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Participatory Processes and Integrated Modelling Supporting Nexus Implementations

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Abstract

Policymakers and donors are increasingly requesting researchers to investigate the water, food, and energy nexus. This is largely due to the investment risks in the form of unintended side effects causing trade-offs between these three highly connected sectors. Meeting stakeholder aspirations to apply nexus approaches requires researchers to step from a pure conceptualisation of the water, food, and energy nexus to nexus implementations that effectively inform policy and planning processes. Nexus implementations refer to activities that contextualise a Nexus conceptualisation for a particular policy or management situation to lead to real-world improvements of Nexus related processes. Implementations of the nexus paradigm, however, come with two major challenges. One challenge is the development of diagnostic and analytical tool that may be applied to (at least) three sectors in an integrative way, which would allow us to investigate cross-sector dynamics. The second challenge is concerned with stakeholder engagement during the implementation as nexus-related decision making processes involve competing sector interests. Facilitating evidence-based policy negotiation demands research processes to effectively bridge science and a highly contested policy space.

This paper explores solutions for these two challenges and presents new and refined approaches to support the implementation of the water, food, and energy nexus in real world planning and policymaking contexts. This paper presents experiences with real world solutions for the methodological and the engagement-related challenge. For instance, advances in empirical agent-based modelling or with Bayesian Belief Networks provide examples of analytical method that effectively treat multiple sectors in an integrative way. Nexus implementations can utilise (stochastic or deterministic) agent-based modelling to simulate possible nexus trade-offs. Bayesian approaches, on the other hand, can quantify probabilities of expected outcomes. Despite the increase in analytical complexity, stakeholder learning and policy uptake can be achieved through participatory processes. Emerging research on this topic suggests very different process designs, which come with different strengths and weaknesses. Some process designs are more suitable for engaging with policymakers while others are more suitable for community level engagement. Also, some designs have a stronger focus on learning while others aim for conflict resolution. Robust monitoring and evaluation of research process designs is paramount for improving our ability to effectively implement complex nexus approaches in applied policy contexts. This paper presents a few participatory process designs, including the Challenge and Reconstruct Learning (ChaRL) process and Companion Modelling, and suggests a monitoring and evaluation framework for the comparison of participatory processes.

1. Introduction

Many assessments of economic development strategies reveal substantial trade-offs between key economic sectors (Bazilian et al., 2011; QEERI, 2012). Investments in the energy sector that aim to meet the growing demand for energy trigger in many cases a decline in food security or changes in water availability. Equally, food security-focused interventions can have implications for the energy sector and for water-related issues. Also, water management-focused improvements can impact on food and energy-related goals. These experiences highlight the need for assessments to consider the interactions between these three sectors. With the increasing awareness of the cross-sector connectivity the water, food, and energy nexus emerged as a new paradigm. Increasingly, policymakers and donors demand researchers to apply the nexus paradigm. This is largely due to the risk decision makers perceive in the form of aforementioned potential for trade-offs and synergies between these three highly connected sectors.

Over the past few years numerous papers have been published that present a conceptualisation of the water, food, and energy nexus (i.e. Hoff, 2011; Smajgl and Ward, 2013a; WEF, 2011). However, fewer studies document an application of a nexus concept to a real world case (European Report on Development, 2012; Mohtar and Daher, 2012) and even fewer studies implemented the applied nexus analysis as part of a policy negotiation (Smajgl and Ward, 2013c; Smajgl et al., 2016). Yet, the policy space is where the demand for a Nexus Approach originates from and to which scientists need to present their empirical nexus analysis. Despite the rapid uptake of the nexus paradigm, the implementation of a Nexus Approach is difficult as it introduces two major challenges (Smajgl et al., 2015b). The first challenge is to develop diagnostic and/or analytical capacity that allow for integrated assessments of the water, food, and energy sectors and their relationships in an empirical policy setting. This requires the consideration of many complex dynamics, which defines a methodological challenge. Second, the division of the policy space into sectors or line ministries constitutes competing interests. For scientists to provide evidence to such a contested value space is the second major challenge. The dominant outcomes are for scientific results to either be accepted if they match pre-existing opinions or for them to be disregarded if they contradict prevailing expectations. The challenge is to facilitate evidence-based decision making despite contradicting stakeholders expectations. This challenge is concerned with the design and management of the research-policy interface and the study-related engagement process.

This paper discusses new and refined solutions for these two major policy-related challenges to support the implementation of a Nexus Approach. First, integrated modelling methods are discussed that help investigating cross-sector dynamics. Second, processes are presented that aim to effectively bridge the science-policy gap in complex and contested contexts.

2. Analytical Methods Conducive to Effective Nexus Implementations

The challenge of integration has been a focus of scientific work since the emergence of the sustainability paradigm in the 1980s (Argent et al., 1999; Ascough Ii et al., 2008; Brouwer and van Ek, 2004). The Nexus Approach builds on the sustainability commitments of many governments but is more focused on the water, food, and energy sectors (Hoff et al., 2012; WEF, 2011). These sectors have been identified as critical for development processes and susceptible to costly trade-offs if investments and their side effects are not carefully assessed. Many investments in one sector can trigger losses or synergies in other sectors.

Most methods deployed during nexus studies have a disciplinary focus, which means that cross-sector trade-offs and synergies are not part of the analytical scope of the calculation or simulation. In these cases, sector-specific results need to be further processed to reveal trade-offs or synergies. Typically, this can be achieved by qualitative methods such as expert panels. For instance, Smajgl and Ward (2013c) designed an expert panel approach that asked disciplinary experts to identify first-order impacts of a variety of disciplinary modelling results. Then, the first-order impacts were presented and experts were asked to identify which impacts are likely to result in consequence. Then, these secondary impacts were again presented and experts were asked to identify tertiary impacts. The combination of first, second, and third-order impacts provided inputs for the development of system diagrams that specified the mechanisms that constitute cross-sector relationships. This approach established (qualitatively) how nexus sectors interact and how these relationships might change over time. Ultimately, the strength of such an approach is to highlight critical factors (or system elements) policy and planning could focus on.

Such qualitative methods allow experts to design likely cause-effect relationships, the specification of risks, and the identification of thresholds. However, the weakness is that complex cross-sector dynamics would not be considered and would require model-based assessment. This could be achieved by combining qualitative methods with disciplinary modelling or with integrated modelling.

Here, nexus-focused scholars can build on many advances sustainability research has made. The sustainability paradigm has guided substantial research towards integrated assessment, including the consideration of multiple sectors and their disciplinary indicators (or variables) (Alvargonzález, 2011; Hirsch Hadorn et al., 2006). These methods include agent-based modelling, system dynamics modelling, and Bayesian Belief Network, to name three of the most widely applied methods. Any of these approaches can be combined to cover different types of research questions (e.g., stochastic, deterministic, probabilistic), or assess variables at multiple scales and their scale-specific resolution (Smajgl, 2006; Smajgl et al., 2009).

In this paper, particular attention is dedicated to agent-based modelling because of its potential for nexus-type research. The need to improve our understanding of complex social-ecological dynamics created a substantial push for agent-based modelling due to its ability to consider highly complex relationships of multiple variables, including human behaviour (Barreteau and Smajgl, 2013; Gilbert, 2008). In particular its capacity to incorporate social dimensions creates a methodological advantage over most other modelling techniques (Edmonds et al., 2007; Squazzoni, 2010). In an applied policy context, sustainability-focused simulations often require the explicit modelling of social, economic and environmental interactions and feedbacks, which implies mostly non-linear relationships (Edmonds et al., 2007; Wuelser et al., 2012). From a modelling perspective this goal requires the definition of functional relationships in the form of logical rules (behavioural and social variables) and in the form of mathematical equations (biophysical variables) (Axelrod et al., 2006; Gilbert, 2008).

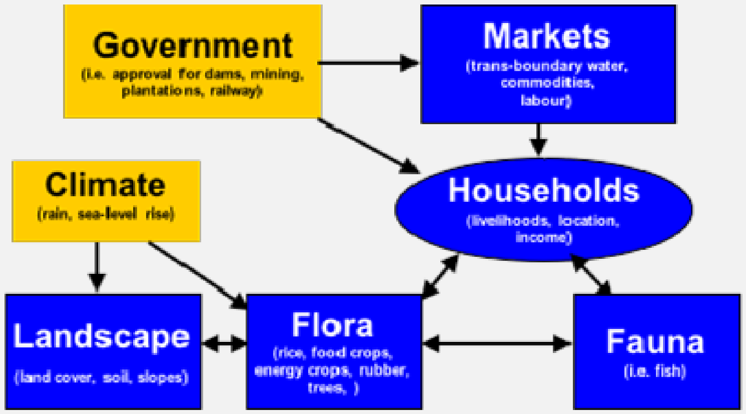
Nexus-focused assessments benefit from these modelling advances as many outcomes regarding water, food, and energy emerge from the bottom up as a result of decision making and interactions of many households. Water demand is often dependent on decisions made by individual farmers that perceive and respond to a variety of factors (i.e. crop prices, water price). In urban settings water demand results from a set of other factors, including habits, type of appliances, or water prices. Energy use depends on similar factors, while energy production is largely a consequence of corporate investment calculations and institutional arrangements. Food production in rural settings is linked to similar factors as water but experiences show a decline due to the increasing profitability of energy crops. All these influencing factors have in common that the decisions are being made by individuals, households, or companies based on what they perceive as effective incentives or constraints. Increasingly, the modelling community acknowledges that designing such modelling efforts from the bottom up is paramount for analysing nexus outcomes and trade-offs.

This requires modelling methodologies that allow for the explicit simulation of human decision making, which is a distinct advantage of agent-based modelling as it allows for the simulation of individual or households and their interaction with the environment (Smajgl and Barreteau, 2017; Smajgl and Bohensky, 2013). Behavioural rules can be derived from psychological understanding, experimental or monitoring-based evidence for behavioural responses to economic and other incentive changes, and other empirical or theoretical assumptions on human behaviour and adaptation (Smajgl and Barreteau, 2013b, 2017). Uncertainties can easily be integrated by defining parameters in ranges instead of point values to capture possible or experienced fluctuations (Barreteau and Smajgl, 2013; Müller et al., 2014). The development of such a genuinely integrated agent-based model can draw on widely tested approaches for model parameterisation (Doscher et al., 2014; Smajgl and Barreteau, 2013a, 2017), model calibration (Beaudouin et al., 2008; Bohensky et al., 2007) and model validation (Moss, 2008; Smajgl et al., 2011).

Many agent-based models have been developed since this methodology emerged in the 1970s and in particular since it started establishing itself in the empirical policy analysis space in the 1990s. One example for an agent-based model that was implemented to support policy-driven nexus studies is the MerSim model, the Mekong region Simulation model (Smajgl et al., 2013), see also Box 1. MerSim was utilised during various policy-focused studies to reveal nexus-related trade-offs and outcomes (Smajgl et al., 2015a; Smajgl et al., 2015b). Three nexus studies should illustrate the potential of agent-based model. First, the MerSim model was implemented to assess cumulative impacts of Mekong mainstream dams and climate change (i.e. changes in rainfall patterns and sea-level) on rice production, poverty, and migration in Vietnam's Mekong Delta (Smajgl et al., 2015a). Policy outcomes included changes in land-use planning to improve resilience to upstream developments and to sea-level rise. This example explicitly focused on energy (mainstream dams), food (rice production and fish), and water (flow and salinity levels), and provided effective analytical capacity to investigate nexus dynamics for different investment and under different conditions (see for more details, results and policy impacts Smajgl et al., 2015a; Smajgl et al., 2015b). In another application, MerSim revealed land-use change dynamics in Northeast Thailand involving commodity price-driven decisions at the farm level to replace food crops (mainly rice) by energy crops (cassava and sugar cane) (Smajgl et al., 2015b). These farm-level decisions are either accelerated by government investments in water diversion infrastructure for large-scale irrigation schemes or generate water demands that result in decentralised irrigation. This case portrays another typical nexus situation, which resulted in substantial policy changes concerning large-scale irrigation plans due to the unexpected outcomes the simulation model suggests. In a third policy-focused nexus application the MerSim model was implemented to the Nam Xong sub-catchment in Lao PDR to investigate trade-offs between upstream water uses (mining and rubber plantations), and downstream water uses (agriculture, tourism, and hydropower) (Smajgl and Nuangnong, forthcoming). Similar to the Vietnam study, this implementation of the Nexus Approach included water quality indicators as well as water quantity indicators. As a result of this study land-use plans were adjusted and investments in improved water treatment are being negotiated. All three MerSim applications were implemented as part of participatory processes to facilitate stakeholder learning and policy uptake (see ChaRL process – Challenge and Reconstruct Learning process – described in Section 3).

Box 1: MerSim model details

The description of the agent-based model Mersim (Mekong region simulation) (Smajgl et al. 2013) follows the ODD (Overview – Design concepts – Details) protocol (Grimm et al. 2006; Grimm et al. 2010).



Purpose of the model: MerSim aims to support the analysis of complex social-ecological interactions.

State variables (selected): Household income, Household livelihood, Household location, land cover, subsistence production and poverty rate, water flow, water quality, food commodity production, hydropower.

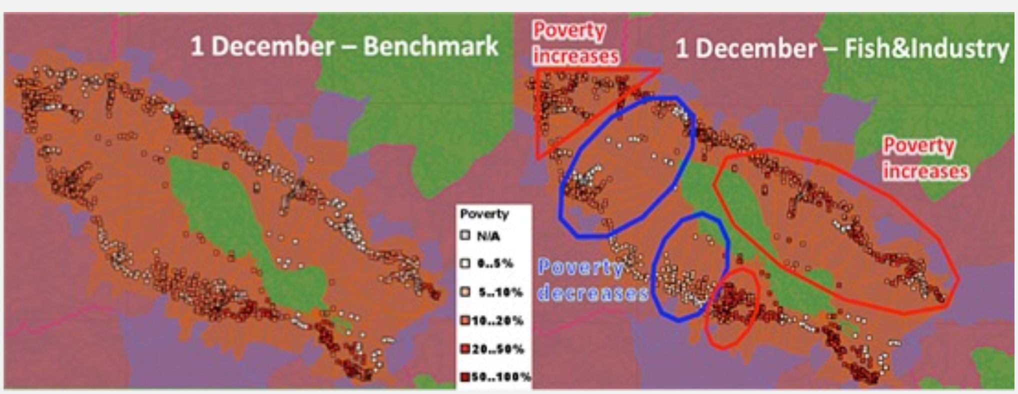
Emergence: Poverty dynamics, spatial poverty patterns, livelihood changes, and land use patterns.

Adaptation & Objective: Household agents respond to changes in the socio-ecological system that affect their livelihoods. Households' objectives are implicit to their behavioural response functionsthat is derived from intentional data elicited in the large-scale surveys.

Stochasticity: Most parameters are assumed to be stochastic to resemble more realistic model assumptions, including crop prices, productivity, wages, and rainfall.

Initialisation: The MerSim model utilises five sets of GIS data: (1) administrative boundaries down to administrative villages, (2) soil data, (3) land cover data, (4) rainfall projections, and (5) a digital elevation model. These datasets were used to specify the artificial landscape while household attributes and behavioural responses were parameterised based on the household survey.

Submodels: Household income is calculated in weekly steps as the sum of all livelihood activities that all household members engage in. Crop growth algorithms are defined for 16 crop types. Water flow algorithms



The diagram above shows MerSim outputs from a Nexus analysis, which assessed impacts of upstream hydropower on fish population in the Tonle Sap. This scenario includes climate change and government investments in alternative manufacturing focused investments. The poverty maps (dots are villages; increasing red pigment indicates increasing poverty) show the spatial shifts of poverty in Cambodia's Tonle Sap area.

The MerSim applications demonstrate how effectively agent-based modelling can support nexus implementations in real world policy and planning contexts. Unfortunately, so far, no other empirical agent-based model has implemented the water, food, and energy nexus comprehensively. However, many partial nexus applications have been developed as agent-based models, primarily for energy-water analyses (Ng et al., 2011; Santhosh et al., 2014) and for water-food focused analyses (Becu et al., 2003; Sahrbacher et al., 2014; Valbuena et al., 2008).

Agent-based modelling is not the only promising method. Other advanced techniques include games, Bayesian Belief Networks, and hydro-economic models. Several research groups have explored very successfully the effect of *serious games* (see also the DNC2017 position paper by Mochizuki, Magnuszewski, and Linnerooth-Bayer on "Games for Aiding Stakeholder Deliberation on Nexus Policy Issues") as a method to facilitate stakeholder engagement and stakeholder negotiations (Annetta, 2010; Barreteau et al., 2003; Wood et al., 2014). Such games can be designed as computer games, board games, or as role-playing games that target improved systems understanding among stakeholders or to make stakeholder better understand each other's actions by taking on each other's role (Annetta, 2010; Barreteau et al., 2003; Zellner et al., 2009). Considering the relevance of conflict, negotiations, and complexity in nexus-type situations, serious games are likely to offer substantial potential to reduce nexus trade-offs and achieve more sustainable outcomes. Many approaches that utilise serious games in participatory processes combine this with, for instance, agent-based modelling.

Bayesian Belief Networks (BBN) provide a different approach to agent-based models. With this modelling technique probabilities can be quantified for expected consequences (Lynam, 2016; Sun and Müller, 2013). This provides an effective tool if the goal is to quantify the probabilities or risks of specified outcomes (Lynam, 2016; Lynam et al., 2007). However, only a few BBNs have been implemented in nexus studies (Biggs et al., 2015; Varis et al., 2012).

Considering that the nexus discussion is largely driven by hydrologists (see discussion in Smajgl et al., 2016), an emerging approach involves the extension of hydrological models by economic variables. Hydro-economic models integrate hydrological variables and their physical dynamics with the economic value of water considering the economic value of water uses (i.e. crops) (Harou et al., 2009). A growing number of hydro-economic models have been developed for the analysis of (mostly partial) nexus trade-offs (He-Lambert et al., 2016; Mainuddin et al., 2011; Singh et al., 2014).

Any of these methods has a specific focus and the complexity of many contexts require the combination of multiple methods, which is often coordinated in so-called decision support systems (DSS). Since the 1970s and in a rapidly increasing number of contexts, stakeholders invest in the development of such DSS (Mysiak et al., 2005). A typical application domain of an environmental DSS is a watershed to help improve water management considering competing water demands (Andreu et al., 1996; Giupponi, 2007). These developments facilitated a stronger focus on cross-sector and cross-disciplinary integration and, thereby a broader understanding of emerging data gaps. While this movement is very promising, many of these computer modelling-supported processes are not achieving expected policy outcomes (Loucks, 1995; Matthies et al., 2007). In many cases this results from the fact that the DSS development process is driven by modellers, largely separated from the actual decision making or planning process. This separation introduces the risk that these DSS have no policy impacts. Growing evidence emphasises that in situations characterised by high complexity and highly contested values, decision support needs to actively design and employ processes that allow them to engage with stakeholders and, thereby mitigate the policy impact failure risk (Hassenforder et al., 2015; Smajgl and Ward, 2013b). Considering that the water, food, and energy nexus is in most situations highly complex and contested, the success of a nexus implementation depends not only on an effective methodology but also on the design of an effective stakeholder engagement process. The following section describes process design options that would benefit the implementation of nexus projects.

3. Process Designs for Effective Nexus Implementations

Applying an effective methodology for analysing cross-sector relationships and how their outcomes change due to certain development investments is only one important challenge of successful nexus implementations. Designing the engagement with decision makers and planners is the second major challenge. By definition, any applied nexus study needs to engage with at least three sector agencies, which have competing mandates. Considering that most of these cross-sector relations harbour complex interactions, the science-policy partnership is problematic because highly contested values establish incentives to argue for the first-best solution for any of the involved sectors. Complexity makes it difficult to dispute the benefits of a particular solution or present evidence for dis-benefits the investment would cause in other sectors.

Complexity is a key characteristic of nexus (and sustainability) focused research (and modelling in particular). Complex systems modelling is applied where system interactions are difficult or impossible to analyse based on human cognition, often simply due to the sheer number of interacting variables and the non-linearity many real world interactions imply. Additionally, sector-specific processes have to be understood as self-organising systems across multiple levels, which emphasises the unpredictability of emerging interactions (Boschetti et al., 2010; Miller and Page, 2008; Sawyer, 2005). Translating complex model outputs to useful information for multiple, competing stakeholders requires a *process* that guides stakeholder in perceiving and understanding complex cause-effect relationships. Without an effective process design that considers the cognitive aspects of the individual learning experience and the group level negotiation, the translation of complex modelling results is unlikely to have any policy impact.

Thus, in any situation that can be characterised by high complexity and highly contested values (or sector mandates) evidence-based decision making is challenging and demands careful planning of the engagement process with the competing policymakers and planners. Consequentially, the design of research processes and its policy engagement becomes a research topic of its own – to understand which process design options exist and which sequence of what actions is likely to lead to what policy outcome. Mounting evidence points at the effectiveness of participatory research processes to effectively bridge science and policy in complex and contested situations, which implies nexus-relevant situations (Barreteau et al., 2010; Cornwall and Jewkes, 1995; d'Aquino and Bah, 2013).

Participatory research is a very diverse field, largely applied in the domains of public health, environmental management, and education (Cornwall and Jewkes, 1995). The common denominator for participatory approaches is that the (research) process constructively engages non-scientists to consider their knowledge (Cornwall and Jewkes, 1995). Cash et al. (2003) argue that for effective participation of affected interests, knowledge needs to be agreed as valid, salient, and legitimate. However, the degree to which stakeholder knowledge is considered, what knowledge is exchanged, and what engagement techniques are being implemented varies widely (Barreteau et al., 2010). Increasingly, scientists observe that studies claim to conduct participatory research while the influence of stakeholders on the research remains minimal. In response, the research community developed robust definitions of what participation needs to entail and what levels of participation exist (see for details Barreteau et al., 2010). In cases with strong utilisation of modelling the terminology mostly changes to participatory modelling. Voinov and Bousquet (2010) provide an excellent overview of participatory modelling. Most prominent examples for participatory research include Community-based Participatory Research and Action Research (Cornwall and Jewkes, 1995) and Participatory Action Research (McIntyre, 2008). It needs to be emphasised that both of these groups include a range of diverse approaches. Prominent approaches within participatory modelling include Companion Modelling (Barreteau and et al., 2003; Bousquet et al., 2006) and Mediated Modelling (Antunes et al., 2006; van den Belt, 2004).

These developments are encouraging and establish a new research domain that will benefit nexus-focused research to effectively interact with multiple competing sectors and facilitate evidence-based decision making despite the significance of complex dynamics. One participatory process design that has been successfully tested in a few empirical nexus processes is the psychologically founded Challenge and Reconstruct Learning (ChaRL) process.

The Challenge and Reconstruct Learning (ChaRL) framework (Smajgl and Ward, 2013b, 2015b) aims to effectively bridge science and policy by guiding policymakers and planners through a highly structured participatory process (see *Figure 1*). This systematic science-policy engagement framework puts stakeholder learning centre-stage. It utilises visions, beliefs, and values as key entry points for scientific evidence to inform policy and planning processes.

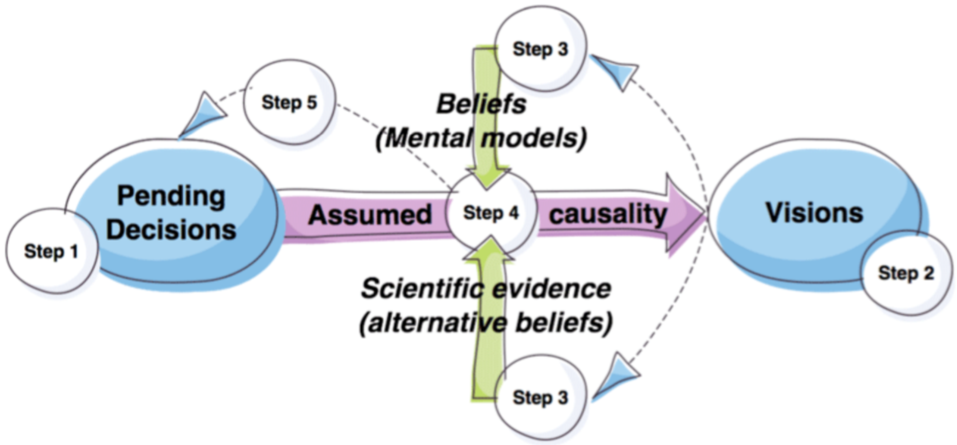


Figure 1. Five-step process of the Challenge and Reconstruct Learning (ChaRL) design

The ChaRL framework approaches the introduction of scientific evidence into ongoing policy or planning processes from the perspective of discovery-based learning, aiming to ground truth existing assumptions about cause-effect relationships relevant to the decision-making situation at hand. “Discovery learning occurs whenever the learner is not provided with the target information or conceptual understanding and must find it independently and with only the provided materials” (Alfieri et al., 2011). The ChaRL process elicits and challenges these underpinning causal beliefs (or heuristics) in five steps and *reconstructs* revised beliefs within the understanding of the functionality of the larger systems. The ChaRL process understands such reconstruction in the tradition of Habermas (2005) as the key process of learning, which is facilitated as an exchange of intuitive knowledge. Thus, scientific knowledge is not a priori assumed to be superior to stakeholder knowledge. The ChaRL process is in line with psychological research, particularly in the domains of cognitive research and discovery-based learning. These research communities provide substantial evidence for the effectiveness of discovery-based learning methods to achieve learning goals if compared with passively perceived instruction (Alfieri et al., 2011; Dean and Kuhn, 2006). However, experiments have also emphasised the importance of guidance during the discovery process (Kirschner et al., 2006; Mayer, 2004), which ChaRL provides through a highly structured five-step process.

Step 1 scopes out the objectives, including the decision making context and options, and the relevant success indicators as perceived by the decision makers. Inviting the relevant decision makers to co-design the research is critical to ensure high levels of ownership and, therefore stakeholder engagement (Smajgl, 2010). Co-designing the research gives stakeholders control over the focus and a commitment that this research is actually addressing their interests and needs (Barreteau et al., 2010). In the ChaRL process it involves at this early stage that stakeholders define principle ‘inputs’ and ‘outputs’ of the analysis. Stakeholders specify a list of external changes (i.e. climate change) and a list of possible intervention options. These *inputs* translate for the analytical steps into scenarios. Additionally, stakeholders define a list of policy-relevant indicators. These two lists provide the foundation for choosing the most effective methodologies (for examples see: Smajgl and Nuangnong, forthcoming; Smajgl et al., 2015a; Smajgl et al., 2015c). To further improve stakeholders’ ownership of the research design, the methodological choice is also made by the participants. The research team presents possible options for effective methods against the backdrop of requested scenarios and indicators. This presentation includes a transparent discussion of methodological strengths and weaknesses, which considers data requirements and available context-specific models. Allowing stakeholders to make these fundamental decisions translates into more active participation and a genuine interest in the progress and results of the study. It also reduces the perception that the research team enters the decision making process with a specific agenda (Smajgl et al., 2015b).

In step 2 visions for a specified geographic location are developed as narratives of plausible futures desirable for all relevant stakeholders (Foran et al., 2013). This step may need to be completed iteratively if the set of decisions are likely to affect multiple action arenas, each demanding separate facilitation. The iterative approach allows revision of the original vision based on presentation of visions from other locations or governance levels. This step is critical to any applied nexus study (Smajgl et al., 2015b) because shared visions are essential to prevent participants from reverting to their own sector goals when debating the benefits of development strategies or the relevance of assessment results. Thereby, visions become normative benchmarks that are shared across competing interests. Without such shared visions, the normative benchmark for participants to perceive research results remains the sector mandate, which means that sector representatives will continued to maximise sector goals instead of taking the overall systems perspective. The shared visions define the most desirable future scenario of the overall systems and re-direct stakeholders' attention towards improving overall system outcomes, which implies for the nexus domain a reduction of trade-offs. Developing shared visions requires focussing on long-term outcomes and indicators that are not sector specific, for instance desired levels of poverty, employment, state of the environment. Past trends (or drivers) need to be discussed followed by future trends and possible shocks. Highly effective is to develop three sets of possible futures with the participants, a most desirable future, a most likely and a least desirable future. For the latter participants develop risk mitigation plans while action plans are developed for the most desirable outcomes. This visioning process produces regularly action plans that combine a variety of interventions across multiple sectors. Foran et al. (2013) provides a detailed description of an effective visioning process. Most importantly, the most desirable vision constitutes a normative benchmark and replaces in the following participatory process the sector mandates to debate the utility of interventions.

Without shifting the normative benchmark to the systems level, scientific evidence is likely to result in two possible policy outcomes, either the evidence matches stakeholder expectations and provides thereby a basis for justifying already prevailing sector arguments, or the evidence gets rejected because it does not match previous expectations. The visioning process facilitates a shift in the normative benchmark and opens the possibility for scientific evidence to contradict initial understanding and yet lead to policy impact. However, shared ownership and shared visions are only two important design principles. Additionally, the evidence needs to be presented as part of a discovery process to facilitate actual learning and result in policy impact, which is largely achieved during the next ChaRL steps.

During step 3 results for the assessment of potential impacts of planned investments on policy-relevant indicators (e.g. poverty, migration, water flow) are presented as preliminary and uncertain findings. The emphasis of uncertainty invites opinions and criticism that reveal how participating stakeholders perceive the world to work from their perspective. These discussions are captured and later analysed to identify statements that specify cause-effect relationships. Cognitive psychology typically refers to these as causal beliefs (Fishbein and Ajzen, 1975). These beliefs are later presented and compared between stakeholder agencies (step 4) and then compared with (or challenged by) scientific evidence. This *unsettling* of longstanding beliefs facilitates a cognitive shift that unlocks participants' assertion and opens up their attitude towards new insights. Discovery learning and other empirically tested theories suggest similar approaches to facilitate learning (Alfieri et al., 2011; Mayer, 2004). Notably, during ChaRL processes participants do indeed consider the validity of evidence that contradicts their initial beliefs, which is often not achieved by traditional research approaches (Smajgl, 2010; Smajgl et al., 2015b).

The combination of challenging beliefs and operating towards a shared vision creates an effective space for participants with different nexus mandates to discuss revised investments or sector strategies. Experiences demonstrate that during step 5 sector representatives often stop aiming for the sector optimum and start considering second or third best solutions for the sector as long as overall system outcomes are improved; the relevant benchmark is provided by the shared vision. The ChaRL process has been implemented in various applied nexus studies and helped effectively bridge science and policy in very complex and contested decision making situations (Smajgl, 2010; Smajgl and Ward, 2013a; Smajgl et al., 2015b).

Box 2: Examples for a ChaRL process implementation

The Nexus in Vietnam's Mekong Delta

Salinity intrusion due to sea-level rise poses a substantial threat for rice production in Vietnam's Mekong delta faces. This process is predicted to intensify over the coming decades and substantially accelerate due to the mainstream dams planned for the Mekong river. Considering the considerable challenge these changes pose for existing food production (e.g. rice) it defines an archetypical case of the Water-Food-Energy Nexus. The participatory process involved mainly Vietnam's central Government and province level planning agencies. The policy context involved opposing preferences for adaptation measures between agricultural and environmental agencies. While one side proposed the construction of dykes ('hard' adaptation measures), the other side was endorsing land use and management changes ('soft' adaptation measures). The ChaRL process invited all relevant agencies to co-design the research project. Then, the visioning process was conducted, which requested participants to specify most relevant (and most uncertain) drivers, agreeing on likely future trends of these drivers, and then developing most desirable, most likely and least desirable futures for the Mekong Delta. In a third and fourth workshop, hydrological modelling and household survey results were presented. The assessment focused on dykes and land use change. Participants debated the validity of the presented evidence. During this debate, all statements involving causal relationships (if this then…) were recorded. In a following workshop results from an agent-based model were presented that combine social, economic, hydrological and ecological processes (see Box 1). This integrated assessment focused on the proposed adaptation options and on the recorded belief statements. Belief statements were presented to participants and compared with modelling results. The beliefs that were challenged included the efficacy of dykes, the resilience of land use change, and the likely trajectory of human migration and spatial poverty patterns. Most importantly, results emphasised that dykes are likely to be an efficient adaptation solution in the eastern coastline of the Mekong Delta while in the west of the coastal zone land use change and management changes would be most effective. The ChaRL process was able to bridge the policy factions and facilitate adaptation to safeguard Nexus outcomes for the communities in Vietnam's Mekong Delta. Smajgl et al. (2015a) provides further details for this Nexus case study and how the ChaRL process was effectively implemented (and supported by an agent-based modelling approach).

Development strategies in Lao PDR

The ChaRL process was also implemented in Lao PDR to facilitate stakeholder learning in another Nexus context. This Nexus project aimed to assess trade-offs between water trading, large-scale irrigation, and hydropower development in the Nam Ngum sub-catchment. The process invited the river basin organisation and agencies from central and province Governments to co-design this Nexus focused project and define assessment indicators, scenarios, and select assessment methods. Then, the stakeholder group developed most desirable, most likely, and least desirable futures based on most uncertain and most influencing drivers. During the next workshops, preliminary assessments were presented based on hydrological modelling, household survey analysis, and agent-based simulations. Stakeholders debated the validity of these results. This debate was analysed to identify causal beliefs stakeholders hold. These beliefs were then compared with the scientific evidence available. Based on this participatory process water trading was not implemented and large-scale irrigation investments were withdrawn in favour of small-scale irrigation schemes. These planning and investment changes were due to the surprising contradictions between scientific evidence and initial beliefs, involving expected poverty reductions, environmental flow requirements, irrigation-based food security improvements, and migration based changes in spatial poverty patterns. Smajgl et al. (2015b) provides more details for this Nexus case study.

Typically, these five steps have been implemented over a two to three-year time period, involving a series of four to seven workshops, many face-to-face meetings, and the training of government staff. The processes are normally initiated by a government agency or by a donor agency that observes or expects trade-offs between sector specific investments. Initially, all decision makers that are likely to influence the system level outcomes are invited. This involves multiple tiers of governance from the village and from district, province, and central governments, and sometimes even supranational agencies. The evaluation of past ChaRL process implementations has shown that the best results are achieved if at least three governance levels and all context-relevant sectors (i.e. water, food, energy) participate throughout the process (Hassenforder et al., 2015; Smajgl and Ward, 2015b).

Several publications list and compare participatory processes (Barreteau et al., 2010; Cornwall and Jewkes, 1995). Such comparisons are useful to guide the selection of the best suited process design for the task at hand. Comparing ChaRL briefly with a few other process designs points out three key differences that can be outlined. First, ChaRL develops shared visions as normative benchmarks to circumvent competitive sectoral interests. Second, in the wider domain of participatory research most approaches work at the level of households or individuals, while ChaRL is designed for multi-level governance interactions. Third, in contrast to most participatory research, ChaRL does not explicitly elicit stakeholder knowledge and treat it as scientific evidence. Instead, both stakeholder and scientific knowledge is elicited or produced, but kept separate to develop contrasts to facilitate learning in the final step 5 workshop. This is also a key difference from most participatory modelling approaches, which aim to translate stakeholders' perception of the world into model design, as implemented in Companion Modelling (Barreteau et al., 2003; Castella and Verburg, 2007; d'Aquino and Bah, 2013; Le Page et al., 2014), Mediated Modelling (Antunes et al., 2006; van den Belt, 2004), or Participatory Simulation (Briot et al., 2007; Diehl, 1992; Ishida et al., 2007). The main reason for building the models based on primary data (i.e. information provided by household survey, rainfall data, crop price ranges) and expert knowledge only is to maximise the model's potential to challenge participants' beliefs. Designing the model based on participant beliefs would reinforce existing beliefs and heuristics, constraining debate to align prevailing beliefs instead of potentially contradicting existing beliefs. Maintaining the independence of the two knowledge pools allows for a controlled introduction of evidence and comparative analysis.

The development of improved process designs for implementing a Nexus Approach requires the testing and further enhancement of any of these research process designs. Each process design has a particular strength and is likely to perform better in some circumstances than in others. Nexus implementations could further improve the understanding of the effectiveness of particular process steps or sequences if the process is accompanied by a robust monitoring and evaluation approach to identify contextual strengths and limitations for each design option. This requires collective action within the research community (Poteete et al., 2010) to derive the necessary evidence for enhancing participatory process designs. However, such an experimental approach requires a generic framework for testing research processes to allow for cross-comparative analyses.

So far, the evaluation of participatory research processes and participatory modelling is largely limited to qualitative descriptions of impacts without a systematic and replicable experimental design. Hassenforder et al. (2015) developed a framework for the comparative analysis of participatory processes. Their COPP (Comparison of Participatory Processes) framework defines 30 criteria across 4 dimensions: context (6 criteria), process design (14 criteria), monitoring and evaluation (4 criteria), and the impacts, outputs, and outcomes (6 criteria). ***Error! Reference source not found.*** lists the variables for the key dimensions of the COPP framework; more details and the actual framework application template are provided in Hassenforder et al. (2015). The framework application elicits evidence to derive testable hypothesis. These hypotheses would state that specific process activities implemented in a particular sequence lead to a particular outcome in a specific context. Ultimately, once widely tested, this evidence would define for a small number of contexts which activities are most critical and which activities should be avoided. Such design principles can provide the nexus community with robust understanding of effective science-policy deliberation processes.

Table 1. Variables for three (of four) dimensions of the framework for the Comparison of Participatory Processes (COPP)

Context	Participatory Process	Output(S), Outcomes & Impacts
• Target system elements • Levels of governance influencing the target system elements • Other past/present intervention attempts • Preexisting relationships among participants • Participants' understanding of target system elements	• Participatory process objectives • Instigator(s) of the process • Team origin of the team • Selection of the participants • Size of the group • Level of participants' process expectations • Governance level(s) engaged • Length of process • Number of events • Degree of participation retention • Setting of exchange • Degree of participation • Participatory methods and tools	• Impact on participants • Impact on actions • Social scales of the impacts • Spatial extent • Time scales of impact

Recent implementations of the COPP framework have pointed at a few design principles (Hassenforder et al. (2015). First, effective engagement processes combine multiple levels of governance. This is supported by other literature (e.g. Daniell and Barreteau, 2014; Smajgl, 2009; Smajgl et al., 2009; Smajgl and Ward, 2015a). Second, policy impacts are less dependent on methods, which contradicts some other empirical studies comparing disciplinary models with complex system models (Smajgl and Ward, 2015b; Smajgl et al., 2015b). These results emphasise the need to further investigate the relevance of methods in the broader research design, which seems also highly relevant for the nexus discussion. Third, high policy impact is more likely to be achieved in two years or more, while low impact studies engaged for twelve months or less. This could mean that there is a threshold for nexus studies and the need to engage for two years or more to make policy outcomes more likely. These types of findings resulting from a wider application of the COPP framework and a subsequent comparative analysis would help develop robust design principles nexus implementations could build on.

4. Summary and Conclusion

This paper presented two major challenges for the implementation of nexus approaches, (1) the need for methods that allow for an effective integration to provide the necessary diagnostic and analytical capacity to investigate nexus dynamics, and (2) the design of processes that facilitate evidence-based decision making despite the competing mandates of most nexus concerned negotiations.

The methodological solutions presented above could provide nexus studies with effective tools to analyse cross-sector dynamics. The political impetus to realise genuine integration in analytical assessment methods is very likely to remain high. The Nexus Approach accentuates this policy demand and continues what various sustainability-focused paradigms flagged as critical for effective decision support for decades. Therefore, it seems paramount to further advance genuinely integrated assessment methods and participatory process designs. This paper presents solutions for these two dimensions that are critical for any Nexus-type situation. However, there are still limitations. For instance, in the domain of agent-based modelling major challenges remain in sourcing data, implementing and parameterising realistic representations of social networks, or linking socio-economic and bio-physical processes. Also, the model validation remains challenging in an applied policy context due to the highly complex model designs. The ChaRL process design can also face substantial limitations or even fail if prevailing power relationships cannot be managed, or informal incentives overwrite policy processes. Effectively advancing this scientific domain requires large-scale initiatives to test a variety of process steps and the implementation sequence while monitoring and evaluating emerging policy impacts with a shared monitoring and evaluation framework.

In the long term, however, research agencies need to adopt these innovative methods more widely. This scientific transformation towards cross-disciplinary or transdisciplinary approaches is slowed down by two important impediments. Research facilities like universities follow the traditional structure and conduct research activities in disciplinary units. Not many universities have created cross-disciplinary entities. This results in the majority of (applied) nexus studies being designed and implemented by researchers that have a *unidisciplinary* assessment background. This leads to the second factor, which is linked to the change in skill sets. Any established researcher follows strong incentives to use familiar methods. Consequentially, most nexus research has been implemented by disciplinary units trying to connect to groups from other disciplines and each running their own method. However, effective nexus research requires researchers trained in transdisciplinary methods and operating from transdisciplinary research facilities.

Similarly, applied research is still dominated by traditional process designs, which separates researchers and stakeholders in a mostly academically driven research design and implementation approach. Such limited stakeholder engagement (and the resulting lack of stakeholders' ownership of the study and its results) is likely to leave the study to either being accepted because it confirms prevalent beliefs or being ignored because it contradicts initial beliefs. However, nexus research requires robust and effective engagement processes that allow contradicting scientific evidence to still influence decision making. Robustness, however, requires the scientific testing of participatory and other research processes to reveal what engagement process options exist and which process design is likely to lead to real-world uptake in what context.

In addition to these two challenges, applied nexus studies face also other challenges, which have not been discussed in this paper. For instance, most countries do not collect the necessary data for a comprehensive nexus analysis. Many mechanisms that facilitate or accelerate nexus trade-offs are context-specific and involve ecosystem services, social processes, and economic dynamics. Typically, any robust analysis of these relationships depends on highly disaggregated data. This data demand is in addition to the sector-specific data needs to understand hydrological, energy-related, and food-specific data.

In synthesis, applied nexus studies are in high demand and considering the evidence for cross-sector trade-offs the nexus paradigm is likely to continue to influence applied research. Developing solutions for the two challenges discussed in this paper will be an important research agenda to improve the support for robust implementations of nexus studies in the future.

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