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Tools for Integrated Sustainability Assessment: A two-track approach

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Abstract

Sustainable development has become an overarching policy target for the global policy arena. However, the international policy-making process and that of the individual countries remains largely sectoral in nature: a wide spectrum of international policies pursue narrow sectoral concerns and do not contribute fully enough to the achievement of broader sustainability targets. New policy tools such as Sustainability Impact Assessment (SIA) have therefore been adopted by the European Union to ensure that sectoral policies can be evaluated in relation to their wider sustainability impacts. However, what is really needed is a cross-sectoral approach to assessing sustainable development at an even higher, much more strategic level: Integrated Sustainability Assessment (ISA). ISA involves a long-term, comprehensive assessment of international and national policy programmes against sustainability targets and criteria.

In order to perform ISA at the international level, new assessment tools and methods are needed which are rooted in a new paradigm. Sustainable development is a complex, multi-dimensional phenomenon, with a breadth and depth that cannot be fully covered by the current portfolio of ISA tools. We therefore need a new generation of ISA tools, in particular modelling tools that can (semi-)quantitatively assess the multiple dimensions of sustainable development, in terms of multiple scales, multiple domains and multiple generations. Although a new paradigm is on the horizon and its contours are gradually becoming clearer, it will take a while before it can be used to develop practical ISA tools.

Within the context of the European MATISSE project we therefore propose a two-track strategy: find new ways to use the current portfolio of ISA tools as efficiently and effectively as possible, while at the same time developing building blocks to support the next generation of ISA tools.

Keywords: Integrated Sustainability Assessment (ISA), MATISSE

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1 Problematique

Nowadays our society faces structural problems that cannot be solved by incremental policies leading to sub-optimal solutions. These problems are complex, ill-structured, involve many stakeholders, are surrounded by structural uncertainties, and are hard to manage. We call these problems persistent problems (Rotmans, 2005), an even higher grade of complex problems than what Rittel and Webber called "wicked" problems (Rittel & Webber, 1973). Examples of these problems can be found in many international sectors: the agricultural sector with its many symptoms of unsustainability, visible through diseases like BSE and Foot & Mouth; the energy sector with its one-sided and environmentally-detrimental energy supply system; the transport system with its concomitant air pollution and congestion. These problems seem different in scope and nature, but they have certain commonalities. The symptoms of unsustainability reflect a deeper-lying problem: these persistent problems are deeply rooted in our societal structures and institutions, and are closely interwoven with manifold societal processes, so that they cannot be solved in isolation. They are complex because they have multiple causalities, cover multiple fields, whereas ready-made solutions are absent. The persistence of these problems is the result of system failures that have crept into our societal systems. Market failures concern imperfections of the market system and can be corrected by the market or by external interventions in the market. System failures, however, concern profound flaws in our societal systems that cannot be corrected by the market or by external market interventions (Rotmans, 2003). These system failures are profound barriers that prevent systems from functioning in an optimal manner. System failures operate at different levels and may differ by nature: institutional system failures (dominance of institutions that block innovation), economic system failures (insufficient market development or investment capital), social system failures (worn-in behaviour and habits that hamper change in behaviour), or ecological system failures (dominance of species or ecosystems that threaten biodiversity).

In the societal domains given as an example we speak of a systems crisis. This demands a revision of both development processes and the institutions in which the underlying system failures take place. Not only does it demand a re-orientation, but it also requires a different form of governance and planning, shifting away from the old directing and controlling mode. We need a different form of planning for the persistent problems that mark unsustainability trends in our current society. Such a new form of planning aims at the sustainable innovation of societal systems rather than their optimization, takes uncertainty and complexity as a starting point rather than as closing entry, takes learning and experimenting as guiding principle rather than fixed goals based on blueprint thinking, and is evolutionary by nature. An example of such a new form of planning is 'transition management' (Rotmans et al., 2001; Kemp & Rotmans, 2005; Loorbach, 2006), which uses basic notions of complex systems science: co-evolution, emergence and self-organisation, in order to organize a cyclical process of envisioning, agenda-building, coalition-forming, experimenting and learning. In fact, transition management involves a long-term (several decades) sustainability planning process in small, incremental steps: 'perspective incrementalism' as a variant on disjointed incrementalism of Lindblom (1979) and logical incrementalism of Quinn (1978). The experimentation and learning character of transition management has also similarities with adaptive management (Gunderson & Holling, 2002; March & Olson, 1995). However, transition management is not only adaptive, but also anticipating (pro-active, focusing on the long term) and involves relatively high-risk experiments rather than low-risk or 'no regret' experiments adaptive management often involves (Rotmans, 2005).

On the other hand, scientists attempting to assess the complex phenomenon of sustainable development also failed so far to develop adequate tools to comprehensively analyse the complexity of sustainable development. Here we run into the 'sustainability paradox': the unsustainability problems humankind is faced cannot be solved with current tools and methods that were applied—or seemed to work—in the past. Obviously, the paradox is that we cannot wait for the next generation of tools and methods (and minds). What we can do, however, is using current knowledge, tools and methods in the best possible manner, while developing a new paradigm that better reflects the complexity of sustainable development. This because the current paradigm used for assessing sustainability has reached its limits in creating lock-ins for new tools and instruments that are better suited to address the multiplicity of sustainable development. So we need new tools and instruments to support the sustainability decision-making process in a more adequate manner. These tools and instruments need to analyse the non-sustainability symptoms at the systems level in relation to their deeper driving forces; they need to recognise and monitor early warning signals of non-sustainability patterns, in order to disentangle the short-term fluctuations from the long-term slow wave patterns; and they need to evaluate the sustainability impacts of strategic policies at different scales.

In conclusion, the nature and context of a new generation of societal problems, called persistent problems, require a new way of thinking and acting. Acting in terms of an evolutionary planning and decision-making process, aimed at different intervention patterns and mechanisms at different levels in time and space. And thinking in terms of a new paradigm that allows for an interdisciplinary approach towards sustainable development, that enables us to deal adequately with transition patterns towards sustainability.

2 State-of-the-art of Sustainability Assessment

Sustainable development is an essentially contested notion, because it is inherently complex, normative, subjective and ambiguous (Kasemir et al., 2003). There are, nonetheless, a number of commonalities even in diverging interpretations, upon which the notion of sustainable development can be implemented in practice. These commonalities include that it is an intergenerational phenomenon, that it operates at multiple scale levels, and that it covers social-cultural, economic and ecological dimensions. The overall challenge is to make the tensions between these scale levels and dimensions explicit and to develop policy strategies to alleviate them. The need for Integrated Sustainability Assessments (ISAs) to support the development of integrated sustainability policies is a challenge not only for policy makers but also for science.

Over the past two decades many researchers have been engaged in a quest to develop tools and methods for sustainability assessments. While many started working from a mono-disciplinary basis, others made an attempt to develop generic tools and instruments for the phenomenon of sustainable development. This has resulted in a diverse field of approaches: concepts for sustainable developments (Munasinghe, 1993), indicators for sustainable development (Grosskurth & Rotmans, 2005), models for sustainable development (Van den Bergh, 1991) and scenarios for sustainable development (Rotmans et al., 2001). Without pretending to be comprehensive, important lessons and insights can be drawn from these sustainability assessment studies. In general, these efforts have resulted in the following insights:

1. an overall generic tool, capturing the multi-dimensionality of sustainable development, is not possible;
2. the diversity of the tools and methods developed hinders the efficient use of sustainability assessment in a practical policy-making setting;
3. the multi-dimensionality of sustainability requires an integrated and interdisciplinary approach, in the sense of developing and using analytical tools and instruments within a participatory setting;
4. the current paradigm underlying sustainability assessment has reached its limits in creating lock-ins for new tools that are better suited to address the complexity of sustainable development.

Although it is difficult—if not impossible—to speak of a unifying paradigm currently used for assessing sustainability, the prevailing approach is rooted in neo-classical economics. Sustainability assessment is still dominated by neo-classical thinking, which essentially implies the usage of the rational actor paradigm and standard equilibrium approximations to describe the behaviour of actors in socio-economic systems. It is broadly acknowledged that a neo-classical approach is inadequate for addressing the multi-dimensionality and complexity of sustainable development (Jæger et al., 1998). The non-linear dynamics at both the macro- and the micro-level cannot be described in terms of one equilibrium, price-driven actor behaviour, efficient resource allocation, and market failures that can be remedied by corrective tax policies or subsidies. Such an approach may be valid within a strict economic framework, but is certainly inappropriate for describing real world dynamics of non-sustainable development characterized by system failures (Rotmans, 1998).

The required integrated approach for sustainability assessment makes the research field of Integrated Assessment a potentially suitable candidate for addressing the complexity of sustainable development. Integrated Assessment is the science that deals with an integrated systems approach to complex societal problems embedded in a process-based context. IA aims to analyse the multiple causes and impacts of a complex problem in order to develop policy options for a strategic solution of the problem in question. IA itself involves a process whereby IA tools form the equipment to perform the assessment. The IA toolkit is rich, including both analytical tools/methods (such as models, scenarios, uncertainty and risk analyses), and participatory methods (such as focus groups, policy exercises and dialogue methods). For a survey of IA methods the reader is referred to Rotmans (1998); Rotmans & Dowlatabadi (1998); Toth & Hizsnyik (1998); Toth (2003) and Kasemir et al. (2003). IA has been successfully applied in fields such as acid rain and climate change, using IA models such as RAINS (Alcamo et al., 1990) and IMAGE (Rotmans, 1990). The role of stakeholders in IA has become more and more important over the past decade(s) (Van de Kerkhof, 2004).

Integrated Assessment is now exploring new challenges in new fields, such as sustainable development. We refer to this as Integrated Sustainability Assessment (ISA). Integrated Sustainability Assessment (ISA) is closely related to Sustainability Impact Assessment (SIA). While SIA is focused on the short-term and very practical, ISA is broader, explorative, forward-looking and long-term oriented. The two are positively correlated and should go hand in hand. For example, applied to agriculture, ISA could involve an assessment of the sustainability implications of the CAP reform in a particular Western-European country versus an accession country, while SIA could mean assessing the impact of bio-fuels on small-scale agricultural production in particular EU regions. ISA and SIA are considered as complementary, and both will be used in a harmonious manner (Weaver & Rotmans, In Press).

While the ambitions of ISA are high, the current tool-kit of IA is not well enough equipped to address the multi-dimensional complexity of sustainable development. Although significant progress has been made over the past decades in the use of ISA, obvious deficiencies and limitations of current Integrated Assessment tools have become clear: the imbalance between the socio-economic-technological dimension versus the ecological dimension, the purely rational representation of actors, the poor treatment of uncertainties and the single-scale process representation. Sustainable development, however, puts new requirements on Integrated Assessment tools, in terms of trade-offs between multiple scales and multiple generations, and between socio-economic-technological and ecological processes. New Integrated Assessment tools are therefore needed which are grounded in a new paradigm, without losing contact with the old paradigm. The time seems ripe to start developing new Integrated Assessment tools, here referred to as ISA tools, without discarding the current Integrated Assessment tools. However, developing new ISA tools is a time-consuming activity, so a more harmonized and efficient use of existing ISA tools is as important as developing new ISA tools.

The overall challenge is to perform Integrated Sustainability Assessment in a way similar to what has been done for global climate change and, to a lesser extent, for acidification. In concrete terms this means that ISA involves the whole palette of: (i) analysing human activities as driving forces; (ii) estimating the impacts on ecosystems functioning and human health; (iii) indicating critical thresholds and potential damage; (iv) setting policy-targets; (v) developing mitigation and adaptation strategies; and (vi) monitoring the process. As a consequence, we need a portfolio of Integrated Assessment models and participatory methods to support ISA at the various stages in specific contexts and domains. No single tool or instrument can capture all stages and dimensions of ISA. Furthermore, given the range of applications contexts and domains, a flexible, hierarchical approach to linking elements together is needed. In practice, ISA encompasses the following tasks and tools:

1. analysing the dynamics of sustainable development, using Integrated Assessment models;
2. forecasting (un)sustainable trends and developments, using Integrated Assessment-models and scenarios of the future;
3. assessing the sustainability impact of policy options, using model-based cost-benefit and cost-effectiveness analyses;
4. monitoring the long-term process of sustainable development, using model-based indicators;
5. designing the process underlying Integrated Sustainability Assessment, using participatory methods.

The challenge is to use the above ISA tools in a more advanced manner (i.e., interlinking and adjusting/improving existing tools to better cope with the complexity that SD requires), while working on the next generation of ISA tools grounded in a new scientific paradigm.

3 Science Perspective for new ISA paradigm

A new paradigm for ISA has not yet taken shape in a mature form, but its contours can be portrayed by formulating a number of shared research principles underlying such a new paradigm. "Shared" means broadly recognised by a growing group of people working within diverging networks in the sustainability research field.

1. The first shared principle is that of interdisciplinarity: sustainable development runs across several disciplines and cannot be addressed adequately from a mono-disciplinary viewpoint. We need to develop a new interdiscipline using building blocks from a variety of disciplines, where the building blocks in turn are cross-disciplinary adventures. The human behaviour dimension of sustainable development needs to be addressed from micro-economics, social psychology and artificial intelligence; the ecological dimension by ecology, ecological economics and economic valuation theory, the social-cultural dimension by anthropology, sociology and

social geography, and the institutional component by institutional economics and social psychology. In this way we can build up a systemic puzzle, where the various cross-disciplinary concepts forming the pieces of the sustainability puzzle need to be combined and integrated.

2. The second shared principle is the use of complex systems theory as an overarching framework that brings the different pieces of the sustainability puzzle together. This implies that we study societal systems from a complex systems viewpoint, using three key notions of that complexity science field: co-evolution, emergence and self-organisation (Holland, 1995; Kauffman, 1995). We speak of co-evolution if the interaction between different systems influences the dynamics of the individual systems, leading to irreversible patterns of change. Further, patterns in complex systems emerge 'spontaneously' as a result of relationships between the components of the system. As a consequence, these systems have the ability to self-organise: for ordered patterns to emerge simply as a result of the relations and interactions among the constituent components, without any external control. Viewing unsustainably functioning societal systems through complexity glasses has serious consequences for managing these systems. Forget about command-and-control management of these systems, only a co-evolutionary management approach, which subtly takes emergence, co-evolution and self-organisation as starting-point, might work (Kemp et al., 2006).

3. The notion of non-linear knowledge generation forms the third shared principle. This means that knowledge is developed in a complex, interactive process of co-production with a range of stakeholders involved. There is a continuous interaction between knowledge producers and consumers, but knowledge producers may be knowledge consumers at the same time and vice versa. Only through frequent confrontation of theoretical knowledge with actual practice can innovation get its ultimate shape and embed at the system level. Silverstone & Hirsch (1992) refer to this process as the domestication of knowledge. Knowledge institutions then become co-innovators in new innovation-creating networks, which fits within the context of the currently ongoing switch from mode-1 science to mode-2 science as postulated by Gibbons et al. (1994). Where in mode-1 science the orientation is purely academic and mono-disciplinary, in mode-2 science inter- and transdisciplinarity and societal accountability play a key role. This means that ISA, by definition, involves transdisciplinary research, where the development and usage of fundamental knowledge, applied knowledge and practical knowledge go hand-in-hand and do influence each other directly and interactively.

4. Another shared principle shapes the learning process. In complex and uncertain search processes for sustainable directions with no ready-made solutions at hand, all one can do is experiment and learn from these experiments. We refer to social learning rather than cognitive learning:

learning in a social environment through interaction with other actors (Social Learning Group, 2001). The learning process has three components: learning-by-doing (developing theoretical knowledge and testing that by practical experience), doing-by-learning (developing empirical knowledge and testing that against the theory) and learning-by-learning (developing learning strategies, applying and evaluating them).

5. A final shared principle is that of system innovation rather than system optimisation. Many societal systems are in a kind of dynamic equilibrium stage, often in a sub-optimal state from the viewpoint of sustainability. The punctuated equilibrium theory suggests that complex societal systems do not evolve gradually from one (non-sustainable) equilibrium to the other (sustainable) equilibrium, but that this takes radical change (Gersick, 1991). The deep structure underlying complex systems, which represents internal rules, practices, networks, etc. prevents the system from moving gradually away from the equilibrium stage. Only radical "punctuations" of rapid change, denoted as a transition period, brings the system into a new equilibrium period. The system needs to be "forced" out of its equilibrium, quite far from the existing equilibrium, which requires an enormous amount of energy. These forces operate at different levels, and cannot be generated externally, but should both emerge endogenously and be stimulated exogenously. This explains why gradual system innovation often leads to a lock-in, a non-preferred situation from the viewpoint of sustainable development. To direct a system onto a higher level of sustainability requires radical, non-linear change instead of gradual change, which can only be realised by a form of co-evolutionary management.

The new scientific paradigm for Integrated Sustainability Assessment is emerging from a scientific undercurrent that marks the evolution in science in general and in decision-support science in particular. Unmistakably, a scientific undercurrent is evolving towards the already above-mentioned transition from mode-1 science to mode-2 science, as postulated by Gibbons et al. (1994). In mode-1 scientists are supposed to be accountable primarily for their scientific achievements within the scientific arena. In mode-2, however, scientists are part of more heterogeneous networks, where their scientific tasks are part of a broader process of knowledge production, and where they are accountable for more than just scientific productivity. This is comparable to the new accountability mechanism for businesses, where responsibility extends beyond financial profitability; companies have to live up to higher expectations with regard to social corporate responsibility. Another paradigm that has gained influence is that of postnormal science, not to be confused with postmodern science (Funtowicz & Ravetz, 1990). Postnormal science results from the unavoidability of uncertainty in data and models. One way of managing uncertainty is through the organization of participatory processes in which different sorts of knowledge (not only scientific knowledge) are used to inform policy-making on complex societal problems with high stakes as well as possible. Notwithstanding the growing influence of the scientific undercurrent, it has to be noticed that although the direction of the undercurrent is clear, the pace of the evolutionary trend is rather slow.

If we zoom into the decision-support scientific arena, we observe a congruent evolutionary pattern, with similar characteristics as the shift from mode-1 to mode-2 science. A new generation of decision-support tools and instruments has emerged over the past decades. For the sake of brevity we focus here on Integrated Assessment tools, in particular on IA models, as an illustration of the trend. We describe this evolution in IA tools by means of a number of characteristics beginning with the evolution from supply-driven to demand-driven models. The first generations of IA models were almost all supply-driven, in particular by the scientific curiosity of the researchers involved, who ex-post were looking for users or clients. Only occasionally these users or clients were found: the vast majority (roughly estimated more than 90%) of IA models has never been used by clients or users. The model developers themselves were the major clients, leading to a self-referential modelling arena, tending to a closed shop (Rotmans, 1998). This has generated the awareness that potential users of IA models need to be involved from onset. The upcoming generation of IA models therefore is or will be more demand-driven, in the sense that stakeholders are or will be involved already in an early stage of the model development. That is not a sufficient guarantee that IA models will be used more often, but at least it is a prerequisite for potential use of these decision-support tools.

The nature of these IA models is also changing. Previous generations of models were quite technocratic and deterministic by nature, with a high level of engineering, and were often considered as 'truth machines'. The current and future generation of models are considered more as heuristic tools, as aids to gain more insight into and achieve a better understanding of a persistent problem in question. This implies that it is more accepted by both model builders and users that models contain both objective knowledge also subjectivity; and also that uncertainty is not any longer considered as a mathematical artefact that can be reduced or avoided, but that uncertainty is a given as symptom of complexity in the world around is (Van Asselt, 2000; Van Asselt & Rotmans, 2002).

Where the previous IA models focused on the predictive capability as a basic strength, with a firm belief in the model outcomes (with the exception of those modellers who those days already recognised the limitations of their models and did not blindly accepted their modelling results as reflection of reality), the current and next generation of IA models focuses on their exploratory value rather than on the predictive value. For the current and future generation of IA models their exploratory value is much more important than the predictive value, something that cannot be detached from the increased awareness of complexity and uncertainty among model developers. In line with this is the shift from the purely deterministic character of IA models to a more stochastic character.

A final striking difference between the next generation of IA models and the previous ones is that the first generation of IA models were built by individuals, researchers within universities or research institutes operating on a solo basis, whereas the next generation of IA models will be built by networks and collaborations between research institutes. The complexity of IA models these days requires a collaborative effort rather than an individual attempt, where modules can be exchanged easily and flexibly between research institutes. The previous generations of IA models formed a monolithic whole, which severely limits the applicability and transportability of separate modules. Often, the modelling or at least reprogramming from other models of all components is very time-consuming to such an extent that little time remains for the Integrated Assessment itself. In the next generation of IA models, modules are separate entities that can communicate with others.

These are confusing times for both model builders and model users. On the one hand the time is ripe for a new generation of IA models based on a new interdisciplinary paradigm as sketched above, on the other hand the modelling scenery is still dominated by (neo-)classical models. Aggregating this to the level of decision-support tools and instruments, one could say that the evolutionary transition of decision-support tools to user-friendly, exploratory, participatory, heuristic tools has not succeeded. Still, the point of no return has been reached, so the overall pathway is irreversible.

3.1 Lessons learned in IA modelling

IA models have unmistakably demonstrated to be useful tools in the international policy arena, especially in the fields of acidification and climate change (Rotmans & Dowlatabadi, 1998). At the same time it needs to be stated that it is difficult to measure their impact, and that IA models mostly dance around the policy arena and not in that arena. The reason why IA models often dance around policy makers and not with them, is grounded in the fact that it takes two to tango. But each of the dancers has its own rationality, and the scientific rationality is essentially different from the political rationality. Model builders often do not recognize these differences and have a fairly naïve picture of how policy makers think, act and learn. This hinders a successful application of IA models in the policy arena, and is a source of frustration for many model builders. This has been signalled earlier with respect to the use and applicability of scientific models in general in the policy context (Greenberger et al., 1976). Research into model-client relations has shown that if the problem conceptualisation of the client significantly differs from that of the model developer, it is extremely difficult for the client to understand, let alone trust, the model (Robinson, 1978). This underlines the need to engage potential users already in an early stage in the model development. In this way the potential user gets familiar with the model, which helps to build up more credibility and authority for the model.

Numerous factors can be mentioned that mark the differences in rationality between developers and users. Important determinants are: lack of transparency, unnecessary complexity, irrelevance for policy and inadequate treatment of uncertainties. But generally, it can be postulated that model rationality and policy rationality can only converge if brought together in a participatory process. In such a participatory process IA models are developed in dialogue with potential users, in particular policy makers. It is important to engage the potential users already in an early stage, the conceptual model development. In practice this means that model aspects such as temporal and spatial resolution, scale level, aggregation level, in- and output, exogenous and endogenous factors and processes, model structure and the presentation of model results, need to be determined in mutual consultation. Because this is a continuous and iterative process, it needs to be managed carefully.

That's not to say that all IA models should be developed along these participatory lines. There is also a need for 'early warning' models that anticipate future problems that haven't been recognized yet by policy makers or other clients. Headstrong scholars who swim against the mainstream and develop models for new environmental problems are slowed down rather than stimulated by participation of others. The IMAGE (Rotmans, 1990) and RAINS (Alcamo et al., 1990) model are good examples thereof: the right model at the right time, developed during a phase when the problems of climate change and acidification were no priority at all on the policy agenda.

4 The next generation of ISA tools and instruments

The requirements that sustainable development demands of the next generation of ISA tools and instruments can be captured by means of the so-called "Triple-I" approach: Innovative, Integrated and Interactive. Innovative, because the paradigmatic basis of these models will be different: following the new, evolutionary paradigm as sketched above (involving inter- and transdisciplinarity through co-development of knowledge with stakeholders, system innovation and transition, adaptation and social learning processes, and complexity principles as self-organising behaviour, chaotic behaviour and emergent processes), and more oriented towards the dynamic behaviour of individual and collective actors, explicitly incorporated into the IA tools. Integrated, because of the better integration of different strands of knowledge at different spatial and functional scale levels, and because of the integration of quantitative and qualitative knowledge. And interactive, because the influence and role of stakeholders becomes more important. This influence manifests itself in both the conceptual and implementation phase of the ISA tools, but also in the use of these tools, realising that multiple stakeholders perceive a problem from different perspectives, and therefore act differently, which needs to be reflected in the ISA tools and instruments.

To illustrate the practical implications of the "Triple-I" approach, we work these out in more detail for a particular group of ISA tools, namely ISA models. We sketch some important elements of a future research agenda for ISA models for the next years, encapsulated in terms of the required level of innovation, integration and interactivity. The "Triple-I" challenges are clustered around three different themes: transitions, scaling and stakeholder involvement.

4.1 Transitions

The first challenge is to represent transitional patterns in socio-economic systems in a more adequate manner in ISA models. Advances in complexity science have pointed towards the need to develop models of the socio-economic system that better capture the non-linear dynamics and adaptive behaviour of this system. Over the last decade advances have been made in IA modelling of technological change (Barker et al., 2002), the cultural dimension (Rotmans & de Vries, 1997) and demographic-migration patterns (Hilderink, 2000). A full representation of social-cultural-economic-technological-environmental systems is still impossible. The challenge is that such systems are hugely complex and on the one hand are difficult to make tractable to a manageable IA modelling activity, while on the other hand advances in participatory methods are clearly highlighting the value of simple models that are readily understandable to trained policy analysts. In this way the next generation of ISA models become social learning tools rather than the present highly complex forecasting IA models. Transition patterns are simple representations of highly complex societal patterns, and could therefore serve as a useful concept to strive for a balance between simplicity and complexity. It is proposed to develop relatively simple ISA models (prototypes) that are able to describe transition patterns, where in particular the incorporation of some relevant social, cultural and institutional dynamics in a less primitive form is important. The overall challenge is to develop relatively simple ISA models that contain transition patterns representing the complex interactions between socio-cultural, economic and environmental systems for particular case studies.

4.2 Multiple scaling

Because there is no unifying theory in IA modelling about how to deal with multiple scales, we have to develop and use heuristic scaling methods. A first possibility is to use the grid-cell approach, in which model processes are allocated to grid cells, making the model outcomes also grid-cell dependent. An example of this type is the IMAGE 2.0 model (Alcamo, 1994). The problem here is twofold: (i) driving forces in terms of social, economic and demographic processes cannot be easily captured in a grid-cell pattern; and (ii) these drivers are represented in a highly aggregated form, which means that the dynamics are not modelled at the level of grid-cells, but at the regional or supra-regional level. And finally, there is hardly any dynamic interaction between the grid-cells in IA models. That means that the outcomes of these models suggest more precision than can be fulfilled. A second possibility is to use cellular automata models. These are based on grid-cells that communicate with each other in an intelligent manner. The dynamic state of each cell depends on the state of surrounding cells, the characteristics of the cells and the distance to the core cell. Usually, these types of models operate at two different scale levels: the local level (micro-level) and the regional level (macro-level). An example is the Environmental Explorer developed by Engelen et al. (2002). A potential drawback of these models is that they seem to be more suitable at the micro-level for the short-term, and that their reliability is reduced on a larger scale level. A third possibility could be multiple scale regression modelling, based on the interaction between a relatively coarse and a relatively fine scale level. The driving forces are modelled at the relatively coarse scale level, while at the fine scale level local patterns are modelled, taking into account local constraints and limitations. An example is the CLUE-model (Verburg, 2000). However, the interaction between scale levels is based on correlation patterns rather than on causal patterns. This quasi-static method is especially useful for the short time horizon, and but less so for the longer time horizon. Based on this analysis of how to deal with scaling in current IA models, it is proposed to strive for combinations of the above methods, because of the complementarity of the various methods, which makes it possible to combine them. In concrete terms this means that simple IA models could be built which combine a causal grid-cell approach and a correlative multiple scale approach (Rotmans & Rothman, 2003).

4.3 Stakeholder involvement

A final challenge relates to the involvement of stakeholders in the process of model development and model usage. In this process of interaction we can distinguish three types of stakeholders: (i) stakeholders as advisor, using the knowledge and expertise of stakeholders as well as possible, both ex ante and ex post, but in both cases the stakeholders directly influence the modelling process; (ii) stakeholders as user. There may be strategic reasons, political reasons, but also educational or moral reasons for using IA models. Preferably the potential user is already involved in the design of the IA model at the conceptual stage; (iii) stakeholder as actor, where an attempt is made to incorporate the dynamic behaviour of stakeholders in the model. We then speak of agent-based models, simulating the dynamic, cognitive behaviour of both individual and collective (institutions and organisations) actors. We will develop examples of each of the three stakeholder-based IA models. In particular experiments will be conducted with agent-based models, building on previous attempts to model agents, such as the EU-FIRMA project (Valkering et al., 2005). In the case of agent-based models the rationale is to represent the dynamic behaviour of agents by a set of rules on the one hand (rational behaviour) and by the interaction with other agents (emergent behaviour). Prototypes have been developed which contain agents that can make autonomous decisions, and are equipped with goals, beliefs and social norms, as shown by van der Veen & Rotmans (2001). The physical part of an IA model can be combined with the actor-part, where there is mutual interaction between the two subsystems.

The latter, most active involvement of stakeholders in IA models is interesting, because stakeholders can recognise and reflect on their behaviour, which is represented in a simplified manner in IA models.

5 A two-track strategy for ISA tools and instruments

We have pointed to the need for robust, (semi-)quantitative tools to support the development of integrated sustainability policies, and that such tools need to be developed so as to be of most use to the emerging research context of Integrated Sustainability Assessment (ISA). The overall challenge is to improve the current tool kit available for conducting Integrated Sustainability Assessments. The current tool kit does not meet the needs of sustainable development. Complexity and multi-dimensionality cannot be fully covered by the current portfolio of ISA tools. We therefore need new tools and instruments rooted in a new paradigm that enable us to assess quantitatively the multiple dimensions of sustainable development, in terms of multiple scales, multiple domains and multiple generations. Although a new paradigm is on the horizon looming and its contours are gradually becoming clearer, it will take a while before it can be used to implement practical tools. On the other hand we don't want to lose contact with the prevailing paradigm, making use of the current portfolio of ISA tools and instruments as efficiently and effectively as possible.

We therefore propose a two-track strategy for improving the current ISA toolbox for conducting Integrated Sustainability Assessments. The first track involves the interlinkage and improvement of existing ISA tools: this involves the use of a portfolio of existing ISA tools in a more creative and coherent manner, while also adjusting and improving them. The improvements need to be guided by priorities and needs as identified by stakeholders. The second track concerns the development of new ISA tools: this involves the development of co-evolutionary, stakeholder-oriented, explorative, and more integrated ISA tools, using past and current experiences as important guidance. Both tracks can be run in parallel mode, and can even reinforce each other.

In terms of organising this two-track strategy, it is important to organise both tracks as a social learning process, where stakeholders learn from ISA analysts, where ISA modellers learn from ISA users, where policy makers learn from ISA analysts in an optimal way. This can be realised by taking three principles as a starting-point: (i) setting up a cyclical and iterative framework, in which learning, interaction and feedback are crucial elements, where past learning experiences form the basis for best practice rules for ISA; (ii) seeking the involvement of stakeholders at an early stage and in a structured manner, by actively engaging them in the improvement and development of ISA tools; and (iii) building up a user community by using the notions of co-development and reflexive mutual learning with potential users, varying from policy makers and policy analysts to practitioners and scholars.

5.1 Track I: Interlinking and improving existing ISA tools.

This track will use a portfolio of existing ISA tools and methods in a more creative and coherent manner, while also adjusting and improving them, in order to better enable current policies and programmes to be assessed. To overcome the deficiencies and limitations of current tools for sustainability assessment, it is necessary to inter-link them. This enables estimation of how policies contribute to specified sustainability targets, and it allows assessment of the distance between a future projection and specified sustainability targets, and exploration of the reasons for any gap between them. There is also much room for improvement of current ISA tools and instruments; in particular the limited level of integration between the various subsystems and the high level of abstraction of the processes represented are facets that need to be improved.

An overall challenge is to use ISA models in conjunction with sustainability indicators and scenarios, and to provide them with an appropriate and adequate participatory setting. For instance, a hierarchical set or framework of indicators might be dynamically linked to IAMs; in this way, indicators can serve as vehicles to communicate IAM results and as a basis for mapping response strategies. ISA models might also provide scenarios with quantitative rigour and accuracy, whereas scenarios could provide communication vehicles for models (as tested in the EU-VISIONS project, Van Asselt et al., 2005). Existing ISA models could be used in a participatory context (as tested in the EU-ULYSSES projects, Kasemir et al., 2003). Systematic uncertainty and risk analyses performed with ISA models can help in conveying the nature of the uncertainty and provide a link to different risk strategies.

And finally, different kinds of ISA models could be interlinked. ISA models that could be interlinked range from integrated system models, macro-economic integrated models, general equilibrium models to Input-Output models. A common link between these is material flows between terrestrial land surfaces (natural or artificial ecosystems) on the one hand, and human societies on the other. Questions to be pursued concern (1) the impact of human economy on natural and agricultural systems and the potential for their sustainable use, (2) patterns of flows and their potential transformations through the economic system and (3) impacts and options of policies relevant to sustainability. The few experiences from the past, such as the coupling of the IMAGE 2 model and Worldscan model (Timmer et al., 1995) show that a successful interlinkage between ISA models is far from trivial, but can generate a considerable added-value for the models involved. Both conceptual and technical problems need to be solved by interlinking different ISA models, requiring agreement on spatial and temporal coverage, spatial and time resolution, basic scenario assumptions, etc. Model interlinkages will be probed for their improved ability to provide hindsight (verification of model relationships using historical data), foresight (extrapolations based on past trends) and insight (identification of 'missing links' where existing models are apparently inadequate to explain or illuminate current problems).

5.2 Track II: Developing new ISA tools and methods.

To address the complexity of SD we need to develop the next generation of ISA tools, in particular the next generation of IAMs. These should handle multiple scales, in particular micro-scale dynamics that can deal with the dynamic behaviour of actors, and are rooted in a new paradigm, that is rooted in complex systems theory, evolutionary economics, multi-level governance and multi-agent modelling. It can be described in terms of common characteristics: (i) better integration of science; (ii) co-evolution of subsystems and underlying driving forces; (iii) more explorative than predictive; and (iv) more demand (stakeholder)-oriented than supply-oriented. New concepts are needed which are based on the above characteristics of the new paradigm. An example is the transition concept (Rotmans et al., 2001), which enables us to unravel complex societal patterns of transitions in terms of time, scale and actors. Transition models are models that describe and explain radical changes in between periods of dynamic equilibrium. This requires a complex systems representation rather than an integrated systems description. Transition models do exist, i.e. simulating demographic or technological transition patterns (Hilderink, 2000; Barker et al., 2002), but not at the level of a societal system, i.e. for the agricultural, transport or energy system, or at the city level. A systemic representation of the driving forces, system changes, impacts, feedbacks, potential lock-ins and lock-outs is developed per selected transition. This systemic representation of transitions contains qualitative and quantitative causal relationships between stocks, flows and agents. It also allows for a series of experiments that yields insights into the positioning of the transition in question in terms of the phase where in which the transition is, the co-evolution and emergence of processes at different levels, the nature of change of the transition phase at the different levels, and the self-organizing ability of the transition domain. So the transition concepts of multi-phase and multi-level (Rotmans et al., 2001) are tested within the complex systems representation of each transition. The challenge is to detect historical, current and future transitional patterns which consist of emerging processes, autonomous trends, surprises, market forces, institutional changes and actor-oriented actions, all co-evolving with each other. In a similar manner, transition scenarios can be developed: future patterns in which transitional patterns are interwoven, including unexpected events, surprises and discontinuities. Transition scenarios differ from most 'regular' scenarios in the sense that both the analytical content and process context is different (Sondeijker et al., 2006; Van Asselt et al., 2005). Again, the transition domains should be the focus for the scenarios to be developed: scenarios for agriculture, energy, water, transport and spatial use.

Because developing new ISA tools is a time-consuming activity, our strategy is to work in a step-wise fashion: first, conceptual models and modules will be developed, then these modules/conceptual models will be implemented and tested in case studies, and if successful, these modules can be incorporated into existing ISA models, gradually evolving into the next generation of ISA models. In developing new ISA tools, learning from past experiences, both in terms of failures and successes, plays an important role. Therefore, the guidance from activity 2, providing a set of principles, priorities and needs for the next generation of ISA tools, is of crucial importance.

6 Implementation strategy for ISA tools and instruments

Developing ISA tools is challenging, but implementing them successfully is even more challenging and might be cumbersome. The implementation of ISA tools requires a sensible strategy that is built upon a few pillars, which are briefly described below:

6.1 Contextualising ISA tools

First of all the context in which ISA tools are used needs to be studied and defined. This involves an exploration of the demand and supply side for ISA tools. On the demand side this includes an exploration of the usage of ISA tools in relation to different domains and contexts of application, including important institutional factors at the science-policy interface, the complex mechanisms that shape policy-making in terms of actors, interests, preferences, information needs and what the role of ISA tools should be. On the supply side this requires insights into the scientific potential of the ISA toolkit currently available. A systematic inventory of ISA tools is needed, including tools and methods that are available but not widely used in the policy arena, and including critical gaps, deficiencies and overlap between tools and methods. This has been done within the EU project Sustainability—A Test (de Ridder, 2006).

6.2 Guidelines for developing and using ISA tools

A following aspect is that the lessons and principles learned from past IA experiences need to be formulated into guidelines, backed by examples of best practice and appropriate use. There is a need to clarify to prospective ISA users and practitioners what methodological options and tools are available, which principles are appropriate for selecting among these and how factors pertaining to applications domain and context might best be handled in the selection process. This may be achieved through the development of "best practice" guidelines for ISA, capable of providing design principles and guidance on how different ISA tools can be interlinked and integrated flexibly according to the application need and context. Different authors have already addressed the issue of developing guidelines for good IA practice (Rotmans, 1998). Often it is distinguished between analytical criteria, methodological criteria and criteria for quality in terms of usability. There already exists a wealth of tools and approaches that will constitute important elements of a coherent ISA guidance tool and associated portfolio of tools. But there are also significant gaps to be filled and consistency checks to perform (to ensure compatibility of individual elements in terms of data, assumptions and underlying principles), and innovations needed in tools and methods to address the full complexity of sustainable development. Achieving take-up of such a framework from stakeholders and ISA users will be vital. This requires a co-learning and co-development approach to the research (working closely and interactively with users and stakeholders) together with the wider dissemination of the ISA knowledge-base developed.

6.3 Experimenting with ISA tools in case studies

In order to test improved and new ISA tools we need a set of case study applications. The case studies need to be selected carefully in order to exemplify priority substantive policy issues and urgent analytical challenges that face ISA tool development. The case studies also need to be linked, allowing for the possibility for further integration by considering interactions between them. The case studies need a common format and a common working mode. The common case study format addresses the following aspects: (i) what is the deeper-lying problem in terms of non-sustainability?; (ii) what are the underlying driving forces and potential impacts?; (iii) which visions, solutions, outcomes have been produced by others in the past? And in terms of methodological aspects the format addresses: (iv) what kind of ISA will be performed in the case study?; (v) which ISA tools can be used in the case study?; (vi) what is the role of the various stakeholders in the case study?; (vii) what are base line assumptions and common methods to be used in the case study?

The case studies will provide not only a testing ground for the new and improved ISA tools, but will also provide both substantive results of value to stakeholders and a body of best practice examples. Feedback from experiences in the case studies will be used to further adjust and improve the ISA tools and methods.

6.4 Dissemination and capacity building

Learning, interaction and feedback are crucial elements in the development of the next generation of ISA tools. Obviously, dissemination of these learning experiences and feedback is of crucial importance. In the spirit of the new paradigm underlying the new ISA tools, in which knowledge development is a co-production process, the involvement and engagement of stakeholders throughout the process of dissemination and capacity building needs to be safeguarded.

Dissemination activities are often limited to the publication of technical reports and are subsequently distributed with the help of standardised mailing lists. To achieve the desired impact with the stakeholders, the basic rules of communications have to be followed: Reach the right people, at the right time, with the right message using the right means (communication channels).

However, the dissemination process should go beyond the traditional dissemination strategy of producing reports, books, publications or websites. A major part of the dissemination strategy deals with the active participation of users and other stakeholders in co-developing ISA tools, and internalising the ISA knowledge and expertise that arise out of this participatory process. The ultimate aim is that the active involvement of users and stakeholders will lead to an active social learning process, which will influence the wider development process of ISA tools and methods. And finally, the next generation of ISA models will be used by the next generation of scientists and stakeholders. We therefore need to train young ISA scientists to build a future community of experienced practitioners capable of implementing ISA in accordance with the ambitious vision for ISA set out earlier.

7 Conclusions and recommendations

The overall challenge is to assess sustainability at the global, national and local level, using the best available current ISA tools in a more coherent and interlinked manner, while also developing new ISA tools. In this way the current paradigm can gradually evolve into a new paradigm that better reflects the complexity and multi-dimensionality of sustainable development. This new paradigm is rooted in complex systems science with principles of co-evolution, emergence and self-organisation on the one hand, and in mode-2 science principles on the other hand, reflected in the notions of co-production of knowledge, non-linear knowledge production and social learning.

In order to implement this two-track approach we propose a cyclical and iterative procedure, following the principles of adaptive management and learning. Past learning experiences with ISA tools form the basis for the guidelines and best practice rules for ISA tool development. Because we need a variety of ISA tools, they are tested in case studies, where the results form the input to the further development of existing and new ISA tools, and further sharpen the guidelines and best practice rules. These are then used in the case studies, which in their turn feed back into the development of ISA tools and methods, etc. Obviously, dissemination of these learning experiences and feedback is of crucial importance in this cyclical and iterative process.

Overall, this proposed ISA tool development strategy follows a learning-by-doing and doing-by-learning approach, which is a risky but highly challenging strategy.

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