shared meaning were observed a few instance. The combined use of interactive maps and the 'rich picture' drawing was particularly found to be useful to support articulation, sharing and integration of both locally spatialized knowledge and non-spatial or yet to be spatialized knowledge in the discussion. As part of the approach stakeholders' knowledge and perspectives on the problem situation in Dortmund were mapped. In doing so, various underlying drivers and causes for the detected inequalities in the area were identified jointly, including both constraints and potentials. Nonetheless, certain challenges with respect to completeness and comprehensiveness of indicators and supporting larger number of participants in a single session were found while implementing the approach.

The point of departure taken in chapter 3 is that people living in urban environment are exposed to multiple environmental burdens and benefits that

are distributed disproportionately across a population with varying levels of vulnerability. Therefore, this study has developed an index-based approach to assess these multiple burdens and benefits in combination with vulnerability factors, particularly at a detailed intra-urban level. Data for environmental indicators were obtained at a fine resolution from the city administration whereas social data for vulnerability indicators were disaggregated by employing a dasymetric method. The approach was applied to the city of Dortmund to identify ‘hotspots’ of high cumulative burdens of multiple environmental factors and high social vulnerability. Results show modest inequalities burdening higher vulnerable groups in Dortmund. However, at the detailed intra-urban level, inequalities showed strong geographical patterns. Large number of ‘hotspots’ exist in the norther part of the city compared to the southern part.

Owing to the need to support stakeholders in collaborative assessment of cumulative burdens, a methodological approach namely interactive stakeholder-based cumulative burden assessment (Interactive-CuBA) is developed in chapter 4. The approach aimed at facilitating science-based stakeholder dialogues as an interface for engendering social learning and knowledge co-production among stakeholders. The index-based approach developed in chapter 3 has been adopted for this purpose. Two workshops, one in Dortmund and another in Munich, were conducted to test the approach. The approach allowed the participants to interact with each other using a flexible and auditable CuBA model implemented within a shared workspace of the MapTable and supported with facilitation. Findings showed that the participants were enabled to deliberate on cumulative burdens collaboratively, to learn about various issues with respect to cumulative burdens and thereby to co-produce knowledge on problem and opportunities for assessing cumulative burdens in the context of resource allocation. Further needs for improvement with respect to the approach were identified: e.g. explicit inclusion of qualitative information, design of the model and tools to avoid distraction, and extending the CuBA model with other indicators.

A conceptual framework for an approach of interactive map-based support system to support social learning and knowledge co-production is presented in chapter 5. The framework integrates the lessons learned from the development and testing of the two approaches—ISUSS and Interactive-CuBA—with the framework on social learning as described in chapter 1. The framework intends to serve as a conceptual basis of an approach of interactive map-based support systems for promoting social learning and knowledge co-production.

In conclusion, this study presents novel approaches of interactive map-based support systems for promoting social learning and knowledge co-production among stakeholders on environmental health issues. The approaches developed in this study provided a platform to engage various stakeholders in deliberation on environmental health issues, to include diverse knowledge and perspectives and to facilitate social learning thereby co-producing knowledge interactively. These approaches could potentially support health-related planning processes to engage stakeholders from both planning and health. The conceptual framework developed in this study provides a basis for the design of an interactive map-based support system with respect to the exploration of complex spatial problems.

Samenvatting

Een afnemende gezondheid van stedelingen wereldwijd heeft geleid tot een groeiende bezorgdheid bij tal van internationale organisaties als ook bij nationale en gemeentelijke overheden. In het bijzonder krijgt daarbij een onrechtvaardige verdeling van gezondheidsaspecten de aandacht. In dit kader wordt onrechtvaardigheid gedefinieerd als vastgestelde verschillen in gezondheidseffecten onder de bevolking, zowel op wereldschaal tussen landen als ook lokaal binnen steden, met inbegrip van steden in ontwikkelde landen. Op binnenstedelijke schaal worden deze onrechtvaardigheden toegeschreven aan complexe interacties tussen sociale, economische en fysieke condities van de omgeving, ook wel aangeduid met de term omgeving gerelateerde gezondheid. Hieronder worden verstaan die aspecten van de gezondheid van mensen die bepaald of beïnvloed worden door factoren in de directe omgeving. Deze omgevingsfactoren vertonen doorgaans ongelijkheden in ruimtelijk spreiding. De algemene vraag met betrekking tot deze ongelijkheden is, of en in welke mate milieuvoordelen en –lasten die betrekking hebben op de gezondheid van mensen ruimtelijk gelijk zijn verdeeld over een gebied of tussen bevolkingsgroepen. Daarbij wordt erkend dat deze milieuvoordelen en –lasten simultaan voorkomen, interacteren en daardoor op een complexe wijze van invloed zijn op de gezondheid van mensen.

Zowel vanuit de stedelijke planning als vanuit de gezondheidszorg wordt aandacht geschonken aan een verbetering van deze onrechtvaardigheden in gezondheidseffecten. Stedelijke planning kan de gezondheid en het welzijn van mensen beïnvloeden door aanpassingen in de fysieke omgeving. Vanuit de gezondheidszorg is er een groeiend bewustzijn voor het belang van sociale determinanten van gezondheid, en deze sector beschikt over waardevolle expertise en middelen om de gezondheidstoestand van mensen te verbeteren. Om deze reden is samenwerking, overleg en een dialoog gewenst tussen de sectoren van stedelijke planning en gezondheidszorg om deze omgeving gerelateerde gezondheidsonderwerpen aan te pakken. Desalniettemin constateren wetenschappers dat er slechts sporadisch sprake is van contacten tussen stedelijke planners en mensen in de gezondheidszorg. Behalve institutionele en legale uitdagingen wordt een verklaring hiervoor gezocht in de ‘wicked problem’ karakteristieken van deze gezondheidsonderwerpen. Wetenschappers roepen daarom op om te komen tot nieuwe vormen van samenwerking waarbij verschillende manieren van denken van belanghebbenden uit verschillende sectoren van de samenleving op constructieve wijze worden geïntegreerd. Overleg tussen belanghebbenden in sociale leerprocessen en via kennis co-creatie is nodig opdat dergelijke

problemen worden verkend vanuit verschillend perspectief, er sprake is van een groeiend bewustzijn van wederzijdse verwachtingen, inzicht wordt verkregen in oorzaken, en de middelen om hieraan iets te doen. Wetenschappers geven evenwel aan dat sociale leerprocessen niet ontstaan uit elke willekeurige groepsinteractie. Leermogelijkheden dienen te worden gekoesterd via participatieve activiteiten waarbij verschillende actoren moeten worden betrokken in kennis co-creatie.

De ontwikkeling van Planning Support Systemen (PSSs) leert dat deze hulpmiddelen in potentie belanghebbenden kunnen ondersteunen in de processen van sociaal leren en kennis co-creatie. Dergelijke tools kunnen waardevol zijn bij het integreren van de ruimtelijke dimensies van omgeving gerelateerde gezondheidsonderwerpen met de kennis, waarden en perspectieven van belanghebbenden in het proces. De bruikbaarheid van dergelijke hulpmiddelen in de context van deze gezondheidsaspecten is echter nog niet verkend. Het leidt tot de onderzoeksvraag: "Hoe kan een interactief, op kaarten gebaseerd support systeem belanghebbenden bij elkaar brengen en verbinden in een proces van sociaal leren en kennis co-creatie op het terrein van omgeving gerelateerde gezondheid, rekening houdend met de ruimtelijke dimensies van deze vorm van gezondheid op lokale schaal, als ook met de cumulatieve effecten van meervoudige milieulasten?" Aan de hand van deze vraag heeft de studie tot doel de bruikbaarheid van interactieve, op kaarten gebaseerde support systemen te onderzoeken in genoemde context. Vier subdoelstellingen zijn geformuleerd waarvoor de belangrijkste bevindingen in het vervolg zijn samengevat.

In hoofdstuk 2 is een methodologische benadering ontwikkeld, genaamd 'Interactive Spatial Understanding Support System' (ISUSS), die de belanghebbenden ondersteunt in een vroege planning fase om een gedeeld probleembegrip te creëren. De benadering, die getest is met een groep belangstellenden in Dortmund, combineerde twee methoden: interactieve kaarten geïntegreerd op een MapTable en de constructie van een 'rijke probleemschets'. De resultaten tonen aan dat de benadering de communicatie van zowel expliciete als impliciete kennis onder deelnemers bevorderde op een interactieve en dynamische wijze. De MapTable bleek een nuttig medium om mensen bij elkaar te brengen. Door hen gestructureerd te faciliteren waren de deelnemers actief betrokken. Sociale leerprocessen kwamen op verschillende momenten naar voren als de deelnemers hun bestaande kennis probeerden uit te wisselen via redeneringen en interactie. Een enkele keer werd de realisatie van een gedeelde opinie waargenomen. Het gecombineerde gebruik van interactieve kaarten en de constructie van een 'rijke probleemschets' was met name nuttig bij het ondersteunen van het articuleren, het delen en de integratie van zowel lokale, ruimtelijk gemaakte kennis als niet-ruimtelijke of nog steeds ruimtelijk te maken kennis in de discussie. Als onderdeel van de benadering werden de kennis van en de perspectieven van de belanghebbenden over de probleemsituatie in Dortmund in kaart gebracht. Langs deze weg werden verschillende onderliggende factoren en oorzaken van gedetecteerde ongelijkheden in het gebied gezamenlijk geïdentificeerd, met inbegrip van zowel beperkingen als mogelijkheden. Niettemin werden tijdens de implementatie van de benadering ook bepaalde uitdagingen vastgesteld met betrekking tot de volledigheid en veelomvattendheid van indicatoren, als ook het ondersteunen van een groot aantal deelnemers in een enkele sessie.

Het uitgangspunt in hoofdstuk 3 is dat mensen woonachtig in een stedelijke omgeving blootgesteld worden aan meervoudige milieulasten en –voordelen, die disproportioneel verdeeld zijn over een bevolking met verschillende niveaus van kwetsbaarheid. Om deze reden is in de studie een index-benadering ontwikkeld waarmee deze meervoudige lasten en voordelen kunnen worden bepaald in combinatie met factoren van kwetsbaarheid, in het bijzonder op een gedetailleerd intra-stedelijk niveau. Data over omgevingsfactoren met een fijne resolutie zijn verkregen via gemeentelijke diensten, terwijl sociale data voor kwetsbaarheid indicatoren zijn gedisaggregeerd met behulp van een dasymetric methode. De benadering is toegepast voor de stad Dortmund met het doel om 'hotspots' te identificeren van hoge cumulatieve lasten van meervoudige milieufactoren en grote sociale kwetsbaarheden. De resultaten leiden tot bescheiden ongelijkheden in de belasting van meer kwetsbare bevolkingsgroepen in Dortmund. Op gedetailleerd intra-stedelijk niveau vertonen de ongelijkheden echter sterke geografische patronen. Een groot aantal van de 'hotspots' bevindt zich in het noordelijke stadsdeel vergeleken met het zuidelijke stadsdeel.

Vanwege de behoefte belanghebbenden te ondersteunen bij de gezamenlijke beoordeling van cumulatieve lasten is in hoofdstuk 4 een methode ontwikkeld genaamd 'Interactive stakeholder-based cumulative burden assessment' (Interactive-CuBA). De methode heeft tot doel een op wetenschappelijke leest geschoeide dialoog tussen belanghebbenden te faciliteren als interface voor het tot stand brengen van sociale leerprocessen en kennis co-creatie onder belanghebbenden. onDe index-benadering uit hoofdstuk 3 is hiervoor aangepast. Om de benadering te testen zijn twee workshops gehouden, één in Dortmund en één in München. De benadering stelde de deelnemers in staat met elkaar te interacteren met een flexibel en controleerbaar CuBA-model, geïmplementeerd op een gedeelde MapTable werkomgeving en ondersteund door facilitators. De resultaten toonden aan dat de deelnemers gemeenschappelijk konden discussiëren over cumulatieve lasten, konden leren over verscheidene onderwerpen hieromtrent, en in staat waren gezamenlijk kennis te ontwikkelen over het probleem en de mogelijkheden om cumulatieve lasten te bepalen in de context van middelen toewijzing. Ook de noodzaak tot verbeteringen met betrekking tot de benadering zijn vastgesteld: bijvoorbeeld expliciete opname van kwalitatieve informatie, het ontwerp van het model en middelen om afleiding te voorkomen, en het uitbreiden van het CuBA model met andere indicatoren.

Hoofdstuk 5 bevat een conceptueel kader voor een benadering met een interactief, op kaarten gebaseerd systeem om sociale leerprocessen en kennis co-creatie te ondersteunen. In het kader zijn verwerkt de lessen die zijn geleerd in het ontwikkeltraject en het testen van de twee benaderingen – 'ISSUS' en 'Interactive-CuBA' – en het eerdere kader over sociale leerprocessen zoals beschreven in hoofdstuk 1. Het kader beoogt een conceptuele basis te leveren voor een benadering met interactieve, op kaarten gebaseerde ondersteunende systemen ten behoeve van sociale leerprocessen en kennis co-creatie.

Tenslotte presenteert deze studie nieuwe benaderingen voor interactieve, op kaarten gebaseerde support systemen voor het promoten van sociale leerprocessen en kennis co-creatie onder belanghebbenden in omgeving gerelateerde gezondheidsonderwerpen. De benaderingen ontwikkeld in deze studie verschaffen een platform om verschillende belanghebbenden te betrekken in discussies over deze gezondheidsproblematiek, om kennis en perspectieven van verschillende aard bijeen te brengen, en om sociale leerprocessen te faciliteren en daardoor interactief nieuwe kennis te creëren. De benaderingen hebben de potentie om gezondheid gerelateerde planningsproblemen te ondersteunen door planners en mensen in de gezondheidszorg met elkaar te verbinden. Het conceptuele kader ontwikkeld in deze studie kan als basis dienen voor het ontwerp van een benadering met een interactief, op kaarten gebaseerd systeem om complexe ruimtelijke problemen te verkennen.

Author's Biography

I obtained my Bachelor degree in Architecture in 2009 from Purbanachal University, Nepal. I was employed in an architectural firm for one and half years. In 2010 I received a grant from Netherlands Fellowship Program (NFP) to pursue Master of Science in Geo-information Science and Earth Observation: specialization in Urban Planning and Management in the University of Twente, Faculty of Geoinformation Science and Earth Observation (ITC). After graduating in 2012 I worked as urban planner in a private consultancy in Nepal. During one year of employment (2012 to 2013) I was involved in several government projects related to planning and urban studies with the implication of geo-information science. Since 2013 to 2018 I was associated with the research group Jufo Salus funded by Fritz and Hildergard Berg-Foundation for carrying out my PhD research in the University of Twente, Faculty of Geo-information Science and Earth Observation (ITC). My PhD research aimed at developing and implementing approaches on Interactive Map-Based Support Systems using MapTable (horizontal table with touch sensitive screen that works as a common map interface); thereby explore their usefulness for supporting professionals on social learning and knowledge co-production in the interface between urban planning and public health. The case study cities included Dortmund and Munich, in Germany. The result of this research led to publications and this thesis.

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The SENSE Research School declares that Ms Rehana Shrestha has successfully fulfilled all requirements of the Educational PhD Programme of SENSE with a work load of 36.6 EC, including the following activities:

SENSE PhD Courses

- Environmental research in context (2013)
- Research in context activity: 'Initiating and organizing Workshop for Interactive Spatial Understanding Support System for Supporting Collaboration on Healthy Urban Development (26 October 2014 in Nordstadt, Germany)'

Other PhD and Advanced MSc Courses

- Distance Course on Spatial Decision Support System, University of Twente (2013)
- Companion modelling: a participatory modelling approach, Wageningen University (2014)
- Academic writing courses, Premier Taal Training, The Netherlands (2014)
- German Planning System, TU Dortmund (2014-2015)

Management and Didactic Skills Training

- Supervising two MSc students with thesis entitled 'Design of spatial decision support tool for understanding cumulative environmental exposure' (2014) and 'Mapping health opportunities' (2016)
- Organized half day stakeholder workshops on ISUSS (2014) and on Cumulative burden assessment (2015)
- Co-organized half day workshop entitled 'Innovative methods and tools for Healthy City Planning' within the conference: 'Stadt der Zukunft: Nachhaltigkeit und Gesundheit gemeinsam fördern – Neue methodische Ansätze' (2016)
- Supported in 4 Collage Twente Energy Workshops (2017)

Selection of Oral Presentations

- Suss Revisited: An Interactive Spatial Understanding Support System (ISUSS) for Collaborative Spatial Problem-Structuring . From Control to co-evolution AESOP, 09-12 July 2014, Utrecht, The Netherlands
- Interactive Spatial Decisions Support System for Supporting Collaborative Planning: A Concept for Spatial Understanding Support System. Konferenz Stadtwandel als Chance, 28 November 2013 Wüppertal, Germany
- Interactive Spatial Decision Support System for Supporting Collaboration between Spatial Planning and Public Health. Environmental Justice Workshop, 18 September 2014, Dortmund, Germany

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