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Abstract: When building a (interdisciplinary) model for policy support, modellers are faced with many choices that influence the model, and may influence the model outcomes. When a personal judgement is involved in a choice process, this can make the model biased. A model and its outcomes may be unacceptable to the users and stakeholders and may lead to conflict if the model does not adequately take their knowledge and perspectives into account. This study explored how choice processes in the modelling practice take place and what biases may occur that may influence the knowledge and perspectives incorporated in a model. Based on qualitative interviews with modellers at IIASA, it was analysed how modellers deal with choices on problem framing, variables and indicators, uncertainties, computational limitations and interdisciplinary modelling. This paper shows that in the course of modelling for policy support many choice moments are encountered. Moments at which bias may occur are: when determining that an issue requires choices to be taken; while making an inventory of options to choose from; while making the actual choice; and while evaluating the choice made. Goals, restrictions, common practice, the values of the person making the choice, and the opinions of users, stakeholders and peers seem to influence the eventual choices made. Insight into how choices are made, and into what biases may be introduced in a model, may help modellers in treating the incorporation of knowledge and perspectives in their models more consciously and more transparent. This analysis of choice processes in modelling is a first onset of a checklist on choices in modelling assisting this task.

Keywords: Modelling; Choice processes; Bias; Subjectivity; Perspectives

1. INTRODUCTION

When building a (interdisciplinary) model for policy support, modellers are faced with many choices regarding what to include and what to exclude in the model, regarding model structure, regarding assumptions, etc. Personal judgement inevitably plays a role in some of these choices. When a personal (and sometimes unreasoned) judgement is involved in a choice process, this can make the model biased.

All choices made in the modelling process influence the model and may influence the model outcomes. As Stern and Fineberg [1996] pointed out with respect to risk characterisation, the outcomes of a risk characterisation process may be unacceptable to the interested and affected parties of the risk problem and may lead to conflict if their knowledge and perspectives are not adequately taken into account. Similar problems can be expected if a policy oriented model does not adequately take the users' and stakeholders' knowledge and perspectives into account and if the model is not clear on what knowledge and perspectives are accounted for in the model. Especially when biases in the model are involved, the model and model results can become controversial.

By means of interviews, this study has explored how choice processes in the modelling practice take place and what biases may occur that may influence the knowledge and perspectives incorporated in a model. The study focussed on the choices that modellers themselves make while working on a model. Choices made by others that may influence the model or model outcomes, such as choices with regard to funding, choices with regard to the research strategy of a research institute were not considered.

This paper first gives a brief description of the set up of the interviews, then describes how modellers, according to the interviews, deal with choices on problem framing, variables and indicators, uncertainties, computational limitations and interdisciplinary modelling. Then, successively (1) the steps that can be identified in choice processes, (2) factors that choices are based on, (3) ways of

involving users and stakeholders in the choice process, and (4) biases in choice processes with possible influence on knowledge and perspectives incorporated in the model are presented.

2. SET UP OF THE INTERVIEWS

Fifteen modellers of the International Institute of Applied System Analysis (IIASA) and four modellers attending the IIASA Young Summer Scientist Program (YSSP) in 2001 were interviewed. Additional observations of choice processes were gathered by attending project meetings where discussions took place on model development. IIASA is a renowned international and interdisciplinary institute with extensive knowledge and experience regarding modelling. A great variety of simulation / optimisation / analytical / numerical models can be found at IIASA, mostly addressing environmental and societal problems and aimed at supporting policy.

The interviewees were selected in such a way that the variety of the modelling work at IIASA was covered by our selection.

The interviews were qualitative and of a semi-structured nature. At the start of the interviews only the general topic - choice processes in modelling for policy support - was introduced. The modellers were free to bring up any topic with regard to this subject. A topic list was used by the interviewer as a reminder to make sure that problem framing, choosing variables and indicators, dealing with uncertainties, dealing with computational limitations and dealing with interdisciplinary modelling all were addressed in the interviews.

3. DEALING WITH CHOICES WHILE MODELLING

In the interviews, the modellers elaborated on how they deal with issues regarding problem framing, choosing variables and indicators, uncertainties, computational limitations and interdisciplinary modelling. The findings are presented in the paragraphs below.

3.1 Choices regarding problem framing

Modellers have to make choices on how to represent the system they want to model: they have to determine what the boundaries are of the system under study and how this system will be represented in the model.

With respect to what formed the basis of their choices regarding problem boundaries and problem definitions, respondents mentioned:

- The background of the research group;
- The background (education) of the modellers;
- The data that are available;
- Choosing the problem definition in such a way that there is a learning effect;
- Whether or not certain simplifications with regard to the problem can be justified.

Reasons mentioned why certain variables were modelled exogenously were:

- Feedbacks are negligible;
- The variable is very unpredictable;
- Low priority (other variables are more important to treat endogenously);
- No expertise in the disciplinary domain of a variable (modelling such variables is left up to the specialists in that field);
- Practical problems (e.g., because it would require too much work)
- Lack of empirical data.

With regard to how the modellers decided on what policy measures and techniques to solve the problem they would incorporate in the model, the experts mentioned:

- The availability of information on policy measures/techniques;
- Preferences of the modellers;
- Familiarity with policy measures/techniques;
- Resonance with policy agenda;
- Feasibility of the measures/techniques;
- Feasibility of fitting them in the model framework;
- Robustness of policy measures/techniques (would they work under different circumstances).

3.2 Choices regarding variables and indicators

Modellers have to make choices with regard to the variables and indicators that will be used in the model to represent the system under study.

The modellers mentioned the following ways of choosing indicators and variables for their models:

- Take the ones the problem owners use;
- Choose those which were approved by users/stakeholders;
- Make sure they are understandable;
- Copy them from previous models;

- Base them on physical flows;
- Base them on literature;
- Choose those that are practical (in terms of modelling);
- Choose different ones if a formerly chosen indicator/variable turned out to be 'wrong';
- Choose them in such a way that they match with variables/indicators in other sub-models
- No choice (it is obvious which ones to use).

3.3 Dealing with uncertainties

Modellers have to make choices regarding how to handle uncertainties surrounding the problem at hand.

Ways of dealing with uncertainty in general[1] that were mentioned were:

- Analyse the uncertainties in the model and assess their influence;
- Study the issue with uncertainties in isolation. E.g., in a small separate model;
- Work with multiple values, ranges or probabilities;
- Model backwards in the cause-effect chain. In this way values regarding uncertain issues can be set in such a way that the outcome of this model is the event minimally needed to create a certain undesired impact;
- Comparison. Outcomes calculated using different methods can be compared, studies can be compared, a detailed study can be compared to the model's results and different databases suitable for the model can be compared;
- Make adjustments in the model as soon as new information arises;
- Avoid influence of uncertainties. This can be done by incorporating the most important issues in the model in such a way that they have limited influence on the outcomes of the model;
- Develop a framework suitable for decisions under uncertainty. In such a framework emphasis is put on the exploration of robust solutions;
- Use the knowledge, views and wishes of experts and/or lay people;
- Let the users decide. In this case several options regarding the uncertain issue are included in the model and the user is left with the choice;
- Take a reserved position. When large uncertainties play a role, modellers can choose to make qualitative statements instead of quantitative statements. Also, modellers can admit they are not able to build a model that is good enough to base a decision on;
- Communication. The results of uncertainty analyses can be communicated. Also, in the communication about a model attention can be paid to choices in the model regarding uncertainties.

According to two experts, the importance of the choices made in the model regarding uncertain issues depends on the political situation. When the modelling becomes more policy relevant, the importance increases. Also, the more 'tricky' the policy that needs to be implemented in the future, the more emphasis is put on uncertainties, and the bigger the need for good answers to questions on how uncertainties are dealt with.

In case of plurality (the coexistence of more than one tenable idea regarding an issue), many interviewed experts think it to be important not to choose one, but to incorporate several ideas. Reasons mentioned were:

- Plurality means not knowing;
- It is valuable for stakeholders to see that there is more than one view on a certain issue;
- Not all users will agree with 'the right choice' that the modeller has made;
- A wide range of expert opinions should be presented, otherwise the democratic debate is undermined.

In three interviews it was mentioned that modellers at times have to decide which values and developments in the model are plausible and which ones are not. This is done by looking at whether relationships between driving forces are logical, by looking at which values and developments there is consensus on, or by not commenting at all on plausibility.

When modellers have to make assumptions due to uncertainties, according to one of the modellers, more than one assumption should be included in the model and the user should have the opportunity to make his own choice. Another expert mentioned that when an assumption deals with an issue that

[1] In the interviews no distinction was made between different types of uncertainty; uncertainties in general were addressed. Therefore 'uncertainty' in this analysis can refer to ignorance, inexactness and unreliability.

the modeller has no expertise on, it is easy to misapply them.

3.4 Dealing with computational limitations

When computational limitations are met, modellers may be forced to make different choices than they would have if no limitations had been present.

Some of the interviewed modellers view computational limitations as a phenomenon inherent to modelling. Others indicated that in today's world it is not a problem anymore, thanks to the development of more powerful computers. Often, interviewees responded that data availability is a much bigger problem than computational limitations. Also limitations of the human brain to interpret model results was mentioned as being more limiting. Two modellers did see problems with computational limitations when the model has to be used interactively, i.e. when the model has to be run in a certain location and model runs have to meet time constraints.

The interviewees mentioned that, due to computational limitations, they have to:

- Simplify and exclude aspects of the problem at hand;
- Adjust parameter values in such a way that the model requires less computational capacity;
- Model only part of the problem;
- Design sets of scenarios based on model outcomes (instead of running the model each time to obtain an outcome).

3.5 Dealing with interdisciplinary modelling

In interdisciplinary modelling, sub-models that have their roots in different disciplines have to be coupled, which requires choice-making on how to do this and choice-making on how to develop or adjust sub-models in such a way that coupling them is possible.

In order to couple sub-models, according to the interviews up or down scaling may be required, simplifications, and extra assumptions on e.g. data. If results of the coupled system turn out to be strange, assumptions on how the models are linked may have to be changed.

Several modellers indicated that adjusting and simplifying sub-models in order to couple them does not seem problematic to modellers. People working in the field of interdisciplinary modelling seem to be willing to make these choices, even if it is not good in view of their own discipline.

4. STEPS IN THE CHOICE PROCESS

The following steps could be identified based on the accounts of the interviewees on how they make choices while modelling:

- Determine that an issue requires choices to be taken. Several modellers mentioned that modellers sometimes neglect issues that, according to these interviewees, should have been paid attention to;
- Making an inventory of options to choose from. If a certain issue requires a choice, modellers explore what options are possible;
- Choosing an option. If an inventory is made of the options possible, modellers can choose one of the options. Some options will be turned down immediately. To choose between the options that are left, the modeller will have to examine pros and cons of these options;
- Checking/evaluating a choice. After making a choice, its consequences can be evaluated and the modeller can decide whether the 'right' choice was made or that, in retrospect, a different option should be chosen.

5. FACTORS CHOICES ARE BASED ON

After the inventarisation of options, the modeller has to choose one or more options. Based on the interview data, here a categorisation is presented of factors influencing the choices that are eventually made:

- Objectives. Choices are made in order to reach certain objectives. Modellers make choices regarding data, methods, computer resources, etc. that 'serve the answer you need', as one interviewee put it. E.g., in order to reach the objective of being able to estimate the technical potential of wind turbines, learning curves were chosen.
- Restrictions. When making choices, it is often not possible to choose the option which would be best in view of the objective, due to restrictions. An example mentioned is choosing not to treat a variable endogenously (which is preferred), because of a lack of data. Restrictions encountered in the interviews are: time constraints, political situation (for instance, one would like to include a certain solution to the problem, but this seems useless since it is not a political issue), other choices already made (for instance, the choice of variables in a sub-model depends on the variables that were chosen in the other sub-models), modelling limitations, lack of data/theory and practical reasons;

- Common practice. Modellers base their choice on what is usually chosen in their field (e.g. using birth rates and death rates as variables in a population model) or on what they usually choose in a similar choice situation;
- Values of the person making the choice. Modellers, for instance, make judgements on what they think is important to include in a model and they make judgements on which numbers they think are plausible in case of uncertainty. An extreme example is a modeller making a deliberate choice for the option that brings the model closer to the outcomes he prefers.
- Wishes or choices of users, stakeholders or peers. In this case, the modeller makes the eventual choice, but bases his decision (partly) on the opinions of others.

6. INVOLVEMENT OF USERS AND STAKEHOLDERS IN CHOICE PROCESSES

The interviews showed that (future) users of the model and stakeholders (people that are affected by the problem at hand or by solutions to this problem) can be involved in choice processes in three stages of the modelling process:

- During model development. Future users of the model are, for example, asked which indicators they prefer in the model;
- While running the model. The modellers, for example, set scenario assumptions during runs together with the users.
- While evaluating the model and/or model results. Users/stakeholders can, for instance, be asked whether they think the outcomes of the model are plausible. If not, choices can be refined and adjusted based on their input.

User and stakeholder involvement by the interviewees took place in the form of elicitation (e.g., the modeller makes choices based on information from stakeholder questionnaires), consultation (e.g., the modeller asks users and stakeholders whether they are satisfied with certain choices) and participation (e.g., the users/stakeholders make choices together with the modeller).

7. BIASES IN CHOICE PROCESSES WITH POSSIBLE INFLUENCE ON KNOWLEDGE AND PERSPECTIVES

Based on the interview data, in each step of the choice process potential biases can be pinpointed, that may have an influence on what knowledge and perspectives are incorporated in a model.

A possible bias in the first step of the choice process (in which it is determined whether an issue requires choices to be made) is that issues are (consciously or unconsciously) neglected. Neglected issues do not reach the next steps of the choice process.

In the second step (inventarising options to choose from), several biases may occur:

- The exploration of options is inhibited, because of restrictions or common practice. Other options than those that meet the restrictions, and options that lie outside the domain of common practice are not considered.
- The exploration of options only takes place in a certain ‘direction’, because of the modellers values. Only options are explored that are in accordance with those values.
- Limited knowledge may prevent options from being included in the list of options. Some overlap exists between this category and the previous one: the values of a modeller will direct him towards gathering information in areas that are relevant in view of those values. Knowledge that becomes relevant if a different value orientation had been taken, may not be acquired.
- The modeller’s judgement on whether or not enough options have been inventarised may be biased.

Biases may occur in the third step of the choice process (choosing certain option(s)):

- When including or excluding options. This process may be biased, due to the values of the modeller.
- When the modeller is determining the pros and cons of including each available option. Judgements on the usefulness, relevance, plausibility etc. can be biased. Also, pros and cons can be overlooked, if certain consequences of choices are not considered.
- When repeating or copying choices that were previously made (by the modeller himself or by others). These previous choices can contain biases.
- When basing the choice on wishes or choices of user, stakeholders or peers. Their wishes and choices may be biased.

In the fourth step, the choice made in the third step is evaluated. Biases can occur in the judgement of

the modeller on whether the consequences of the choice are satisfactory.

8. CONCLUSION AND DISCUSSION

This paper shows that in the course of modelling for policy support many choice moments are encountered. Some of these choices may lead to biases in the model and in the model results. Moments at which biases may occur are: when determining that an issue requires choices to be taken; while making an inventory of options to choose from, while making the actual choice, and while evaluating the choice. Goals, restrictions, common practice, the values of the person making the choice, and the opinions of users, stakeholders and peers seem to influence the eventual choices made.

Insight into how choices are made, and into what biases may be introduced in a model may help modellers in treating the incorporation of knowledge and perspectives in their models more consciously. This may lead to quality improvement and may help in avoiding acceptability problems concerning the model and the model outcomes.

With respect to specific choices in modelling, it may have been the case that more issues would have been encountered in this study, had more experts been interviewed and had the interviews been longer. However, in later interviews, no new categories with respect to the different topics were identified. This is in line with the saturation-rule observed by Dunn [1998, 2000], stating that the cumulative distribution of entities brought up by respondents in successive interviews, flattens out after a limited number of respondents, usually somewhere between 15 and 25. Consequently, the framework developed on how choice processes take place, is not expected to change substantially in case of a larger data collection.

The interviews were limited to modellers of one institute. However, in view of the wide variety of models at IIASA and the wide variety in background (disciplines, nationalities, etc.) of the modellers, this study can be expected to offer a representative view on choice processes in modelling for policy support.

This analysis of choice processes in modelling is a first onset of a checklist on choices in modelling for policy support that may assist modellers in identifying (subjective) choice moments in the modelling process, assists them in assessing what choices to make transparent to users, stakeholders and peers, and assists them in incorporating multiple views in the model (with or without the active involvement of users and stakeholders). A similar checklist with regard to quality assurance was designed by Risbey *et al.* [Risbey et al., 2001, 2002].

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