18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009
http://mssanz.org.au/modsim09

Necessary but not sufficient: Tools for Analysing Multi-Scale Integrated Eco-Social Systems

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Abstract: This paper describes the application of the DECOIN toolkit to a UK regional level case study. DECOIN is a set of three tools to help us understand the social metabolism of multi-level systems. The overall purpose of the study is to use the toolkit to assess trends in sustainability at national, sectoral and regional levels within six European case studies and to assess the utility of such assessments to policy makers. The DECOIN tools are advanced methods for bio-economic accounting at multiple levels over time, to illustrate trajectories of development. It focuses on the concept of social metabolism that draws attention to how energy, material, money and ideas are utilised by society, drawing on natural capital and generating material, waste and social outputs. This paper will focus on the required first step in the application of the toolkit to illustrate the relationship between the impact of using tools, the meaning associated with tool results and the formalisms within the tools themselves. These inter-relationships illustrate the problem of letting the tools drive the analysis and measuring what we can measure, rather than the actual issues that matter to the wider society. The steps for the application of the tools as outlined by their proponents focus on how to integrate the three formal models with less explicit emphasis on agreeing the problem orientation for the application of the tool or the normative interpretations of why we should do these analyses and what the results might mean. However, without agreeing these normative aspects, the tools are likely to lack salience, relevance and credibility with their potential end users. Therefore, we recognised that we had to establish the semantic approach that would frame the way that the formalisms can be applied for the case study. We used participatory system diagramming to establish what were perceived to be the main elements of the system and their important inter-relationships. This was particularly important for our case study, a National Park, whose statutory basis is to enable sustainable development whilst safeguarding natural and cultural heritage, providing a complex set of interactions within the Park and also the flows into and out of the Park to the surrounding region. This was done three times, once within the scientific study team itself, once with members of the National Park Authority Staff and once from a content analysis of documents that reflect a normative vision based on consultation processes. The paper will illustrate how the outcomes of the diagrams made many aspects of sustainable development visible that the formal models cannot, or do not, measure. These elements in turn have helped shape the trade-offs and synergies that the toolkit has been designed to calculate, demonstrating the importance of this semantic step in the process.

Keywords: *Stakeholder engagement; participatory system diagramming; sustainable development; Cairngorms National Park; multi-level, integrated assessment*

INTRODUCTION

This paper follows the tradition of stakeholder participation in generating, refining and using 'models' or tools (ranging from conceptual through to mathematical and/or simulation approaches) and describes the challenges that this process raises. These challenges are felt by the developers of the tool, when issues arise that the tool cannot or does not consider; and by policy makers whose decisions and actions may be re-evaluated in light of model outputs. The paper focuses on the role of the researcher(s) as a process manager, constantly facilitating this process of challenge, evaluation, refinement and application; and the relationship s within the case study (Sterk *et al.*, 2006, 1). The paper focuses on the multiple dimensions of systems and the difficulty in representing all facets coherently when there are multiple and contested views held. Achieving 'Occam's Razor' (Gauch, 2003) – whereby the formal model is as simple as possible without becoming an over-simplification – is a particular challenge for complex socio-ecological systems at a regional scale.

THE TOOL KIT

The Synergies of Multi-Level Integrated Linkages in Eco-social Systems (SMILE) project seeks to implement a set of models from the ongoing DECOIN project. The DECOIN tool kit (http://www.smile-fp7.eu/deliverables/SMILE%20D3.pdf) consists of three bio-economic accounting methods that work at multiple levels over time, to illustrate trajectories of development. It focuses on the concept of social metabolism that draws attention to how energy, material, money and ideas are utilised by society. The first, ASA (Advanced Sustainability Analysis); will not be discussed as it is not being applied in our case study. The other two are MUSIASEM (Multi-Scale Integrated Analysis Societal Ecosystem Metabolism) and SUMMA (Sustainability Multi-criteria Multi-scale Assessment). MUSIASEM calculates relationships between extensive variables (stocks) of land and human labour, which create flows of money, energy and materials expressed in intensity ratios (Giampietro & Mayumi, 2000). SUMMA is an empirically based set of co-efficients that also consider how stocks create, and are created by, flows of money, energy and materials through the system. These flows are expressed as emergy to illustrate the embodied energy and materials being utilised by the system (Brown & Ulgiati, 2004). The tools are being applied, in various combinations, to six case studies across Finland; Romania; Catalonia; Laos; Italy and Scotland. The research questions for the Scottish case study are: how does the system perform at different levels?; what are the implications of its current performance for possible future states?; and how can the tool kit inform and influence policy? This paper focuses on whether the toolkit can represent the system as perceived by the many actors involved.

1. THE CAIRNGORMS NATIONAL PARK

The Cairngorms National Park is the largest national park in the UK and was created as a result of the National Park (Scotland) Act in 2003. It covers approximately 3,800 km^2 and is home to approximately 16,000 human residents as well as significant protected habitats and species. National Parks in Scotland are explicitly required to achieve 'sustainable development', as illustrated by the four statutory duties set out in the Park Act: to conserve and enhance the natural and cultural heritage of the area; to promote sustainable use of the natural resources of the area; to promote understanding and enjoyment of the special qualities of the area by the public; and to promote sustainable economic and social development of the area's communities. Therefore, they are not 'wilderness reserves' but fit the IUCN category V (protected landscape). The Park has a statutory management authority – Cairngorms National Park Authority (CNPA) but unusually, the CNPA are not land owners, regulators or service providers *per se*, but instead seek to coordinate the multiple private, public and voluntary/NGO sector land owners at the local, regional and national (Scottish) level.

2. TAKING THE FIRST STEPS

2.1. Identifying the tool application cycles

Although there has been detailed guidance provided on the toolkit's application, it was important to identify the procedural aspects of applying the tool from start to finish in the Cairngorms case study. Given the overall aim of the SMILE project to consider how useful these tools are in helping policy makers understand their system and its sustainability trends, it was particularly important to understand how to 'close the loop' between the outputs from the tools and the governance processes enacted within the case study.

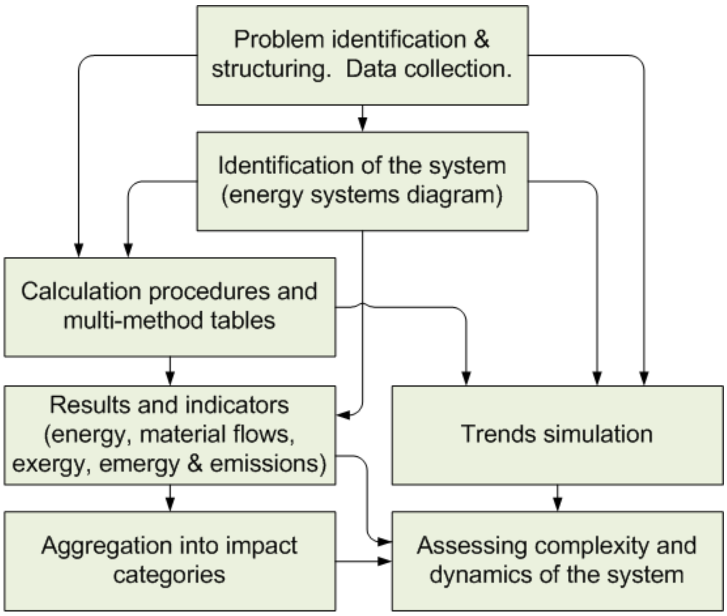

Figure Two: Applying the SUMMA Tool

The SUMMA tool provided the guidance shown in Figure Two. There are seven steps to work through, starting with problem identification, problem structuring and data collection. However, the approach does not explicitly recognise multiple representations of the system or a participatory process to generate the energy systems diagram, nor does it relate the final outputs back to the initial phases. In other words, the institutional context remains outside the seven steps. The MUSIASEM did not provide explicit guidance on the procedures for implementing the tool. However, as the tool followed Rosen's (1978) principles of modeling, we were able to construct a procedural diagram (Figure three), that shows how to close the loop between the outputs of the formal model and the perceptions of the system expressed by stakeholders.

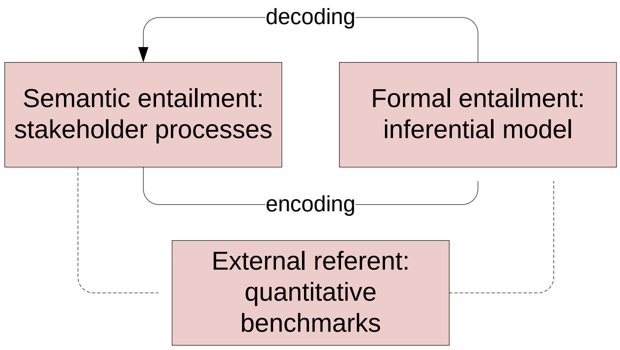

Figure Three: Interpretation of Rosen's Modelling Theory

It is essential to identify the multiple possible representations of the system at a conceptual and qualitative level for two reasons. The first is to act as a check that the process is driven by the real world problems and preferences of those managing the system rather than reflecting what the tools can do or the data available. The second is to provide a very concrete set of semantic outputs to compare to the outputs of the formal models in order to close the loop. Whilst both tools do advise doing this step, it is striking that there is little explanation of *how* to do this stage compared to the detailed guidance on the formal modeling procedures.

2.2. Identifying the components of the system

There are many possible ways of identifying and characterizing a system. We used a simple process of generating conceptual diagrams to compare and discuss. We generated three diagrams: one developed by the research team from the Macaulay Institute (six people); one developed by a set of managers from the CNPA (five people); and one based on a content and thematic analysis of the key documents describing the national park (one researcher). It was useful to contrast our external view of the system, based on our experiences of visiting the Park, as well as our theoretical understanding of how such systems worked in rural Scotland; with the views of those living, working and managing the Park. The final process used the outputs from a two year strategic planning process that had involved considerable stakeholder involvement (CNPA, 2007) and could be considered to be a useful proxy for a wider set of views on the Park system.

The first two diagrams were created using a deliberative group process. Working initially in pairs, the participants were asked to write what they thought were the main important components of the Cairngorms system onto post it notes. Once a reasonable number had been generated, this exercise was stopped and the pairs of participants were given the opportunity to reflect on what they had generated. The entire group then discussed the post it notes they had generated, grouping duplicate or similar concepts, and identifying any gaps that became obvious. This process started to create higher level groupings. The group then started to arrange the post it notes onto a large piece of A0 paper to develop a 'systems diagram'. Note this was a rapid participatory process to illustrate the main content of the system and their relationships to one another. During this diagramming stage, 'missing' content was identified and added. There was much debate about how to construct the diagram – do you start from the natural capital or the people? Do you work from left to right or from the centre out? And as a result of discussion and debate, some post it notes were moved around several times. Furthermore, it became clear how many components were linked in different ways to many other components – illustrating the complexity and the richness of the system. The 'diagram' of post it notes were then entered onto an Excel spreadsheet and converted into a graphics package called flow-charter, providing an electronic version of the diagrams (Figure Four – discussion of the content is found in 3.1 and larger versions and figure five can be found at www.macaulay.ac.uk/smile/).

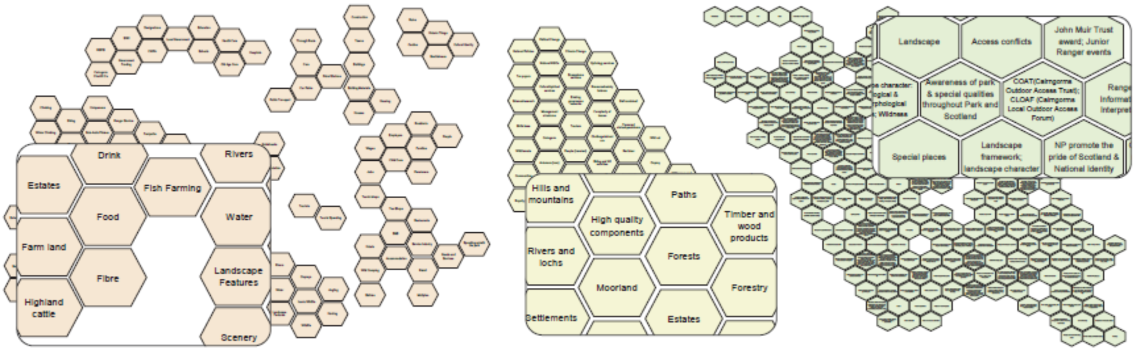

Figure Four (a) Macaulay diagram; (b) CNPA diagram (c) content analysis diagram.

2.3. Generating Energy System Diagrams

The SUMMA tool required us to convert the information we generated from these processes into a formal energy systems diagram. This step is useful to MUSIASEM as it helps to reduce the complexity of the representation to those components that are required for the formal models. The diagram should be read from left to right – with extensive and natural inputs to the system on the far left, and increasingly anthropogenic inputs of the system along the top border of the system. The outputs of the system should be found on the right hand edge and the waste exiting the system is indicated along the bottom. The aim is to illustrate the main relationships within a system without the detail overwhelming the structure of the system.

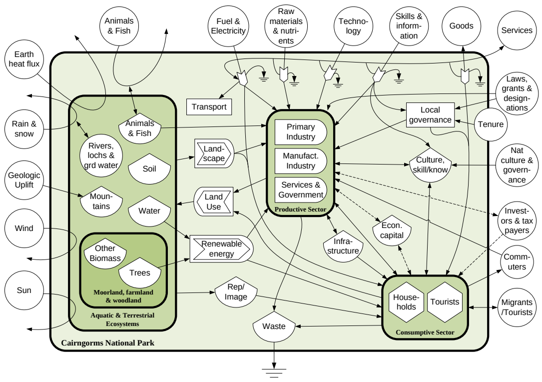

Figure Five: Draft Energy System Diagram

We used the system diagrams created in step 2.2 above to generate the energy system diagram, although often we used the higher level clusters, or groups, generated in the diagramming discussions rather than the detail on individual post it notes. It was important to use our field notes, supplemented by the transcript of the CNPA meeting discussions, to remind ourselves of how the different participants saw the relationships, rather than impose the logic of the energy system approach onto the data. In future applications, this step could also be done as part of a deliberative group process. Section three discusses how effectively we could find a home for all the post it note components in the energy system diagram.

2.4. Relating the Diagrams to the Formalisms

We subjected the list of post it notes (representing elements of the system) to several different classifications of the data in a spread-sheet to try to ensure that we arrived at the simplest representation of the system (and its context) whilst not over-simplifying or ignoring important issues. The spread-sheet stage allowed us to interrogate the data-using concepts, such as capitals from the sustainable livelihoods model (Carney, 1998); notions of stocks and flows; whether things were exogenous or endogenous or heuristics such as PESTLE (Grundy, 2006). This step was another check to ensure that all aspects of the system had been considered. As suggested in figure two above, both SUMMA and MUSIASEM require a translation from qualitative and conceptual ideas of how a system functions to quantifying key relationships and benchmarking these indicators against the same system at a different time, the sub- or national level system at the same time;

and/or other equivalent systems. For SUMMA, this requires taking the inputs, components and outputs of the energy systems diagram and creating tables of technical co-efficients to calculate the energy, emergy and monetary flows. For MUSIASEM, far more simplification is required for the formal model at the level N (although the hierarchical decomposition into levels N-1 etc can be very detailed and complex) as the key relationships of interest are between land use and human activity. As with the energy systems diagrams, this process is an iteration between the detail of our system diagrams and the formal requirements of the tools.

3. RESULTS AND DISCUSSION

This section draws attention to the areas where we had difficulty including aspects of the system identified in the diagrams and spread sheets within the formal models. If the formal representation of the system is not both coherent and complete, the quantitative outputs will not help us to truly understand system performance.

3.1. Content of the diagrams and spread sheet

The elements of the diagrams were categorized as described in section 2.4 above. The Macaulay diagram had 107 elements; the CNPA diagram had 57 elements; and the content analysis diagram had 212 elements. These differences are a result of the different amount of time taken to construct each diagram and to what degree issues were 'lumped' or 'split'. In terms of classification, the most interesting areas for our project are those that are exogenous in origin but play out in the Park (e.g. policies) and those that are endogenous but are also found elsewhere too, as they helped us look at relationships across the system boundary and where there are unique incidences that a more generic and deductive framework might miss out. Stocks and flows are useful concepts for bio-economic modeling but they ignore the interpretive approach whereby people interpret the same component in different ways and do not capture the institutional aspects that enable a stock to become a flow. This problem of how to handle the transformative nature of human aspects of a complex socio-ecological system also pertains to the capital coding. It was important to consider how some of the capitals are stocks that are generated *by* flows; whilst others are stocks that *generate* the flows. Working within a framework of strong sustainability means that relationships between components have different weightings or directionality and are not equally substitutable.

The elements were put into higher level 'clusters' during the diagram process; to help us abstract from the detail being recorded and identify the relationships within the system; and across the system boundary. They are not 'perfect' but capture the broad output of the workshop/process that we underwent. Using a process of comparing and contrasting the elements and clusters from each diagram; alongside the field notes recorded during the workshops and as the content analysis was being done; the authors identified a set of clusters that reflecting all three diagrams (in alphabetical order): Governance & Land Tenure; Habitats and Species; History & Culture; Knowledge, Skills, Management; Land Use & associated industries; People (multiple types); Settlements & Infrastructure; and Tourism & Recreation. Some of the external factors that influence the elements of the CNP system were listed as the economic context, institutions, climate change, and regional effects such as proximity to major settlements (e.g. Inverness).

We have learnt three lessons from this process. Firstly, the outputs of the process will reflect the world views of who participates. It is vital to carefully record how participants generate and 'map' the components of the system – it is the meanings embodied in these choices that are important (Kesby *et al.*, 2007). This process could be done with more sets of stakeholders but represents the maximum investment we could afford to make. We recommend that this process is provided for in the timescale of future projects. Secondly, we could have used other deductive sustainability frameworks, such as Tabara & Pahl-Wostl's (2007) or Newell *et al.*'s (2005) to analyse the diagrams. These conceptual models were too different to the content of our formal models to act as check on the analysis but would provide another lens on whether the DECOIN toolkit does capture the complexity required for sustainability science. Thirdly, the discursive approach to our diagramming created an '*unholy mess of different types of concepts and often composite issues within one post-it note*' (field notes). Therefore, our analysis had to deal with things that were incommensurable; at different resolutions; and many were repetitions of similar things, yet not the same. This demonstrated the richness and complexity of the system and its many possible interpretations but did not help with the classification system. It raised an epistemological issue about whether to represent what the post-its said or whether to abstract early on, to come up with a more manageable set of categories for classification.

3.2. Implications for the tools

Our analysis based on of the diagrams and the spread sheet classifications suggests following tentative conclusions for the application of MUSIASEM and SUMMA. As illustrated by Figure 3, these perceptions will have to be checked against quantitative external benchmarks. SUMMA adopts an explicit focus on the bio-physical thresholds of any socio-ecological system. There are important seasonal variations within the system in terms of demand for stocks and the direction and strength of the flows. Climate can be an important enabling and constraining factor for the tourism and agricultural sectors but these seasonal dynamics may not be captured by the 'snap shot' approach of MUSIASEM or the indicators within SUMMA. In terms of the human system, there are different types of tourists whose behaviour has implications for the consumption of resources in the Park. There are different residents, and there are also the second home owners who have to be accounted for. Tourism, second home owners and residents also have implications for the stock and flow of housing and the resources used within this sector. Much of the public management of land is funded by the tax payer – this has implications for capital flows but is also another kind of human actor to consider. This can be handled by MUSIASEM but it is less clear how to account for this in SUMMA..

The main employment is provided by government/services, tourism/recreation and agriculture/forestry. The first two are particularly reliant on economics at the N+1 (Scotland) level and draw on stocks held at N+1 as well as within the Park. Agricultural & Forestry are reliant on markets at N+1 level. The Cairngorms National Park is a dissipative system (a sink) in economic and energy terms. It uses monies generated through taxes and directed by government – so we will have to account for how public monies are spent in the productive and service sectors; and ensure there is a feedback loop to these capital sources out with the Park. There are inter-relationships between services and tourism – particularly in terms of the provision of retail, hospitality and human services. There are conflicts between the provision of services for different types of tourism e.g. ski resorts versus wilderness trekking. There is a limited inter-relationship between tourism and farming (the use of local food products is being promoted by the Park Authority). Field sports are a high value sector associated with land management, although it is unclear whether these activities should be allocated to agriculture or tourism.

These findings highlight the importance of understanding the non-consumptive use of land and the land's multi-functionality. Our findings ask us to account for land that is simultaneously used for different purposes, with different stakeholders benefiting from these uses. This finding led the tool developers to realize that we needed a formal representation of the link between land use and landscape. Currently, the tools, whilst trying to deliver a systems level view of sustainable development, tend to focus on consumptive use of resources - what resources are used rather than how land use is enacted and what meanings are attached to these practices. For example, MUSIASEM does not indicate 'quality' of land use but generates metrics for its outputs and its intensity variables that might be a proxy for these 'qualities'. But these model outputs cannot answer the normative questions of: what is to be sustained? for whom? at whose cost? and who benefits?

There are marked differences in land tenure in different parts of the Park with implications for the economic mix and use of resources. Again, it is essential to link sustainability assessment to the insights from institutional analysis as different forms of property rights have implications for how resources are mobilized and managed. Management arrangements and policy objectives are also very important in understanding the historical pattern of the system metabolism and in thinking about how different future options might be delivered; but it is not clear how these can be incorporated into the formal models. The ratio between the land area and the number of human actors utilising the land resource (residents and tourists) means that stakeholders believe the stocks are less pressurised than in other parts of the UK – this could be explored using metrics generated by SUMMA and MUSIASEM. This perception, that the park system is under less pressure than other areas, could be contrasted with the perception that it is a dissipative system. It gives, rise to questions of why the rest of Scotland should support this 'haven' if this situation is shown to exist.

3.3. Conclusions and relationship to the Literature

This paper is positioned within a much wider literature on using decision aids, including simulation models, with stakeholders (Matthews *et al.*., 2008; McIntosh *et al.*, 2007). Stakeholders and scientists are equally fallible in seeing the system through particular lens, and putting weight on some areas and ignoring others. Sterk *et al.* (2009) note that land use models play a heuristic role to help multiple stakeholders understand complex systems; a symbolic role in making issues visible to politicians and a relational role by creating a boundary object around which a social network can be developed. Our paper supports their conclusions that it is the interactive learning involved that facilitates these roles; and that the practice of working with models requires more attention. Our findings also reinforce calls to practice sustainability science that takes non-academic knowledge seriously (Carolan; 2006) and pays attention to the politics and power relationships involved in any evaluation of a system (Smith and Stirling, 2008). The DECOIN tools are extremely useful at illuminating the constraints on the existing system and the trade offs that have to be considered when pursuing normative goals of sustainable development. They quantify these trade-offs and illustrate whether certain policy goals are feasible and/or desirable. With particular reference to modelling, our results illustrate the importance of having a shared semantic understanding *before* implementing formal representations of a system using inferential, mathematical or simulation models. Our contribution has been to set out an approach to capturing the semantic aspects and how this can be used to 'decode' the model outputs with the stakeholders in later steps; before working around the cycle once more (see figure 3). These semantic steps are essential if the tools are to be seen as credible, salient and legitimate (Matthews *et al.*, 2008).

ACKNOWLEDGMENTS

The research is funded through the European Commission FP7 SMILE project, with match funding from the Scottish Government's Environment: Land Use and Rural Stewardship Programme. We would like to thank Gillian McCrum, Alana Gilbert, Hamish Trench, Murray Fergusson, Chris Bremner, and Gavin Miles for their contribution to the diagrams and ongoing support to the project. We could not have written this paper without Mario Giampietro, and Sergio Ulgiati and their teams, who coached through the use of their tools.

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