COLLABORATION TOOLS FOR LAND USE POLICY DEVELOPMENT

Peter Verweij

PROPOSITIONS

1. Useful land use tools are best developed in collaboration with end users. (this thesis)
2. Building a shared understanding of land use is more important than increasing land use model complexity. (this thesis)
3. A scientist's retirement is the strongest incentive for making research data freely available.
4. A dialogue must replace the practice of question and answer during a PhD defence.
5. Sustainability can only be achieved if we as individuals experience the environmental and social damage we do.
6. By banning wood burning, you deprive man of the joy of lumbering.

Propositions belonging to the thesis entitled

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Peter Verweij

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Collaboration tools for land use policy development

Peter Verweij

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“A SHARED REALITY

IS CONDITIONAL

FOR EVERY FORM

OF COMMUNALITY”

Neiman, S., 2017,
Resistance and reason in post-truth times

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It is more or less three years ago that I decided to start my PhD. It all started during a chat at the coffee machine with my colleague Gert-Jan Nabuurs. We were discussing a method to map European forest management strategies and the potential to publish a scientific article on it. Gert-Jan asked me why I'd never done a PhD, since I had been (co-)authoring papers. Wouldn't it be interesting to build on the work I'd already done, take it further, and synthesize on the outcomes? Thank you for triggering the start of my PhD, and also for leading the European forest management mapping method into a Nature sustainability article.

Soon after my talk with Gert-Jan I brought up the idea to do a PhD with my team lead Sander Janssen. Sander responded enthusiastically and we further explored possibilities. The chair group of Geo-Information science, with professor Arnold Bregt, seemed the most appropriate location for me. The rest is history.

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SUMMARY

The scientific community develops data-driven tools to support land use policy development. These tools capture facts and knowledge in various forms, such as: land cover maps, trend graphs of agricultural yields and, more complex, scenario based impact assessment models. Tools vary in different ways; in their purpose, their targeted form of use and technically. Purposes include: obtaining system understanding, doing future projections, social learning, and communicating synthesized findings. Forms of use are for example a desk study or interactively in a stakeholder workshop. Despite the demand for tools and their large supply, literature indicates that uptake of available tools for policy making, is low.

Data-driven tools for land use policy are complex. Their complexity lies in i) the multiple scientific disciplines that interact through land use and ii) the contextual political process that involves balancing different needs and wants from a variety of stakeholders. Addressing these complexities requires dialogue and collaboration between those involved. Tools that facilitate and advance this process of dialogue and collaboration are therefore particularly helpful. Consequently, a tool is defined here as a data- and software based object that informs and facilitates dialogue, both through its joint development and its associated application process.

This thesis makes a scientific contribution to the field of dialogue and collective thinking for tools for land use policy development, by integrating methods from software engineering with participatory approaches and workshop design. In particular it investigates how collaboration methods and practices can help overcome issues hampering the use of data-driven tools with the overall objective to support the formulation of supported and feasible land use policies. The latter is where this thesis' societal contribution lies.

The overall objective of this thesis is: **to provide collaboration practices for scientists, stakeholders and policymakers for developing and utilising data-driven tools to support land use policy development.** The objective is further specified in four research questions: How can different scientific communities, tool developers and users work together to develop an integrated land use policy assessment tool? How can the applicability and transparency of a land use policy assessment tool be enhanced to better understand drivers and impacts of land use change? How can a land use policy tool include stakeholder knowledge and facilitate to rapidly reach a common understanding between different views on land use? How can tool development enhance and facilitate collaboration with the overall objective to influence land use policy?

Chapter 1 introduces this thesis by looking into context in which the tools are to operate: (a) the different conceptualisations of land (land cover, land use and landscape) and how perspectives on land management are tied to land ethics of individuals. This is followed by (b) a brief explanation of the land use policy making process, the actors involved and the role that data-based scientific tools play in it. Tools that support collaboration are of particular interest, as they improve the chance for finding an acceptable solution for those involved. Collaboration is defined as the process that involves continuous interaction between all team members. During these interactions knowledge is produced and internalized; relationships are developed; and the understanding of a problem, and its solution, is jointly shaped and reshaped. Despite the large number of available tools, only a few are used due to a mismatch with what is demanded. Causes listed include: the tool is too complex; applicability is too slow to answer to the urgency of decision making, too technocratic/missing human dimension, and missing political support.

Chapter 2 investigates how land use tool developers can use methods and practices from software engineering to help close the demand-supply mismatch. Software engineering is a discipline that studies how people work together to build a useful computer system, how a (real-world) system should be broken down in meaningful abstractions, and technology. This chapter uses a case to illustrate how the User Centered Design and agile methodologies from software engineering were used in the field of environmental modelling to develop an integrated assessment tool. The development involved researchers from different land use related disciplines, the donor, designers and policy advisors as proxies for end-users. This chapter describes i) the use of collaborative screen sketching sessions to create a joint vision on the end product, ii) the development of a conceptual model to develop a shared vocabulary and system understanding, iii) the use of short time-boxed design-implement-feedback iterations to have a growing solution from the onset of a project. These iterations made it also possible to adjust development direction based on evolving understanding.

Chapter 3 studies how the transparency and applicability of a land use change model can be enhanced by inventorying current bottlenecks of an existing model, visioning the ideal solution and reimplementing and testing it in several case studies. In this process experienced and inexperienced modelers worked together to identify learning curves and persistent difficulties. These difficulties discourage the use of the tool in an improving iterative fashion, and included: i) the lack of self-explanatory results in relation to the underlying land use change processes and ii) the large amount of time consuming and error prone manual operations between the sub-tools that made up the model. During workshops, visual diagrams were drawn to clarify the overall model concept and the internal flow of reasoning. Application screens were sketched on whiteboard to create a joint vision on how to interact with the model and to design interactive analysis tools to empower users to analyse and interpret results. The resulting reimplementation of the model has been tested in four cases that vary in size and detail from north eastern Spain to Portugal, Bangladesh and Latin America.

Chapter 4 introduces a method to include stakeholder knowledge in a spatially explicit tool during moderated group sessions. During these sessions stakeholders tell stories supported by data, policy problems are scoped, the most important interactions investigated and the state of relevant knowledge and data is assessed. Knowledge and preferences of workshop participants are captured in a computer program and linked to available spatial- and spatio-statistical data. During such workshops an iterative approach is followed, starting with simple (knowledge-based) rules and step-by-step adding complexity, using the participants' interpretation of model-results. In these multi-stakeholder processes, science is not merely a messenger of data and knowledge products through reports and briefings, but enables participants to internalize scientific knowledge, and integrate it together with local and tacit knowledge.

Chapter 5 describes the co-design of a web-based information platform. In their search for an evidence base to inform policy making, the Dutch government initiated a collaboration with stakeholders (NGO's, researchers, local government) to jointly vision and develop that information platform. These stakeholders operate within an environment that experiences data loss as result of a high turnover in project funds and personnel. In early iterations with data providers and information users, ideas on the way of working together and the technical solution converged. Technology push had to be downscaled while concise and visual messages had to be developed. The iterative process built trust and willingness to collaborate amongst the involved. Three principles made the platform's uptake and growth possible: It is funded, promoted and used by national and regional policy makers; it simplifies tasks of rapporteurs, data providers and local management; and it is continuously being adapted to changing needs and insights.

The final **chapter 6** synthesizes the methodological findings and recommends practices to address the barriers for tool uptake from chapter 1. These are followed up by three overall reflections.

Firstly, on the advantages and limitations of the use of data. While data are a crucial asset to find time, place and event relationships that are hard to see otherwise, limiting the view of the world to 'data-only' causes to miss out on relevant other aspects. Especially aspects that are intrinsically about values (e.g. landscape beauty), or aspects that are complex and multi-interpretable (e.g. habitat health or social cohesion) fall in this last group.

Secondly, I reflect on collaboration as a means to converge perceptions towards supported solutions. Collaboration aids to: a) reach a common understanding by getting to know each other's thinking, identifying similarities and differences, and what these mean for each other; b) facilitate the development of a shared vision under a feeling of shared ownership and c) reflect on one's own thinking and recognising assumptions and values in it. While in general I argue that collaboration is worthy of pursuit, it sometimes is a burden, and it is not always successful.

And thirdly, I reflect on choosing the right tool. Tools are helpful for making informed decisions by separating factual knowledge from biases and beliefs. In their simplified representations of reality, tools have limitations that are not always explicit. Moreover, the choice for what simplification to use is driven by the background and interest of the researchers and donors. As land use, and land use policy development, is inherently complex, a single tool cannot capture all associated aspects on its own. Methods that facilitate to see the big picture by encouraging systemic thinking and recognising the role of actors and contexts, are needed to bring together disconnected worlds in people's minds.

Finally, issues requiring further research are listed in the form of questions: 1) how can psychological and educational insights be used to enhance the inter- and transdisciplinary learning with tools in group sessions? 2) how can collaboration tools be used to reduce the disconnect between evidence informed policy making and plan realisation? 3) how can (big) data and (cluster) computing transparently be used in interactive working sessions with stakeholders?

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Chapter 1

INTRODUCTION

As a teenager I visited the hilly landscape in the south of the Netherlands for the first time. I saw patches of grasslands bordered by hedges in the valleys, forest covered hilltops, small villages and scattered farmhouses along meandering streams. Like numerous other tourists I hiked the scenic area, crossing farmers' fields by the right of way and enjoyed refreshments at one of the many picturesque half-timbered cafes and restaurants. Looking back I wonder, would the farmers be just as happy with us crossing their land, or would they rather scale-up and increase productivity and revenue? Why weren't they enhancing their business operations like most of the farmers in the Netherlands had to do, to make a living? Were they too much embedded in the cultural heritage of the land, or were they facing legal restrictions on how to manage the land that kept them from changing their practices? And if there was such legislation, where and how was it made? Who had a say in their development, were all voices heard equally and on what basis had decisions been made?

The above is just an example from the Netherlands. Everywhere people have different values and preferences on how land should be used and managed. Measures on a single piece of land often impact neighbouring areas. Impacts that may be unwanted, unforeseen, or simply ignored. For example, clear-cutting forests on a hilltop may cause flooding and siltation downhill, the use of fertilizer or pesticides to increase crop yields may affect water quality and plant and animal life downstream, or a newly built road to improve accessibility may result in a noisy and dangerous barrier in a local community. Different expectations, demands and viewpoints are often cause for conflict, while actually people's interdependency calls for collaboration. Taking distance from polarized disputes, offering factual knowledge and helping people to –more intersubjectively-share their perspectives, facilitates mutual understanding and creates more space for negotiation which is a prerequisite for finding a common action perspective and to align practices that last (Galinsky & Moskowitz, 2000; Pettigrew & Tropp, 2006; Todd and Galinksy, 2014). In the above example from the south of the Netherlands, several of such action perspectives are found, for example: farmers are paid by the tourism sector for the preservation of attractive hedges that also separate footpaths from their field, or farmers start a farm campsite to have direct benefits from the tourists crossing their lands.

Data-driven spatial planning and decision-support tools are a means to facilitate this process of objectification, communication and mutual learning, and make it possible to try out alternative solutions before venturing in an actual implementation, i.e. test the likely ecological and societal effects of land-based measures and policies. Such tools can also record views, opinions and experiments in thinking and thereby document discussions, are measures of progress and can be used as foundations to inform a follow up in the decision-making process on the use of the land. Despite these obvious advantages, and the wide range of tools developed by scientists for this purpose, many tools are not used.

In the following four sections, this chapter examines why tools are not used. First the context in which these tools are to operate are described: (a) the different ways on how the land can be conceptualized and how people relate to it and; (b) the different aspects of policy making and its influence on shaping the land. Second, an outline is given on the broadness of available tools and how they are intended to support policy making. And third, the issues hampering the use of tools for policy making are listed.

1.1 LAND USE

The world's landmasses are diverse, with mountains, deserts, forests and metropolitan and industrial landscapes. Natural processes and humans change the land by season and even transform the structure of the land for the longer term. Examples of seasonal change include: the harvesting of agricultural crops leaving a bare soil, grasslands disappearing under a thick layer of snow during winter, or a desert bursting into life after heavy rains. Structural changes take place when land is cleared for agriculture, land is transformed for urban expansion, floods wash away existing land cover, or when natural ecological succession occurs. All these changes affect the functioning of the land and all that depends on it (MA, 2003; de Groot et al., 2010).

Landscapes may appear as a vast homogeneous surface or as a patchwork of different covers and uses. Where '*land cover*' gives a notion of what is actually physically present on the land (e.g. trees, grass, buildings), '*land use*' expresses how people utilize the land, possibly for multiple functions simultaneously, e.g. forestry and recreation, or agriculture and biodiversity (Huang et al., 2015). Typically '*land use*' is related to and delineated by ownership, such as farms, or national parks. '*Landscape*' supersedes the notions of '*land cover*' and '*land use*' and includes elements of the physical system and the cultural elements and management. Humans perceive, value and use landscapes differently, based on their aesthetical well-feeling, cultural relations to areas, personal preference and life style goals (Antrop, 2000; Karmanov, 2009; Greiner et al., 2009; Simensen et al, 2018).

Different perspectives on how land should be managed are strongly tied to how we as individuals regard, value and use the land. Where some libertarians advocate that a landowner can use his land and produce the maximum of goods and services for whatever purpose, others call for a minimum social foundation and restrict the production to an ecological ceiling (Raworth, 2017). Creutzig (2017) promotes an egalitarian ethic and calls for "*international coordination of land use, governing land as global commons to ensure everyone's adequate standard of living and to provide access to food, clothing, housing and medicine*" (see also Dietz et al., 2003; Ostrom, 1990). Leopold (1949) and Millstein (2018) suggest an ecological ethic in which the fates of humans, other species and the ecosystem are interdependent and inseparable. Advocates of either ethic may exert political pressure and influence policy making to shape society in accordance with their values and preferences (Xu, 2019).

1.2 POLICY AND LAND MANAGEMENT

Through policies and spatial planning the use of land is regulated in an effort to direct towards more desirable, and away from undesirable, social, economic and environmental outcomes (Young, 2013). Land use planning, as part of spatial planning[1], and regulation restrict how land can be used while (monetary) policies may provide incentives to guide land use by encouraging or discouraging (economic) activities (OECD[a], 2017). Goals of land-use planning and land use policies include: identifying locations for productive (e.g. agriculture) and extractive (e.g. mining, or forestry) activities, locating recreational and environmental and resource conservation areas, pointing out areas exposed to natural hazards (e.g. flooding, droughts, or earthquakes), assignment of management for restoration, or prevention of land-use conflicts and pollution constraints.

The development of public policies by governments is a social process involving the interplay of competing and collaborating parties including: different ministries and other governmental organisations, business, interest groups, nongovernmental organisations and individuals. These parties seek to influence the policy making process through lobbying, public advocating for their position and education of supporters and opponents. The result is often a compromise formulated under influence of political ideology, intuition, tradition, public opinion, economic conditions and technological

[1] Spatial planning is an all-purpose concept and includes master planning (describe long term goals and strategies consisting of comprehensive sets of measures, to get there.), regional planning (e.g. appointing urban zones, industrial zones and rural zones), urban planning (e.g. neighbourhoods possibly accompanied by architectural demands, roads, canals), project planning (e.g. bridge over a river, parking lot for a shopping centre), land use planning, etc. (Couclelis, 2005; Baptist et al., 2019). Where spatial plans on a regional level are rather sketchy and lay out a contextual design, with envisioned design principles to be detailed during project implementation, land use plans prescribe specific land use at specific locations on the basis of socio-economic, physical and ecological suitability (Hersperger et al, 2018; OECD[b], 2017; Theuns et al., 2016).

developments (Saylor academy, 2012; Kooiman, 2003). The influential power of each of the parties is affected by the regime type (e.g. democracy or oligarchy) and style of governance, such as hierarchical regulation or voluntary and participatory approaches (Pahl-Wostl, 2019).

While policies try to steer land use from above, the realisation on the ground can turn out quite different. Land managers and -owners may choose different from the policy objective due to local- and personal circumstances, such as: bio-physical restrictions and opportunities, access to financial capital, the market, personal preferences and relationships, and pressure and pull factors from social arenas (Borras et al., 2018 in Xu, 2019; Hersperger et al., 2018; Renn, 1993). Mismatches between government expectations and the actual on the ground effect, could be reduced if policy developers were better informed with evidence (Howlett, 2009; Gluckman et al., 2021) on the current conditions under which the land managers and -owners have to work, and on the likely effects of potential policies.

Scientific evidence, i.e. tested information based on data measured in the field, or generated via modelling (e.g. interpolation or extrapolation), can significantly contribute to policy effectiveness as it downsizes the role of intuition and ideology and tells us 'what most likely works' to achieve goals or what should not be done to avoid harm (Becker et al., 2019; Timmerman & Langaas, 2005; Sutherland et al., 2004). Unlike in engineering, policy making does not strictly use scientific knowledge and evidence to make decisions, but uses fact selection, interpretation and trade-off analysis between multiple competing social values and preferences (Parkhurst, 2017; Head, 2016; Aarts, 2015). Preferably, facts are not used to close a discussion, but form a starting point for a dialogue. A dialogue is about collective thinking and inquiry. A dialogue recognizes different truths to work together towards viable solutions (Aarts, 2015).

1.3 COLLABORATION TOOLS

The interactions between social, economic, technological- and ecological processes, policy development and institutions are complex. Data-driven tools that integrate facts and knowledge on these interactions help to understand the current situation, how it was formed, and assess the likely effects of potential future policies. These tools enable to explore beforehand and understand feedback, side effects, the spatial variation of impacts, trade-offs between objectives of different stakeholders and are therefore essential to effective policy making (Kelly et al., 2013).

There are hundreds of tools to capture facts and knowledge on land use and policy. These tools range from relatively simple to highly complex. Their perceived difficulty or complexity, is the product of the data-requirements of the tool, the users' experience with the tool and knowledge of the domain, the use-context and time and resource requirements (Harrison et al., 2017). Table 1-1 illustrates this great variety in tools on the basis of several studies on tool inventories and characterisations. Some of the characterisations focus on technical aspects (e.g. the application domain, data requirements, or modelling method). Other characterisations are based on the organisational conditions (e.g. capacity needs, throughput time, stakeholder inclusion), or on the purpose for which they are used (e.g. system understanding, exploration of effects of management options).

Tool characteristics that support collaboration are of particular relevance in this thesis, as they improve the chance for finding an acceptable solution for those involved, under the condition that everyone's values and perspectives are considered in the negotiation process (Pouwels, 2019; Barnaud et al, 2013; Cash et al, 2003). These characteristics facilitate the individuals, groups, or organisations with divergent interest(s) in land use development, to jointly engage in problem solving, and include: fact finding (Karl et al., 2007), storytelling (a technique to organize and communicate thinking and emotions (Bassano et al., 2019)), developing system understanding and social learning, i.e. learning via an interactive process of observation and imitation, that leads to a convergent change in the stakeholders' perspectives (van der Wal et al., 2016).

Collaboration is an intensive modus of information sharing, knowledge production and involves the development of relationships that may lead to behavioural change (Fisher, C., 2010; Michaels, S., 2009). Collaboration is often confused with cooperation. In both concepts people work together to reach a mutual objective. However, where cooperation is about dividing tasks to responsible individuals to reach a predefined result, collaboration involves continuous interaction between all team members. During these interactions the understanding of a problem and its solution, is jointly shaped and reshaped.

Not only can collaboration be enhanced through the *use of tools*, collaboration may also be improved through joint *tool development*. During the tool development process practitioners, policy and decision makers, scientists and tool developers carry out complex technical tasks while at the same time undertaking social relational activities (Kelly et al., 2013; Maurel et al., 2007) in order to integrate knowledge and enhance understanding that potentially result in behavioural change, personal growth and contribute to removing the challenge of dealing with conflicting expectations, demands and viewpoints (Rodela et al., 2017).

Table 1-1 common tool inventory studies. Each listed study is described in short together with the tool characterisation as given by the authors and the number of tools within the study. The focus of the characterisation is indicated in the last column.

AUTHORS	SHORT DESCRIPTION
Gasparatos and Scolobig (2012)	provide an overview of sustainability assessment tools
Gret-Regamy et al. (2017)	review of decision support tools for ecosystem service
Harrison et al. (2017)	offer decision trees for selecting ecosystem, service assessment methods
Voinov et al. (2018)	provide guidance to practitioners for selecting participatory modelling tools
Kelly et al. (2013)	reviews approaches that have the capacity to integrate knowledge in models for understanding trade-offs to advise policy-making
Gupta et al. (2012) and Argent et al.(2016)	Provide principles of conceptual modelling to enable mathematical and computational developments on the basis of the conceptual model
McIntosh et al. (2011) and Power et al. (2015)	describe Decision Support Systems to inform environmental policy and management organisations and enhance a person or group's ability to make decisions
McInerny et al. (2014) and Pelzer et al. (2015) in Rodela et al. (2017)	explain the qualities of spatial decision support systems and how they bring together scientific knowledge from different disciplines and support the emergence, and integration of tacit, local and traditional knowledge in decision-making
Perez-Soba et al. (2018),	Offer guidance tools for land and water based ecosystem services
Edmonds et al. (2019)	Looks at the need for re-justification of a model when it is used for another purpose than for which it was built
Ness et al. (2007)	Provides a categorisation of sustainability assessment tools to widen its interpretation from environment alone
Van Schrojenstein Lantman et al., (2011)	Describes core principles and concepts in land-use modelling

NUMBER OF TOOLS OR TOOL TYPES DESCRIBED	CHARACTERISATIONS OF TOOLS AS USED BY AUTHORS	FOCUS OF THE CHARACTERISATION
17 tools	monetary, biophysical and indicator-based	Technical
68 tools	differentiation based on spatial scales, data type requirements and policy application	Technical
36 tools	Biophysical, socio-cultural, monetary, integrative	Technical and organisational
23 tool types (e.g. role playing games, or integrated modelling).	Fact finding, process orchestration, qualitative modelling and (semi-) quantitative modelling	Technical and organisational
64 tools	Prediction, forecasting, management and decision-making under uncertainty, social learning, developing system understanding	Purpose
8 tool types (Cognitive mapping, participatory modelling, integrated modelling, quantitative and qualitative scenario analysis, system dynamics, mathematical models)	Conceptual models, mathematical models, computational models	Technical
19 tools	Structure of the decision context (agreeability and arguability of the decision formulation and solution) and the decision phase (intelligence, design and choice)	Technical and organisational
36 tools	Spatial vs more abstract non-spatial visualisations, level of knowledge integration (different scientific disciplines, tacit, local and traditional knowledge), scale, level of integration with user demands and learning ability	Technical and organisational
4 guidance tools to hundreds of tools	Stakeholder identification, problem structuring, indicator identification, biophysical assessments, socio-cultural and monetary assessments	Technical
7 tool types	Purpose of modelling: Prediction, explanation, description, theoretical exploration, illustration, analogy and social learning	Purpose
32 tool types (incl. ecological food print, well-being, cost-benefit, life cycle assessment)	Indicators/indices, product related assessments and integrated (nature-society) assessment tools	Technical
8 specific tools and 9 tools types	Continuation of historical development, suitability of land (in monetary or other units), result of neighbourhood interactions, result of actor interaction	Technical

In literature the term tool often remains ambiguous, but several definitions exist. Voinov et al. (2018) and Maurel et al.(2007) differentiate between 'methods' (as a structured set of processes and activities), 'tools' (artefacts, software, that do not change during their use) and 'applications' (outcomes of a tool often related to a specific policy and region, e.g. in the form of maps, charts and tables). Ness et al. (2007) refer to indicators as a tool for quantitatively measuring an economic, social or environmental state and Perez-Soba et al. (2018) describe structured processes, computer-based models and maps depicting the spatial distribution of phenomena as tools for decision making.

This thesis closely follows Voinov et al.(2018) and defines a tool as a data- and software based object that informs and facilitates dialogue, both through its joint development and its associated application process.

1.4 ISSUES HAMPERING THE USE OF TOOLS

There has been a considerable growth in the demand and supply of computer-based tools to support spatial planning and decision making, to better understand the complex socio-ecological interactions and to balance between multiple, and often competing, objectives (McIntosh et al., 2011; Rodela et al., 2015). These tools have been successful in informing and facilitating the dialogue between stakeholders and have helped to find viable solutions. Common examples include the climate projection-based implementation of coastal development set-back zones by cities, to protect against the increased risk of sea level rise and flooding (Aguiar et al., 2018); avoiding harm to protected species during dyke- and floodplain- -maintenance and -development activities by Dutch water authorities by consulting a community-based species' observations database (Ticheler, 2020); the embrace of hydrological and fire risk models by South African nature park managers and brewery companies resulting in the joint investment in wildfire and drought risk reducing measures, by clearing non-native invasive tree species from catchments supplying water to hop farms (Reyers et al., 2015; Nel et al., 2014).

Although there are successes and despite the research and development effort, tool uptake is low due to a variety of reasons (Geertman, 2006; McIntosh et al. 2011; Argent et al., 2016; Zasada et al., 2017; Gibson et al., 2017). These reasons can be categorized in the following main groups:

- *Tool capabilities do not align with the users' demand.* Often caused by too little or unclear communication between tool developer and tool user and the interpretations that are made by both parties. Adding more people between developer and user adds to the number of interpretations. It also happens that scientists push their scientific interest and position it prominently in a tool which does not necessarily help users.

- *The tool is too complex in terms of ease of use.* Ideally a tool is intuitive and self-explanatory in its use and builds on prior knowledge of topics, possibly supported by minor explanations of a tool expert or a manual. Literature as a resource for understanding and working with a tool is seldom helpful for users with a practical instead of a scientific interest.
- *Lack of transparency.* Users need to understand the reasoning and causalities and sometimes even the internal mechanics, to be able to relate to it and to address the mistrust that might occur.
- *The applicability of the tool is too time consuming*, as a result of necessary model parameterisation, calibration and validation, or model calculation time. Lead time is especially important when tools are used in explorative participatory modelling workshops (Voinov et al., 2018) in which the impact of emerging plans or measures are sought.
- *Tool adaptation is too slow to answer to the urgency of decision-making.* Rapidly evolving contexts demand tool flexibility (Pope et al., 2013). Although most tools have some flexibility, it is not necessarily the flexibility needed, e.g. land use change models were unable to cope with policies for biofuel-crops when these were first proposed (Banse et al., 2011) and took months to adapt. The more complex and data-intensive tools take more resources and more lead time to adapt. This is especially true when tools consist of model frameworks in which the complex interplay of the separate models (Janssen et al., 2011) may need adaptation and involves multiple experts from different domains.
- *Too technocratic, missing human dimension.* Tacit knowledge and preferences arising from qualitative and creative social processes are preferred to rational and predictive modelling approaches (de Wit et al., 2009; Addison et al., 2013; van Oosten et al, 2018)
- *No access to data.* There is a reluctance to share data because of legal restrictions, fear of missing out on opportunities, or fear of reputation loss as result of inadequate quality assurance or drawing erroneous conclusions (Verweij et al., 2019; UNEP, 2012). A champion advocating the tool or a prior relationship between the tool developers, data providers and users, can help to achieve the trust needed for data sharing.
- *Missing political support.* Public opinion, and thereby perceptions, on a collective problem influence the shaping and reinforcement of policies and vice versa (Soroka and Wlezien, 2012). The processes of interaction and decision-making among the actors, and the arena's in which they take place, lead to the creation and reproduction of social norms (Hufty, 2011). These social norms further influence political support for the use of evidence captured in- and made accessible through tools.

Given these issues, the overall objective of this thesis is: **to provide collaboration practices for scientists, stakeholders and policymakers for developing and utilising data-driven tools to support land use policy development.**

1.5 OBJECTIVES OF THIS THESIS

The objective of this study is further specified in four research questions that each deal with one aspect of collaboration tools for land use policy development:

1. How can different scientific communities, tool developers and users work together to develop an integrated land use policy assessment tool?
2. How can the applicability and transparency of a land use policy assessment tool be enhanced to better understand drivers and impacts of land use change?
3. How can a land use policy tool include stakeholder knowledge and facilitate to rapidly reach a common understanding between different views on land use?
4. How can tool development enhance and facilitate collaboration with the overall objective to influence land use policy?

Answers to these research questions will provide collaboration practices for developing and utilising data-based tools to support land use policy development.

1.6 THIS THESIS

This thesis makes a scientific contribution to the field of dialogue and collective thinking for tools for land use policy development. In particular it investigates how collaboration methods and practices can help overcome issues hampering the use of data-driven tools with the overall objective to support the formulation of supported and feasible land use policies. The latter is where this thesis' societal contribution lies.

In this introduction, chapter 1, the overall objective and context of this thesis is described. The remainder of this thesis is organised as listed below. Chapter 2 to 5 have already been published and describe four methodologies and associated case studies, that together answer the separate research questions.

Chapter 2 investigates software engineering practices to enable land use modellers to include advancing system understanding and user requirements within and during their tool development.

Chapter 3 describes how a black-box land use tool was redeveloped with its current and foreseen users, to enable experimenting by speeding up the modelling process, and through (intermediate) result visualisations.

Chapter 4 presents a participatory land use modelling tool that uses a combination of human and computational analysis to exchange scientific and tacit knowledge, values and preferences during the exploratory phase of decision making.

Chapter 5 elaborates on the role of continuous reflection on ways of working together to maintain reciprocity and trust, to inform the development of policies through the co-design of a web-platform

Chapter 6 synthesizes the work carried out in this study and positions the results in the broader context of collaborative tools for spatial policies. Based on these reflections directions for future research are suggested.

Chapter 2

AN IT PERSPECTIVE ON INTEGRATED ENVIRONMENTAL MODELLING: THE SIAT CASE

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ABSTRACT

Policy makers have a growing interest in integrated assessments of policies. The Integrated Assessment Modelling (IAM) community is reacting to this interest by extending the application of model development from pure scientific analysis towards application in decision making or policy context by giving tools a higher capability for analysis targeted at non-experts, but intelligent users. Many parties are involved in the construction of such tools including modellers, domain experts and tool users, resulting in as many views on the proposed tool. During tool development research continues which leads to advanced understanding of the system and may alter early specifications. Accumulation of changes to the initial design obscures the design, usually vastly increasing the number of defects in the software. The software engineering community uses concepts, methods and practices to deal with ambiguous specifications, changing requirements and incompletely conceived visions, and to design and develop maintainable/extensible quality software. The aim of this paper is to introduce modellers to software engineering concepts and methods which have the potential to improve model and tool development using experiences from the development of the Sustainability Impact Assessment Tool. These range from choosing a software development methodology for planning activities and coordinating people, technical design principles impacting maintainability, quality and reusability of the software to prototyping and user involvement. It is argued that adaptive development methods seem to best fit research projects, that typically have unclear upfront and changing requirements. The break-down of a system into elements that overlap as little as possible in features and behaviour helps to divide the work across teams and to achieve a modular and flexible system. However, this must be accompanied by proper automated testing methods and automated continuous integration of the elements. Prototypes, screen sketches and mock-ups are useful to align the different views, build a shared vision of required functionality and to match expectations.

2.1 INTRODUCTION

The last three decades the environmental modelling community has developed numerous models (Reynolds and Acock, 1997, Papajorgji et al., 2004). These modelling efforts have evolved from single disciplinary to interdisciplinary models “to allow for a better understanding of complex phenomena enabling the evaluation of the whole cause effect chain from a synoptic perspective by combining, interpreting and communicating knowledge from diverse scientific disciplines” (Rotmans and Dowlatabadi, 1998). Integrated Assessment Modelling (IAM) simulates both the natural and socio-economic systems in applications like scenario analysis and evaluation of the environmental, economic and social consequences of different policy strategies (Parker et al., 2002, Van de Sluijs, 2002).

Policy makers have a growing interest in integrated assessments of policies (Van Ittersum and Brouwer, 2009) on which the IAM community is reacting by extending the application of model development from pure scientific analysis towards application in decision making or policy context (Matthies et al., 2007, Sterk et al., 2009).

Typically many individuals from different institutions, diverse background and roles are involved in the development of an IAM (Hinkel, 2009), modellers, indicator experts, domain experts, tool users, software engineers, managers and donor representatives, resulting in as many views on the proposed tool which especially in the early phases are not always exactly envisioned. Dissenting views may continue to exist unnoticed when design is not made concrete from the beginning. Even during the development advancing research continues to lead to an improved understanding of the system. Therefore, early specifications tend to be altered later on. Accumulation of changes to the initial design obscures the design, usually vastly increasing the number of defects in the software (Larman, 2004).

Initial IAM was targeted at the development of comprehensive integrated systems, like the RAINS model (Alcamo et al., 1990), or IMAGE model (Rotmans, 1990). Current IAM development focuses at the modelling itself e.g., steps to develop a model (Jakeman et al., 2006); participatory modelling (Voinov and Gaddis, 2008); quality assurance in modelling (Scholten et al., 2007), or on modularity to allow configuration in accordance with the question at hand (Reynolds and Acock, 1997, Donatelli et al., 2002, Gijsbers et al., 2002, Argent, 2004, Leimbach and Jaeger, 2004, Papajorgji et al., 2004, Hinkel, 2009). Although IAM models are implemented through software, IAM seems to make little use of software engineering methodologies. The software engineering community uses concepts, methods and practices to deal with ambiguous specifications, changing requirements and incompletely conceived visions, and to design and develop maintainable/extensible quality software while safeguarding usability aspects.

This paper aims to introduce environmental modellers to software engineering concepts and methods which have the potential to improve model and tool development. Experiences with the development of the Sustainability Impact Assessment Tool (SIAT) will serve as an illustrative case study.

Section 2 introduces some important software engineering concepts and methods which can have a large effect on software quality and are easy to implement. All of these concepts and methods were used for the development of SIAT as explained in Section 3. Finally, Section 4, discusses what has been learned by applying the software engineering concepts and methods for the development of SIAT, confronts it with literature and concludes by explaining its added value to IAM development in general.

2.2 SOFTWARE ENGINEERING METHODS AND CONCEPTS

Software engineering is a field of study concerning the application of a systematic and disciplined approach for the development, operation and maintenance of complex software (Abran and Moore, 2004). Main clusters of interest are: (i) the process – how to get from system requirements to a product; (ii) structure – the design of the system; (iii) technology – what technology will be (re)used, and; (iv) organization – assign tasks to responsible individuals and/or organizations. Software quality assurance (Srivastava and Kumar, 2009) intersects with all clusters.

IAM is at an early stage of applying software engineering principles. The following paragraphs introduce elementary methods and concepts which can have a large effect on quality and are easy to implement.

2.2.1 Software development methodology

A common metaphor for software engineering is construction. This metaphor works out well when all requirements can be specified upfront in detail. Typically in research projects requirements are not clear from the beginning. Here the gardening metaphor from Hunt and Thomas is more suitable (Hunt and Thomas, 1999). Constant work is needed to keep it in the required shape. Choosing the right development process is a critical success factor to the development and use of a software system.

A software development methodology is a prescriptive model that establishes the order in which a project specifies, prototypes, designs, implements, reviews, tests and performs its activities. It primarily exists to co-ordinate people involved in the development of the software (Cockburn, 2000): architects, designers, implementers, testers, users, researchers and project co-ordinators. Literature gives us many development methods to choose from, varying from the formal Rational Unified Process (Kruchten, 2003) and strictly phased waterfall method (Royce, 1970) to highly adaptive agile methods like eXtreme Programming (Beck and Andres, 2004), SCRUM (Schwaber and Beedle, 2001), or Chrystal (Cockburn, 2004). Agile methods demand to get continuous user feedback during short design-implement-test-deliver iterations.

Which method to choose depends on: (i) understanding of system requirements and the ability to update them during project execution; (ii) software development expertise; (iii) team size and team distribution; (iv) decision making, leadership and culture; (v) necessity to have visual presentations before the end of the project, either for customers, or management; and (vi) predefined schedule constraints (McConnell, 1996, Cockburn, 2000, Tate, 2005, Poppendieck and Poppendieck, 2006).

2.2.2 Domain analysis

A common language and a shared understanding of the application context by all stakeholders is crucial as this is the basis for further analysis. The design of a software product starts therefore by analysing the *conceptual domain* to which the software applies. A *conceptual domain analysis* yields common grounds for further specific analysis (Champeaux et al., 1993) by identifying, collecting, organizing, and representing the relevant information in a domain, based upon the study of knowledge captured from users and domain experts by means of workshops and interviews; underlying theory in literature; and the study of existing systems within the domain. Domain analysis carefully delineates the domain being considered, organizes an understanding of the relationships between the various elements in the domain, considers commonalities and differences of the systems in the domain and represents this understanding in a useful way (Nilsen et al., 1994). Result of the analysis is a *domain model*: a simplified, abstract image of reality. In the analysis notions from the domain and relations between those notions are described.

2.2.3 Usability and prototyping

A broader scope and applicability can be achieved when an assessment tool is targeted at the less technical experienced user (Matthies et al., 2007). Within the User Centered Design approach (Raskin, 2000) usability requirements drive the features and technical development by studying the usefulness with the intended users. Central usability characteristics include: learnability, efficiency, memorability, low error rate and satisfaction of user experiences when working with the software (Nielsen, 1992, Holzinger, 2005).

Prototypes of an interface design can be used to test usability with users. Holzinger (2005) gives an overview on methods to inspect and test usability aspects with prototypes. Prototypes can be incomplete versions of the software product, but may as well be screen designs in a software presentation tool, or even hand drawn sketches on paper (Sefelin et al., 2003). They allow users to evaluate developers' proposals for the interface construction of the product by actual testing, rather than having to interpret and valuate the design based on descriptions. The main objective of a prototype is to find out if the developers are on the right track and to further feed requirement discussion.

Prototypes are also useful to test technical issues, such as performance, interfacing between components and service availability. In general a prototype is an inexpensive way to try out ideas so that as many issues as possible are understood before the real implementation is made (Tate, 2005).

2.2.4 Architecture

The increasing size and complexity of software force the use of abstraction and to break the system down into separate elements of concern in which each element has its own functional responsibilities. Such a common abstraction of a system, or architecture, manifests early design decisions through which the system to be build can be analysed. As such an architecture helps communication among stakeholders as a basis for mutual understanding, negotiation and consensus by documenting system qualities, like modularity, adaptability, extensibility, maintainability and portability. Through an architecture the system can be compared with others, reusable components can be located and cost estimates can be made. Understanding of and consensus on an architecture is important as it defines early design decisions which are hardest to change and therefore most critical to get right (Bass et al., 2003).

From the many existing software architectures there is one that is very often used for many applications: the *layered architecture*. In the layered software architecture the system is split up into a number of layers in which each layer can be built, tested, changed and reused independently. As a general rule each layer only has dependencies on those below it, limiting the effect of changes and thereby increasing maintainability. For instance the layers of 5-layered architecture consist of: (1) *presentation*, user interface; (2) *application*, workflow, e.g. what screen appears when a certain button is pressed, or enabling of controls when login is valid; (3) *services* for controlling transactions; (4) *domain*, program logic representing domain knowledge; and (5) *persistence* for storing state.

The different layers may be running on a single computer, but can also be divided on separate machines. For example the *presentation* and *application* layer could be running as a web-client and the *persistence* layer can be implemented by a relational database running on a separate server. This is referred to as a multi-tier architecture.

2.2.5 Quality

Many aspects co-determine the quality of software (McConnell, 2004). Full elaboration of the subject is beyond the scope of this paper. Reusability of components or services, possibly based on standards (Krueger, 1992, Simcoe, 2006), is mentioned as quality characteristic in the context of ecological and agricultural modelling (Reynolds and Acock, 1997, Donatelli et al., 2002, Papajorgji et al., 2004, Holzworth et al., 2010). Two other quality aspects are detailed here and are easy to implement into the development process and have a profound effect on the defect rate, coding efficiency, the understandability and the spread of knowledge of the code.

Like scientific papers, source code quality is improved by reviews. The most intensive form of code reviewing is pair programming, where one developer continually monitors another developer that is entering the code (Beck and Andres, 2004). A large number of defects and small-scale design flaws are intercepted this way before they become part of the standing code base. The code tends to be better readable, understandable, and maintainable. While at first sight it may seem unproductive to have two developers producing the code, the early interception of defects saves much time later that needs not be spent on finding and solving defects and refactoring weak design choices. Even more important is the reduction of the number of effects that otherwise would remain unnoticed unto the final product (McConnell, 1996, Tate, 2005).

In addition to code reviews, correct functioning of code can be guaranteed by accompanying all production code by unit tests. These tests can be run automatically and are to test various kinds of foreseen and unforeseen calls to the code against a predicted result. The collection of unit tests builds up during the entire development period and can be run any moment to check whether new alterations may have unwanted side effects to existing code. Seemingly complex code defects can be automatically traced back to simpler underlying code. Hence the extra time invested in writing unit tests saves time solving unwanted side effects.

2.3 SIAT DEVELOPMENT

2.3.1 What is SIAT

SIAT is a web application to estimate the possible consequences of different policy assumptions on multifunctional land use and its sustainability within different images of the future (Verweij et al., 2009). SIAT (Figure 2-1) allows the user to identify those geographical areas that are most sensitive to particular policies, identify regional differences and analyse causes, look at potential 'trade-offs' and undertake all analysis dynamically (Potschin and Haines-Young, 2008).

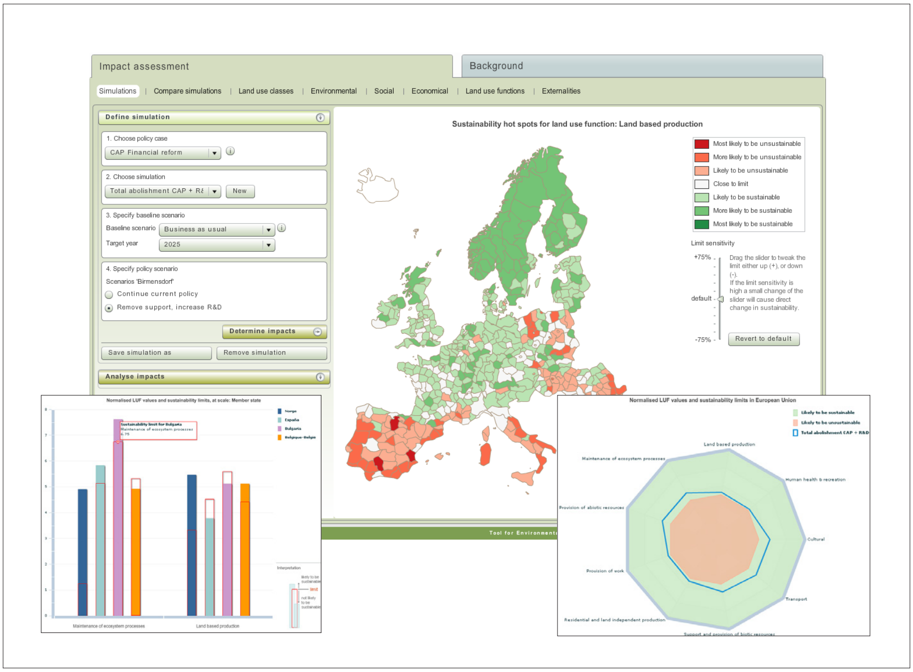

Figure 2-1 - SIAT user interface impression. The main screen shows the definition of a policy and a map depicting regional differences of the land use function 'land based production'. In the radar chart in the inset on the bottom-right, all land use functions' scores in relation to the sustainability limit (edge of the red circle) are drawn allowing to find trade-offs. In the chart in the inset on the bottom-left, bars are drawn representing scores of 2 land use functions and 4 member states. Bars are grouped by land use function. The thin red lines plotted on top of the bars represent limits which vary per land-use function and member state.

SIAT was developed within the integrated research project entitled 'Sustainability Impact Assessment: Tools for Environmental, Social and Economic Effects of Multifunctional Land Use in European Regions (SENSOR)' funded through the EU Framework Programme 6. The project covered the sectors forestry, nature conservation, agriculture, energy, transport and tourism (Helming et al., 2008).

SIAT uses a model chain to translate policies together with certain images of the future into impacts (Figure 2-2a). These drivers are translated into land-use changes from which in turn in combination with constant-factor maps social, economic and environmental indicators are derived. Constant-factor maps contain parameters which are expected to be constant throughout the modelling. Finally, regional sustainability limits for the indicators by means of land-use functions are assessed (Pérez-Soba et al., 2008, Paracchini et al., in press).

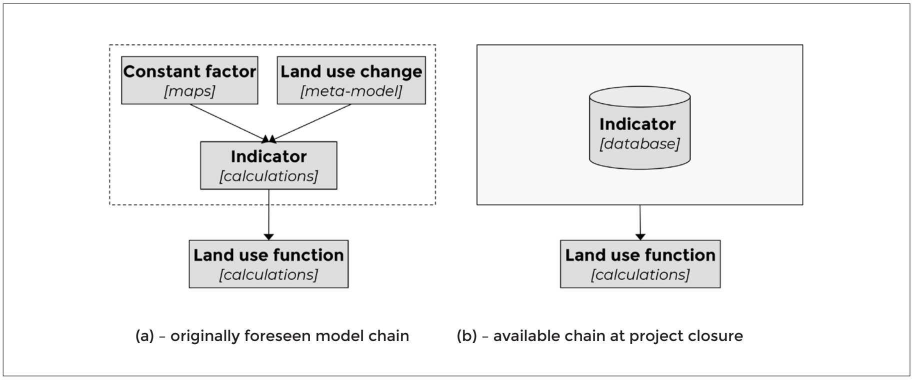

Figure 2-2 - Model chain. Model components making up the model chain use a standardized interface making them (technically) interchangeable. This is the case between figure a and b in which three model components are replaced by one with equal behaviour. (a) Originally foreseen model chain and (b) available chain at project closure.

Land-use changes are determined by the use of a modelling framework (Jansson et al., 2008) including the macro-econometric model NEMISIS (Brecard et al., 2006), the forestry model EFISCEN (Nabuurs et al., 2001, Schelhaas et al., 2007), the agricultural model CAPRI (Britz et al., 2003, Britz and Witzke, 2008) and the land-use allocation model DYNA-CLUE (Verburg et al., 2004). Since the modelling framework was complex to work with and took a long time to calculate impacts of various policies SIAT was planned to use a meta-model (Sieber et al., 2008) derived from the modelling framework (Kuhlman, 2008).

New policies, baselines, target times and indicators at different spatial extent and spatial resolution can be added to SIAT making it adaptable to future applications.

2.3.2 Development process

During workshops, meetings and interviews with scientists from within the project, policy makers at EU level and regional stakeholders we disseminated ideas and received feedback that further specified system requirements. Iteratively the same group of scientists and policy makers and different groups of regional stakeholders were contacted during the full four and half year project duration. The presentations and discussions in the workshops were structured around definitions of policies, impact comparisons and visualizations, and the need of explaining assumptions and the causal relation between drivers and impacts.

Initially several detailed interpretations of the system were presented. A common vision and integrating concept, however, did not arise until the presentation of a first prototype that was developed together with a graphical designer (Verweij et al., 2006). This prototype provoked adequate feedback that helped to stabilize the conceptual domain model and gave direction to system development (Figure 2-3).

The domain model (Figure 2-4) shows that an integrated assessment compares indicators in different images of the future that are influenced by several drivers. Drivers have been divided between those that can be affected by policy versus external drivers such as climate change, technological innovations and world population.

Based on the feedback a multi-tier architecture was selected, in which the models and visual representations of impacts find a place as exchangeable components. Like all other system components, in the agile development process that has been used, the design of the system architecture was not rigidly fixed, but subject to change whenever required. However, since the architecture is fundamental to the application, major changes at this level were less likely to occur.

To speed up development we searched for reusable components and services with a strong preference for open standards, such as the OpenMI to provide a standardized interface to describe, link and transfer data between models on a time step basis (Moore and Tindall, 2005) and Web Mapping Service to produce maps of spatially referenced data dynamically from geographic information (OGC, 2004). Components and services for architecture were searched for during its design, while others were searched for as required at any stage in the development. Examples of the latter category include graph visualization components, or data parsing components.

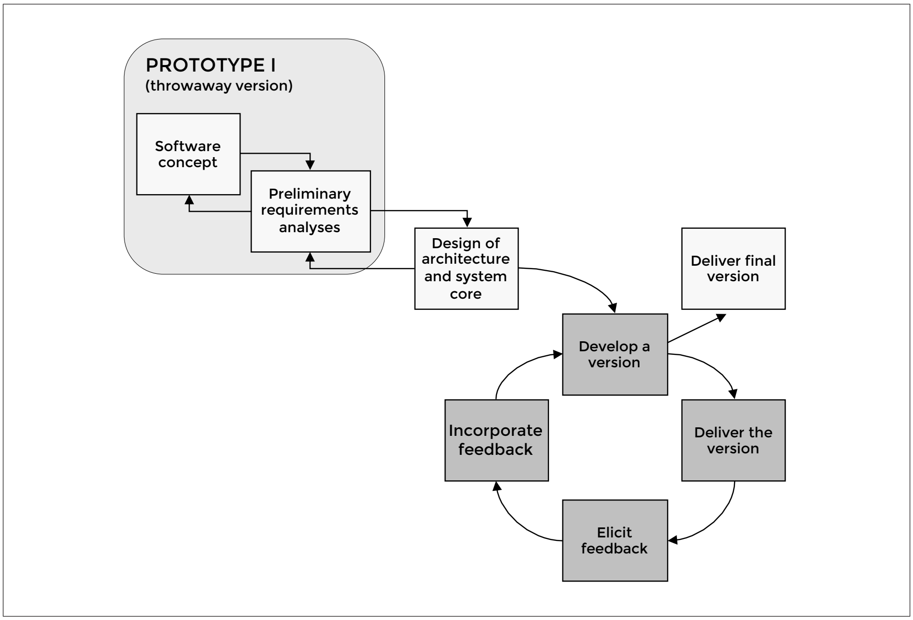

Figure 2-3 - Evolutionary development methodology (after (McConnell, 1996)). Project activities are located in the boxes while the arrows establish the order in which the activities are carried out. The box with rounded corners delimits the activities resulting in SIAT prototype I.

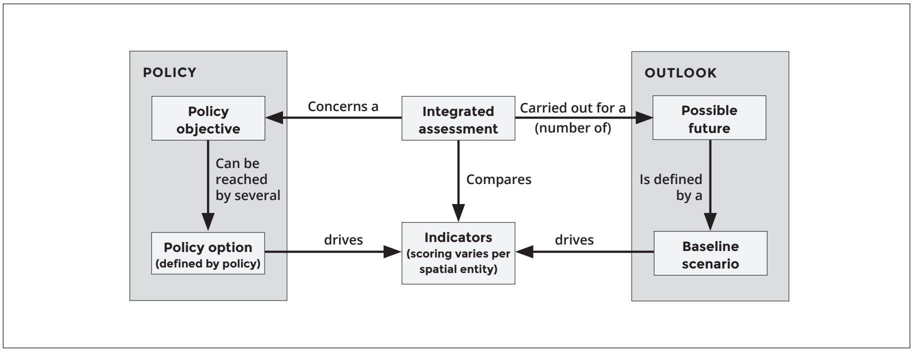

Figure 2-4 - SIAT domain model. SIAT estimates the possible consequences (quantified by indicators) of different policy options within different images of the future.

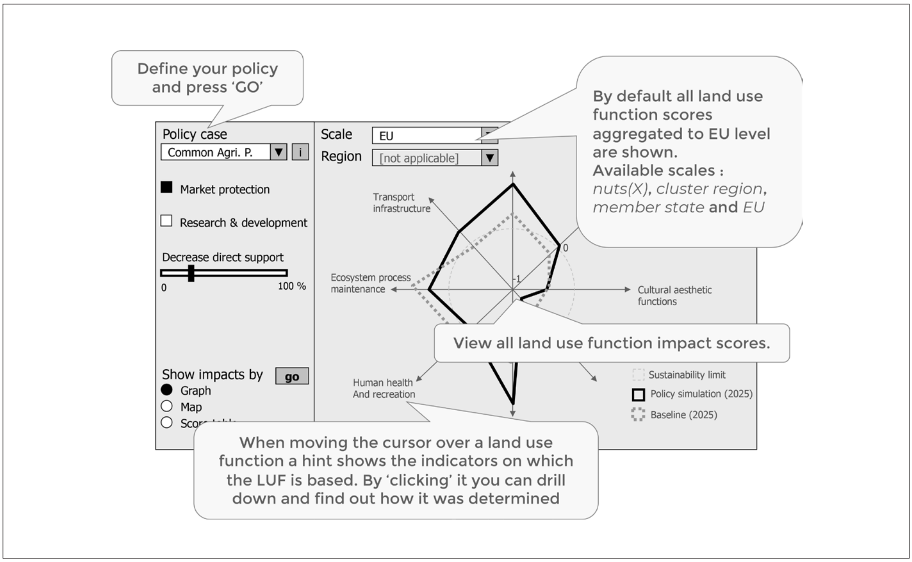

Figure 2-5 - Screen sketch example. A Graphical User Interface sketch showing all controls in an anticipated state. Major points of interest are explained in text balloons.

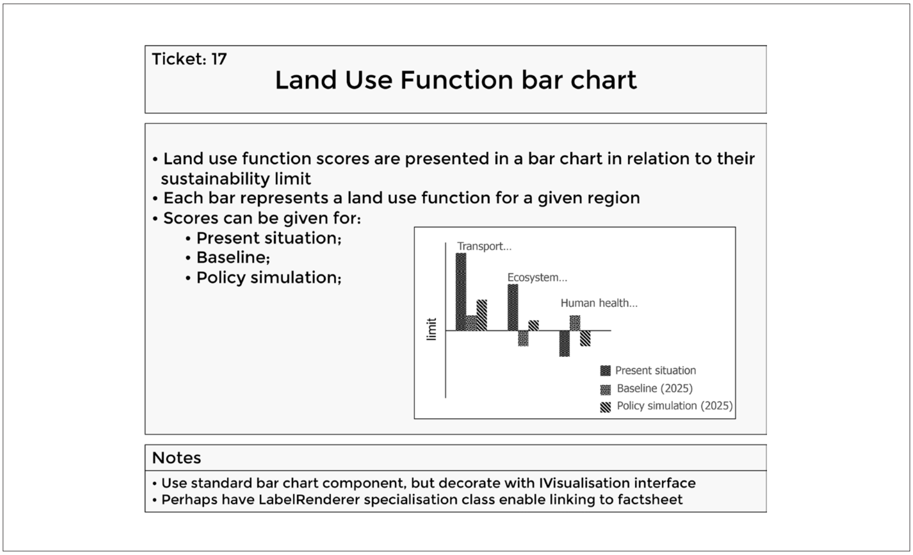

Figure 2-6 - Story card example. Three elements make up the story card: (i) a unique identifier and a concise (but possibly improved) title; (ii) a short formulation of a requirement in user terminology which may be supported by a sketch; and (iii) developer notes.

Usability testing included *storyboards*, a sequence of *screen sketches* on how we understood the targeted impact assessment tool, how it should/could look and was to be interacted with (Figure 2-5).

At the same time we gathered feedback creating new *story cards*, a short formulation of a user requirement (Beck and Andres, 2004), to be implemented in a following iteration (Figure 2-6). A story card was implemented vertically through all architectural layers in contrast to the more classical approach of developing layer-by-layer horizontally.

Iterations implemented as many story cards as would fit in a time frame of 3 weeks. Iterations resulted in an operational new release, on which user feedback and new story cards or new prioritization of story cards were based. Story cards were stacked with the highest priority card on top. Three releases have been tagged as prototypes for formal project deliverables.

Within every iteration, source code was added to and changed within the existing code base. Unit tests were used to ensure proper functioning of previously developed code. Refactoring (Fowler et al., 1999) was applied liberally to make the internal structure of software easier to understand and cheaper to modify without changing its observable behaviour. All code and unit tests were checked into a version control system on a daily basis.

Software development took place in two teams based at separate locations and organizations. One team worked on a single model component without formal development method. The larger team consisted of 4–6 software developers in one room and used the development method 'evolutionary development' using story cards. Implementing a story card started with the design and break-down into smaller tasks. Day tasks were assigned each morning during a 20 min stand-up meeting in which each developer also shortly reported on the progress made the previous day. Story cards were assigned starting with the highest priority. The implementation of story cards was done using pair programming assuring continuous code review by the pair partners. The composition of the pairs was reshuffled after each card completion.

2.3.3 Results

Using the 5-layered architecture (paragraph 2.2.4) the SIAT system was broken down into elements that overlap as little as possible in features and behaviour. This principle of Separation of Concerns accommodated the organizational structure of the SENSOR project in which different engineering groups were responsible for development of different software elements. Figure 2-7 shows the elements which make up the total

SIAT system and their relation to each other:

- Graphical User Interface *(GUI)*;
- *Simulation services* – access to the domain model such as available policy instruments, indicators, spatial divisions, meta-information;
- *Models* – are wrapped in a standardized interface using the OpenMI (Moore and Tindall, 2005) which supports to use modular model compositions;
- *Map services* – gives access to geo-referenced images representing maps (WMS: OGC, 2004);
- *Factsheet service* – resources containing fact sheets in xml format;
- *3D landscape visualization services* – provides 3D landscape images showing how the landscape might look in a modelled future (Snizek et al., 2008).

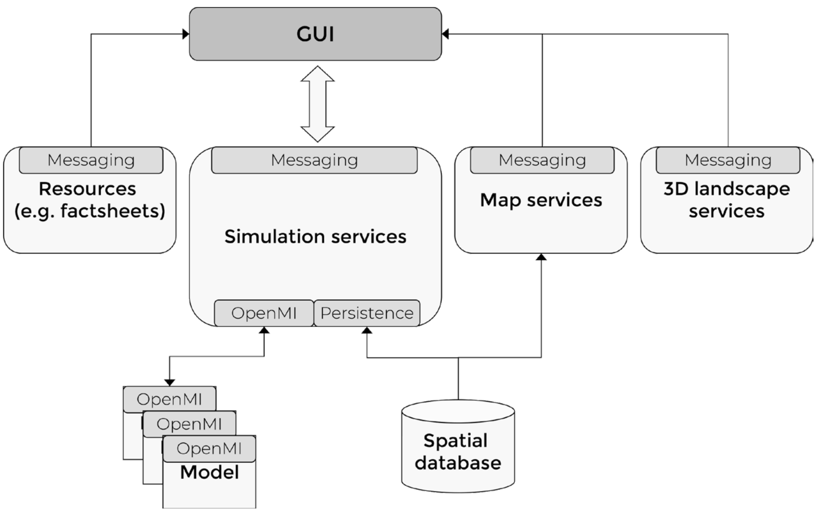

Figure 2-7 - SIAT system architecture. Each box represents an element within the system. The arrows between the elements indicate the communication direction between them. The Graphical User Interface (GUI) element resides at the client's computer, while all others are located on the server. Models are wrapped using a standardized interface (OpenMI) facilitating the formation of a modular model composition.

Each element can be located at a different physical location. For practical reasons such as maintenance, performance, or security this would not be optimal. The GUI runs at the client's machine in a web browser. The larger part of the systems' elements reside on a single web server while the database is located on another server within the same domain. The 3D visualization services are hosted by another organization.

The architecture is data driven, in terms of policy instruments, baseline scenarios, spatial divisions, indicators, documents, geo-related data (e.g. climate zones), etc. Models are substitutable, i.e. they can be substituted with other implementations without the need to re-engineer the entire software system. The core system services are loosely coupled to the (web based) user interface, facilitating the production of specific front-ends interacting with the same back end.

The 3D landscape visualization and the meta-model implementations were excluded from the latest release due to instability. A pre-calculated (result-based) component model replaced the originally planned regression based meta-model (Figure 2-2 b). The decision not to release SIAT with the meta-model component could be postponed until late in the project without running into problems as a consequence of the open model architecture.

2.4 DISCUSSION

2.4.1 Agile development method

Agile development methods were used in the implementation of the SIAT tool. These were most suitable, as the outcome of research projects are to some extent unpredictable due to their innovative nature. Unpredictable outcomes lead to ambiguous and changing specifications of what SIAT should do. Part of this unpredictable outcomes are caused by advances in scientific understanding of the domain. Generally speaking these unpredictable outcomes make it hard to direct the development from the onset of the project and use exhaustive upfront design phases. Instead, the development process must be agile and quickly adjust to changing or new insights from the rest of the research project, resulting in modified specifications. Agile processes are among the top ten key factors that determine the success of software projects (Standish Group, 2005).

A selection (e.g. story cards, pair programming, daily stand-ups) of best-practices from agile methods was chosen, based on the literature and personal preference. The software development was based on short responsive iterations, in which the specifications of the SIAT tool were adjusted to the lessons learned. Each development iteration consisted of short design, implementation, testing and release-phases and lasted no longer than 4 weeks. Other parts of the research project operated on longer iterations. The use of these agile practices helped to match the results of the software development with the results from the others domains in the research project and to manage expectations of users with respect to tool functionality.

The agile approach was challenged, however, by differences in culture between the two teams. One team operated more on the basis of authorized craftsmanship, which implies a focus on delivering a functional tool instead of documenting a semi-functional tool and is based on trust in the software development team. The other team followed a more procedural approach to software development, which is advisable when the employing organization prefers clear policies and procedures (Boehm and Turner, 2004). The team using the agile practices developed the major part of the tool, while the other team developed a replaceable component with a clear interface. The clear interface resolved the conflict in development methods, and allowed the teams to cooperate. The parallel use of different development methods was only possible in this case, as the definition and interface of one component was rigidly fixed at the start of the development process. If it is not possible to rigidly define these components and their interfaces, it is advisable to use agile methods in all cases and not trying to mix methods.

Literature (Salo and Abrahamsson, 2008) reports the increased development speed and improved code quality characteristics of agile methods compared to formal methods, which was not experienced at the start of the development process of SIAT. Initially there were fluctuations in development speed and quality, due to team members working on all layers of the architecture. This typically required team members to learn new skills, for example a database developer learning about the user interface. This learning process was facilitated through the use of pair programming. Later on in the development process, the use of agile methods resulted in a shared understanding of the system between team members and a stable and productive development pace.

2.4.2 Continuous integration and separation of concerns

SIAT was divided in tiers (e.g. presentation, model, data) and components (e.g. meta-model, map services) according to the principle of Separation of Concerns. This enabled us to distribute the workload over two development teams. Both teams could progress at their own pace, however some safeguards were needed to prevent integration problems, because of changing component interfaces during development by one team.

The selected integration approach for components and tiers during the development process was the use of proxies. Most components were initially represented by proxies, i.e. simple substitutes that display the same behaviour externally, but not necessarily produced semantically valid data. Proxies allow gradual implementation of functionality of a component and at the same time have a working end-to-end system. A drawback of the use of proxies is that component interface changes during the development phase can easily be made and not be detected until the integration phase, as multiple components often are maintained separately. The integration phase is close to a milestone or deadline and problems in this phase can be costly and stressful to solve. Solving such integration problems could profit from continuous integration as utilized in the SEAMLESS-Integrated Project (Van Ittersum et al., 2008, Wien et al., 2010). Continuous integration means semantically and technically validating the integration of each of the components and tiers into the whole. It is a software development practice where team members integrate their work (at least) daily. Each integration is verified by automated tests and automated builds (Fowler, 2006).

Automated unit testing provides trust in the proper functioning of the code base when all tests pass. Ideally all methods of all classes are verified through unit tests. We built unit tests for the *simulation services* and the OpenMI compliant *models*. Incremental development and refactoring of these elements were safe as errors could be quickly identified and fixed. For the *GUI* we did not use unit tests as we found the technology of the testing framework immature and burdensome to work with. As the *GUI* grew in time and became in need of refactoring this was understood as a wrong decision. Even some simple errors were time consuming to locate. As it is advisable to write unit tests for source code of domain or application tiers, unit tests must also be available for source code that is part of the presentation tier (i.e. *GUI*). Fortunately, testing frameworks for presentation tiers are still improving.

As part of the separation of concerns, SIAT strictly separates subject matter (data, or a modular model) from program logic permitting changes in application behaviour. This implies that when adding additional policy instruments, indicators, or spatial divisions to the database, they will become available through the system without the need to recompile. Data deliveries were often late due to reservations researchers have to deliver premature data. Since no assumptions were made about the contents of the data in the program code, work on it could continue independently, without interfering with the data production. Nevertheless it must be stressed that early integration of data and application is important to check the relations and format of the data against the program logic. In addition, such a separation of data and logic facilitates the application of the system in areas where it was not originally developed for. Or, with substitutable models, specific model components could be exchanged with versions suitable to the new application.

Originating from the water domain the OpenMI was successfully used for linking models in SIAT and in other environmental applications (Janssen et al., 2009, Lindner et al., 2010). By using OpenMI we were able to have an alternative component act as substitute for the ones that could not be realized. An extension to the standard of OpenMI for the description and exchange of non-numerical, or complex data simplified the application for SIAT models (Verweij et al., 2007, Wien et al., 2010). Knapen et al. (2009) describe the use of ontologies (Villa et al., 2009) for describing exchangeable information with OpenMI components. The architecture helped us to find similarities with the SEAMLESS-IF tool (Wien et al., 2010) providing a basis for cooperation on technical design and implementation.

2.4.3 Users and usability

Clear objectives for tool development are not obvious since often various stakeholders have different goals. A concise and comprehensive vision statement that is agreed upon or at least acknowledged by the stakeholders is necessary to ensure a successful tool development. Furthermore, user involvement is prerequisite for directing the development process (Mysiak et al., 2005, Standish Group, 2005, Jakeman et al., 2006, McIntosh et al., 2008) and raising and balancing expectations (Sterk et al., 2008) throughout the project.

Like the first version of mDSS (Mysiak et al., 2005) we focused on the *GUI* while using dummy data and models for illustration. Rizzoli and Young (1997) distinguish three main categories of users: the scientist, the manager/policy maker and the stakeholder. We targeted SIAT at the last two categories and started looking for examples in a similar domain such as the unpublished 'ATEAM mapping tool' and EURURALIS (Westhoek et al., 2006). The EURURALIS tool was appreciated for the visualization of output helping users to get an improved understanding on interdependencies (Sterk et al., 2009). The assignment of user roles to virtual user representatives at the EU level as assessed in several workshops (Tabbush et al., 2008) provided an opportunity to disseminate ideas while real user representatives were selected from the project participants for attaining the required development direction.

Uncertainty on the user type targeted with the SIAT tool during the early project stages made us decide to develop a throw away prototype as a starting point. Argent and Grayson (2001) suggest that such an initial system helps users to overcome difficulties to explicitly express what they expect from a system. As such the throw away prototype was invaluable to arrive at a shared and explicit vision and receive detailed feedback on software requirements. Subsequent incremental releases ensured that software development stayed close to expectations based on the shared vision of the end-product.

As part of the development of the throw away prototype and releases, screen sketches and story boards depicting GUI suggestions were drawn. These can be drawn fast in comparison to implementing them in actual software and are far less ambiguous than textual suggestions without pictures. Participatory design of screen sketches was found especially effective in small workshops where participants drew jointly on a whiteboard while discussing their design.

All SIAT versions have benefited from the participation of a graphical designer for drawing sketches during the development. Literature highlights the importance of design to remove barriers, which results in an increasing willingness to use a tool (Lu et al., 2001). Tractinsky et al. (2000) even states that a well-designed product is a better usable product and the SIAT tool attracted positive feedback with its professional appearance.

2.5 CONCLUSION

This paper introduces some common software engineering principles and demonstrated their usefulness through an application of these principles to the SIAT tool development. As a software development method, agile practices seem to best fit research projects, that typically have unclear upfront and changing requirements and many different views on the functionality. Separation of concerns helps to divide the work across teams participating in the research project and to achieve a modular and flexible system. However, this must be accompanied by proper automated testing methods and continuous integration. To align the different views on functionality prototyping, screen sketches and mock-ups can be used to build a shared vision of required functionality and to match expectations.

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Chapter 3

IMPROVING THE APPLICABILITY AND TRANSPARENCY OF LAND USE CHANGE MODELLING: THE ICLUE MODEL

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HIGHLIGHTS

- iCLUE is a new member of the commonly used CLUE land use change model family.
- Ease of use and model transparency enhance learning opportunities.
- Inclusion in a modelling framework enables scenario analysis and impact assessment.
- The software architecture creates opportunity for model enhancements.

ABSTRACT

Human use of land increasingly alters the structure and the functioning of the environment. To ex-ante understand and anticipate these changes there is an increased need for readily available and operational land use change models. One of these models is CLUE, which has been used in many studies all over the world. These studies brought forward operational hurdles, that hamper model application. The overall objective of this paper is to present a new version of the CLUE model, iCLUE, that helps to overcome these hurdles. We describe the technical redevelopment, conceptual innovations, several applications and success factors and critical reflections. iCLUE minimizes manual error-prone actions, enhances ease-of-use, speeds up the operational modelling process and provides data visualisations to empower users to analyse and interpret results.

3.1 INTRODUCTION

3.1.1 History of land use modelling practice

Humanity and its socio-economical system are maintained by and depend upon the natural environment (PEER, 2010). Human use of land alters structure and functioning of this natural environment (Vitousek et al., 1997). Changes in land cover through agriculture, forestry and urbanisation represent the most substantial alteration through their interaction with most components of global environmental change (Ojima et al., 1994, Turner et al., 1994), particularly related to climate change. Since the last decade, land use and land use change have been gaining importance (e.g. Pielke, 2005) because of their role in both climate adaptation and climate mitigation. Biofuels are needed to reduce fossil fuel consumption and mitigate climate change, while land also needs to be altered to increase food production and adapt to droughts and floods. Overall, there is an increased need for readily available and operational land use change models. This also calls for a re-evaluation and reconstruction of existing models.

Land use models have a rather long history, starting with a number of seminal papers in the 1970s (e.g. Wilson, 1971). Particularly important for the current generation of land use models were cellular automata models (Batty et al., 1997). Boosted by increasing (remote sensed) data availability, the number of land use models started increasing and diversifying in the last decades, including: specialised urban growth models (e.g. Clarke et al., 2007, Liao et al., 2016), forest landscape (Thompson et al., 2016) and deforestation models (Soares-Filho et al., 2006), and agricultural land use models. The latter category has spawned a rather large number of (agricultural) spatially explicit, integrated land use models (see for an overview, National Research Council, 2014, Verburg et al., 2004). In this paper, we focus on an empirical, data-driven, spatially explicit model. There are two categories of these models that are of importance: models with a predominantly top-down logic of first determining narrative scenario’s with overall demand (Mallampalli et al., 2016), which is subsequently allocated, and models with a predominantly bottom-up logic of determining which spatially explicit land use changes are likely to happen. The topic of study, the CLUE modelling framework, is an example of this first category.

3.1.2 The iCLUE model and its history

The iCLUE land use change model originates from the CLUE model family (Veldkamp and Fresco, 1996, Kok et al., 2001, Verburg et al., 2002, Verburg and Overmars, 2009). The CLUE model has been used in many studies all over the world for land use planning, environmental impact assessment and ex-ante policy assessments (Lesschen et al., 2007, Luo et al., 2010, Britz et al., 2011, Gibreel et al., 2014). CLUE

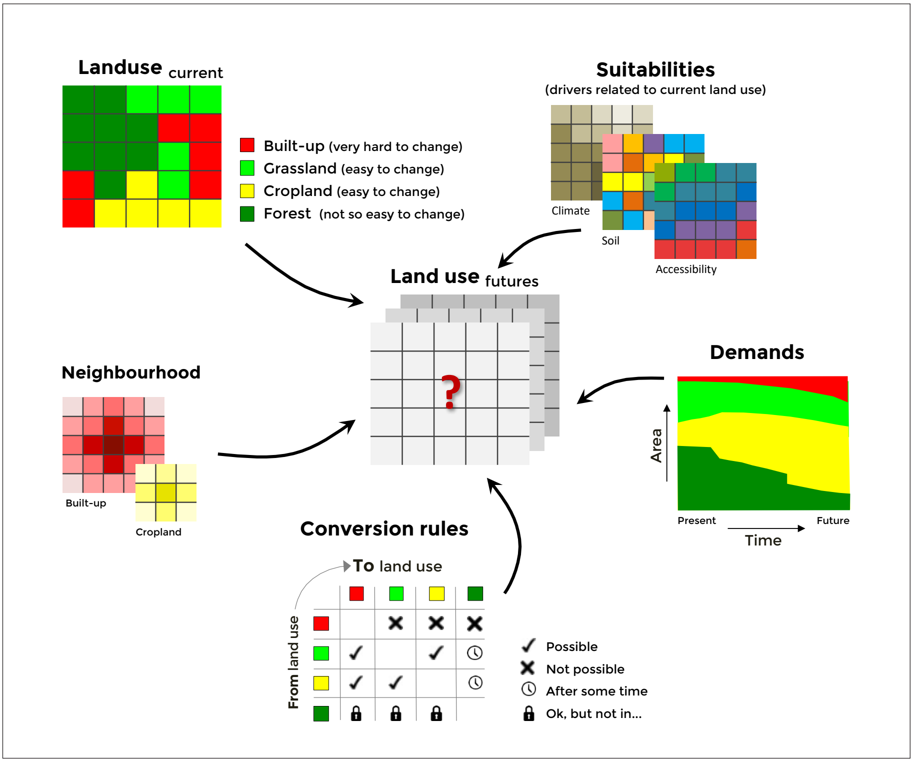


Figure 3-1 - Land use projections by the CLUE model are determined based on land use suitability, conversion rules, neighbouring land use and the areal demand for specific land use types.

allocates land use based on areal land use demands. Allocation takes place based on: (1) land use suitability (e.g. no agriculture on steep slopes with dry unfertile soils), (2) conversion rules (e.g. ‘urban cannot change into pasture’, or ‘new production forest can be harvested only after 20 years and turned into fallow land’), (3) neighbouring land use (e.g. built-up area is likely to expand next to existing built-up area), and (4) the areal demand for specific land use types (e.g. 250 ha of agriculture in my study area in 2030) (Figure 3-1).

The land use suitability describes how well a certain land use type fits on a specific location based on the characteristics of that location, such as soil type, slope, climate and accessibility of markets. The suitability can be determined by statistical methods, e.g. empirically using logistic regression analysis, expert knowledge, or sequential assimilation of observations using Bayesian Belief Networks (Kjaerullf and Madson, 2013, Verstegen et al., 2014).

Conversion rules determine if and under which conditions a conversion from one land use type to another is allowed. Typically these rules are defined by scientific experts, but may also be gathered from stakeholders. Rules include: conversion possible, conversion impossible, conversion possible after a specified amount of time and, conversion (im) possible within specified areas. In addition, the ease-of-change indicates the reluctance of a land use type to change.

Neighbouring land use influences the spatial allocation of a specific land use type at a specific spot. Nearby land use is more determinant than areas further away.

The land use demand can be determined on simple trend extrapolations or (complex economic) models. Typically demands are defined per administrative unit due to the political and/or institutional target setting (e.g. to determine land use changes for Europe in 2050, each country implements its own policies, finally determining land use demands). The future land use demands need to specify, at least for the final year of model simulation, the area covered by the different land use types.

The sum of these four determinants specify the probability for each potential land use type per location. This results in a location-specific probability distribution across the potential future land use types. Each location is allocated to a single specific land use type using the probability distribution. In this way, the allocated land use does not necessarily match the predetermined demands, neither when a tolerance for deviation from the demands is indicated. Hence the model iterates until the demands are met within the pre-defined tolerances. In each iteration the probabilities are adapted to reduce the mismatch in demand and allocation.

3.1.3 Problem definition and objective

In a great number of studies in different parts of the world on different scales and different domains, CLUE has been used as land use change model. The need to understand processes involving past and future land use changes will always remain highly relevant. However, these studies brought forward operational hurdles that made us reluctant to apply the model and that we seek to solve:

- There is a dependency on a small amount of experts to apply the model, implicating that the workforce in projects is limited by the availability and preferences of individual experts;

- Results are not self-explanatory in relation to the underlying land use change processes;
- Data preparation for, and post-processing of CLUE runs are time consuming (as also identified by Mas et al., 2014);
- Error prone due to the many manual actions required for data conversion scripts and tools, the many coding, file naming and file structuring conventions, and manual guarantee of coding consistencies across files.
- Lacking clear warnings and error messages hampering efficient handling of causes.

The overall objective of the paper is, therefore, to present a new version of the CLUE model, iCLUE, which was constructed to provide solutions for the issues above and evaluate its ease of application. In the paper we describe the development process, the technical architecture, several applications and the way we solved the issues above.

3.2 METHOD

3.2.1 Scoping

During half a day workshop with 5 modelling experts and 3 software engineers we exchanged experiences from CLUE modellers and identified common bottlenecks and formulated joint visions. Next we did an in-depth literature review of peer-reviewed published CLUE papers (Kok et al., 2001, Veldkamp and Fresco, 1996, Verburg et al., 2002, Verburg and Overmars, 2009), the manual (Verburg, 2010, Overmars et al., unpublished.), scrutinizing the code of the various software tools and listing the file-naming, coding and file-structuring conventions. Despite differences in detail and realization between the sources we derived a single scheme describing the process of doing a CLUE run in which all manual data-conversion interventions are identified (see Figure 3-2). While scrutinizing the code we ran into conceptual model imperfections for which model innovations were sought.

We jointly envisioned the model to use a minimum of manual –error prone-data-conversion actions and include integrated result visualisations and transparent analysis tools. In addition the statistical method and conversion rule base of the model should be adaptable and extensible. Several existing software solutions were considered as implementation platform: DINAMICA (Soares-Filho et al., 2002), R (R Core Team, 2015), QUICKScan (Verweij et al., 2016), IDRISI[2] and dataflow management systems. The visualisation, data storage and readily available algorithms of these platforms

[2] https://clarklabs.org/products/

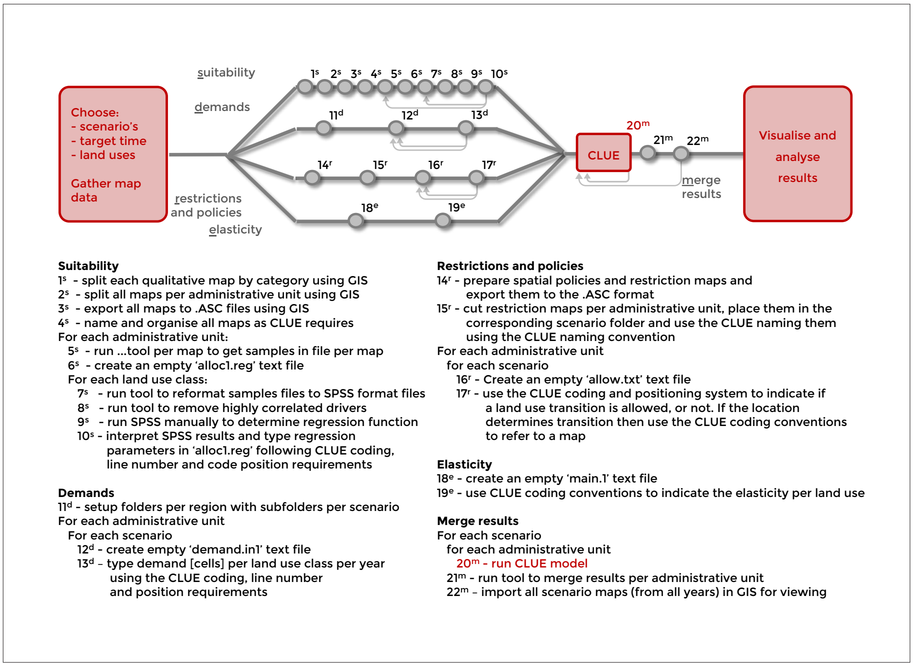


Figure 3-2 - CLUE process overview. The red rectangles represent the main steps for doing a CLUE run: define and prepare scenarios, run the model and analyse model results. The grey dots indicate technical manual data conversion steps to be taken in between. In specific cases iterative technical manual steps are required (grey arrows).

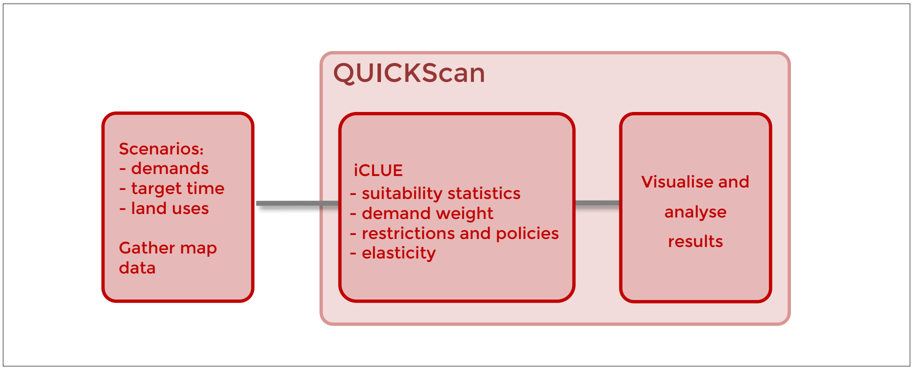


Figure 3-3 - Vision on new CLUE process overview.

were seen as an important added value in contrast to developing the model fully from scratch. QUICKScan was chosen as the implementation platform since it offers many visualisations, data storage mechanisms, Application Programming Interfaces (API's) for result analysis and back-tracing into modelled results, and focus (though not limited) on categorical data (like land use data). Moreover the involved software engineers are familiar with its technical architecture. See Figure 3-3 for the envisioned model setup.

3.2.2 Vision definition through wire frames

A functional design is a formal documentation of what an application should do and how an application should function in interaction with a user. It is a reference for the implementation. Within the User Centered Design approach (Raskin, 2000) usability requirements drive the features and technical development by studying the usefulness with the intended users. Prototypes of interface design can be used to test usability with users. Prototypes can be incomplete versions of the software product, but may as well be screen designs in a software presentation tool, or even hand drawn sketches on paper (Sefelin et al., 2003). They allow users to evaluate developers' proposals for the interface construction of the product by actual testing, rather than having to interpret and valuate the design based on descriptions. The main objective of a prototype is to find out if the developers are on the right track and to further feed requirement discussion (Verweij et al., 2014). In general a prototype is an inexpensive way to try out ideas so that as many issues as possible are understood before the real implementation is made (Tate, 2005).

'Wire frames' are prototypes addressing the layout of a screen and deal with information, structure, relationships between information and flow between screens. They are a graphical means of communication to further feed discussion on structure and information. Wire frames do not address aesthetics. During the user feedback/ design phase in an agile method new wire frames might be added for new functionality, or existing ones might be revised (Verweij et al., 2014).

During three two-day sessions with land use modellers and software engineers many versions of screen designs were jointly sketched on paper. Each version was tested against modelling experience on the logical sequence of modelling processes and options, and iteratively resulting in an improved sketch. At the end of each session the paper sketches were transformed into a set of digital wire frames. Figure 3-4 shows an example of a developed wire frame.

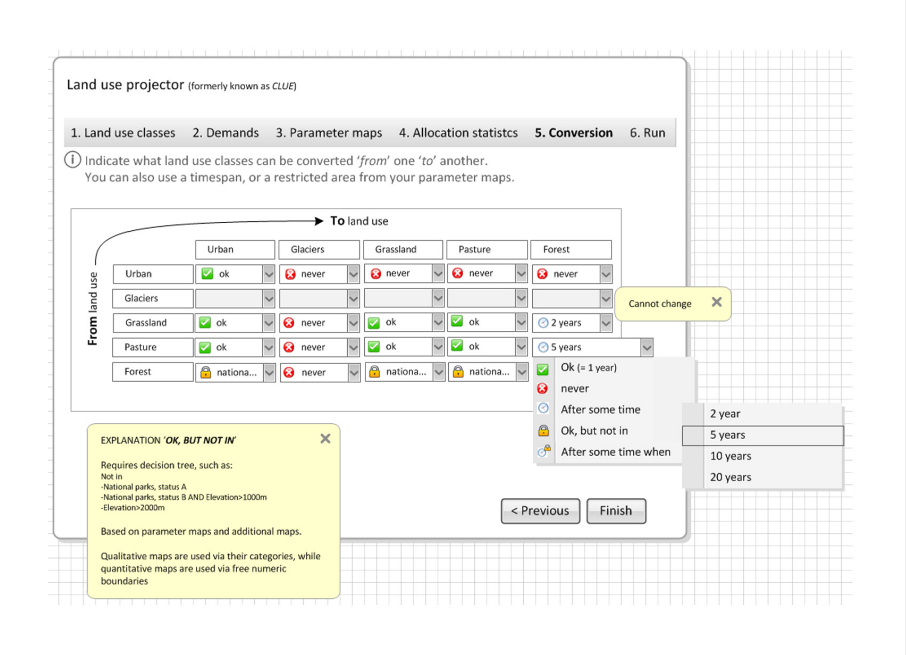


Figure 3-4 - Example wire frame showing a wizard-like interface with 6 steps. In the displayed screen step 5 'Conversion' is active. The main part of the screen shows how a user can change the conversion possibilities 'from' one land use class 'to' another. The text balloons provide additional explanations.

3.2.3 Result visualisation and analysis

The most important outcome of a land use model are the spatially projected allocations of land use classes through time. In interviews the land use modellers wish-listed the following result visualisations to get understanding on the occurring changes (what, where and how):

- Map of land use at any modelled time (possibly dynamically displayed like a movie through time)
- Summary statistics of the area of each land use class at any modelled time (possibly dynamically displayed like a movie through time)
- Hotspot maps, i.e. land use transition frequency per location over the modelled time

- Type of land use transitions between two modelled times, i.e.:
  - the area gained and lost per land use class (e.g. pastures may have disappeared in some locations while appeared at other locations). This provides an immediate overview of the areal changes.
  - the area gained and lost per land use class defined by its originating and target land use class (e.g. pastures that have disappeared have been replaced partly by forest and partly by urban areas. Where pasture appeared, this was at the expense of arable land and forest. These types of relocation are a result of the interplay between demands and local suitabilities. In this case, the relocation of pasture is enforced by the high demand for forest and urban areas). This provides details on areal transitions.

See Figure 3-5 for screenshots of these visualisations.

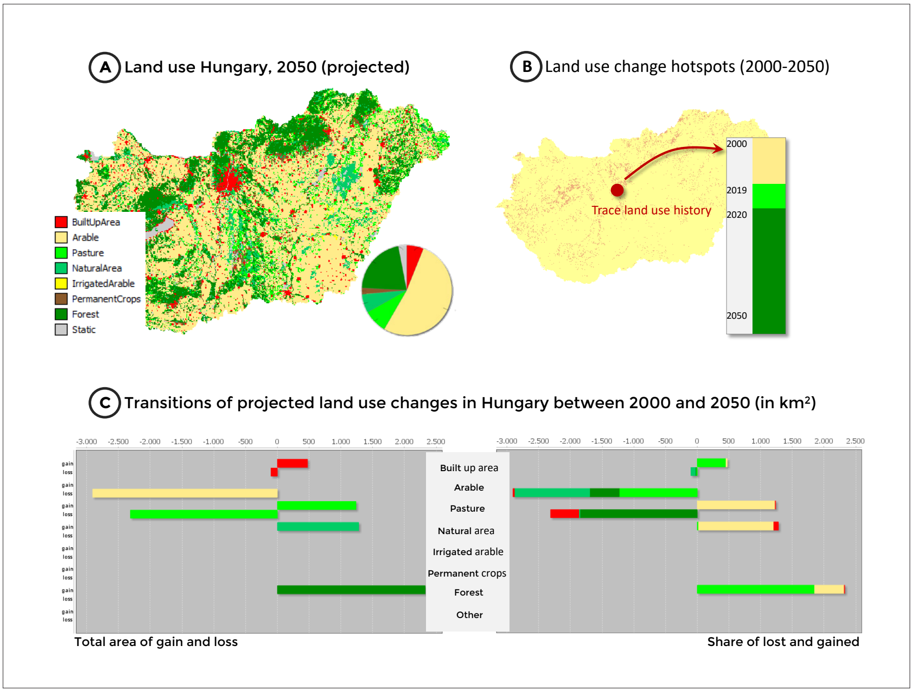


Figure 3-5 - Screenshots of envisioned model result visualisations. A. Land use distribution maps with summary statistics. B. Hotspot, or change frequency map with land use change history for back-tracing purposes. C. Land use transitions between two modelled times, both total areas and shares.

3.3 RESULTS

3.3.1 Technical architecture and model setup

An architecture is a common abstraction of a system that manifests early design decisions through which the system to be build can be analysed. As such, an architecture helps communication among stakeholders as a basis for mutual understanding, negotiation and consensus by documenting system qualities, like modularity, adaptability, extensibility, maintainability and portability (Bass et al., 2003; Verweij et al., 2010).

The iCLUE model was developed as an independent piece of java[3] software equipped with a plugin API for using it within the QUICKScan framework application (see Figure 3-6). QUICKScan[4] is a java based spatial modelling environment developed using the OpenMI OGC standard[5] model integration framework (Gijsbers et al., 2002, Knapen et al., 2013). QUICKScan offers support for scenario- and indicator concepts and provides

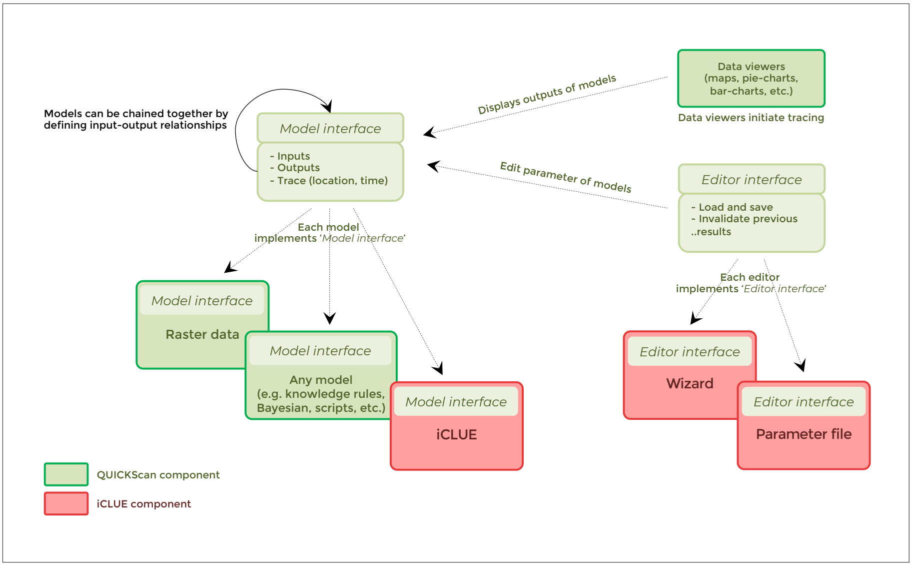


Figure 3-6 - Architecture of iCLUE as a module into the framework of QUICKScan.

[3] https://www.oracle.com/java/index.html

[4] http://www.quickscan.pro/

[5] http://www.opengeospatial.org/standards/openmi

many built-in visualisations, analysis tools, possibilities to trace back into modelled results and user interface templates for model parameter editors. These tools have been designed according to the separation of concerns principle, i.e. separation of software logic, user interface and data. For iCLUE two parameter editors were developed: a wizard – similar to the wire frames-, and a parameter file. The model was developed incrementally. Given the short development iterations in which new functionality was added we chose to start with the parameter file editor which was easy and quick to adapt during the iterations in contrast to a fully functioning wizard user interface. See Annex I for the template of the parameter file format.

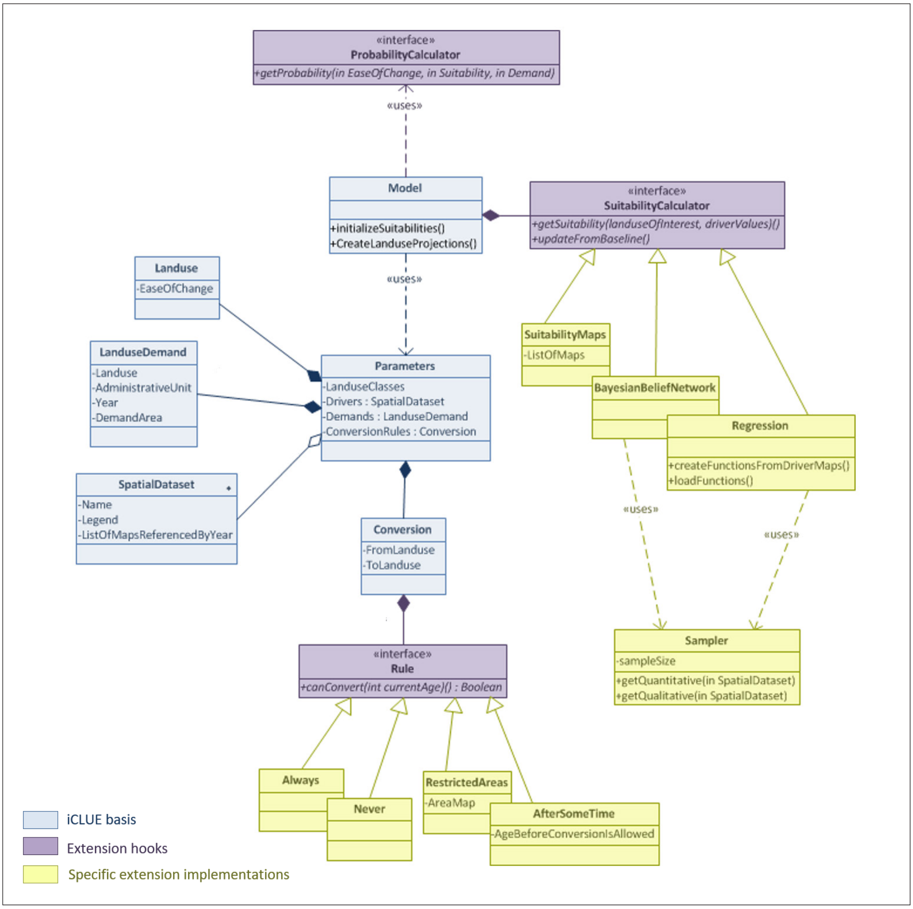


Figure 3-7 - UML diagram of the main classes of the iCLUE model.

During the scoping phase the modellers explained the need for flexibility for the suitability method and the conversion rules. These requirements have a central role in the architecture of the model as extension hooks for which several implementations were made based on the requirements of different modelling cases (see Figure 3-7).

3.3.2 Model implementation

The logical calculation process of the iCLUE model as described above is illustrated in Figure 3-8. Conceptual model innovations include:

- Demand deviation validation per land use type;
- Sampling from land use probability distribution;
- Probability calculation;
- Using sigmoid function to calculate demand weight;
- Using shocks on the demand weight, in iterative matching of allocation and demand.

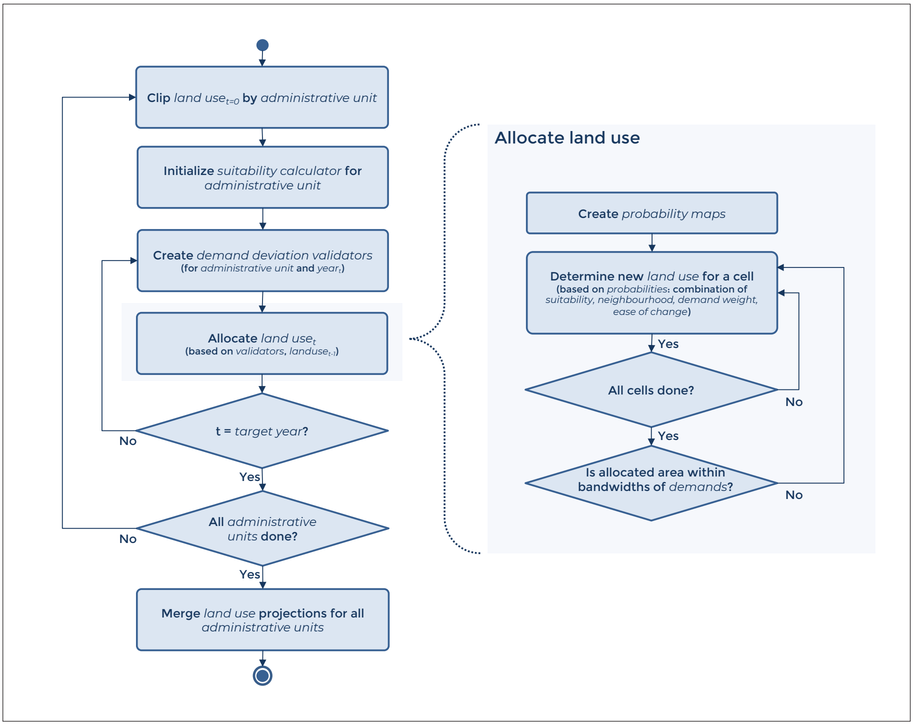


Figure 3-8 - UML activity diagram of the logical calculation process of the iCLUE model.

These innovations are described below.

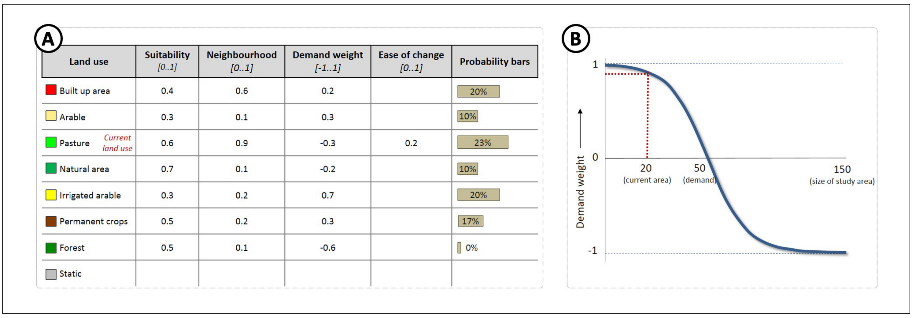
The allocated land use area does not necessarily match the demand exactly. The user can specify the allowable deviation per land use class and indicate whether it is an absolute areal deviation (in number of cells, or hectares), or a relative areal deviation (in percentage of the total demand). Typically land use types covering large areas are given a relative deviation while land use types covering small areas use an absolute deviation.

During allocation each cell is appointed a single specific land use type. In iCLUE this is based on a sample drawn from this location-specific probability distribution for including stochastic behaviour (Mas et al., 2014) and a fair representation of the probability distribution.

Land use probabilities are calculated by summing the suitability, neighbourhood and demand weight. The probability for the current land use is calculated by also adding the ease of change. Each determinant is represented by a number between 0 (low) and 1 (high) with the exception of demand weight (Figure 3-9 A).

$$\text{Probability}_{i,t,lu} = \text{Suitability}_{i,t,lu} + \text{Neighbourhood}_{i,t,lu} + \text{Demand Weight}_{i,t,lu} + \text{Ease of Change}_{i,t,lu}$$

$$\text{Probability fraction} = \frac{\text{Probability}_{i,t,lu}}{\Sigma_{lu}\ \text{Probability}_{i,t}} * 100\%$$



Land use	Suitability [0..1]	Neighbourhood [0..1]	Demand weight [-1..1]	Ease of change [0..1]	Probability bars
Built up area	0.4	0.6	0.2		20%
Arable	0.3	0.1	0.3		10%
Pasture *Current land use*	0.6	0.9	-0.3	0.2	23%
Natural area	0.7	0.1	-0.2		10%
Irrigated arable	0.3	0.2	0.7		20%
Permanent crops	0.5	0.2	0.3		17%
Forest	0.5	0.1	-0.6		0%
Static					

Figure 3-9 - A: Example probability calculation. The ease of change is added only for the current land use ('pasture'). The last column 'probability bars' displays a probability fraction distribution and is used for drawing a sample. **B: example sigmoid function which is used to calculate the demand weight.** The current area of the land use is 20 areal units, while the demand is 50 (sigmoid crosses the 0-line at the demand value), requiring a strong increase in the area.

The difference between the future demand and the actual area covered by a land use type is used to derive the demand weight. The bigger the difference, the bigger the weight, derived from a sigmoid function between −1 (the actual area has to decrease strongly) and 1 (the actual areas has to increase strongly) (Figure 3-9 B).

The model uses iterations to find a solution fitting within all tolerance limits. In each iteration the probabilities are adapted towards reducing the mismatch in demand and allocation. The bigger the mismatch the larger the adaptation. Per iteration a maximum of 5% is added or removed from the probabilities for land use classes that do not pass the tolerance limit validation.

If the moving average of the deviation between iterations becomes too small (<5% over 10 iterations) the pseudorandom number generator Mersenne Twister (Matsumoto and Nishimura, 1998) redefines the probability of land use classes with unmatched demands within the range of 95%–105% of the original probability value. Mersenne Twister is also used to break flip-flopping -or continuous switching of allocated land use-, again by redefining the probability within the 95%–105% range.

3.3.3 Approach validation

Sofar iCLUE has been applied in 4 independent projects by 8 individuals from various organisations across the world. The 8 model operators have experience with using other CLUE versions. These applications vary in resolution, size of the study area, number of projected years, number of land use classes, number of drivers and complexity of the conversion rules. Detailed descriptions of these applications and the observations on the use of iCLUE are given below.

3.3.3.1 Sustainable mineral exploitation

For sustainable exploitation of minerals in Europe, the current mineral requirements of society must be met without compromising the ability of future generations to meet their own needs. Accordingly, within the framework of the EU Horizon2020 MINATURA2020 project, potentially exploitable mineral deposits and resources have been assessed against other - both current and future - land uses, taking into account criteria such as priorities for settlements, natural habitats, etc. The iCLUE model was used to project future land use in eight case study countries: Hungary, Italy, Poland, Portugal, Slovenia, Sweden and the United Kingdom. Eleven land use classes were dynamically modelled into the future from 2012 till 2050: forest, arable land with annual crops, arable land with permanent crops, grassland, non-grazed grassland, shrubland, non-grazed shrubland, sparsely vegetated areas, non-grazed sparsely vegetated areas, built-up area, and open pit mineral extraction sites or dump sites. Overall, the most prominent changes are the increase in built-up area (urban sprawl) and the decrease in cropped land. For several case study countries, we see a major increase in shrubland, which can be seen as land abandonment. These patterns are mainly driven by distance to the coast, population density (or global night lights index as a proxy), impervious area and cropping frequency. Below the case study of Portugal is exemplified.

Portugal, the southwesternmost country of mainland Europe, has a total area of about 90.000 km^2. Portugal's northern inland is mountainous with several plateaus indented by river valleys, whereas the south is characterized by rolling plains. Portugal is a significant European minerals producer, especially of copper, tin, tungsten and uranium. For Portugal, a clear segregation in land use change was projected: extensive urban sprawl along the coast, and a succession of inland annual crop areas into grassland and subsequently shrubland, reflecting the process of agricultural land abandonment. These patterns are mainly driven by distance to the coast, population density (or global night lights index as a proxy), impervious area and cropping frequency. GIS data used has a resolution of 100 m^2 with a total of 3470 rows and 5770 columns. 34 drivers were used (Cormont et al., 2016).

"We coded the driver '*accessibility*' as quantitative with values 1, 2 and 3, which we later changed to ordinal with values '*near*', '*far*' and '*very far*' as advised by a colleague statistician since the value 2 is not necessarily two times as far as 1. Instead accessibility could also have been expressed as travel time in hours or distance to in kilometres. A similar case is related to the driver '*aspect*' which runs from 0 to 360°, where 0 equals 360°. The solution used was to qualitatively classify it in '*north*', '*northwest*', 'west', etc. Since all driver files are required to have the same spatial extent, resolution and projection, we developed a small script to process all GIS-data to a given template. Initially we used a coarse spatial resolution to be able to do quick model runs to test effects of demand tolerances and conversion rules, which we later replaced by the targeted spatial resolution. We processed multiple countries using the same drivers, conveniently allowing us to copy the parameters from one country to another. iCLUE runs varied in processing time depending on the size of the country from roughly 10 min to a bit more than 1 h"

3.3.3.2 Biodiversity to mitigate climate change

Tropical forests provide us with foods, fibres and medicines, they filter water and control its flow. They also 'soak up' carbon dioxide from the air, mitigating climate change. Within the EU Seventh Framework Programme project ROBIN, we analysed the impacts of three alternative land use policy scenarios aimed at maximising climate mitigation potential. The projection of these policies was executed with both CLUE and iCLUE. This was done at continental level, covering all 21 countries of South and Meso-America. Eight land use classes were dynamically modelled into the future from 2005 till 2050: forest, shrubland, grazed shrubland, grassland, grazed grassland, cropland for food, feed and fodder, cropland for food with perennial trees or shrubs, and cropland with energy crops (Van Eupen et al., 2014).

"The cell-based sampling of the probability distribution results in a speckled image of allocated land use. In the applications this undesirable effect was prevented by including distance-to drivers, e.g. distance to roads, or distance to edge of forest. This effect could also have been prevented by using neighbourhood functions. To understand the transitions the trace-back tool offered the possibility to see the history of land use changes at a certain location. Even more insight would be gained by showing the probability distribution change through time by location, de-composed to its determinants."

3.3.3.3 Water scarcity in Europe and northern Africa

Water scarcity affects ecosystems and the services they provide to society. In five river basins in Europe and one Moroccan basin the prevalence of, and interaction between, stressors were identified in the context of the EU-funded project GLOBAQUA. Climate change is expected to worsen the situation. iCLUE was used in all six river basins to understand the complex relations between ecosystems and their stressors and to analyse the effects under changing conditions. One of them, the Ebro river basin in Spain, is exemplified below.

The Ebro catchment (over 85.000 km^2) is located in North-eastern Spain and includes Andorra and a small part of France. The basin experiences a Mediterranean climate. Grasslands and coniferous forests dominate in the Pyrenees, broadleaved forests are prevalent in the western mountain regions. The mean discharge has been decreasing in the last decades due to infrastructural works and regrowth of forest. Climate change is expected to worsen the water scarcity problems thereby impacting ecosystems and their services to society. GIS data of a 1 km^2 resolution included 21 drivers such as: employment in different sectors, distances to settlements, river and roads, hydrogeology, elevation, aspect, slope, erosion levels, population, Gross Domestic Product and water use. The CORINE land use map of 2000 was used as a baseline for a projection to 2030. The following land use classes have been modelled: non-irrigated arable land, permanently irrigated land, vineyards, fruit trees and olives, grasslands & pastures, complex cultivation patterns, agriculture with natural vegetation, broad-leaved forest, coniferous and mixed forest, sealed area, transitional woodland (incl. shrub and sclerophyllous vegetation), open spaces with little or no vegetation and water (Huber Garcia et al., 2018). GIS data used has a resolution of 1 km^2 with a total of 313 rows and 527 columns.

“Learning to work with iCLUE is easy. After half-a-day training users could independently parametrize, run and validate the model for other study areas. The possibilities to introduce errors are next to nil. GIS data preparation still requires to use the same spatial extent, resolution and projection and this quite a lot of time. iCLUE runs in less than 10 min”

3.3.3.4 Bangladesh

Bangladesh is one of the least developed countries of the world dominated by rural areas with a total area of almost 150.000 km^2 in the south of Asia. Bangladesh is experiencing an increasing rate of land use change as a result of population dynamics, economic development, climate change, improved accessibility and technological developments in agriculture. For strategic planning and informed decision making iCLUE was used to project future land use under different scenarios. GIS data used has a resolution of 1 km^2 with a total of 520 rows and 718 columns. Drivers include: administrative units, elevation, distance to the main road network, Gross Domestic Product, population density, soil and various climate variables and their projections. The land use map of 2000 was used as baseline for a projection over 30 years distinguishing between: cultivated land, forest, grassland, water bodies, built-up area and unused land (Hasan et al., submitted).

“For this study we wanted to use a well-known and well-accepted model with as little effort and capacity as possible. With a download from the internet and some email assistance we were able to run the model for three scenarios. The evident error messages allowed us to progress without further technical assistance. Initially the model did not find a solution within the tolerances we defined. In order to successfully allocate the demands we set very loose tolerances which we then increasingly tightened in a trial-and-error manner. For our study area and model parametrization iCLUE runs in a few minutes.”

3.4 DISCUSSION

With the new iCLUE model, we minimized operational hurdles that previously made us reluctant to apply the model. We solved these issues in the following manner:

- *There is a dependency on a small amount of experts to apply the model, implicating that the workforce in projects is limited by the availability and preferences of individual* *experts.* To concentrate on the complex endeavour of land use modelling, the operational part of the modelling must be as simple as possible. Through the separation of concerns, the model can be fully run with a self-explanatory single set of parameters and enables users to independently run the model after a very short (about half a day) training.

- *Results are not self-explanatory in relation to the underlying land use change processes.* Land use modelling brings together many different mutually dependent factors. The many built-in data visualisations empower users to disentangle the underlying land use transitions that take place both at cell level and for the study area as a whole. Although the visualisations facilitate analysis the user must have good understanding of land use change processes to correctly interpret the results.
- *Data preparation for, and post-processing of CLUE runs are time consuming.* Since iCLUE only uses a single parameters file, there is no longer a need to manually harmonise a set of parameter files as input. Post-processing into the analysis and visualisation tools is automatically handled by the integrated QUICKScan environment. Less input files and automatic post-processing speed up the cycle of model execution and result analysis. It stimulates to do iterations to improve the modelling results. Just like in CLUE, GIS data is required to all be in the same spatial extent, resolution and projection.
- *Error prone due to the many manual actions required for data conversion scripts and tools, the many coding, file naming and file structuring conventions, and manual guarantee of coding consistencies across files.* The automation of the many manual steps in iCLUE makes the whole procedure of data preparation and model run less error prone. The user no longer needs to know how data is transformed and coded and how the separate processes make use of that data. However, the automation also implies that the user does not necessarily has to look into the results of the statistical analysis and thereby might miss out on algebraic insights.
- *Lacking clear warnings and error messages hampering efficient handling of causes.* A syntax and semantic check takes place over the parameters file. In case of incorrectness or incompleteness of the parameters file, an error report with suggestions for improvement is shown.

In addition to the issues forming the rationale behind the development of iCLUE we observed new forms of use emerging. Firstly, the accelerated operation and introduced transparency facilitates the understanding of the underlying processes and stimulates and enables the adaptation of model parameters for subsequent runs. Thereby creating opportunities for interactive use during participatory spatial planning and participatory modelling (Voinov and Brown Gaddis, 2008, Hewitt et al., 2014, Verweij et al., 2016). Secondly, the introduced transparency enhances understanding of modelled land use change processes, opening up new possibilities for methodological innovations for land use modelling. Thirdly, the embedding into a modelling framework enhances flexibility in terms of integrated linkages to other models (e.g. Wagner et al., 2017, Connor et al., 2015, Knapen et al., 2013) and it allows to do further post-processing, e.g. into land use dependant indicators, such as ecosystem services or sustainability indicators, or impact assessment and scenario analysis.

Although we argue that iCLUE is a technical and conceptual improvement over previous versions of the CLUE model, there are also some critical issues:

- Each member of the CLUE model family produces slightly different results. So does iCLUE because of the model innovations (e.g. demand deviation validation per land use type and the sampling from the land use probability distribution). Changes are relatively small and do not influence the overall interpretation.
- iCLUE allocates demands for each time step (year). If demands are not met in a time step, the model stops execution and displays a warning explaining why the model halts. When demands are met within tolerance limits the model does not automatically show how far off the results are. This deviation could be helpful in fine-tuning the tolerances. The deviation can currently be analysed by performing manual diagnostics.
- Including a random number generator inhibits reproducibility. However, various model runs using the same input parameters result in similar output patterns. This type of model is targeted at scenario studies in which the focus is on patterns of change rather than exact predictions for each location.
- So far all applications used regressions to determine suitabilities. Try outs with Bayesian Belief Networks -and especially the interactive visualisation of belief bars- show that these are likely to improve the transparency of the suitability statistics. Bayesian Belief Networks are also a useful tool to include stakeholder knowledge, non-spatial information (e.g. policies and management options) and decision hierarchy (Celio et al., 2014, Hewitt et al., 2014, Mahamane et al., 2017). However, further developments are required to fully automatically derive Bayesian models with probability tables from driver-samples as Bayesian ‘evidence’.
- Currently the trace-back tool displays land use through time for a given location (see Figure 3-5 B). The trace-back tool would profit from additionally showing graphical overviews of probability bars for each land use type through time and the contribution of each determinant in the total probability.
- iCLUE does not and cannot address all issues related to land use modelling. Verstegen et al., 2014, Celio et al., 2014 and Van Vliet et al. (2016) provide methods for calibrating and validating land use projection models to improve the allocation.

Future improvements could seek links with other types of models to improve e.g. agency (Grashof-Bokdam et al., 2017, Murray-Rust et al., 2014, Ralha et al., 2013) or representation of process-based information.

During the development of iCLUE the authors worked intensively together in building the software. Amongst the team, this co-creation process built trust in the model software and its usage, as each member reviewed the work done by the other team members.

The iCLUE source code is freely available (https://doi.org/10.5281/zenodo.1100980) under EUPL[6] and as part of the QUICKScan modeling environment. QUICKScan can be obtained via www.quickscan.pro. iCLUE can directly be included in java based software, or wrapped in scripting languages like R[7] or Python[8] for further analysis.

AUTHOR CONTRIBUTIONS

PV, KK, MvE, AC, SJ and JtR designed the research, KK, MvE, PV, AC, WdW and IGS designed the model, PV, JtR and WdW developed the software, MvE, PV and AC ran and tested the model, PV, AC, SJ, KK wrote the paper and MPS raised funds and commented on the paper.

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[6] https://joinup.ec.europa.eu/sites/default/files/custom-page/attachment/eupl_v1.2_en.pdf

[7] https://www.r-project.org/

[8] https://www.python.org/

Chapter 4

QUICKSCAN AS A QUICK AND PARTICIPATORY METHODOLOGY FOR PROBLEM IDENTIFICATION AND SCOPING IN POLICY PROCESSES

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HIGHLIGHTS

- QUICKScan speeds up the exploratory phases of the policy cycle.
- It creates a joint understanding through a participatory process.
- Integrate quantitative and qualitative scientific-, local- and tacit knowledge.
- 70 workshops in 20 countries: diversity of problems and spatial and temporal scale.

ABSTRACT

Policy making is required in cases in which a public good needs to be either maintained or created, and private or civil initiatives cannot deal alone with this. Policy making thus starts with a phase of problem identification and determining whether there is a problem that needs to be dealt with. Rapidly evolving contexts exert influence on policy makers who have to take decisions much faster and more accurately than in the past, also facing greater complexity. There is a need for a method that lowers the lead time of the exploratory phase of the policy cycle. At the same time the method should create a joint understanding of the most important interactions. This paper proposes QUICKScan, a method, process and spatially explicit tool, to jointly scope policy problems in a participatory setting, investigate the most important interactions and feedbacks and assesses the state of knowledge and data of relevance to the problem. QUICKScan uses strongly moderated participatory workshops bringing together a wide range of stakeholders relevant to the policy issue. These moderated workshops jointly build an expert system in a spatially explicit tool using functionality of bayesian belief networks, python programming, simple map algebra and knowledge matrices, with a strong focus on visualization of results. QUICKScan has been applied in 70 different applications in a range of different policy contexts, stakeholders and physical locations. Through these applications participants were able to internalize the knowledge that was usually handed to them in briefs and reports, to develop a joint understanding of the main interactions and their link to impacts and to develop a problem statement and solution space in a reduced lead time. Ultimately, QUICKScan demonstrates another role of science, not solely as a knowledge production, but also facilitating the knowledge consumption.

4.1 INTRODUCTION

It has become clear that it is extremely difficult to have societal and economic development without compromising environmental sustainability, which is the eco-social system that humanity maintains and depends upon (PEER, 2010). Drivers of change, such as demographic development, resource depletion, loss of ecosystem services, natural hazards and climate change have become threats to social and policy issues such as water- and food security, social wellbeing, energy security and a prosperous economy (United Nations, 2014). The spatial distribution, scale and complexity of the interactions between these issues and drivers represent a challenge for policy makers, spatial planners, researchers and the public at large. While the scientific community tries to find testable explanations between drivers and issues, the public sector sets societal goals such as sustainable development, nature conservation and environmental quality. Spatial planners organize the distribution of human activities across territories of different scales according to an overall strategy (United Nations, 1987). It is the role of policy makers at different levels of government to facilitate and encourage mitigation, adaptation and prepare for likely changes by achieving the level of transparency needed to obtain the public support for taking far reaching measures. For both it is a challenge to formulate initiatives which bring together as many, often conflicting, interests as achievable.

Policy making is required in cases in which a public good needs to be either maintained or created, and private or civil initiatives cannot deal (alone) with this. Policy making is typically conceptualized as a cyclical process (Figure 4-1), that goes through different stages of analysis, design of policy options, implementation and review (Zamparutti et al., 2012, Jansen et al., 2007, Winsemius, 1989). Especially in the first stages of problem identification, evidence gathering and design of different options, science has a role to play, and is traditionally seen as the supplier of evidence (Gibbons et al., 1994, Sterk et al., 2009), that can then be consumed by policy makers.

As an example of a step in the policy cycle and its relation to evidence, Impact Assessment (IA) is a decision support method to ensure that sustainability concerns are taken into consideration by identifying a problem, setting an objective and choosing between alternative options to reach that objective. An evidence based IA is becoming increasingly important in societal decision making and policy development (Turnpenny et al., 2009). It enables policy makers, decision makers and spatial planners to maximize benefits to society and minimize unwanted side-effects. The analysis should cover the impacts in the targeted domain and regions, as well as unintended impacts, side effects and trade-offs in adjacent domains and regions.

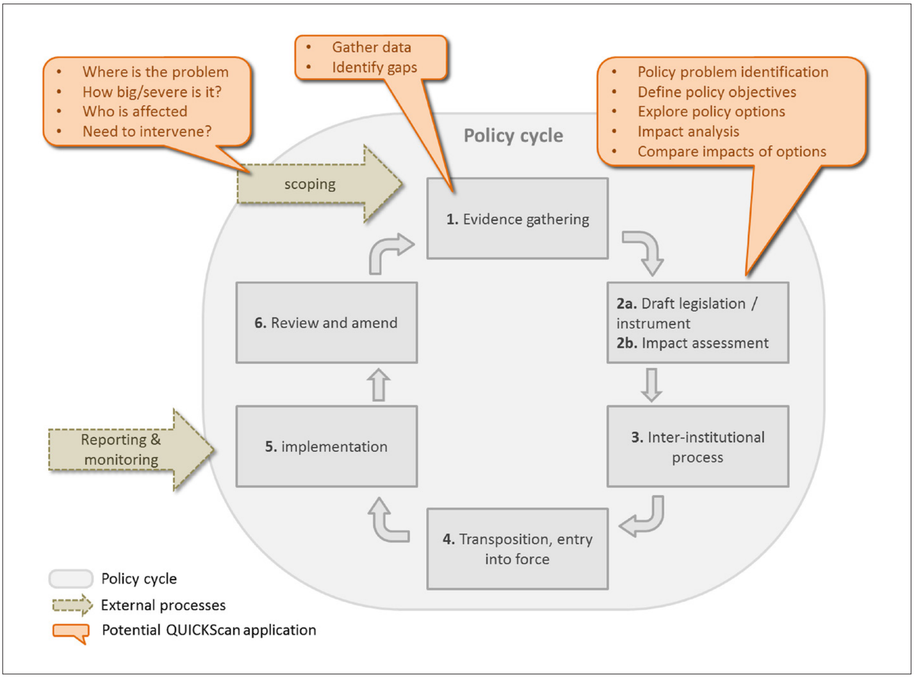

Figure 4-1 - Policy cycle of dealing with a problem.

Rapidly evolving contexts exert influence on policy makers who have to take decisions much faster and more accurately than in the past. Current practise of IA is often found to be '*an expensive and time consuming regulatory hurdle*' (Pope et al., 2013), while also methods of evidence provisioning in science through modelling or experimental work are time and resource intensive. Often by the time the evidence is produced through scientific methods, the (policy) context has changed, and is concerned with other items (Adelle et al., 2012). "Increasingly science is expected to support decisions by providing urgent answers to complex, uncertain questions. Typical complaints are that science takes too long, or provides unreliable answers that turn out to contradict stakeholders' experiences resulting in stakeholder disappointment. Stakeholders must necessarily work together to define the right question, and delineate how approximate the answer can be, and still be useful. Scientists must define how vague the question can be, and still be studied. Both require certainty − of expectations for a given question, and of reliability of the answer (contingent on current understanding)" (Guillaume and Jakeman, 2012). Where the integral character of policy making and planning hampers a responsive adaptation to new circumstances a demand for more agility exists. Especially steps requiring 'scientific evidence' and 'consultation with external stakeholders' need to be streamlined into the process.While policies are often conceived on the basis of current trends, there is a growing need to improve anticipatory thinking to capture both the future risks and opportunities (European Commission, 2013a, European Commission, 2013b).

In response to the demand for shorter lead times and more agility, scientific methods have been developed for the early phases in policy making and spatial planning, which are exploratory by nature. In these phases, problems and stakeholders are identified, objectives are set and alternative options (i.e. scenarios, (spatial) strategies) defined. Scientific methods available in the exploratory phase are expert groups (European Commission, 2010), Rapid (Participatory) Appraisal (McCracken et al., 1988, Ison and Ampt, 1992), qualitative deliberative participatory methods (Davies and Dwyer, 2008), preference elicitation (Kodikara et al., 2010, Aloysius et al., 2006) or fuzzy cognitive mapping (Kosko, 1986, Jetter and Kok, 2014). These methods result in storylines, preference functions, score tables, or concept maps showing linkages and directions of influence between major problems, drivers, valuations and other concepts. However, additional steps such as modelling are required to quantify impacts and use those to iterate, fine tune or improve preferences, options and storylines. Ideally, this would be done during the participatory sessions, resulting in an understanding of the influence of key drivers on key outputs as perceived by the stakeholders engaged in the participatory process. Thus, there is a need for a method that lowers the lead time of the exploratory phase of the policy cycle and that results in a joint understanding of the most important interactions in a participatory setting, as a way of capacity building across actors.

This paper introduces a method, process and spatially explicit mapping and assessment tool, named QUICKScan, to jointly scope policy problems in a participatory setting, investigate the most important interactions and feedbacks and assesses the state of knowledge and data of relevance to the problem (see Fig. 1). The paper demonstrates the usability and usefulness of the QUICKScan through an overview of a large number of applications with different policy contexts and questions considered across a range of spatial and temporal scales.

4.2 METHODS

4.2.1 Overview

QUICKScan is a participatory modelling method (KorfMacher, 2001, Voinov and Brown Gaddis, 2008) that links stakeholder- and decision maker knowledge and preferences to available spatial- and spatio-statistical data, and is designed for group use, e.g. in a multi-stakeholder workshop setting.

During such workshops an iterative approach is followed, starting with simple (knowledge-based) rules (equations) and step-by-step adding complexity, using the participants' interpretation of model-results. Results are visualized in interactive maps (McCall, 2003, Jankowski, 2009), and summary charts and trade-off diagrams. Successive iterations are used to 1) improve the quality of the model, 2) try out alternative (spatial) plans and policy options and, 3) include different stakeholder values and perspectives.

Knowledge of the participants is captured in a computer program and encrypted in a conditional (e.g. 'if A then B'), mostly qualitative form, as is common in expert systems; humans tend to represent their knowledge qualitatively rather than quantitatively (Newell and Simon, 1972) (e.g. '*Mary is small, but Clarissa is smaller*' as opposed to '*Mary is 1.68 m and Clarissa is 1.62 m*'). The computer program can show how a conclusion is reached by visualising the chain of knowledge and the data. The knowledge is separated from the reasoning and from the data on which it is applied. (Negnevitsky, 2002, Buchanan and Smith, 2003, Yuchuan Chen et al., 2012).

4.2.2 Process

Each QUICKScan follows a number of logical steps: *scoping*, workshop *preparation*, the *workshop* itself and *reporting* on results and observations (Figure 4-2).

The scoping phase starts with clarifying the decision context (Gregory et al., 2012) and defining the objectives. It ends with the formulation of key questions by the client. Examples of key questions are: '*what are Ecosystem service impacts of ecological reconstruction plans? Which are relevant ecosystem services?* ', or '*what management options are available for increasing agricultural production? Which ones are acceptable?* '.

In the *preparation* phase participants are identified, evidence and potential alternatives are gathered and data is collected. There are various techniques to identify participants. The choice of a specific participant identification technique strongly depends on the project context, the project phase and the available resources (Luyet et al., 2012). To ensure inclusion of all relevant stakeholders, to avoid bias and to minimize the

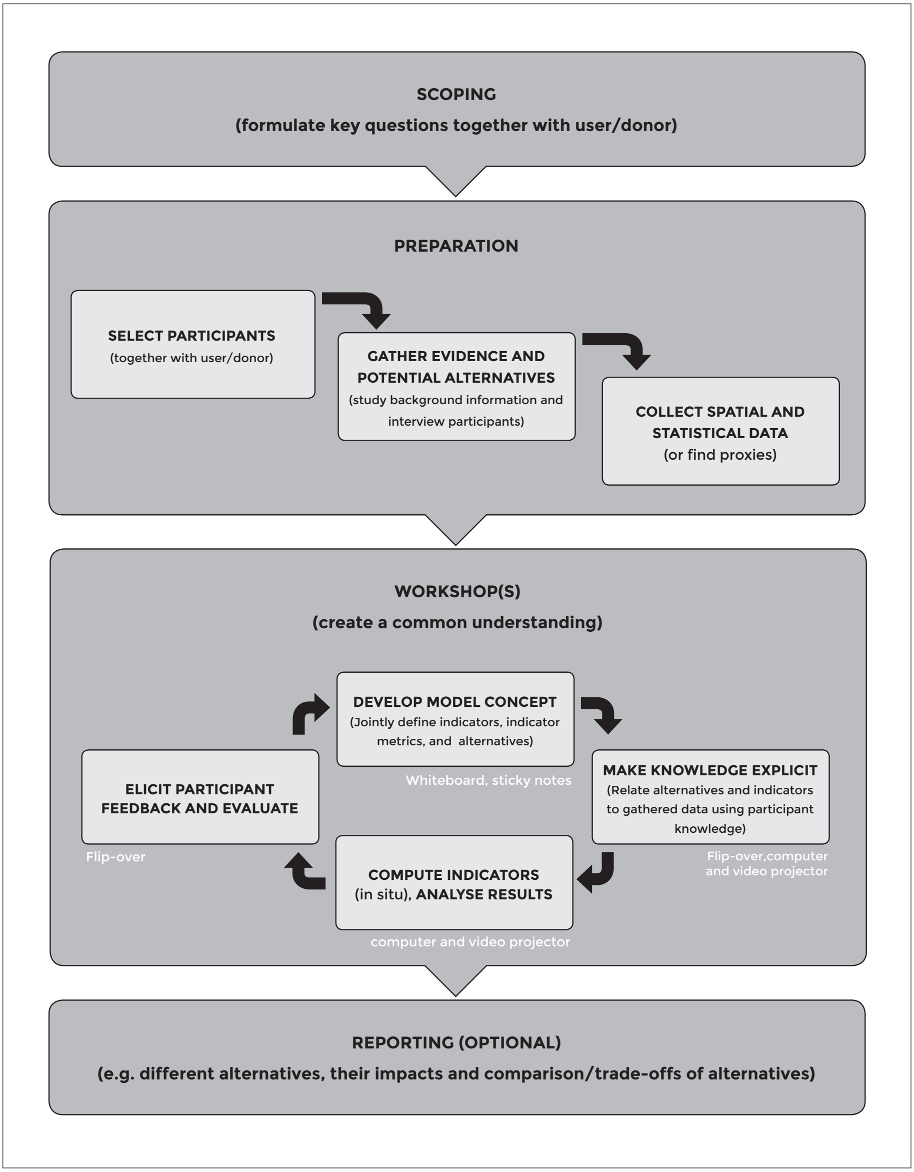

Figure 4-2 - Sequence of QUICKScan phases: scoping, preparation, workshop and reporting. The workshop phase is characterised by many iterations in which each iteration adds complexity. Several tools are used to support knowledge exchange between participants: whiteboard, post-it, flipchart, computer and video projector.

complexity of the process, we identify key participants together with the donor and problem holder. Subsequently additional participants may be identified by consulting the key stakeholders. Typically we aim at a variety of participants including decision makers, interest groups, topic experts and data experts that have different attitudes, conflicting perspectives, power, urgency and proximity to the key question (Mitchell et al., 1997).

Evidence is gathered by studying background information and interviewing participants aiming at new ideas (Ampt and Ison, 1989, Ison and Ampt, 1992). Together with the background information these semi-structured interviews provide the basis for data collection as the interviews provide insight on participant perspectives on criteria, consequences, trade-offs, alternatives, estimations and perceived values. Data may refer to bio-physical (e.g. soil, elevation), classified Remote Sensing (e.g. land cover), census data (e.g. population density), results from model runs (e.g. climate projections), or spatial plans. If required data are not available a proxy might be used (e.g. when in need of information about accessibility of forests, e.g. for timber harvesting, slope may function as a proxy).

The *workshop* is setup following iterations of *model conceptualisation*, *make stakeholder knowledge explicit*, *compute indicators* and model *evaluation* based on the resulting indicators. The evaluation is used to adapt the model in the successive iterations.

- *Develop model concept*—The participants jointly inventory relevant indicators, indicator metrics and alternatives. i.e. the indicator 'timber production' might be measured qualitatively in terms of {low, medium, high}, or quantitative in tons/hectare/year. That indicator 'timber production' might be derived following different alternatives, such as: from land cover map, or from forest management, growing stock and forest type. Other alternatives might include: timber production in the current situation and in a possible future (e.g. from spatial plans, or climate projections); or compare different stakeholder perspectives.
- *Make stakeholder knowledge explicit*—The participants relate indicator concepts to available data by building a causal chain of participants' knowledge. Their knowledge can be a mix of formal science, local and indigenous knowledge (Pert et al., 2015, Thaman et al., 2013), tacit knowledge, assumptions and perceived values.
- *Compute indicators*—The tool operator calculates indicator maps and summary charts as requested by the participants (e.g. average per administrative unit, or trade-off of a number of indicators per administrative unit).

- *Evaluate*—the participants evaluate the performance of the indicators in a single alternative, or evaluate the performance of summaries of indicators across alternatives. The evaluation might trigger another iteration in which participants identify additional indicators, perspectives and refining knowledge.

After the workshop has ended the results and the participants' evaluations are documented in a report to secure progress, and establish agreements and disagreements.

4.2.3 People

Several people are involved in a QUICKScan workshop with the following roles:

- Participants—decision makers, interest groups and topic experts.
- Discussion facilitator—guiding the group with a focus on how things are discussed and securing that tasks are done and specified problems are addressed.
- Modeller—analysing the participants' discussion, extracts spoken knowledge and transfers it into modelling terms.
- Computer program operator—puts modelling terms into the computer program and, initiates calculations, shows maps and summary graphs, keeps it all organised and ensures every participant understands the model. Often the role of operator and modeller are combined in one individual.

4.2.4 The tool

The QUICKScan computer program encompasses a modelling environment that needs to be filled with spatial and statistical data during the preparation phase. The tool is not restricted to a specific geographic location or spatial resolution. Knowledge rules, capturing participant knowledge, are used to combine data and derive indicators. Typically the rules use classifications to describe quantitative data and typologies to give qualitative data meaning. Rules may be linked together to form a chain of rules. Alternative (chains of) rules are used to capture different options. Derived data from alternatives can be aggregated (e.g. by administrative units, or biophysical units such as catchments, or climatic zones) to be displayed in tables and charts for overviews (Figure 4-3). Additional functionality is listed in Table 4-1.

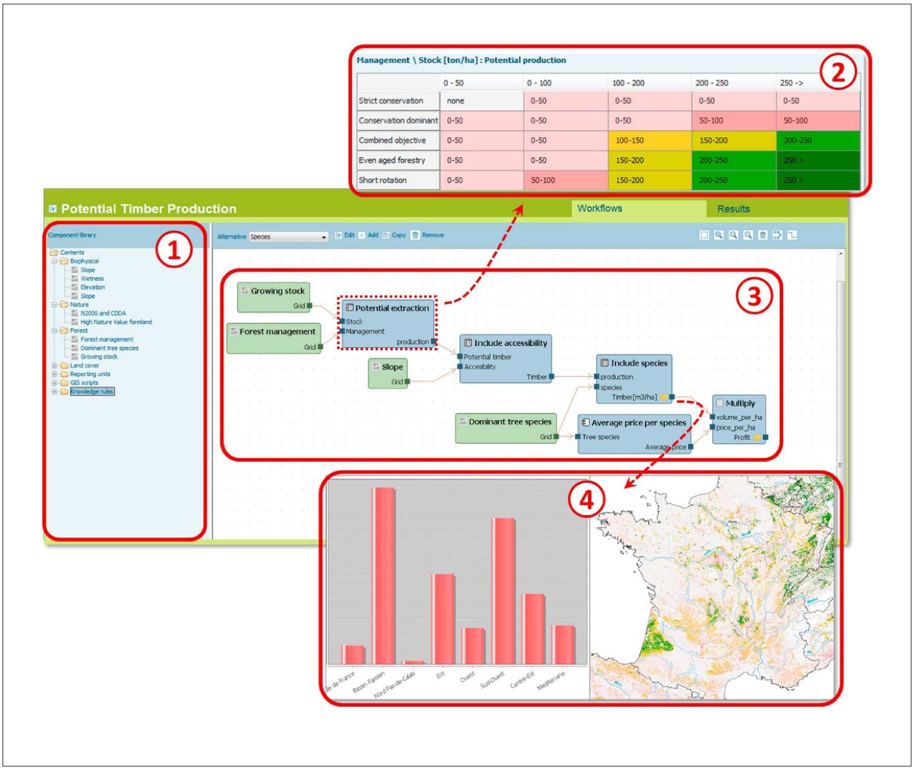

Figure 4-3 - Screen shot compilation of the QUICKScan tool. A typical QUICKScan exercise starts by populating the system's data and rule library '1' with spatial and statistical data relevant for the study (e.g. elevation and forest management). '2' is an example of an if.then.else rule defining potential timber production based on the growing stock and forest management. Data and rules are dragged onto the canvas and linked together forming a chain (see '3'). Rules are applied to the data to create maps ('4'). Results of alternative chains may be compared in aggregated bar charts (e.g. potential timber production profit per administrative unit, or climatic zone).

Table 4-1 - Listing of software functionality and its rationale.

Function	Rationale	Description
Standardisation	Bring all indicators in the same domain space.	Standardize quantitative and ordinal data between 0.100.
Spider diagram	Trade-off analysis between indicators, alternatives and regions.	Display multiple indicators of multiple alternatives in a single spider. Each indicator is standardised before display.
Linked maps	Facilitate the visual comparison of several indicator maps.	Show multiple driver and indicator maps in separate, but spatially synchronized windows. Zooming and panning in one map makes the other window follow. Moving your cursor on one window makes the cursor in the other maps follow.
Difference map	Compare alternatives.	Highlight the differences from two alternatives that specified the same indicator (e.g. different times, or with different assumptions).
Difference chart	Compare alternatives.	Show areal loss and gain between two alternatives.
Bar chart	Compare alternatives and regions.	Show indicator scores summarised per spatial unit (e.g. administrative units) and alternatives.
Sustainability limits	Show how sustainable a location, or spatial aggregation is from a limit. Either below, or above the limit.	Sustainability limits include thresholds, standards and policy targets (Paracchini et al., 2011). Limits can be defined per indicator and may vary per spatial unit (e.g. administrative unit, or biophysical stratification).
Weighted average	Create a composite indicator (for Multi-Criteria Analysis).	Do a weighted sum on two or more indicators. The indicators are standardised before summing them up.
Bayesian Belief Networks (Stelzenmueller et al., 2010, Haines-Young, 2011, Gret-Regamy et al., 2013)	Support reasoning with uncertainties.	Include uncertainties in the knowledge rules and visualise the propagation the (un)certainties.
ArcPy	Support map algebra (Burrough et al., 1998).	A set-based algebraic language to manipulate geographic data, such as subtraction, multiplication, or shortest path analysis.
Tracing	Model transparency. Clarify the causal pathways from drivers and (management) options to the impacts.	From every location in an indicator map the chain of reasoning can be shown following the chain of participant knowledge and data. The path of reasoning is location specific. This tool is commonly used to iterate and tune specific causal relationships.

4.2.5 Tool development process

The development of the QUICKScan started with a *scoping* phase in which the strategic aims, short term objectives and boundaries were set. The development process focused on users and their needs. User involvement was organised by identifying several sounding boards in order to gain: mutual understanding, insights in the user needs and support from the targeted communities. The different sounding boards had different meeting frequencies depending on their role.

The QUICKScan *concept* was shaped via one-on-one semi-structured interviews (Wilson, 2013) and workshops with the sounding boards. This conceptualisation phase resulted in guidance on the workshop process and a software concept in terms of wire frames and a technical architecture. 'Wire frames' are prototypes addressing the layout of a screen and deal with information, structure, relationships between information and flow between screens (Verweij et al., 2014a).

The actual *software development* followed an agile approach with a sequence of time-boxed activities: design, develop, test, deliver, elicit feedback and the planning for another iteration (Verweij et al., 2010a, Verweij et al., 2010b). After several iterations we'd built enough functionality to start using it in actual workshops. Each workshop provided insight on new software functionality to build and deepened and broadened the guidance on the *workshop process*.

4.2.6 Approach to evaluate QUICKScan performance

The findings described in this paper are based on an analysis of two sources of information and data:

1. QUICKScan has been applied in a multitude of situations over the past few years, all with some policy dimension and with a diversity of problems, options considered and spatial and temporal scale. These applications were prepared and facilitated by the author team and some others over the past years. Strategic reflection occurred with representatives of the European Environment Agency over the years to specify the steps in the process and organisation required to reach the expected outcomes. All these applications represent a process of learning by doing and gradual refinement of the approach.
2. Next to these applications, feedback from participants was collected after the workshops, in some cases in structured formats, in other cases by discussion and reflection. The feedback from participants is summarised below to explain aspects of the functioning of QUICKScan and highlight strengths and weaknesses. The feedback of participants has also been used in improvements of the methodology.

4.3 RESULTS

4.3.1 Overview

Since 2010 successive versions of QUICKScan have been applied in approximately 70 workshops in 20 countries (see Annex II), e.g. China, Romania, Darfur, Hungary, Brazil, France and the Netherlands. More than 40 were in a setting with 5–30 participants. The remaining applications have been done by an individual −usually scientist– as a desk study with regular consultations with fellow scientists and/or stakeholders on results and modelling approach. The participatory workshops varied in turnaround time from 3 h to 25 days. The latter involved 5 workshops of 5 days each with a time lag of 3 weeks between each consecutive workshop. The shorter workshops were explorative, while the longer ones focused on getting more accuracy into the assessment. Most of the workshops took a single day. The application domain ranges from environmental planning, ecosystem service assessment, sustainable management, natural capital and green infrastructure to crop production, water management, outdoor recreation, nature development, land use restoration and mineral exploitation. The scale of the applications varied from local to continental with a spatial resolution from 5 × 5 m^2 to 1 × 1 km^2. Most applications have been carried out at regional, national and continental scales with a resolution ranging from 100 × 100 m^2 to 1 × 1 km^2. In the following paragraphs results from three different workshops are described that vary in objective, duration and number of participants.

4.3.2 Sample result 1, explorative assessment – potential timber production of France

In the context of the EU Biodiversity Strategy to 2020 Member States map and assess the state of ecosystems and their services (Braat and de Groot, 2012)in their national territory with the assistance of the Commission (European Commission, 2011) to help decide on what ecosystems to restore with priority where (Maes et al., 2013). 17 Member States were trained in mapping ecosystem services (Braat et al., 2015, Pérez-Soba et al., 2015). The description below illustrates the mapping of a single ecosystem service by France.

During a three hours session a policymaker, an expert on Ecosystem Services and a GIS data expert of France set out to map estimates of '*potential timber production*' supported by a QUICKScan modeller. Initially they explored available maps of France accompanied by storytelling to get a shared understanding of the location of forests, the circumstances under which they grew and the earnings of selling the timber. Maps included: CORINE land cover (EEA, 2013), forest management (Hengeveld et al., 2012), the road network for accessibility to harvest timber, and climate zones (Metzger et al., 2005) influencing growth rates.

The participants discussed the metric to use for measuring the amount of timber production, including ordinal qualities (‘*a lot*’, ‘*moderate*’, ‘*little*’) and quantities in tons/hectare/year. Given the objective, data availability and time availability they chose to use quantitative ranges expressed as ordinal qualities (‘*<50*', '*50-100*', ‘*100-200*', ‘*200-300*', '*>300*' tons/hectare/year). Iteratively the participants developed four alternatives: 1. Map timber production directly from CORINE land cover; 2. Map timber production based on growing stock (EEA, 2014) and forest management; 3. Include accessibility using slope as proxy under the assumption that too steep places are unfavourable to harvest; 4. Include tree species (Brus et al., 2012) to correct for species characteristics influencing the extractable net timber. In the last alternative the average species price per ton was used to calculate the profits per administrative unit for all of France. Figure 1-9 shows part of the rules forming the model as created by the participants.

The participants assessed their modelled results positively using their personal knowledge and official reports with statistics per administrative units as comparison. The monetary valuation was evaluated as a coarse proxy. The government officials clarified that the experienced learning-by-doing (Gavrel et al., 2016) created a much deeper understanding than what they typically get from written, or spoken form. This workshop demonstrated how the Member State can map ecosystem services to help decide on what ecosystems to restore with priority, and where. The workshop clarified the mapping expectations of the European Commission and it enabled the participants to produce additional requested maps independently.

4.3.3 Sample result 2, participatory model development – wetland management in the Chinese Yellow River Delta

The Yellow River Delta (YRD) is located between Bo Sea Bay and Laizhou Bay in China. It is a delta with weak tide, much sediment transport, frequent displacements and forms the most complete and extensive young wetland ecological system in China. On the east-Asian migration routes it offers breeding, wintering and stop-over places for many migratory birds, among which are very rare species like the Red-crowned crane and the Saunders’s gull. The YRD is also an important base for aqua-culture and has been appointed as national agricultural development area. The delta faces influences of urbanization, pollution and fragmentation caused by oil development. In recent years regulation of the river course to the delta and decreased sediment loads have led to salinization and a trend of rapid decrease of wetlands. The freshwater wetland area has decreased half in size in the last 20 years, destroying the connectivity and integrity of the wetland ecosystems. The habitats that are used by rare birds are facing the danger of disappearance.

What would be a more balanced water allocation for sustainable development of the wetland nature reserves, dealing with the effects of land use changes and variations in the flooding regime?

During one and a half year 5 10-day workshops were organised with the Yellow River Conservancy Commission (YRCC), hydrological and ecological experts from the University of Najing and the Chinese Academy of Science, Dutch consultants and local stakeholders to define scenarios, spatial strategies, indicators and compare scenario and strategy impacts. Stakeholders were selected by the YRCC based on their dependency of water from the Yellow River and included the Nature Reserve Authority and urban planning of Dongying municipality. Both also representing agriculture and aqua-culture farmers within their territory. Since it was argued that the oil industry predominates all other interests it was decided not to include it in the workshops. Stakeholder presence varied with relevance per workshop.

The study started with an inception workshop resulting in a diagnosis of the problems, defining the boundary conditions and approach of the study in detail, and including indicators for measuring ecological performance. Four additional workshops were planned. In each workshop focus groups were formed with a specific objective, such as the definition and refinement of scenarios, spatial strategies, ecological qualitative rule-based modelling and hydrological modelling (to be denoted as water models). During each workshop the focus groups worked in daily iterations. At the end of each day each focus group presented their progress for plenary discussion and acceptance by officials.

In the first workshop sessions were organised to: 1) define scenarios, spatial strategies and indicators based on the proposals by YRCC, 2) do an inventory of required available spatial data, 3) choose water management options and, 4) model the ecological effects based on expert rules. In consecutive workshops scenarios, spatial strategies and the knowledge rules were refined.

Each workshop involved modelling. Due to their complexity and data needs the water models were run once, or twice during a workshop. At the start of a workshop parameters for a scenario (water volume per unit of time) and spatial strategy (location of dams) were chosen to be fed to the models. Resulting ground water level and flood duration maps were discussed afterwards.

The semi-quantitative ecological model was built with the stakeholders keeping the targeted indicators constantly in mind and using those as a starting point for back reasoning the causal relationship from habitat suitability towards the inputs generated by the water models (Eupen et al., 2007). The ecological know-how was gathered and implemented during the workshops and included the definition of ecotope-, vegetation and physiotope typologies and rules for vegetation development. During a daily session multiple iterations of ecological model adaptation, execution and result analysis were made.

During the workshop the participant awareness of possible and feasible water allocation increased. Later, part of the wetland nature reserve was given the Ramsar status as result of this study (Ramsar Convention Secretariat, 2013).

4.3.4 Sample result 2, scientific method development – ecosystem integrity in the Brazilian Amazon

Deforestation and climate change heavily impact the ecosystem of the Amazon rainforest threatening its resilience and the sustainability of many human activities. The notion of Ecosystem Integrity is used as a synonym for intactness, completeness and integration of ecosystems. Land protection may prevent ecosystems and their services to deteriorate from the pressures of agricultural expansion, population growth and wood harvesting. In the Brazilian Amazon land protection occurs in several forms such as environmental conservation, setting biodiversity priority areas and the delineation of indigenous lands. Still, the effects are not clear as understanding of the ecosystems is incomplete and responses to human actions are highly uncertain.

Bayesian Belief Networks (BBN) are models that probabilistically represent correlative and causal relationships among variables. BBNs have been successfully applied to natural resource management to address environmental management problems and to assess the impact of alternative management measures. While BBN's are used to study results from deliberative participatory questionnaires linked to GIS-data (e.g. Gret-Regamy et al., 2013) and in preference elicitation methods with a very little amount of spatial entities (e.g. Haines-Young, 2011), few studies have fully integrated BBNs and GIS and explored the resulting benefits (Stelzenmueller et al., 2010). By training the probabilistic relationships using field data, Remote Sensing data and GIS data the BBN can provide information on the ecosystems: the ecosystem integrity and their likely response to climate change or alternative management actions. For this study the QUICKScan software was extended with BBN functionality to allow BBN's to be applied on spatial data without the need for time consuming and error prone manual conversion of data between GIS software and BBN software.

During an initial tele-conference ecosystem experts and spatial modellers set up a conceptual map (Novak, 1991) of ecosystem integrity that fit the perceived reality of the local experts. Based on the identified drivers satellite imagery was used to create driver maps of leaf area index (Watson, 1947), Gross Primary Production (Prince and Goward, 1995), evapotranspiration and vegetation cover (Amthor and Baldocchi, 2001). The conceptual map was transferred to a prototype ecosystem integrity BBN-model and was tested against experts' expectations. To test the effect of the inclusion of probabilities mechanistic rules were developed simultaneously. The results of both approaches were compared. The statistical BBN relationships and the mechanistic rules in both models were iterated upon during several tele-conferences with the Brazilian ecosystem experts, Brazilian Remote Sensing experts and Dutch ecosystem modellers and QUICKScan experts. In between the tele-conferences more Remote Sensing- and GIS data was gathered by the Brazilian experts. which was integrated during the tele-conferences. The iterations stopped when the local experts were satisfied with the result and identified the necessity to further tune and proof the model with field data.

The study showed that the concept of Ecosystem Integrity can be mapped using high resolution satellite imagery. Both the mechanistic rules and the BBN resulted in a similar statistical overall distribution of the Ecosystem Integrity. However, the modelled spatial patterns were quite different. The local experts judged the BBN to better fit reality. The BBN model showed more gradual integrity transitions and better positioned the well-known biodiversity hotspots. This study is input for the evaluation of existing and assessment of potential future conservation areas and indigenous lands. The study has been published in Verweij et al., 2014b and Simões et al., 2015.

4.3.5 Participant feedback

At the end of workshops participants were asked to shortly reflect upon how they perceived the workshop. Annex III provides a list of the feedback. Based on this feedback the following topics supporting the approach were extracted:

- The method speeds up the first stages of the policy cycle (Figure 1-7): gaining understanding, finding evidence, identifying data and knowledge gaps and the rapid evaluation of strategies when doing impact assessments.
- The method stimulates to truly work interdisciplinary. Each individual responds to the visualisations of modelled results, which is then discussed by the group.
- This proves it is possible to do an assessment without complex, time consuming and expensive modelling.

Critical reflections include:

- If the stakeholders don't bring in important information you might miss out the effects that make a difference.
- How strong will the evidence-base of the results of a workshop be back in the political arena?
- The method heavily relies on the availability of spatial data. If the data is of poor quality you will also get poor results.

4.4 DISCUSSION AND CONCLUSION

As demonstrated above, the QUICKScan methodology operates on the science-policy interface and can be employed in a range of different circumstances to jointly develop an understanding of the problem and solution space in early phases of policy development. QUICKScan has matured via a large number of applications (Annex 02) to an off-the shelf methodology for policy-science interaction in the exploratory phase of policy development. We demonstrated that the methodology is capable of developing storylines, selecting indicators for measuring the objective achievement, gaining and processing of stakeholder knowledge and jointly create new model(s) as is done in participatory modelling (Voinov and Brown Gaddis, 2008). QUICKScan offers access to spatially distributed phenomena and provides interactive zooming, overlaying, temporal comparisons and many visualization options as used in participatory GIS as part of its tool (McCall, 2003, Jankowski, 2009, Cutts et al., 2011). QUICKScan is applicable in situations that Ittersum et al., 1998 calls explorative; a situation with high uncertainty and high causality.

4.4.1 Three main benefits of QUICKScan emerged during the applications

First, the use of QUICKScan resulted in a reduction of lead time for the problem scoping phase of the policy cycle. In situations with uncertainty on the precise definition of the problem, the implications in different futures and the possible responses in scenarios, it produced rapidly a joint understanding of the main relevant interactions, the impact on indicators and commitment from different stakeholders for future steps. Even if the lead time includes time for data preparation and initial discussions on problem formulation before the main event in the workshop, in all cases it was still faster as a policy officer contracting out extensive research on a specific problem for evidence gathering, or as expert group consultations. As an added benefit the results of the workshops often provided pointers to questions in which more evidence has to be gathered, or a more extensive stock-take of the available evidence is required in further development of the policy options. Such next steps could for example be executed with more detailed system dynamics models including feedback loops.

Second, the application of QUICKScan resulted in a better joint understanding across stakeholders. Rodela et al. (2015) found that QUICKScan performs well on knowledge integration, learning and shared understanding. Particularly in the workshops, participants could be carefully selected to represent different perspectives, while alternatively the approach to the problem could be adapted to the stakeholders available in some applications where there were more representatives from science seeking a thorough understanding from a scientific point-of-view. Participants are forced to listen to another, and jointly develop model input matrices and relationships between variables, on which they all had their views individually, while at the same time getting an understanding of the impact on indicators, that were jointly agreed as crucial reference points. In future discussions and interactions, the stakeholders could thus have more targeted exchanges on what they see as the most relevant interactions and indicators.

Third, participants emphasized the importance of internalizing the (scientific) knowledge and data, as it was before only presented to them in reports, visualisations and publications. By working with the knowledge, explicitly using it in constructing mental models, and defining the relationships between variables, participants obtained an active understanding of the implications of the knowledge and data, as impacts could be visualized, and changes in causal pathways immediately resulted in changes in indicator values. For this not only the mental model itself was crucial (as captured in other methods such as Fuzzy Cognitive Mapping), but also the computation of indicator values as part of the mental model.

4.4.2 The QUICKScan methodology still has some limitations

First, a clear limitation is its link to spatial thinking, as the tool is spatially explicit, which excludes any non-spatial problems. Arguably all problems will have a spatial dimension, however, this may not be as important nor as apparent as the emphasis it receives through the QUICKScan methodology.

Second, if the logical model has to include feedback loops and focuses on explaining the systemic functioning, then more detailed methods based on system dynamics are required. Arguably an interactive and participatory setting of problem explorations is not appropriate for such investigations in systemic functioning, as the system description will likely soon be too complex for all participants to follow.

Third, a possible drawback of the use of this type of flexible model setup is that important drivers may be overlooked if no expertise, or data of the topic is available.

This makes the modelled values of indicators less accurate or incomplete. To some extent this can be remedied by already identifying variables early on in the process from a problem perspective and finding appropriate data at that stage. If data is not available, suitable proxies can then be identified.

Fourth, participants skills and predispositions may be limitative in some cases. Participants do usually not spend a great deal of time on preparation for the workshop, unless actively involved early on, which may not be possible for all participants. Some participants might then not agree with the approach as important details are overlooked from their perspective, or data was not included in the preparation that they believe is crucial.

This all emphases the importance of skilled facilitators who can also mediate the use of technology and spatial data and thinking in participatory settings.

Further extensions of the QUICKScan methodology are continuously being worked on. As an example, a link to a map table is being explored, in which the map table can be used as an interactive tool for some of the discussions by participants and by directly outlining areas on a map (e.g. conservation areas). Also an online platform is continuously build to document the different applications, which could in the future be used to bring data, results and models together, but also allow for continued discussion and exchanges between participants remotely. Finally, more computational tools are being added to the library of functions available in the spatially explicit tool, including land use and land cover projections (Verweij et al., in prep.) and an extension of Multi Criteria Analysis.

In conclusion, QUICKScan speeds up the early phases of the policy cycle by facilitating knowledge uptake and internalization through a strongly mediated participatory process. In these multi-stakeholder processes, science is not merely a messenger of data and knowledge products through reports and briefings, but is integrated together with local and tacit knowledge to reach broader support for policy making. QUICKScan is relevant to the problem and solution scoping phase in policy processes when there is a clear spatial component. Similar methodologies could be developed in other policy processes.

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Chapter 5

CO-DESIGNING A DATA PLATFORM TO IMPACT NATURE POLICY AND MANAGEMENT: EXPERIENCES FROM THE DUTCH CARIBBEAN

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HIGHLIGHTS

- Web-platforms on nature inform the development of regulations and policies.
- Although many data exist, policy makers are constrained by a lack of information.
- Co-design catalyses reciprocity and trust needed for willingness to share data.
- Rather focus on meeting needs of suppliers and users than new technologies.
- Evolving contexts require continuous reflection on ways of working together.

ABSTRACT

To secure the sustainable use of nature, governments track nature's health and develop regulations and policies. Although there is a seeming abundance in observation-recordings, decision- and policy-makers are constrained by the lack of data and indicators, mostly as a result of barriers preventing existing data from being found, accessed, made suitable for (automated) processing and reused, but also due to missing visualisations targeted at answering questions asked by policy makers. This paper explores the process and principles for developing a biodiversity web-platform that informs policy and management on the state and trends of nature, based on experiences with the Dutch Caribbean Biodiversity Database (DCBD). The DCBD supports the assessment of the state of nature and guarantees long-term data availability in an environment that experiences a high turnover in project funds and personnel. Three principles made DCBD's uptake and growth possible: The platform is funded, promoted and used by national and regional policy makers, it simplifies tasks of local management and rapporteurs, and it is continuously being adapted to changing needs and insights. Stronger dissemination of DCBD's narratives in social arenas (e.g. newspapers, social media) may make Caribbean nature and biodiversity more politically and societally relevant.

5.1 INTRODUCTION

There is an increasing awareness that biological diversity is a global asset of great value for current and future generations. At the same time biodiversity is under pressure by expanding human activities. To secure the sustainable use of nature, governments develop regulations and policies, and monitor nature to track the state and trends of its health. The state and trends also provide the evidence base to evaluate the effectiveness of those policies (Miedziński, 2018), to discover environmental implications of the use of nature (Linton and Warner, 2003; Dahl, 1981), and to counter negative effects by developing effective strategies and action plans (Asongu et al., 2018, Addison et al., 2015; Mascia et al., 2014). Tracking the state and trends of nature is therefore also acknowledged in global monitoring and reporting policies, such as the Sustainable Development Goals (SDGs) and the Aichi Targets of the Convention on Biological Diversity (CBD)[9] .

The clearing-house mechanism of the CBD promotes the use of web-platforms[10] to inform and enable the transparent sharing of information with governments and all other stakeholders, including private and voluntary sectors, science and the public at large (UNEP, 1995; Blurton, 2002; Chemutai, 2009). A great number of biodiversity web-platforms exist, including community interfacing platforms aspiring to bring the science and policy-making communities closer together (e.g. Kovács and Pataki, 2016), syntheses of scientific knowledge (e.g. Pérez-Soba et al., 2018), research infrastructures for open-data (e.g. GBIF[11] ; OBIS[12] ; Beck et al., 2014), GIS-data repositories (e.g. Siles et al., 2018) and citizen-science data collections (e.g. Sullivan et al., 2014).

Biodiversity information is based on data that is gathered by a variety of people. Professionals and nature enthusiasts observe and record nature, either by the use of protocols in field studies, remote sensing and monitoring schemes, or via opportunistic sightings (Proença et al., 2017). Despite this seeming abundance in data availability, decision- and policy-makers are constrained by the lack of targeted data and indicators (Geijzendorffer et al., 2016), mostly as a result of barriers preventing existing data from being found, accessed, fit for (automated) processing and reusable (Wetzel et al., 2015, Wilkinson et al., 2016). Existing data cannot be found when it (or the data's meta-data) is not uploaded to a well-known public data-platform. Existing data are also often not accessible, e.g. because of legal restrictions, or sharing reluctance due to scientific

[9] https://www.cbd.int/sp/targets/ , retrieved August 26, 2018

[10] https://www.cbd.int/chm/network/ retrieved August 26, 2018

[11] https://www.gbif.org/ retrieved September 13, 2018

[12] https://obis.org/ retrieved January 21, 2019

publication possibilities. Finally, processing may be time-consuming or impossible if data descriptions (i.e. meta-data) necessary for data interpretation are missing, or if the data are captured in a handwritten scanned document. Stronger collaborations between policy makers and observers are needed to ensure that observation efforts generate data that can be found, accessed and made suitable for processing and presented in such a way that it answers questions asked by policy makers (Addison, 2015).

In order to develop a sustainable data platform it needs to be embraced by its users, both the data providers and data consumers. Many development methods exist (Curcio et al., 2019; Iden and Bygstad, 2018; Huijgens et al., 2017; Verweij et al., 2010) of which two stand out for their iterative, human-centred and action-oriented characteristics: User-Centred Design (Abras et al., 2004), and Participatory Design (Sanders, 2013) or Co-Design (Blomkamp, 2018). In User-Centred Design, end users influence how ICT experts and designers develop a system, whereas in co-design, users collaborate in exploring, developing and testing solutions to shared challenges. Co-design is a form of co-creation in which the initiative lies with a public organisation (Voorberg et al., 2015; Ramaswamy and Ozcan, 2018) and is considered to be useful for solving complex issues and realizing changes. How can the co-design process and principles be used to develop a sustainable data-platform that answers policy questions and impacts local nature policy and management? In this paper we describe our experiences with the development of the web-platform for Dutch Caribbean nature and biodiversity.

5.1.1 A platform for nature in the Dutch Caribbean

Caribbean terrestrial and marine ecosystems are facing major threats and are undergoing considerable change due to overexploitation, fragmentation, pollution, invasive species and climate change (Linton and Warner, 2003; Jackson et al., 2012; Debrot et al., 2018). The Dutch Caribbean economy depends heavily on incoming tourists and tourism in turn depends mostly on the natural capital of the islands, which underpins the importance of a healthy natural environment (ministry of Economic Affairs, 2013). For example, for the island of Bonaire – one of the Dutch Caribbean islands - the direct tourism expenditure is estimated at around 160 million US dollars, while 415 million US dollars was the Gross Domestic Product in 2015 (Statistics Netherlands, 2017).

The Kingdom of the Netherlands has ratified international and regional biodiversity treaties and conventions and made national legislation for the protection of nature and biodiversity in the Dutch Caribbean. These bring about reporting obligations that ask for monitoring and assessment of nature and biodiversity and in case of decline, taking counteractive policy and management measures and tracking its effectiveness. International and regional conventions are: the Convention on Biological Diversity

(CBD), the Cartagena Convention including the SPAW-protocol (Specially Protected Areas and Wildlife in the wider Caribbean region), Convention on the Conservation of Migratory Species of wild animals (CMS), Memorandum of Understanding on sharks, Inter-American Convention for the protection and conservation of sea-turtles (IAC), International Plant Protection Convention (FAO IPPC) and Convention on wetlands (RAMSAR). A European initiative is target 6 'step-up action to tackle the global biodiversity crises' of the European Biodiversity strategy (European Commission, 2011). National strategies and action plans include the Nature Policy Plan for the Caribbean Netherlands 2013-2017 (Ministry of Economic affairs, 2013). The CBD and the national Nature Policy Plan require the implementation of a national biodiversity web-platform ('clearinghouse mechanism'[13]) to provide effective information services to facilitate the implementation of the national biodiversity strategies and action.

The Dutch ministry of Agriculture, Nature and Food Quality has initiated and funded the development of the Dutch Caribbean Biodiversity Database (DCBD) as a nature and biodiversity web-platform for the Dutch Caribbean since 2010. The DCBD is publicly available at: www.dcbd.nl (see Figure 5-1). It is a central knowledge store for policy making to assist nature management and spatial planning and for science to exchange research information. It guarantees long-term data availability in an environment that experiences a high turnover in project funds and personnel. The DCBD allows the user to assess the status of ecosystems, species and threats and pressures, to explore spatial data on biophysical, socio-economic, ecological and topographical properties, to navigate a listing of biodiversity and ecosystem-based information portals and to search in a library for reports, journal articles, documents and raw data.

[13] https://www.cbd.int/chm/ , retrieved October 10, 2018

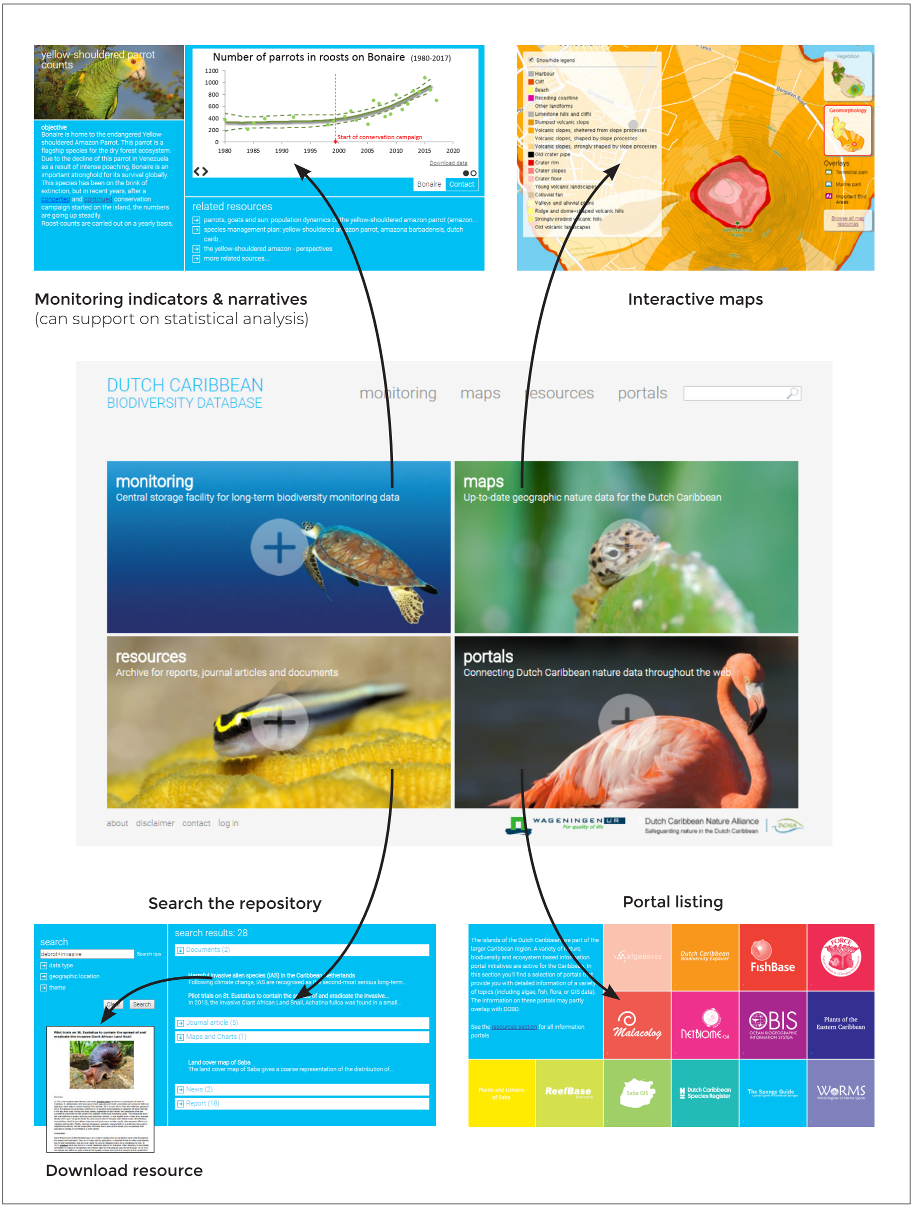


Figure 5-1 - screen compilation of the Dutch Caribbean Biodiversity Database (DCBD) homepage showing the four key services: monitoring, maps, resources and portals (www.dcbd.nl)

5.2 CO-DESIGN OF THE DUTCH CARIBBEAN BIODIVERSITY DATABASE

5.2.1 Development process

In 2011, the development of the DCBD started with a one-day scoping workshop with representatives of about 20 local nature NGO's (park managers and conservationists) and island governments from six islands, scientists and representatives of the Dutch ministry of Economic Affairs, at Bonaire. The 25 invitees were selected by the ministry and the Dutch Caribbean Nature Alliance (DCNA), a regional network of protected areas and conservation organisations spanning the Dutch Caribbean islands of Aruba, Bonaire, Curaçao, Saba, St. Eustatius and St. Maarten. Prior to the workshop, we studied existing nature observation web-portals for inspiration, including seaturtle.org, Dutch Caribbean Biodiversity Explorer[14], eBird.org, Reef.org, SynBioSys[15], observado.org and FloraVanNederland.nl. We also collected in-house available GIS data (soil, geomorphology and vegetation), an excerpt of the sea turtle monitoring data and set up a draft species taxonomy. Based on this we developed a prototype for the DCBD to elicit targeted feedback. This prototype included the aspects that we presumed to be elementary: i) maps, ii) encyclopaedic functionality, iii) observation functionalities (data entry and summary charts) and iv) document sharing (uploading and downloading reports and scientific articles). During the workshop we presented the prototype and asked individual participants for feedback on these four specific aspects. Next, we inventoried additional desired functionalities of the participants and set priorities.

To ensure that the web-platform remains updated in content and connected to user demand, the development process is viewed as ongoing and is organized in iterations that allow the web-platform and the process to adjust to new scientific or managerial insights, reporting obligations, or changing user groups (Sébastien et al., 2014). To maintain the web-platform, the ministry grants a budget to the DCBD development on a yearly basis. To guarantee continuity an informal advisory board provides strategic advice. The advisory board is made up of the donor and the DCNA (Figure 5-2). The Dutch national government and the DCNA are actively involved in the policy process and agenda setting and maintain the DCBD by funding staff and experts to maintain the DCDB. Maintenance activities include scanning research activities, uploading data and reports, maintaining professional and social networks and encouraging their network to share their data and reports on the DCBD.

[14] http://biodivexplorer.dcbd.nl/explorer/home

[15] https://www.synbiosys.alterra.nl/

Most monitoring efforts take place on seasonal basis, e.g. turtle or bird nesting. Bilateral meetings between the DCBD maintainers and the various NGO data collectors provide updated information and data, help to clarify the data structure and share interpretation of the data. These also provide opportunity to learn about their new monitoring and management activities and noteworthy events, such as storms or seaweed invasion. The NGOs responsible for data collection are asked how they use the DCBD (e.g. archiving, communication, learn from others, support in statistical analysis tasks) and if there are refinements to better suit their evolving needs. These user wishes and the updated information and data provide input for the planning of each annual DCBD development iteration. Each iteration starts with the feedback and ideas from the users and advisory board ('ideation'), followed by the 'design' and subsequent 'development' of technical functionalities and graphics. Finally, the new developments are 'tested' through reviews by users, before they are 'published'.

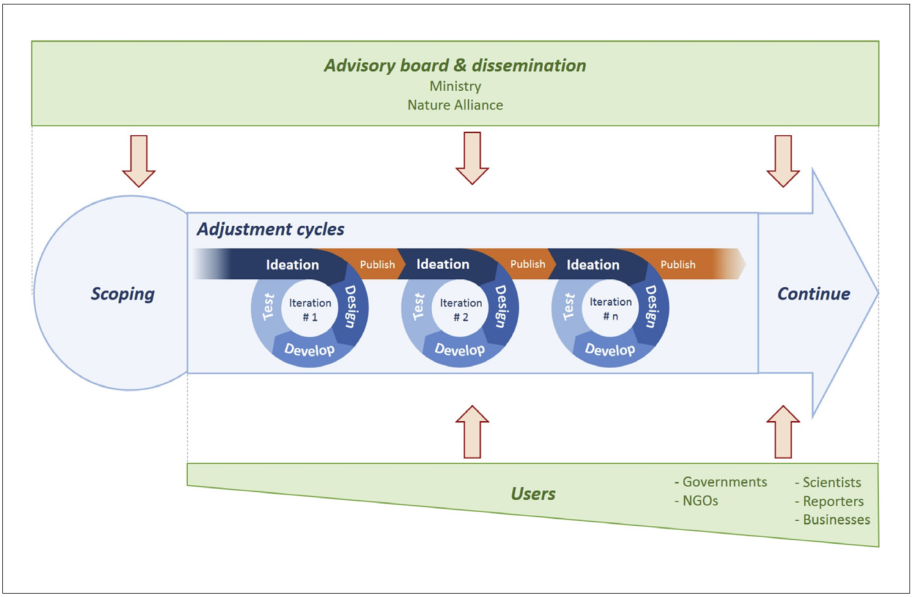


Figure 5-2 - Schematic overview of collaboration with users and advisory board in the development process. The adjustment cycles for the Dutch Caribbean Biodiversity Database occur annually through bilateral meetings with users and database maintainers.

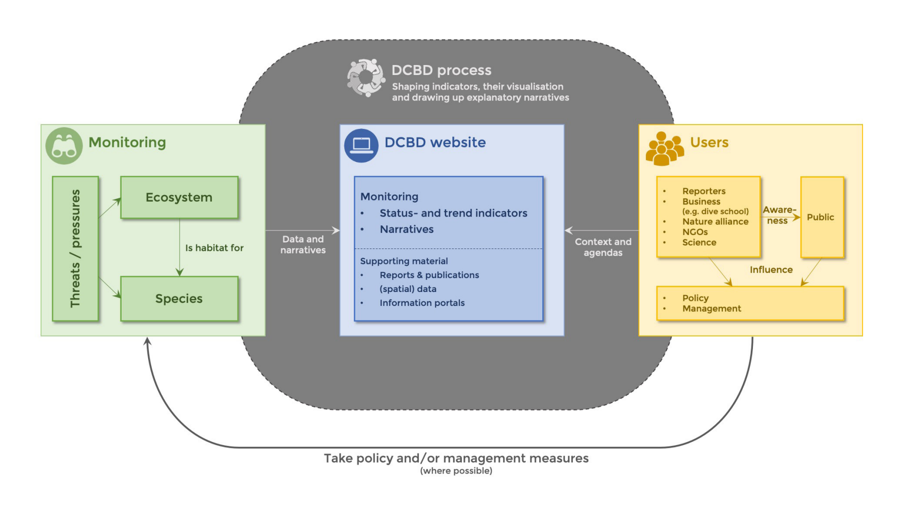


Figure 5-3 - Indicator development is based on managerial and policy requirements, context and agendas and by monitoring activities on ecosystems, species and threats.

During the bilateral meeting week, explicit attempts are made to expand the stakeholder network and community of practice, by engaging additional/new organisations recommended by the NGOs and local government partners, e.g. dive schools started to record their sightings and National Statistics Netherlands recently added DCBD's biodiversity indicators to their annual reporting.

5.2.2 Sketching and storytelling during indicator development

Indicators signal changes in ecosystem health, biodiversity and pressures, and are elementary for taking evidence based policy and management measures (Laihonen et al., 2004). Indicator visualisations and graphics are a powerful means to communicate the status and trends (McInerny et al., 2014). Indicators, therefore, play a central role in the DCBD. Indicators are derived from field observations and remote sensing data. The indicators are defined based on managerial and policy requirements, context and agendas (Figure 5-3). Indicators are jointly designed with data collectors (e.g. park managers, conservationists, local government) who provide their collected raw data (tabular, GIS, photographs, videos) and tacit knowledge on noteworthy events impacting the state of nature, e.g. severe storms, seaweed invasion, poaching, coastal development. Additionally, reporting staff clarify their need for indicators for specific species, species-groups, ecosystems and threats, or pressures that are relevant for reporting obligations.

The process to jointly design the indicators is initiated through iterative dialogue with the data-collectors. This serves to brainstorm and sketch several indicator graphs on paper based on the ideas generated by participant's narratives and data. Dialogues are organized per island per species, species group, ecosystem, pressure or threat. The indicator graphs are then debated in plenary to check whether the trends match expert and are management- and policy-relevant. This provides the basis for the final design stage, where the DCBD maintainers retreat for several hours to convert the paper sketches into real indicator graphs derived from collected raw data, which are then shared with the data collectors for feedback. If necessary, these are refined through one or several iterations of sketching and development, e.g. in case that the data does not support the narrative, or if the graph is not visually compelling. To ensure robustness in the quantitative analyses, Statistics Netherlands - an independent administration - provide input into this analysis and reviews the statistical methods used.

5.2.3 Approach to evaluate and increase the impact of the DCBD

The evaluation of the impact of the DCBD is based on four main sources of information. First, there is an explicit agenda item in every iterative work session in which feedback on DCBD's technical functionalities and the process of cooperation is elicited from individual users. Second, the diversity of returning user groups is monitored, which include those users brought in contact with the DCDB via existing users, those actively sought out through the DCDB process, or those that find the DCBD by themselves. Third, visit statistics of the DCDB website are monitored and fourth, the website statistics and visitor posts are assessed to understand the most common data and information requests and the most utilised parts of the DCBD and by whom.

The Dutch Caribbean Nature Alliance, as part of the advisory board, publishes 'BioNews' a free monthly digital newsletter featuring recent nature related news about the Dutch Caribbean as well as overviews of recent publications, current research and monitoring programmes and upcoming events. News in BioNews contains hyperlink references that lead the reader to the specified resources on the DCBD, increasing the visibility of the DCBD. Articles on the DCBD are published in BioNews on irregular basis.

5.3 RESULTS

5.3.1 Platform evolution

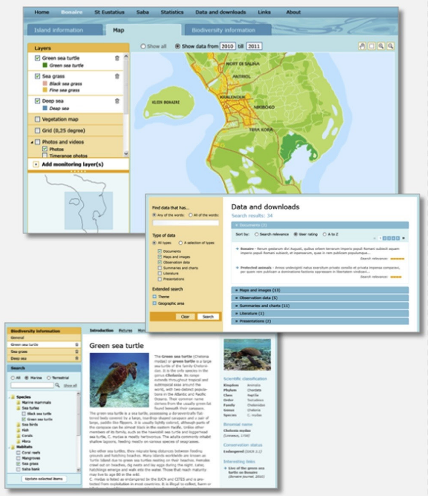
During the scoping workshop the following priorities were set, based on feedback on the prototype (Figure 5-4 A): 1) upload observation data in a well-structured and pre-defined data-entry-form, and download for a restricted set of users, 2) share and search documents, 3) display of GIS maps as a background for observation data (observations only visible for restricted set of users), 4) display encyclopaedic information that cannot be found on general purpose websites like wikipedia (with possible links to specific web-portals, e.g. reefbase.org, fishbase.org and CARMABI's[16] species register with taxonomic and trait information 'Dutch Caribbean Biodiversity Explorer'[17]) and 5) include a professional and high quality design.

Implementation of the first online operational system was based on these priorities and readily available information from the DCNA (Figure 5-4 B). Digital reports and GIS maps were immediately available for publishing, but the sharing conditions for observation and monitoring data had to first be clarified. All data collectors wanted a safe central database repository for their monitoring data as provided by the DCBD, to alleviate their challenges of severe staff turnover. These data collecting organisations viewed the DCBD as important to secure continuity in the structure and storage of their raw data. Some data collectors wanted to make their raw data publicly available, others only wanted to share derived indicators. Both options were made available through the DCBD, depending on the data collector's needs. Multiple devices were suggested for uploading field observations (mobile phone, smart phone, tablet, laptop, or desktop), but the data collectors preferred standard paper forms and water-proof notepads for underwater recordings. Field recordings were then manually entered via web-forms on the DCBD when back in the office, which were tailor-made for each monitoring program and organisation. During data-entry the format of the data was checked automatically to guarantee data consistency and enable automatic indicator graph generation. These indicator graphs were updated every time new data was entered. On specific request of the advisory board, items of special interest were put in the spotlight on the homepage. A graphical designer was added to the development team to secure a consistent, professional and attractive look-and-feel.

[16] http://www.carmabi.org

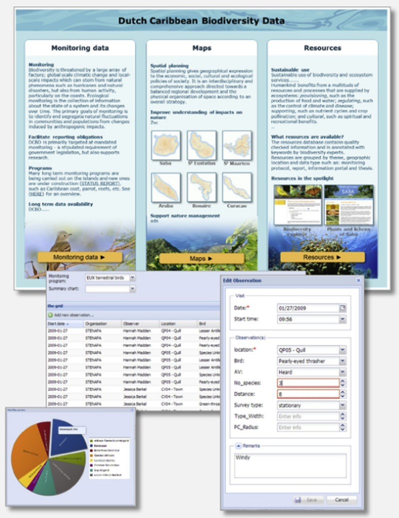
[17] http://biodivexplorer.dcbd.nl/explorer

A. 2011



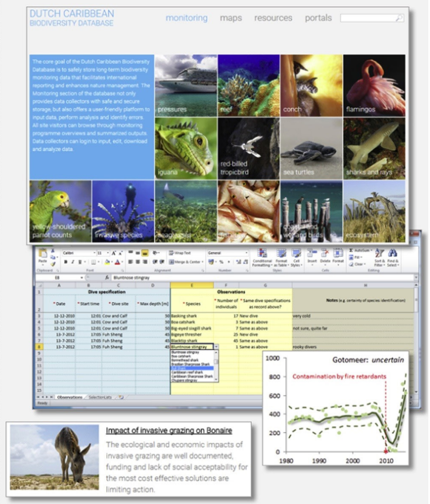
- *Interactive maps* – species observations plotted on thematic maps
- *Data and download* – of documents and datasets
- *Taxonomic tree* – of all species found in the Dutch Caribbean accompanied by a scientific and popular description

B. 2013



- *Data entry on the web* – all observation data is stored in a central database. Access to data may be restricted to data owners
- *Automatic graph generation* – as data is entered the graphs are automatically updated
- *Spotlight* – promote items of special interest

C. 2017



- *Checked data entry forms in spreadsheet* – field survey data can be entered and stored offline in standard and well understood office software
- *Indicators and narratives* – are jointly compiled with field experts, statisticians and policy makers
- *Portals* – connect to other initiatives of interest
- *News* – for interest groups and general public

Figure 5-4 - Milestones in the evolution of DCBD through time.

After a year however, it turned out that, although willing, data collectors hardly used the data entry facilities from the DCBD. The main challenges identified for inhibiting their use of the DCBD were: i) an unstable internet connection, ii) a deviation from their current data-entry practices, iii) the feeling of loss of control over their own data made them reluctant to use the web facility and iv) the limited possibilities of interactive analysis methods.

These challenges were addressed through reverting to custom-made data entry spreadsheets instead of online web-entry forms (Figure 2-3 C). The spreadsheets were given automated consistency checks for data quality. For instance, a field that should express 'distance' only accepts numerical values within a pre-defined range based on the monitoring protocol and the data collectors' expert knowledge. So 'far away' could not be entered. A field that should contain a species name is to be filled via a pre-defined drop-down list to prevent typing errors which would hamper automatic analysis. Each tailor-made spreadsheet is maintained at the data-collectors' premises which ensures that familiar analysis tools and methods can be applied independently. At regular intervals the completed spreadsheets are sent over for storage at the DCBD.

5.3.2 Indicators and narratives

Indicators are created based on data availability and demand. Currently the indicators are grouped into 20 categories, comprising three on ecosystems (coral reefs, seagrasses, ecosystem size), five on pressures (invasive lion fish, corallita and goats, fisheries and tourism) and 12 on species (Queen conch, Caribbean flamingo, Antillean iguana, Red-billed tropicbird, sea turtles, sharks, rays, Yellow-shouldered parrot, coastal and wetland birds, invertebrates, terrestrial birds and terns). Where available, each category contains indicator graphs per island (e.g. sea turtles for Bonaire, St.Eustatius, Saba and St.Maarten). Multiple indicator graphs may be available per island. For example, for sea turtles on Bonaire there are indicator graphs available for nesting and for in-water sightings. The nesting graphs indicate the status of the reproduction, while the in-water sightings are indicative for the health of the foraging grounds.

Where many years of recordings exist, indicator graphs show general trends (Figure 5-5 A). These trends are accompanied by a statistical interpretation conducted in cooperation with experts from Statistics Netherlands. When few repeated recordings are available, bar charts per observation period may visually indicate a trend (Figure 5-5 B). Where a standard analysis and visualisation method exists (e.g. Atlantic and

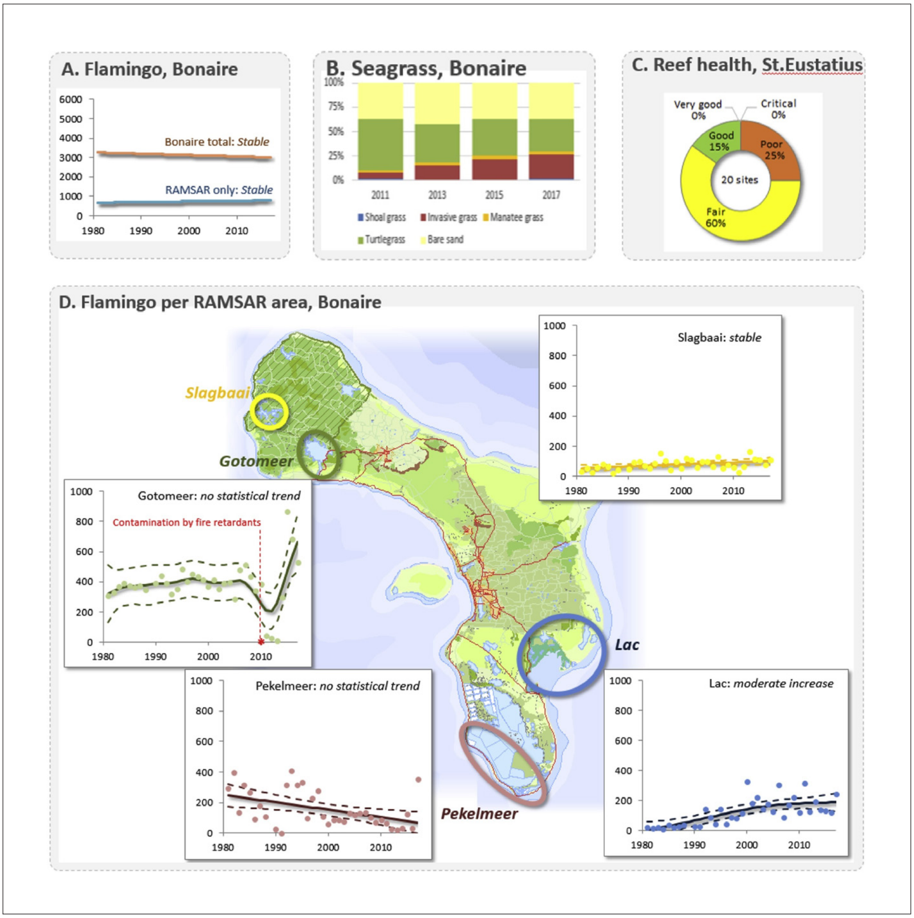


Figure 5-5 – Sample of DCBD indicator graphs

The aim is that each indicator is accompanied by a short narrative with particular attention given to indicators showing sudden changes in trends. In addition, explanations for these trends are shown on the indicator graph. For instance, in the salt lake Gotomeer a contamination by fire retardants as a result of a fire at the nearby oil depot, decimated the number of flamingos and this event is recorded on the indicator graph for flamingos (Figure 5-5 D).

Gulf Rapid Reef Assessment[18]) that method is preferentially used (Figure 2-4 C). Finally, an indicator graph may be accompanied by a detailed indicator to facilitate localized management (see respectively Figure 5-5 A and D).

The aim is that each indicator is accompanied by a short narrative with particular attention given to indicators showing sudden changes in trends. In addition, explanations for these trends are shown on the indicator graph. For instance, in the salt lake Gotomeer a contamination by fire retardants as a result of a fire at the nearby oil depot, decimated the number of flamingos and this event is recorded on the indicator graph for flamingos (Figure 5-5 D).

5.3.3 Impact of the DCBD and its indicators

Interactive maps and resources are the most visited elements of the DCBD. Commonly search requests for reports and maps on the Dutch Caribbean via web-engines result in top-listed hits for the DCBD.

National government (Dutch ministries of Agriculture, Nature and Food Quality and Infrastructure and Water Management, Statistics Netherlands) use the DCBD for their reporting obligations based on the (inter)national treaties. These ministries regularly use the status and trend indicators as published on the DCBD to facilitate these reporting obligations (ministry of Economic Affairs, 2014; Verweij et al., 2015). For example, Statistics Netherlands publishes trends in turtle nests and flamingo abundance (Statistics Netherlands, 2016; Statistics Netherlands, 2017). Debrot et al. (2018) showed living coral cover trends, parrot abundance and the expansion of invasive plants for the national report on the state of nature.

Local authorities and management bodies in the Dutch Caribbean use the DCBD to inform responsibilities for spatial planning and carry out interventions for managing nature and the living environment. The DCBD provides evidence in the form of data and knowledge that underpins decisions on granting of permits, e.g. the annual reports of Sea Turtle Conservation Bonaire (STCB) use the DCBD's indicators on sea turtle nests and in-water sea turtle abundance to inform their decisions on (Willis et al., 2016; Schut et al., 2017). The indicators are developed in cooperation with STCB and are based on their data. Piontek (2015, 2016) as presented to the Island Government of St. Eustatius, includes several of the DCBD's indicator graphs. For the St. Eustatius' annual sea turtle conservation program report STENAPA uses the DCBD's indicators on sea turtle nests

[18] http://www.agrra.org

and in-water sea turtle abundance (Berkel, 2014). St. Maarten Nature Foundation uses the DCBD's indicator graphs on shark and ray sightings, sea turtle nests and brown pelican abundance for outreach and educational purposes[19].

Businesses such as dive schools, provide their observation data that they record during daily dives as advertisement material to attract future customers. That data is handed over to the DCBD to generate indicator graphs. The graphs form outreach and marketing material for these businesses. For researchers, the DCBD offers data and information that is easily found and accessed. The raw data underlying the indicators and maps serve as an inspiration and basis for further research.

5.4 DISCUSSION

5.4.1 Principles for designing a policy relevant data platform

As demonstrated above DCBD has broadened its initial scope from data rescue (Diviacco et al., 2015; Hawkins et al., 2013; Costello, 2009) to a platform with indicators and narratives relevant for decision making. Reflecting on our experiences in co-designing this platform with data collectors, and a range of end users in government, business and research, we have distilled three principles that were critical in DCBD's uptake, growth and use.

First, the DCBD is actively supported by national and regional policy makers and embedded in a mandated local institution. The Dutch ministry organised initial meetings with park managers and non-governmental conservation organisations and continuous to give political credibility, legitimacy and visibility to DCBD, and continued to organise periodic meetings while using their network to expand DCBD's scope. The ministry also supports the maintenance of the DCBD by locally subcontracting staff that scan for and upload relevant resources. Research projects funded by the Dutch ministry are contractually obliged to provide their data and results to DCBD. Since the policy makers use DCBD themselves, they provide specific feedback on the DCBD system, the collaboration process and the network which it services. Their ongoing active role clearly shows they have taken ownership of the platform.

Second, DCBD simplifies mandated tasks of local management and rapporteurs. It simplifies or carries out tasks that would otherwise remain pending or would take much effort. This is facilitated by the co-designed workflow and data-entry practices of data-collectors and the tailor-made digital data-entry forms in software familiar to them. Data-

[19] http://www.naturefoundationsxm.org/activities/ , retrieved 9 August 2018

collectors are forced to structurally input their observation data, which reduces input errors, enhances automated analysis, and meets the needs for central data repositories that cater for high staff turnover. From this workflow, reporting needs, including indicator visualisations, are made explicit. Similarly, needs of reporting staff are defined based on reporting obligations. Specific indicator graphs are created and custom-developed for each target group to meet their specific reporting mandates and needs.

Third, the DCBD must continuously evolve in response to changing external and internal factors, functional requirements, procedures, priorities and institutional environments. Sustaining and adaptation of the platform is made possible through 1) constant dialogue between users, maintainers, developers and donors Figure 2-1, and 2) programmatic government funding, which is crucial for longterm storage and content curation (Arzberger et al., 2004; Bach et al., 2012; Bendix et al., 2012).

There are also principles that had to be revisited:

First, the initial idea to give data-collectors a login-account and to enter and store their data in the system via web-interface was unsuccessful. Contrary to what literature suggests on the necessity for online massive data storage and sophisticated automated analysis and query tools (Balmford et al., 2005; Bendix et al., 2012), data-collectors mostly dismissed the offered technical facilities and stuck to their daily routines. Even after various iterations of functional adaptations, the system was rejected due to limited internet connection availability, time constraints to become familiar with the online functionalities and the initial lack of trust to share data. Letting go of the concept of a large standardised database and focusing on simplifying daily routines resulted in increased participation and trust. Thus, the best technical solution is the one that best fits user practices and preferences.

Second, it was found that researchers are reluctant to share their data due to scientific publication possibilities or presumed insufficient quality. Even if researchers collect data with public money and are contractually obligated to share their data publicly it hardly ever happens. Possibly the contractual obligations are not enforced, because there are no penalties. Scientists and other data providers must be motivated to make their data available to the global community. Sayogo and Pardo (2013) suggest that scientists publish their dataset. As such it can be cited, crediting the ones that share their data, without the necessity or lead time required to publish a research article (e.g. Nature's scientific data[20]).

[20] https://www.nature.com/sdata/publish , retrieved May 3rd 2019

Third, the impact of the platform on nature policy making and management is difficult to quantify. Although Saarela et al. (2015) identified collaboration and informing as important means for generating impact – both characteristics of DCBD – and there are clear examples of policy making influenced through DCBD's information (e.g. Debrot et al., 2017), there is no straightforward relation between DCBD and policy making. Many factors, like public opinion, political will and timing, influence this relation. Stronger dissemination of DCBD's narratives in social arenas (e.g. newspapers, social media) may make Caribbean nature and biodiversity more politically and societally relevant.

5.4.2 Position compared to data platforms and indicator catalogues

Costello & Wieczorek (2014) advise to publish biodiversity data through a data platform, a system that enables integration of harmonised data in other similar datasets and to use a quality checked open-access data repository, to which, preferably, peer-reviewed articles are attached for proof of data quality (e.g. GBIF[21], GenBank[22]). Data platforms are typically used by data scientists. Although the DCBD stores data, it cannot be classified as a data platform in this sense. The DCBD stores all offered observation data in raw, non-harmonised format as practiced in data lakes (Russom, 2017). Data is provided by trained professionals and scientists which is an indication for its quality.

While data platforms target data scientists, indicator catalogues aim to provide condensed information in the form of indicators with accompanying narratives and references (e.g. EEA indicators[23] and Environmental Data Compendium[24]). These catalogues are designed to answer key policy questions and support all phases of environmental policy making, from designing policy frameworks to setting targets, and from policy monitoring and evaluation to communicating to policy makers and the public (EEA, 2018). Likewise, a selection of the DCBD's data and accompanying references is used to derive indicators and narratives for direct use by management and policy making. Where 'EEA indicators' and 'Environmental Data Compendium' can draw on a rich, long-term data collection built by spatially well-distributed monitoring networks, Dutch Caribbean monitoring activities have, almost without exception, a shorter history in monitoring. In general, when funds are limited, monitoring heavily depends on contribution of (skilled) volunteers (Van Swaay et al., 2008). Some monitoring programs in the Dutch Caribbean can draw on a limited number of volunteers willing to

[21] https://www.gbif.org

[22] https://www.ncbi.nlm.nih.gov/genbank

[23] https://www.eea.europa.eu/data-and-maps/indicators

[24] https://www.clo.nl

participate. The possibilities for long-term systematic sampling are constrained due to high turnover of volunteers which is typical for the islands.

5.5 CONCLUSION

What started out as a data rescue process, evolved into a platform with indicators and narratives relevant for decision making, while still offering all underlying data. This development could take place because of the process that was followed which actively sought to engage meaningfully with those who both supply and use data, and to customise the platform to meet both their needs. The process was supported by an Advisory group comprised of government institutions viewed as credible organisations in supporting such a multi-use platform, and was furthermore embedded in an institution responsible for its maintenance. Three principles made DCBD's uptake and growth possible: the platform is funded, promoted and used by national and regional policy makers, it simplifies tasks of local management and rapporteurs, and it is continuously being adapted to changing needs and insights. The development of a data-platform like DCBD is not necessarily about using state-of-the-art technology, but about meeting the needs and priorities of both data supplies and users, which are diverse and require diverse approaches, and growing an active stakeholder network. In this growing stakeholder network, a process that actively seeks to reflect on ways of working, improving and continuously evolving at both the individual level and collective cross-institutional level is key.

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Chapter 6

SYNTHESIS AND RECOMMENDATIONS

6.1 MAIN FINDINGS

The land is subject to constant change, both through natural processes and human interventions. Human use of any particular piece of land is influenced by how the landowners and land managers perceive and value the land. Moreover, its use influences neighbouring lands and thereby neighbouring owners and users, who might have different perspectives on how to use the land. These different perspectives are a potential source for conflict.

Through public policies and spatial planning the use of land is regulated in an effort to direct towards more desirable, and away from undesirable, social, economic and environmental outcomes. The development of these policies is a social process involving competing and collaborating parties that try to influence the policy outcome conform their values and preferences. Policies are therefor often formulated as a compromise between the different wants and needs (Saylor academy, 2012).

While policies take a top-down approach to land use planning, the realisation on the ground can have unexpected and unwanted effects as result of local circumstances (Xu, 2019; Hersperger, 2018). These mismatches could be less frequent if more rational methods were used during policy development (Howlett, 2009). Scientific evidence can significantly contribute to policy effectiveness as it downsizes the role of intuition and ideology and informs us on what works and what not (Becker et al. 2019). As such, scientific evidence, is ideally used as a starting point for dialogue, in which all participants have pieces of the answer, and work together towards viable solutions (Aarts, 2015).

The scientific community develops a multitude of data-driven tools to capture facts and knowledge on land use and policy. Tool uptake for policy making, however, is low. Reasons include: the tool is too complex and capabilities do not align with the users' demand; applicability is too slow too answer to the urgency of decision making, too technocratic/missing human dimension, and missing political support (see chapter 1 for a full listing).

This thesis contributes to the enhancement of dialogue and collective thinking in land use policy development and in particular in **providing collaboration practices for scientists, stakeholders and policy makers for developing and utilising data-driven tools to support land use policy development**. To this end four research questions were addressed:

1. How can different scientific communities, tool developers and users work together to develop an integrated land use policy assessment tool?
2. How can the applicability and transparency of a land use policy assessment tool be enhanced to better understand drivers and impacts of land use change?
3. How can a land use policy tool include stakeholder knowledge and facilitate to rapidly reach a common understanding between different views on land use?
4. How can tool development enhance and facilitate collaboration with the overall objective to influence land use policy?

The following paragraphs provide answers to these questions.

Table 6-1 summarizes the findings in relation to the issues hampering the tool use from chapter 1, grouped by the methodological chapters 2 to 5. Mind: chapters 2 to 5 do not map one-to-one on the research questions, but describe four methodologies and associated case studies, that together answer the separate research questions. The table lists the end user, the collaborating parties, the tool collaboration practices, the result of using the practices and the addressed barrier.

Table 6-1 - listing of collaboration practices and the barriers addressed. The barriers use shortened names to reduce table space: demand mismatch (tool capabilities do not align with the users' demand); complexity (the tool is too complex in terms of ease of use); transparency (lack of transparency); lead time (the applicability of the tool is too time consuming); flexibility (tool adaptation is too slow to answer to the urgency of decision-making); technocratic (too technocratic, missing human dimension); data access (no data access); political support (missing political support); * No direct link with the barriers for tool uptake addressed, but used to focus on enhancing the collaboration process

End user	Collaborating parties	Collaboration practice
Chapter 2 – An IT perspective on integrated environmental modelling: the SIAT case		
Civil servants of the European Commission involved in land use policy making (particularly biodiesel)	- Scientific researchers of agriculture, economy, forestry, land use, social and policy science interface - Software engineers and designers	Develop screen sketches (also called 'wire-frames', 'blue-printing', or 'mock-up') that set out how the software is to be used and what information it should offer.
		Develop a (visual) conceptual model with the most important domain notions and their interactions.
		Describe the technical architecture of the data based tool
		Short time-boxed design-implement-test-deliver iterations
Chapter 3 – Improving the applicability and transparency of land use change modelling: the iCLUE model		
Land use modelers Scale varies from river basin (e.g. Ebro in Spain) to global	- Experienced and inexperienced land use modelers - GIS experts - Statisticians - Software engineers	Develop conceptual models enriched with visual representations of the form of the concepts (e.g. maps and timelines to explicate the role of spatial variety and time in land use projections)
		Develop screen sketches
		Use interactive visualisations to explain how data and causal relations are used in reasoning
		Document the dynamic behaviour in activity diagrams
		Use summary visualisations and statistics (e.g. spatial and content generalisations, or land use transition matrices)
		Jointly and iteratively parameterise, run and analyse the model and model results (Mind: this works best if the model can be interactively used which requires short calculation times)
Chapter 4 – QUICKScan as a quick and participatory methodology for problem identification and scoping in policy processes		
Policy makers, topic experts and interest groups (e.g. on mining, conservation, recreation, land degradation) Scale varies from local (e.g. part of the Danube floodplain in Romania) to continental (e.g. South America)	- Policy makers - Interest groups - Topic experts - GIS experts - Software engineers and designers	Interview participants beforehand
		Story telling by participants supported by visualisations of gathered data
		Inventory of indicators (and selection of their relevant metrics)
		Avoid lengthy digressions or discussions
		Include skilled facilitator
		Break up the participants into smaller groups with mixed background and give them small simple tasks while stimulating them to physically move around (e.g. drawing on flip-over, inventories using sticky notes, or stickering for prioritisation of issues)
		Start with very simple model using participant knowledge and stepwise grow complexity (within a single working session)
		Test modelled results against the participants' image of reality. If necessary, jointly adapt the model
		Drill down in the calculation rules of specified locations in result maps and visualise the causal flow of reasoning that was used to calculate the result value, possibly resulting in the need to revisit the rules
		Visually compare alternative models (i.e. alternative representations of reality)
		Save terms, data and modelled relations representing participants' knowledge, interpretations and preferences

	Result of the practise	Barriers addressed
	To create a joint vision on the end product	Demand mismatch, complexity
	To create a shared vocabulary and system understanding	transparency
	To help divide implementation across specialised teams while taking care of a joint understanding on a more abstract level	*
	To have an growing solution from the onset of a project and be able to adjust development direction based on evolving understanding	Demand mismatch
	To build consensus on the system and highlight key processes (Argent et al., 2016)	transparency
	To create a joint vision on the end product	Demand mismatch, complexity
	To highlight useful information for exploring (and understanding) what drives temporal and spatial patterns of land use change to occur at specific locations	Transparency
	To clarify and document the flow of reasoning	Transparency
	To remove noise and more clearly understand trends, hotspots and differences between alternative situations that apparently are the same	Complexity
	To shorten throughput time to come to a shared understanding and thereby reduce transaction costs	Lead time, transparency
	To direct pre-workshop data gathering and anticipate potential conflicts during the workshop	Demand mismatch
	To build a common understanding on a situation and problems for which solutions are to be sought	Demand mismatch, technocracy
	To guarantee that the assessment represents perspectives of all participants and create a joint vision on the issues to be assessed	Demand mismatch
	To maintain velocity in collaborative work	*
	To cope with potential power relations between participants	*
	To break the ice and let people get to know each other, and to provide a safe atmosphere in which there is room for everyone to express themselves	Technocracy
	To guarantee that each of the participants fully understands the flow of reasoning from the onset and can contribute meaningfully	Complexity, flexibility, applicability, technocracy
	To make all participants part of the process and ensure credibility and acceptance	Technocracy
	To guarantee that the flow of reasoning is fully understood (and ideally accepted) by all	Complexity, transparency
	To fuel group discussion on alternative models and implications thereof	Complexity
	To have a common truth on collective knowledge and progress at a certain point in time	Transparency

Table 6-1 - continued

End user	Collaborating parties	Collaboration practice
Chapter 5 – Co-designing a data platform to impact nature policy and management: experiences from the Dutch Caribbean		
(Inter)national rapporteurs, local nature management, interested parties in biodiversity of the Dutch Caribbean (incl. international researchers)	- National and local government - Nature park management NGO's - Business (mostly dive schools) - Rapporteurs - Scientists - Software engineers and designers	Continuously update collaboration practice and information products (and software) based on feedback of collaborating parties
		Face to face meetings
		Support data collectors with technological tools and scientific methods
		Build narratives (Morgan, 2017) and trend indicators with local experts (data and knowledge supply) and rapporteurs (demand for information)
		Share content maintenance across several organisations
		Have champions promote the platform, both within the government and the domain network
		Collectively produce outreach material both through formal (inter)national reporting obligations, and media
		Long term (governmental) support for technical and content maintenance

6.1.1 Collaboration practices for integrated tool development

There are several practices that facilitate collaboration on the development of data-driven tools. These practices should be used in combination and apply not to a specific type of assessment, but to tool development in general. They also aid in aligning tool capabilities with the users' demand and in securing ease of use. Three of these practices are especially helpful during project start, the fourth is particularly helpful in staying connected during project execution.

Build a *conceptual model* from scratch in a workshop (see chapter 2, 3 and 4). This model must capture the most important system elements with relationships between them. Starting from scratch allows to jointly shape the domain and for everybody to internalize it. Existing models do not describe the same domain under the same circumstances with the same questions, but can be looked at for inspiration. They should not be used during the meeting as they distract from the specific study. In my experience such workshops work well when started by a brainstorm session in which participants write down elements on sticky notes. A facilitator then calls them out loud and groups them on a wall or table based on explanations and feedback from the participants. Naive groupings and arrows between them, help activating participants and overcoming possible hesitation, and can be used to invite them over to the wall to make corrections.

Result of the practise	Barriers addressed
To remain relevant and connected with the user community in a dynamic network environment	Demand mismatch
To build a strong relationship with mutual trust and loyalty (Jiang et al., 2012) which is required for sharing of information for which the feeling of ownership is strong	Data access
To give something in return and have mutual benefits of information sharing	Complexity, data access
To bring together data supply and demand with the overall objective to inform (and thereby influence) policy making	Political support, technocracy
To have shared ownership and an ongoing commitment to maintain and promote the collective efforts	Political support
To generate support and willingness to collaborate	Political support
To inform and influence the political and societal debate	Data access
To have continuity and legitimacy	Political support

Use *screen sketches* to create a joint vision on the end product (see chapter 2, 3 and 4). Ideally the sketches display screen layout with text-blocks, headings and early ideas on data visualisations, preferably based on some real data. Screen sketches are particularly useful in the early stage of tool development to catalyse dialogue, to converge perceptions and to trigger planning activities on what needs to be done, when and by whom. Sketch screens on paper as a way of brainstorming, then detail them more in a presentation tool using graphs, images and pictures from the internet and finally have a graphical designer work on it to be able to have an impression as if it were implemented.

To help divide tool implementation across teams, a *technical architecture*, a common abstraction of a system illustrating the physical and logical connections between tool modules must be made in the early stage of tool development. Each module can be developed separately as long as the interfacing is developed as agreed upon (see chapter 2 and 3).

Focus and refocus development using *short time-boxed design-implement-test-deliver iterations* (chapter 2 and 4). Throughout project execution the understanding of the domain integration progresses and user requirements crystallise. By continuously developing small pieces of functionality and communicating progress by (preferably live) tool demonstrations, all involved can test whether they are still in line with each other and adjust planning or ways of working together when needed.

6.1.2 Enhanced operational and transparency features for improved understanding of drivers and impacts of land use change

For tools, and specifically modelling tools, transparency is a property associated with the tool's internal mechanics. Transparency plays a major role in understanding the formalised reasoning and the consequent trust and acceptance of a tool's output by its users. To deliver transparency, developers produce documentation and provide access to source code and databases. Transparency is also a property of the process of building and parameterising new and existing tools; and of the visual analysis functionalities offered by the tool.

In participatory modelling workshops, transparency is inherently included as participants jointly work on the model concept and the actual modelling (chapter 4). During that process the participants identify, discuss and decide what elements matter for the assessment (including drivers of change, system variables and indicators). As a result the participants improve their understanding of the functioning of the land use system as a whole. Participatory modelling can be done by collaboratively building a model from scratch (chapter 4), or parameterising an existing model.

For existing models to be used in workshops they must be easy to use and be equipped with visual analysis tools to enable result interpretation. These characteristics are also helpful in more classical desk-top studies, but are not the first ones researchers focus on when developing models for system understanding or projection. Logically, time and energy are put into understanding signals from- and relationships between data first. When the model is to be used in a workshop in-situ, or when it is used so frequently that certain operational issues become time-consuming and error-prone hurdles (e.g. manual data pre-processing and post-processing), it is time to reconsider the current implementation.

To find out how to improve the applicability and transparency of an existing tool a good understanding of the current model and its bottlenecks is required, both operational and analytical. Then, in a second step, you must design and test solutions. The following practices guide you to do so (chapter 3).

Gaining insight in the current tool is achieved by developing a conceptual model and by graphically documenting the internal calculation flow and the external workflow of using the tool. Develop a *conceptual model enriched with visualisations* to give an one-pager overview of how the tool captures real world processes (chapter 3). The visualisations must clarify the ambiguity which is associated with the different interpretations that occur when using textual descriptions only. Such an illustration not only helps in communicating an overall view and assumptions with the (end-)user, but also highlights the key elements and processes that likely require transparency features. In my experience drawing on a whiteboard while in dialogue with a handful of model experts will quickly result in a supported proposal. This proposal is elaborated by one, sent around for feedback (allowing individual reflection time) and then finalized.

Graphically document both the *internal calculation flow* and the *external workflow of using the tool*. Use one page for each of the flow diagrams and apply the clarity-over-detail principle. The internal calculation flow diagram describes the order of calculations that together form the model. The external workflow diagram provides a recipe of the sequence of manual steps to be taken with various tools. These diagrams are the basis to map the current model and provide hooks for improvements.

To inventory current bottlenecks and to scope what is needed to solve them, mix experienced and inexperienced tool users in a *focus group* (chapter 3). The inexperienced users often focus on operational problems they encounter in applying a tool, while experienced users (used to the mode of tool operation) have a broader view on the assessment in dialog with end-users. Both bring in what is difficult in understanding, or explaining the spatial patterns resulting from reasoning that is embedded within the tool.

To explore potential solutions the momentum of the focus group must also be used to *draft the ideal workflow* and to *sketch screens* on paper or whiteboard, and to feed the discussion with concrete suggestions (see chapter 3 and 4). The ideal workflow automates repetitive manual tasks that are time consuming and error-prone. Sketch screens for the model parameterisation and for the result display, including *drill-down and summary visualisations* (chapter 3 and 4). Drilling down from a calculated result enables to stepwise go into more detail and helps understanding the flow of reasoning that was used in the model. In contrast, summaries provide overview on trends, hotspots and differences between alternative situations.

6.1.3 Including stakeholder knowledge in a land use policy tool to rapidly reach a common understanding of the different views on land use

When stakeholder knowledge and work processes are integrated into a tool, it is easier for stakeholders to recognise and connect with it, as it is more aligned with their specific context and objectives. This applies to the design and functionalities of the tool itself as well as the data and modelling included in the tool. The joint design of a tool through *screen sketches* is already described in paragraph 6.1.1 (based on chapter 2 and 3). The remainder of this paragraph explains how participatory modelling practices are used in a workshop setting, through which people, share their knowledge, views and experience, by reflecting on presented data. The following practices should be used to prepare, carry out and evaluate such a workshop.

Preparatory interview individual participants to inventory expertise, interests and preferences (chapter 4). Studying background material (e.g. literature and policy documents) supplements the findings from the interviews and together they generate insight into the range of required relevant data. The interviews will also allow to anticipate potential conflicts. I prefer to work with a small group of carefully selected participants. Somewhere between 5 and 10. In a small group it is easier to create a safe atmosphere in which there is room for everyone to express themselves. If working with bigger groups I mix plenary with *smaller breakout sessions* and I highly recommend to *include a skilled facilitator* to manage possible power relations. The facilitator can also intervene to *avoid lengthy discussions* on positions. Define clear roles and tasks for the facilitator and modellers involved in organising the participatory modelling workshop. The modeller must be able to interpret and translate spoken language of participants into modelling terms on-the-fly.

The workshop is broken down in two main phases: 1) to connect to each other, and; 2) to do the joint assessment of the land. First, participants are stimulated to *tell stories* and share their perceptions on the use of the land by using data visualisations. This creates space to get to know each other while building on facts. And it brings up elements that need to be included in the assessment. There are two techniques I often use to initiate the dialogue. Either, I present trend graphs (e.g. urban expansion, declining agricultural yields) and thematic maps (e.g. flood prone areas, travel time) and ask participants whether these fit their observations and if they can explain what they see. Or, I present a topographical map of the area and ask them to describe the landscape, its characteristics and important related (historical) events (chapter 4 and 5). Shy or introvert participants may require explicit invitation to speak their minds. In my experience, posing naive questions entice them to do so.

Second, based on the conversations, *indicators* are defined (e.g. soil and climate suitability for growing coffee, or travel time to educational facilities for children of coffee farmers) and these are jointly modelled from available data. This modelling *starts with a simple* relation between few data by using participant knowledge. The model is then iteratively refined by *testing its results against the participants' image of reality.* I do this by asking whether participants recognize the resulting maps and graphs, where they see mismatches and, if any, what they assume to be the underlying reason (chapter 4). In case the result visualisation does match perceptions, it sometimes contains striking manifestations (e.g. hotspots in maps and trend breaks in graphs). If participants can explain these, I add their explanations as notes (chapter 5).

Finally, at the end of each workshop, *inventory the impact of the workshop* to learn what participants' take-home messages are, how participants worked together, to what extent a common understanding is reached and what must be improved in following workshops. I often ask participants to reflect upon the collaborative work and give them some individual time to come up with two or three supportive reflections and two to three critical ones (chapter 4). Although this collected feedback does provide learnings for the participants and the organisers, more structured formats should be examined (e.g. Sufi et al., 2018).

6.1.4 Influencing land use policy by enhancing and facilitating collaboration through tool development

Scientific evidence and advice are key for informed policy making (chapter 1). In addition to informing, scientists may also try to actively influence policy making. This is for example the case with issues where there is scientific consensus of alarming environmental signals such as climate change or biodiversity loss. Scientists that seek to inform or influence policy with their findings, can work towards being heard which is conditional for having impact. Using a strong evidence base to substantiate a message, having community support, using media to publicly disseminate the message, and having a governmental stakeholder advocating it, improve the chance of being heard. To meet these criteria, the practices listed below can be used separately, but they have the strongest effect when used in combination.

Build a stable and strong knowledge base that you can rely on for policy making (chapter 5). While some knowledge is publicly accessible, others are managed by individuals that are reluctant to share, e.g. due to a strong feeling of ownership. In these cases you must build trust and willingness to work together through *face-to-face meetings,* by *supporting needs of data suppliers* with what they see as practical solutions (e.g. analysis methods, safely storing their data now and in the future, or broaden visibility) and always fully acknowledge their authorship. Face-to-face meetings are also supportive in understanding the demand from-, and informing for policy making. Face-to-face meetings do not exist in isolation, but are part of an *ongoing dialogue to stay connected* and to update collaboration practice and information products when needed. Long term governmental funding must be available to secure and provide legitimacy for such a knowledge base.

Organise a working session with domain experts 'and policy makers while working together to *jointly assess policy indicators* (chapter 4 and 5). A working session is beneficial for policy makers as they can have a (rough) answer to their questions, prioritize the assessment towards the policy context and sought confidence levels and ask for clarification when needed. Domain experts can explore what drivers play a role, which negative impacts are likely to occur, identify what elaborate research is needed and they may suggest alternative policy formulations. One or multiple sessions may be organised depending the complexity and detail of the assessment, through put time and available capacity.

Write compelling narratives that are underpinned by data and supported with visual material (chapter 5). The narratives must be written in short, simple sentences that place mono-thematic indicators in broader context. Use indicator charts and maps to substantiate signals from data: charts to draw attention to (breaks in) trends and maps to illustrate spatial patterns. An appealing design, with a careful mix of texts, charts and images attracts attention and invites reading, thereby increasing the chance to get the message across. To further increase impact, narratives must be distributed through varying channels with diverse audiences using matching writing style. I often start drafting narratives through a dialogue with data collectors to jointly find signals in data, and confront this data analysis with their field experience and relevant events. I explain the relationships in the text and mark them in the chart and ask a policy official to add context by reflecting upon the draft from policy perspective. Ideally, I develop the narrative and the political context in a single *face-to-face* meeting. Finally, depending the media, a graphical designer includes aesthetics and a text editor reformulates the story, e.g. for a social media message, a newsletter, a policy brief or a newspaper article.

Use the donor, project partners and stakeholders to grow your network and deliberately act on power relations and changing contexts. If possible, *join forces with a champion* based on mutual respect and trust (chapter 5). A champion is an individual whose message is likely to be accepted by others, on the basis of authority of knowledge or power, such as a valued domain expert or an influential policy maker.

6.2 REFLECTION

For data-driven tools to contribute to land use policy development, accepted methods and practices for developing and utilising these tools are needed. Several of the methods from chapters 2 to 5 are rooted in software engineering (particularly agile and User Centred Design), participatory modelling and workshop design. This paragraph reflects upon the main findings and on the use and limitations of collaboration practices for data-driven tools in general.

6.2.1 The role of data should not be overestimated nor underestimated

All of the research documented in this thesis is built on data as a crucial asset. Systematically gathered data aids to find the current status (e.g. agricultural yields), trends through time (e.g. the velocity and direction of developments in population numbers) and (spatial) patterns (e.g. hotspots of deforestation). Especially when different trends and events from different data sources are combined, relationships can become apparent (e.g. from Remote Sensing, census, and citizen science). These relationships, together with the extrapolation of trends or scenarios, can be used to project how the future is likely to develop, and test what the likely direct and indirect effects of potential policy interventions are.

Obviously, data must be available at the scale appropriate for the study area. In my experience it is easier to get access to large scale (e.g. country-level or global) data, then detailed case study data (e.g. a small island, or sub-catchment). If no data is available, it can be considered to use proxies or to gather data first. Gathering and analysing data often takes time and may be costly. Gathering data is generally not worthwhile on deemed less important issues. It may not even be possible when urgent decisions have to be made, which forces concessions. The choice what data to use, what not, how to aggregate and display the data, how to interpret and weigh it against other issues, are choices with subjective elements. Data can be used as evidence to give direction in policy development, and it can be used to push a political agenda.

As a first step in identifying data sources I recommend to get an impression of an area by doing a field visit with local experts and residents (chapter 4 and 5). During a walk or drive-through you experience the landscape and get a sense of its size, proportions and of the lifestyles of its residents. The residents could explain their use of the land, identify problems they experience and foresee if certain interventions and policies would be implemented. The local experts may point out specific elements, elaborate on the cultural background, on relations between the environment and human society, or on social dilemmas. Both the residents and experts could share their understanding on implications of past, present or potential future measures and policies.

It might be argued that data are no longer needed, once field visits have been carried out. Although field visits may work well for a small area, they are, however, infeasible for large territories. Another drawback of decision making based on field visits alone is the human tendency to overestimate recent and emotionally charged events (Schwarz et al., 1991), the tendency to rely heavily on a limited set of information (Zhang et al., 2007) and fail to notice slow changes around them. As a result of these cognitive biases, relevant information is at risk of being overlooked. Field visit learnings complemented with (trend) data on a broad variety of issues, may help to overcome these disadvantages. Relevant issues can be found through identifying (Gregory et al., 2020) and interviewing stakeholders (Longhurst, 2016), or doing (literature) research.

In my experience data only tells part of the story. While certain factors are relatively easy to measure and quantify, other factors are more difficult to measure and have the risk to be ignored in assessments. Especially factors that are intrinsically about values (e.g. cultural value, noise nuisance, or landscape beauty), or factors that are complex and multi-interpretable (e.g. habitat health or social cohesion) tend to fall in this last group, although there are well accepted methods to include such qualitative information (Paracchini et al., 2011.; Allain et al., 2018)

In dialogue with stakeholders, policy makers and domain experts, facts, interpretations and opinions are often mixed. A term '*extensive farming*' may be interpreted as '*half of the amount of external inputs (fertilizer, pesticides and labour) in comparison to intensive farming*', or as '*no external inputs. Grazing pressure below the limit of natural regeneration of the agricultural fields*'. The use of such abstract and multi-interpretable terminology glosses over differences in perception, either unconsciously or on purpose (Janssen and van Ittersum, 2009). Data in the form of numbers enable fact checking and lift the obscurity by enabling people to use the same reference and reflect upon it from their own perspective (e.g. '*245 kg of soil injected Nitrogen per hectare in the Netherlands*', Lukacs et al., 2019). Data must be incorporated in policy development when policy makers are present in collaborative settings. This is especially true, when the data is accepted by influential stakeholders and when the data supports the policy agenda. If policy makers are not present, data must not only be made available to inform policy makers (e.g. through reports), but used to nourish political influencers (e.g. civil servants and lobbyists) and the public debate that in turn exert influence on the policy making process (Devarajan, S., 2017). How to get the data to be picked up and internalized up by political influencers and in the public debate, is another challenge.

6.2.2 Collaboration aids to converge different perceptions towards supported solutions

All the research documented in this thesis uses methods and practices for intensive and creative work sessions, as a means for people to come together to formulate and work on a common goal. That goal is to develop tools that are used in policy development with the overall objective to support the formulation of a viable land use policy. The listed practices are helpful to integrate knowledge and experiences that are spread across individuals (see all chapters), to find ways to share and use scarce resources (e.g. land) (see chapter 4), or to join forces to exert influence on policy making (chapter 5). The collaboration practices are about sharing with- and learning from each other, and jointly exploring and deciding. They are instrumental to: 1) reflect on one's own thinking and recognising assumptions and values in it; 2) reach a common understanding by getting to know each other's thinking, identifying similarities and differences, and what these mean for each other; 3) facilitate the development of a shared vision under a feeling of shared ownership. This intensive engagement generates trust, commitment and enthusiasm to jointly work towards the goal, to influence agenda setting and to broaden impact (confirmed by Restrepo et al., 2020; Akbar et al., 2020; Anjum et al., 2021). In effective collaboration people work together on the basis of mutual respect and trust although they do not necessarily always agree with each other. Effective collaboration is also about pushing each other forward and allowing each other visibility and position. To stay connected during progression, the team must periodically reflect on the way of working together, be open to possible changing circumstances and adapt whenever necessary.

Collaboration starts with a group of people that want to work together towards a common objective. It is either actively initiated, or it emerges spontaneously when people are engaged in conversation. Together they decide who else to include (and exclude) on what basis (e.g. for expertise, representation, or influence). Multiple collaborating groups may be formed around the same objective. These groups work together with different intensity and frequency, e.g. a group of scientific modelers that work together on a daily basis, the donor and foreseen users that provide feedback and direction in 3 weekly iterations, and a consultative group that provides input and feedback several times a year (see also Verweij et al., 2014; Nabuurs et al., 2019). Motives for participation may vary between individuals. Some may want to work together as they seek profitable opportunities, fear that they miss out on influencing outcomes, feel that they can meaningfully contribute, out of curiosity, are energized by socially engaging with others, or are obliged to do so as part of their job description.

Although engaging in collaboration has many benefits, not all activities are to be carried out in a collaborative effort. As collaboration is time and energy demanding, the benefits should outweigh the costs (Cross et al., 2016). I have found collaboration especially useful in activities where tools and processes need to be aligned, where complexity and social learning is involved, where awareness of- and access to- networks is needed, and when commitment is sought. Tasks must be split up if they are simple, it is clear what individuals need to do by themselves, or speed is key. If individual tasks are running longer, you must check regularly to see if everyone is still on the same page.

In my experience collaboration efforts are not always a success and may not lead to a viable solution. Several reasons may be involved, such as external constraints (e.g.

political landscape, or mandate of the individuals involved), unrealistic expectations or because of interpersonal issues. Collaboration efforts can provide stage to fierce discussions when: there are different viewpoints, there is competition between participants, or personalities-, working style preferences-, or culture- clash. Although vigorous debates can be a constructive means to make progress, they are not helpful if they put relationships on edge and block continuation. Although maybe not all involved can be kept on board. Collaboration sessions can also feel like a waste of time when conflict-avoiding behaviour dominates critical thinking, and no tangible results or specific agreements are made. Careful preparation and facilitation can reduce risks considerably, for example by interviewing participants beforehand to anticipate potential conflicts, include a skilled facilitator to manage conflicts, or steer and trigger discussion by putting forward (bold or over-simple) proposals. Also, keep probing to unravel abstract notions. While abstract notions are easy to agree upon and give a feeling of unity (e.g. 'we want to have a sustainable solution'), different perceptions remain, and that very likely result in future conflicts. To reduce the disconnect, you must therefore adopt an inquisitive attitude and keep asking. Still, the risk of collaboration failure remains. Despite preparation, setting and experience, it is an illusion to think that collaboration can be steered into a success always. Nevertheless, if you strive for (societal) impact, that risk should not stop you from trying, even if chances of disappointment are substantial.

6.2.3 Choosing the right tool

The tools listed in this thesis are used to describe, compare and communicate simplifications of part of the world (models). They are helpful for making informed decisions by separating factual knowledge from biases and beliefs. Tools, in their simplified representations of land use and land use related processes, have limitations that are not always explicit. First, they are never fully value-free, because of the underlying theory and methods (confirmed by Douglas, 2009), for example the belief in free-markets, or the choice for a specific statistical method. Second, they are based on explicit and (un)conscious implicit assumptions on relationships between system elements, the choice of system elements, the level of detail, and the time horizon and -granularity. And third, they are a simplification of the current status of science. Unknown, or not understood, relationships cannot be captured and are thus missed.

The choice for what simplification to use is driven by the socio-historical discourse (such as cultural background, scientific training and network), and interest of the researchers and donors (confirmed by Parker and Winsberg, 2018; Lagopoulos, 2018). Available budget and lead time also play a major role.

Many researchers push their supply of tools in projects, instead of exploring what would best fit the stakeholders' demand. This is done for a number of reasons: alleged cost efficiency (the tool is available off the shelf), return on investment (investments either in money or people made in previous projects, have to pay off), trust (it has been used and is published in numerous studies), continuity (changing long-used methods complicates comparability), and institutional settings (the researchers, assessment agencies and policy developers have working relationships and networks in place). Tools are pushed already during proposal formulation, when issues to be examined are still fuzzy. Early decisions are made to be able to continue one's own research interest, for cost estimation purposes (it is easier to estimate costs based on similar previous studies), a promising project proposal (a detailed and strictly planned proposal builds credibility and trust with the client), and to split work across project partners. Although these may seem valid arguments, there is a high risk of failure to deliver a useful solution, as detailed understanding of the (research) question only becomes apparent during project execution. The lurking disappointment and dissatisfaction of stakeholders and clients, may damage the relationship and ultimately the trust in science for answering questions. I recommend a more inquisitive attitude in the initial phase of a project in order to explore what tool(s) would be most helpful and to have more options for adaptive project implementation to ensure that tool choices can easily be adjusted during the course of the project. As tools, and their associated tasks and budgets, are often bound to project partners, this different project setup has quite some implications. There may also be implications with the donor as their bureaucracy might be organized around ticking completion of pre-defined deliverables and activities.

An increasing complexity of land use dilemmas lead to a wish to develop integrated tools combining several disciplines into a single all-inclusive one. This combined with a consequence of tool push lead to linking of big existing models that each capture part of the socio-ecological system (e.g. Janssen et al., 2011; Sieber et al., 2013). Although goals are set under one thematic umbrella, knowledge and reasoning captured in individual models remain for the most part conceptually and, for the most part, technically separated ('multidisciplinary', see Wright Morton et al., 2015; Tress et al., 2004). In my experience a lot of time and effort is put in technically realising interfacing between modelling software and data sources (see for example Knapen et al., 2013; Chen et al., 2020). An effort that continues today with new combinations of models and inclusion of promising new technologies like sensor data and digital twins (e.g. Wright and Davidson, 2020; vanderHorn and Mahadevan, 2021). The advantage of developing formalized links is that these prove that conceived links can actually be realized. The linked software systems simply don't run otherwise. However, these challenging technological puzzles detract from the overall objective of assessing the integrated effects and robustness of proposed policies. Such a technology-driven solution makes it hard, for even the model developers themselves, to understand the reasoning hidden within the system as a whole, and as a result, may rather obfuscate than help decision making (confirmed by Lee, 1973; Elsawah et al., 2020).

The tools listed in this thesis vary in degree of interaction with stakeholders. Ordered from a low to a high degree these are: *iClue* (chapter 3) – for a researcher that seeks to understand where land use is likely to change under specific conditions; *SIAT* (chapter 2) – as a focal point for individual modelers that bundles their joint effort in a simplified meta-model for policy makers; *DCBD* (chapter 5) - to link data collectors (scientists and field experts) with users (policy makers and land managers) through a web-platform; *QUICKScan* (chapter 4) - for collaboratively integrating expert and tacit knowledge with available data; and *conceptual modelling* (chapter 2, 3 and 4) - to inventory the relevant system elements and their relationships in a cross sectoral and cross disciplinary workshop. There is a wide range of tools available in addition to the ones listed here (see listing in chapter 1). The choice of what tool to use depends on the purpose (e.g. system understanding, projection, or social learning); the group of stakeholders you are targeting; the anticipated degree of interaction; and personal preferences of researchers and optionally donors and stakeholders. Such a personal preference may concern re-use because of familiarity, or the desire to try out something new. Multiple tools can be used in combination and in different phases of a project. Mid-term progress evaluation helps to identify limitations or new opportunities, and adjust tool choices.

As land use, and land use policy development, is inherently complex (chapter 1), a single tool cannot capture all associated aspects on its own. With different tools, that each explain part of the story and provide a disciplinary, sectoral or stakeholder perspective on the whole, it is up to the eye of the beholder to merge it all together. Methods that facilitate to see the big picture by encouraging systemic thinking and recognising the role of actors and contexts, are needed to bring together disconnected worlds in people’s minds. Such methods facilitate to (i) obtain a holistic understanding, (ii) aid to identify the need for complementary in-depth studies; (iii) understand stakeholder demands and tool(s) requirements, and; (iv) help to put the results of the in-depth studies into perspective. Methods to see the big picture include conceptual modelling (chapter 2, 3, 4, Argent et al., 2016), causal looping (Fernald et al., 2012; Cormont et al., in prep.), participatory mapping (e.g. Jacaobi et al., 2017; Verweij et al., 2017), and joint fact finding (Matsuura and Schenk, 2016; Innes and Booher, 2016; Verweij et al., 2020).

6.3 DIRECTIONS FOR FUTURE RESEARCH

This thesis contributes to the field of tools for land use policy development by providing collaboration methods and practices to scientists for enhancing tool uptake. It also identified issues that require further research. At least three main topics are identified:

Firstly, *how can psychological and educational insights be used to enhance the inter- and transdisciplinary learning with tools in group sessions?* Inter- and transdisciplinary learning (Wright Morton et al., 2015) is elementary to knowledge integration in land use planning and land use assessments. Insights in this thesis are based on experience. A more solid foundation from psychological and educational studies is needed to bring supplementary insights and practical guidance to understand how learning takes place (e.g. social constructivism) and why some persons in collaborative activities are proactive and engaged while others behave passive and alienated. For example Ryan & Deci (2000) describe that motivation requires competence (the activities must build on a persons' knowledge), autonomy (have influence on the process) and a social relation (with the other individuals involved). Assuming that these insights impact how tools are used in collaborative efforts, there will also likely be consequential (functional) requirements changing tool setup.

Secondly, *how can collaboration tools be used to reduce the disconnect between the evidence informed policy making process and plan realisation process?* Tools contribute to the formulation of policies and plans. These intentions for land (use) change are published in policy documents, reports, vision documents and scientific articles. Often, this is where the study ends and momentum with stakeholders is lost. Although possibly, previous stakeholders have become champions for the realisation of plans, this realisation (if any) is often a disconnected process in which relationships (and knowledge) have to be reconstructed (Holl, 2017 in van Oosten et al., 2018), and in which a different, separate set of tools is used. Ideally these processes form a continuum that are supported by relatable data and tools. How to make sure that tools and collaboration practices that are used throughout the process are aligned with each other? And how would that ultimately lead to the realisation of plans?

Thirdly, *how can (big) data and (cluster) computing transparently be used in interactive working sessions with stakeholders?* For the QUICKScan participatory modelling tool described in chapter 4, data, algorithms and the Graphical User Interface are run from a single computer. The increasing availability of (big) data and (cloud- and cluster-) computing power are promising technological advancements to inform the policy making process with more detailed and up to date information. How can these technologies be used in workshops in which multiple explorative assessment iterations are carried out, such that they are transparent and informative to the users?

ANNEXES

ANNEX I – ICLUE PARAMETER TEMPLATE

```
# property file uses key = value notation. The symbol ' = ' cannot be used for other purposes
# key cannot contain any white spaces. Use camel casing instead
# key uses namespace notation (a '.' between key-parts) to denote a hierarchical relation
# a value can contain white spaces
# in value the symbol ',' is used to separate list elements. It can therefore not be used for other purposes

# Baseline landuse map and year that the map represents
# Example: Baseline.filename = D:\\clue\\Mexico\\rob_lu_16a
# Example: Baseline.year = 2005

# Landuse classes
# code in map file, colour code in hex rgb, ease of change, initial age in years, demand deviation type, demand deviation amount
# colour examples: (red ff0000), (green 00ff00), (blue 0000ff), (yellow ffff00), (white ffffff), (black 000000), (grey aaaaaa), (orange ffaa00), (purple aa00ff)
# see also: http://www.color-hex.com/color-names.html
# ease of change: {'Very easy', 'Easy', 'Hard', 'Very hard', 'Cannot change'}
# demand deviation type: {'AbsoluteDeviation' [cell count], 'PercentageDeviation' [0…100]}.
# Example 1: LanduseClass.Forest = 10001,38a800,Hard,100,AbsoluteDeviation,2047
# Example 2: LanduseClass.Urban = 10002,38a800,Very easy,22,PercentageDeviation,15

# Administrative units map and list of unit name and unit code
# Example: AdministrativeUnits.filename = D:\\clue\\Europe\\masker
# Example: AdministrativeUnit.Netherlands = 1
# Example: AdministrativeUnit.Belgium = 2

# Demands
# line with sequence of landuse classes
# line with same sequence of landuse demands per year
# Example: LanduseDemands.sequence = Forest, Urban
# Example: LanduseDemand.Netherlands.2025 = 430787,232460
# Example: LanduseDemand.Netherlands.2050 = 530787,132460
# Example: LanduseDemand.Belgium.2010 = 300,200
# Example: LanduseDemand.Belgium.2050 = 400,100

# Drivers
# Can be 'Constant', or 'Dynamic' driver. Dynamic drivers change over time
# For every driver:
# line 1: DataType = {'Qualitative', 'Quantitative'}
# line 2: filename = full path
# line 3 etc: class.className = class code in map file, class colour in hex rgb
# the following 4 examples illustrate: 1. qualitative constant driver, 2. quantitative constant driver, 3. qualitative dynamic driver, 4. quantitative drynamic driver
# Example 1: ParameterMap.Constant.EcoRegions.DataType = Qualitative
# Example 1: ParameterMap.Constant.EcoRegions.filename = D:\\clue\\Mexico\\wwf_ecoregion
# Example 1: ParameterMap.Constant.EcoRegions.class.Boreal = 204,ffaa5b
# Example 1: ParameterMap.Constant.EcoRegions.class.Pannonioal = 205,22e4ff
# Example 1: ParameterMap.Constant.EcoRegions.class.Tundra = 206,ffff00
# Example 2: ParameterMap.Constant.EnergyCropHectare.DataType = Quantitative
# Example 2: ParameterMap.Constant.EnergyCropHectare.filename = D:\\clue\\Mexico\\rk_encrop_ha
```

```
# Example 3: ParameterMap.Dynamic.Temperature.DataType = Qualitative
# Example 3: ParameterMap.Dynamic.Temperature.class.Cool = 1,0000ff
# Example 3: ParameterMap.Dynamic.Temperature.class.Moderate = 2,ffaa00
# Example 3: ParameterMap.Dynamic.Temperature.class.Hot = 3,ff0000
# Example 3: ParameterMap.Dynamic.Temperature.filename.2005 = D:\\samplePath\\filename_2005
# Example 3: ParameterMap.Dynamic.Temperature.filename.2012 = D:\\samplePath\\filename_2012
# Example 3: ParameterMap.Dynamic.Temperature.filename.2020 = D:\\samplePath\\filename_2020
# Example 4: ParameterMap.Dynamic.PopulationDensity.DataType = Quantitative
# Example 4: ParameterMap.Dynamic.PopulationDensity.filename.2005 = D:\\samplePath\\filename_2005
# Example 4: ParameterMap.Dynamic.PopulationDensity.filename.2010 = D:\\samplePath\\filename_2010
# Example 4: ParameterMap.Dynamic.PopulationDensity.filename.2020 = D:\\samplePath\\filename_2020

# Suitability calculation
# line 1: Method = {StepwiseRegression, FunctionDictionary}
# line 2: depending the method
# line 2: StepwiseRegression.SampleSizePercentage = decimal number between 0…100 (percentage of the number of cells for each land use class that'll be used to do the regression upon)
# line 3: StepwiseRegression.CorrelationThreshold = decimal number between 0…1 (drivers are being correlated for each landuse. If drivers are highly correlated (above threshold), the driver with the lowest correlation with the landuse class is omitted)
# line 4: StepwiseRegression.ExportFileName = d:\\path\\filename.prop
# Example: Suitability.Method = StepwiseRegression
# Example: Suitability.StepwiseRegression.SampleSizePercentage = 7.5
# Example: Suitability.StepwiseRegression.CorrelationThreshold = 0.85
# line 2: FunctionDictionary.<adminUnit>.<landuseClass>.<FunctionConstant ≥ decimal number between −1…1 (constant value in function)
# line 3: FunctionDictionary.<adminUnit>.<landuseClass>.<FunctionCoefficient>.<Driver> = decimal number between −1…1 (coefficient value in function for quantitative driver)
# line 4: FunctionDictionary.<adminUnit>.<landuseClass>.<FunctionCoefficient>.<Driver>.class.<className> = decimal number between −1…1 (coefficient value in function for qualitative driver)
# line 5: etc. for driver and landuse class

# Conversion
# choose from the options: {'always', 'never', 'years, 7', 'location, D:\\samplePath\\conservationAreas.tif'}
# default is 'always' (no need to include a land use conversion that can take place always)
# for 'location': areas with data are NOT allowed to be converted. Areas without data (= nodata) can be converted
# Example 1: Conversion.Urban.Forest = never
# Example 2: Conversion.Forest.Urban = years, 15
# Example 3: Conversion.Forest.Arable = location, D:\\samplePath\\conservationAreas.tif

# Neighbourhood
# Specifiy a neighbourhood (a focal filter in the form of a square) per land use class.
# You can use mix different uneven sizes (e.g. 3, 5, or 7 cells)
# Only listed land use classes will be processed with a weighted sum neighbourhood function
# Example 1: Neighbourhood.Urban=1,3, 1,3,5,3,1,3,1

# Target time
# define until what time land use allocation calculations take place
# Example: TargetTime = 2050
```

ANNEX II : LISTING OF QUICKSCAN CASE STUDIES AND THEIR CHARACTERISTICS

Case study	Objective	Data	Type
Green Infrastructure of Europe (EEA, 2011, Verweij et al., 2012)	What part of the Natura 2000 areas could be seen as Green Infrastructure? And as Natura 2000 is the core, what other areas might be included based on what assumptions?	Pan-European spatial datasets with a 1 km² resolution: protected nature areas, land cover, High Nature Value farmland, eco-tones and various administrative and bio-geographical mappings.	Explorative assessment
Wetland Conservation in the Yellow River delta (Eupen et al., 2007, Verweij et al., 2010b, Wang et al., 2012)	What would be a more balanced water allocation for sustainable development of the wetland nature reserves, dealing with the effects of land use changes and variations in the flooding regime?	50 × 50 m² resolution: land cover, topography (incl. oil pump jacks), soil, water table, hydrological flow, vegetation and elevation.	Participatory model development
Soybean expansion in Brazil (Barreto et al., 2012)	What are likely areas for future soybean expansion? What is the effect of that future expansion on indicator species as birds and large mammals? What areas need protection?	250 × 250 m² resolution: land use (current situation and future projections), topography, soil, elevation	Facilitate scientific method development
Resettlement of displaced persons in South Darfur (Eshitera, 2013)	How much agricultural area is being converted to urban? Is the South Dafur agricultural system able to support the population?	100 × 100 m² resolution: soil, rainfall, land cover (incl. agricultural crops and livestock grazing areas), water access points. Statistical data: consumption per capita, population, actual and maximum agricultural production.	Explorative assessment
Landscape attractiveness of the Dutch countryside (Roos-Klein Lankhorst et al., 2016, Losekoot, 2013)	How do citizens value the scenic beauty of the Dutch living environment different? Can this purely be based on physical characteristics of the landscape? And can citizens be grouped on societal background given their valuation?	50 × 50 m² resolution: land use and topography including high buildings, glass houses, power pylons, wind turbines, lines of trees, ditches, etc.	Facilitate scientific method development
Urban Sprawl in European cities (Winograd et al., 2013)	Where do we expect urban areas to grow? What are the biophysical and socio-economic implications for urban, peri-urban and rural areas in relation with land cover, green infrastructure?	Pan European 1 × 1 km² resolution: land cover (historic data and present situation), urban nigh light, protected nature areas, elevation, economic and population density, accessibility to cities, agricultural soil production, soil suitability for construction, administrative boundaries	Explorative assessment
Ecosystem Integrity of the Brazilian Amazon (Verweij et al., 2014)	Find relation between climate and human imposed drivers and ecosystem integrity to find likely future impacts on biodiversity	Pan Amazonia data at 1 × 1 km² resolution: Remote sensing products (like leaf area index and vegetation cover), land use, land cover, environmental protection zones and zonation of indigenous lands	Facilitate scientific method development

	Participants	Setting	Impact
	European policy assessors and domain experts from across Europe.	During two days, three half-day workshops were organised with European policy assessors and domain experts from across Europe. Within workshop 1 the policy context was delineated and alternatives and indicators defined. The experts used previously gathered maps to derive the indicators for all alternatives in Workshop 2. The next morning the results were presented to the assessors in workshop 3 and iterated upon.	Helping the demand articulation for defining Green Infrastructure
	Municipality officials, conservation commissioners, farmers and hydrological and ecological experts.	During one and a half year 5 ten-day workshops were organised to define scenarios, spatial strategies, indicators and compare scenario and strategy impacts.	Short term: increased participant awareness of possible and feasible water allocation;
	Biological experts, scientific ecological and land use modellers	One year postdoc desk study with regular feedback rounds from fellow scientists	Raised awareness within the scientific community
	Local farmers, agricultural experts, human settlement experts and municipality officials	Half year Msc study including several group discussions and interviews to gather expert knowledge (and data).	Increased local awareness: the study results indicated that the livestock production subsystem is beyond the potential sustainable carrying capacity.
	Policy assessors, social scientists, statisticians, spatial modellers	A group of citizen several locations statisticians determined locations to test for landscape attractiveness and identified citizens to be interviewed to capture their perception of these locations.	Validated model is used in annual reporting obligations of the Dutch government
	European urban experts and policy assessors.	Three workshops with European urban experts and policy assessors. Scoping was performed in workshop 1. Workshop 2, took half a day and resulted in the definition of three alternatives and the identification of required maps and statistics. During the last workshop the alternatives were built and linked to indicators using knowledge of both participating experts and policy assessors.	Results included in European reporting obligation
	Ecosystem experts, biologists, statisticians	Several tele-meetings and workshops with Brazilian scientists and Dutch ecosystem experts and modellers. Fieldwork was carried out to validate the model.	Found quantitative relationships of the components forming the ecosystem integrity

Case study	Objective	Data	Type
High Nature Value Forests within Europe (Winograd et al., 2013)	High Nature Value forests are a hotspot for biodiversity. How can these forests be best characterised and where are they located?	Pan European 1 × 1 km^2 resolution: tree species, forest types, land cover, growing stock, wilderness of natural vegetation, forest connectivity, precipitation, slope, protection status, ecotones.	Explorative assessment
Risk mapping for soil Carbon under climate change (Hijbeek et al., 2016, in prep.)	Find hotspots of soil carbon stock that are sensitive to climate change endangering the sustainability of farming systems.	1 × 1 km resolution: soil texture, aridity, organic matter, slope and farming systems.	Facilitate scientific method development
Impact of climate change on biodiversity in Pan-European protected areas	The aim of the European Natura 2000 network is to assure the long-term survival of Europe's most valuable and threatened species and habitats (European Commission, 2013a, European Commission, 2013b). How does the future climate variability change and how vulnerable are the protected areas to this change?	1 × 1 km^2 resolution: maps of Natura 2000 areas (EEA, 2013), climate projections (from EU FP6 Integrated Project ENSEMBLES, Contract number 505539), Digital Elevation Model, Land cover, population density and accessibility to markets	Explorative assessment
Vulnerability and adaptation assessment for Central America	What are the main vulnerabilities and risks to climate variability and climate change at local, regional and national scale? What are the best mitigation and adaptation options?	Population and agricultural census data, 1 × 1km^2 resolution: land cover, land se, temperature and precipitation (both actual and projections), topography, elevation, administrative areas, accessibility to markets	Participatory model development
Pantanal River, Brazil (Jongman et al., 2005)	Build capacity to develop a coherent river management organisation to reduce unwanted effects in the Brazilian Pantanal, like: permanent inundation caused by sanding up of the Rio Taquari.	100 × 100 m resolution: land use and flooding patterns (based on 30 × 30 m multi-temporal LANDSAT satellite images), geomorphology, vegetation, geology, topography	Participatory model development
Integrated flood mitigation strategies, Taiwan (Yang et al., 2011)	What spatial plan is optimal for both flood prevention and habitat restoration?	25 × 25 m resolution: land use, flooding frequency, elevation, hydro network, man-made water management structures (e.g. dikes)	Explorative assessment
Agricultural value-of-use (Boogaard et al., 2003)	What is the value of land for different agricultural functions? How can we optimally allocate ownership of lands?	30 × 30 m resolution: soil type, water level, organic matter, water storage, soil acidity	Participatory model development
Suitability for nature development (Runhaar et al., 2003)	Determine nature target suitability based on site conditions	25 × 25 m resolution: water type, seepage, acidity infiltration, groundwater levels, other soil characteristics	Participatory model development
Wetland restoration in the Liaohe delta, China, (Xiaowen et al., 2012, Knol and Verweij, 1999)	Develop scenarios and identify measures to realize the landscape targets, locate the spatial areas involved in these measures, and determine the ecological impacts on flagship species.	25 × 25 m resolution: vegetation, land cover, soil, wetness, landscape target scenarios, measures, roads, waterways and oil plants.	Facilitate scientific method development

Participants	Setting	Impact
European forestry experts, ecologists and policy assessors.	Three workshops with European experts and policy assessors. Scoping was performed in workshop 1. Workshop 2, took half a day and resulted in the definition of four alternatives and the identification of required spatial data. During the last workshop the alternatives were built and linked to indicators using knowledge of both participating experts and policy assessors.	Results included in European reporting obligation
Geographers, biological experts, soil scientists, spatial modellers and representatives of local farmers	One month scientific expert desk study with regular feedback rounds from fellow scientists	Improving expert knowledge using local knowledge
European policy makers and experts on climate adaptation.	During a half a day workshop we evaluated the impact of various climate projections on the protected areas on basis of the participants expertise	Created more in depth questions, created awareness of usefulness of IT tools for climate change impacts exploration
United Nations Environment Program – Climate change and adaptation team and all REGATTA project (UNEP, 2013) members for latin America	One month expert desk study with regular feedback rounds from decision makers	Strengthened capacity on how to do a vulnerability assessment
Biologists, water managers, hydrologists, ecologists, regional policy maker and local (large scale) farmers	Three workshops of a week with scientific experts to build the model	Local farmers change position and join forces with policy makers to push forward the enforcement of regulation
Water managers, conservation organisation, municipality officials and landscape ecologists	Preparatory workshop with stakeholders to develop flood preventive scenarios.	Raised political awareness for the importance of integrated assessments
Experts on farm-level agricultural practise, soil and agricultural crops	7 months scientific expert desk study with regular feedback rounds from fellow scientists.	Created valuation of land forming the basis for exchange of land ownership by farmers
Experts on local level water management, vegetation specialists and ecologists	5 months a year scientific expert desk study with regular feedback rounds from fellow scientists	Several Dutch water managers use the NATLES criteria for analysing impacts of hydrological changes on terrestrial ecosystems, such as spatial planning to adapt for climate change and nature conservation
Conservation organisation representatives, water management, municipalities, fisheries, farmers, consultancy (for costing measures), ecologists and hydrologists.	Preparatory interviews and workshops with stakeholders to understand stakes and preferences. Half a year scientific expert desk study with regular feedback rounds from fellow scientists and stakeholders.	Mitigated the competing land-use needs between the ecological conservation and human needs, and to maintain the "no-net-loss" of wetland habitats

Case study	Objective	Data	Type
Integrated water management options for East Africa (Eupen et al., 2014)	What are the costs and what is the effectiveness of measures for (1) minimizing the number of people at risk for flooding and (2) to minimize yield gaps in crop production?	Study area 1500 × 1000 km, 1 × 1 km resolution: land cover, flooded area, soil texture, precipitation, yields, conservation areas, accessibility, grazing density, population density, elevation, slope, river basin boundaries, local measures	Facilitate scientific method development
Adaptive management plan for the lower Danube river, Romania	What are ecosystem service impacts of different ecological reconstruction plans?	10 × 10 m resolution: land use, flooding regimes, protection status and administrative units	Explorative assessment
Central area of the Kiskunság National Park, Hungary	Local experts and nature management organisations together (re)thinking the ongoing land use developments, develop sustainable land use and water management options, and consequently help reveal conflicts over land use change and management.	Study area is part of a long term socio ecological research network site (LTSER) 40 × 40 km, 25 × 25 m resolution: land cover, topographical wetness, accessibility, elevation, distance from roads, administrative units and topography	Explorative assessment
Map current and future ecosystem services in Glenlivit, Scotland	What are currently priority ecosystem services? How will they change under different land use scenarios? Which are the trade-offs?	10 × 10 m resolution: land cover, topographical wetness, accessibility, elevation, distance from rivers, administrative units and topography	Explorative assessment
Effects of land use change on landscape qualities (Roos-Klein Lankhorst et al., 2013)	Determine status and likely impacts of policy scenarios on landscape qualities for the Netherlands (cultural history, landscape scale, historical landscape, recreation capacity, green infrastructure, visual disturbance, morphology)	250 × 250 m resolution: land cover, land use, topography, elevation, vegetation, management of agricultural and natural areas, building- and vegetation height	Participatory model development
Mapping of Ecosystem Services of 17 EU Member States (Maes et al., 2013, Braat et al., 2015, Pérez-Soba et al., 2015).	Train EU Member States on how to map and assess the state of ecosystems and their services in their national territory to help decide on what ecosystems to restore with priority where.	Varies per Member State. Data resolution ranges from 25 × 25 m to 1 × 1 km on land cover, forest types, management, elevation, floods, accessibility of rural areas and coastal waters, fishing activities, standardised prices (e.g. per tree species), protected areas, etc.	Explorative assessment
Planning for ecosystem services in Cities: the Amsterdam case (Zardo et al., 2016, in prep.)	Make an explicit link between physical features of Green Infrastructure and provisioning Ecosystem Services	5 × 5 m resolution: land cover, tree crown coverage, tree species, tree element type (e.g. line of trees, single tree, etc.) NDVI, soil, height of artificial areas, wind direction and wind strength	Facilitate scientific method development
Planning for green functions in the Dutch city of Utrecht (Maes et al., 2016)	The main societal functions for which municipalities design green spaces are the aesthetic value of green spaces and recreation. The Dutch municipality of Utrecht is interested in making more use of green infrastructure in the search of measures that can help to achieve a healthy city; for regulating temperature, air quality, water storage and drainage and noise reduction.	10 × 10 m resolution: land cover, road patterns and road usage, tree crown coverage, tree species, heat peaks, particulates from traffic, green index and noise levels.	Explorative assessment

	Participants	Setting	Impact
	Policy advisors, experts on flood risk modelling, landscape ecologist and an agricultural economist	During one and a half year 10 one-day workshops were organised to define scenarios, spatial strategies, indicators and compare scenario and strategy impacts. These workshops were followed up with desktop improvements.	Learned that linking local measures to global data does not provide plausible information.
	Environmental NGO, water manager, municipality official, farmers, fisheries organisation, tourist organisation	1 day workshop with 12 individuals in which ESS were identified, prioritized and rules defined for quantifying the value of these ESS. Two scenarios were developed and the implications for the ESS assessed	Shared understanding of the stakes. Joint agenda setting
	Forest managers, nature conservation, water authorities and ecologists	1 day workshop in which ecosystem services (ESS) were identified, prioritized and rules defined for quantifying the value of these ESS. Prioritize at the local level relevant services for five different bird groups by evaluation of preference, according to this landscape of pastures (pollen, nectar) service capacity of the local population in terms of priority services.	Organised working group that met on a regular basis using QUICKScan for further exploration and assessment resulting in changing the LTSER management plan
	Nature conservation, tourism, foresters, farmers, sociologist, ecologist, hydrologist, business developer	1 day workshop in which ecosystem services (ESS) were identified, prioritized and rules defined for quantifying the value of these ESS. three scenarios were developed and the implications for the ESS assessed	Safe environment for stakeholders to put forward and try out extreme scenarios and evaluate based on impact visualization
	Policy makers, policy assessors, thematic experts	4 Month study with intense collaboration of thematic experts and policy assessors. Multiple workshop sessions, many bilateral meetings and emails. The model is updated annually by a small group of experts and irregular group discussions.	Validated model is used in annual reporting obligations of the Dutch government
	National policymaker, national Ecosystem Services expert and national (spatial) data expert with the support of an Ecosystem Services champion, representatives from the European Commission and a QUICKScan modeller.	A one hour preparatory tele-meeting to identify key Ecosystem Services and available data per Member State.	Raised awareness on how to map ecosystem services; Created 3 ecosystems service maps per Member State (17*3 = 51 maps in total); Clarification of the European Commission's objective to obtain the maps; Participants are able to create their own (improved) maps.
	Scientists: urban fabric designer, ecologist, ecosystem services experts and a (spatial) data expert	3 Month study in which regular expert discussions and participatory modelling sessions took place.	Understanding how what urban ecosystems services may be mapped.
	Municipal landscape architects and civil servant experts on health, water, catering establishments, recreation, citizen complaints (e.g. stress by noise) and ecology	Half a day workshop with 8 individuals for identifying functions of green and doing trade-off analysis. New functions and indicators where identified, defined and validated via group discussion.	Shared understanding on the effect and scope of green measures

Case study	Objective	Data	Type
Safeguarding access to mineral deposits in 8 European member State regions (Murguia et al., 2015)	The exploitation of minerals in Europe is an indispensable activity to ensure that the present and future needs of the European society can be met. Access may be hindered by legislative, biophysical or community opposition constraints. Perform participatory land use planning to overcome these problems.	Varies per Member State. Data resolution ranges from 25 × 25 m to 1 × 1 km on geology, sea vessel routes, accessibility, cultural heritage, protected natural areas, land cover, fishing grounds.	Explorative assessment
Understanding Ecosystem Services and wellbeing in Mabalane woodland, Mozambique (Mohamane et al., 2016, in prep.)	Despite the key role the charcoal industry plays in the livelihood of the people, the charcoal provisioning ecosystem service has decreased considerably because of changes in land use and land cover. These changes affect developmental initiatives in Mabalane. This study identifies the communities most susceptible to changes and helps targeting how to best support rural communities.	30 × 30 m resolution: land cover, elevation, slope, topography, accessibility to resources, accessibility to markets, topographic wetness index	Facilitate scientific method development
Coffee production in Colombia (Becerra et al., 2015)	Which areas are, production-wise, most affected by climate variability? How and where do what management options affect water quality and – quantity? What are social and farmer profitability impacts?	500 × 500 and 30 × 30 m resolution: altitude, temperature, precipitation patterns, harvest periods, administrative regions, farm types and farm management	Participatory model development

	Participants	Setting	Impact
	National policymaker, national Ecosystem Services expert and national (spatial) data expert with the support of an Ecosystem Services champion, representatives from the European Commission and a QUICKScan modeller.	A one hour preparatory tele-meeting to identify key minerals and available data per Member State.	Deeper understanding of different uses of land and sea influencing the (future) extraction of minerals.
	Communities, park rangers and governmental officials, sociologists and ecologists	Several preparatory workshops to identify ecosystem services, technical interventions, institutional interventions and forest management options to get a local perspective of issues surrounding land use, ecosystem services and well-being. The QUICKScan model (including the Bayesian Belief Network) was built by several scientists and tested against facts and preferences gathered during preparation.	Enhanced understanding effects of land use and land cover change as a result of land management, market and policy, the relationship with Ecosystem Services and the impact on the livelihood of villagers to target aid
	Problem owner, marketing specialist, business expert, field experts, scientific experts	One day preparatory workshop to determine the objective, identify participants and relevant datasets. Followed by a two-week workshop	Uptake of QUICKScan in the management process of the organisation to support early warning decision making

ANNEX III : QUICKSCAN WORKSHOP PARTICIPANT FEEDBACK

Feedback that confirms the QUICKScan approach, include:

- 'QUICKScan speeds up taking management decisions. It provided us with the management information we require for taking decisions in two days. It took our analysts 2 months to do detailed analysis and then aggregate it to the indicators relevant for our job' (Business manager, November 26th 2015)
- 'This workshop pushes us to truly work interdisciplinary, which at home we don't manage to do although we have got the same people around' (Business operational manager, November 18th 2015)
- 'Great to rapidly conduct a semi-qualitative analysis and create map and graph products while doing so' (Regional policy maker, November 5th, 2015)
- 'Although the data is sometimes of poor quality and knowledge of all underlying processes incomplete. Let's work with it and give advice to the best of our capabilities, as lobbyists will push forward their agenda's and decisions are going to be taken anyway' (Marine mineral consultant, November 3, 2015)
- 'The rather extreme scenarios we set up and assessed clarified where we had to refine and which scenarios didn't have a relevant impact. It helped us identify the scenarios that were of potential interest' (spatial planner, October 13th, 2015)
- 'Love the possibility to smoothly shift between scales, numbers, relations and dialogue. Very stimulating' (municipal official, October 13th, 2015)
- 'For several months we have had the idea that our proposed policy would have huge impacts, but within these few hours we have come to understand that it will never have the magnitude we had presumed. We need to adjust our strategy.' (policy maker, February 19th, 2015)
- 'We don't always need to initiate an expensive and time consuming tender to hire a consultant. This can speed up our work considerably' (policy maker, February 19th 2015)
- 'The storytelling of my colleagues at the start of the workshop and their choice of maps to illustrate it was very interesting indeed.' (conservationist, January 22nd 2015)
- 'It is so easy and fast. It feels a bit like a game, but it really makes me think. Very stimulating.' (policy advisor, September 10th 2014)
- 'QUICKScan provides relevant results and is easy to use. GIS tools are more complex. I am happy to find out it is possible to do an assessment without complex, time consuming and expensive modelling' (policy advisor, February 13th 2014)
- 'The iterative approach of starting simple and adding complexity later on is very useful. QUICKScan is very practical and easy. It is a good communication tool' (scientist, February 13th 2014)

- 'We are no longer afraid of modellers who say everything is complex. We can use a far simpler approach and have a useful result. We now see we should substitute missing data by expert estimates, but this requires courage against the critique of hard scientists.' (scientist and policy advisor, February 13th 2014)
- 'the use of Knowledge Tables is quite easy and handy as it is helped us local experts to participate in decision making where we allocated the available land resources to various livelihood zones' (local expert, November 2012)
- 'Information which we can read from internet or from reports brings us intellectual knowledge. In this workshop we gained hands-on knowledge. That experience based knowledge goes much deeper than the theoretical intellectual one' (policy maker, February 13th 2014)
- 'QUICKScan is crisp and clear. A very elegant tool' (policymaker, March 22nd 2013)

Critical reflections include:

- 'This approach uses constant expert gut-feeling assessment of knowledge, results and uncertainties. This is no objective assessment.' (Policy advisor from industry, November 5th, 2015)
- 'There is too little time to study the meta-data to objectively assess the results' (Geological scientist, November 4th, 2015)
- 'The method heavily relies on the availability of spatial data. If the data is of poor quality you will also get poor results.' (scientist and policy advisor, October 2014)
- 'The mechanistic approach is too simplistic. In the real world it is often the sudden unexpected changes or the sum of many small changes that make a difference.' (scientific modeller, July 2014)
- 'You only include the perceptions of the participating stakeholders at the time of the workshop. Isn't that too narrow and too susceptible to change?' (scientist, February 2016)
- 'How strong will the evidence-base of the results of this workshop be back in the political arena?' (scientist and policy advisor, February 2016)
- 'Complex spatial interactions like spill over cannot be modelled within a few hours. You'll miss out on just the effects that make a difference' (scientific economic modeller, 2012)
- 'If your stakeholders don't bring in that peak water levels occur every 100 year you'll miss out the effects that make a difference' (hydrological consultant, 2010)

ABOUT THE AUTHOR

Peter Verweij was born in Wijchen (1969), at that time a small village, between the rivers Meuse and Rhine, close to the city of Nijmegen in the Netherlands. In 1990 he moved to Utrecht to study at the university's department of philosophy. After several months, Peter switched to the more practical field of geo-informatics and specialised in cartography (1991-1995). During his study's internship in New Zealand, he worked together with craft cartographers and designers on the country's historical atlas. That experience, of mixing maps with graphics to communicate spatial phenomena and tell stories, has been an inspiration for his career.

Peter started his working career as Remote Sensing specialist at a small consultancy firm. This short term job provided him with his first earnings which he used to travel to the Chilean Atacama desert and the Peruvian rainforest. Back in the Netherlands,

he worked as ecological modeler to support landscape planning, which combined the disciplines of spatial modelling and programming (1996-2000). His interest in software technology and development methodologies drew him to work at a commercial software enterprise.

Peter’s first contact with land use policy making came in 2004 while working on decision support systems on eco-toxicology and agricultural subsidiary schemes at Wageningen Research. These software systems forced to synthesize information by understanding the end-user’s need, and formally bring together different scientific disciplines and modelling approaches. To do so, a good overall insight was necessary, for which Peter used constant dialogue with the involved. He worked on this type of integrated system for several years. Since 2010 his interest is more on the use of land use data and knowledge in workshop settings through the same type of dialogue with experts, policy makers and stakeholders.

Throughout his career Peter worked on a variety of topics and in different settings, such as: renewable energy, climate adaptation, land degradation, bio-diversity, forestry, urban development and food systems, for EU research projects, UN capacity building projects, Dutch government and business consultancies. His work has enabled him to travel and explore new places and (working) cultures, which he experiences as enriching.

Peter lives in Wageningen, with his wife and three sons. He loves camping out with his family in France and in the alps, and is regularly found backpacking with his friends in northern Scandinavia.

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