Towards a Knowledge Commons for Integrated Assessment Models of Climate Change

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[Preliminary draft]

Abstract
Integrated assessment models, models that integrate the dynamics of economic and geo-physical systems to explore alternative policy scenarios, play a central role in public debates on climate change. Unfortunately, it is typically difficult to access the models themselves. Efforts are being undertaken to improve access to integrated assessment models. In this paper I describe two cases of integrated assessment modelling activities at the International Institute for Applied Systems Analysis. These two cases illustrate the significant progress that is being made to share information with respect to model inputs and interfaces. In these two cases the sharing of information with respect to the actual implementation remains quite limited however. I speculate why this might be and offer suggestions for improvement.

INTRODUCTION

In view of the engagements made at Kyoto and Copenhagen, and the limited success governments around the world so far have had in keeping with these engagements, it would appear of the utmost importance that more effective strategies were implemented quickly to reduce the emissions of greenhouse gases. Integrated assessment models form a crucial tool for the exploration of the costs and benefits of such strategies. The working group III of the IPCC, which reports on measures for mitigating climate change, heavily relies on integrated assessment models to evaluate the options that might be available. Also the Stern review, which advised the British government on the necessity to address climate change, relied heavily on the outcomes of simulations it carried out with an integrated assessment model for its recommendations.

The number of people who actually understand these models and can discuss them cogently would appear to be rather limited. Moreover, when there are discussions about aspects of the models themselves, they appear to be carried out in a rather roundabout way. For instance, after the Stern review came out in 2007 there was a bit of a debate instigated by Nordhaus on the discount rate adopted by the model used in the review, but as he didn't have access to the review's model, Nordhaus had to resort to his own model to illustrate his argument. Similarly, when the IPCC models were criticized for using market exchange rates rather than purchasing power parities, neither the criticasters nor the defendants backed up their arguments with experiments on the models themselves, but resorted to simplified versions to make their points (Holtsmark and Alfsen, 2005).

The problem, it appears, is that model implementations are not shared, or if they are shared, that the implementation is so intricate or badly documented that it is exceedingly hard to get the model running without direct involvement of the model's original development team. If this is indeed the problem, apparently there are no sufficient incentives to share this kind of information and so we need to search for institutional structures that provide such incentives and for the technological infrastructure that makes it possible.

What we need, in short, is a knowledge commons for integrated assessment models. Already five years ago, in 2007, Schweik pointed out that the organization of open source software development could serve as inspiration for efforts to construct a knowledge commons in science. When distributed software developers around the world are able to coordinate and share the knowledge needed to build artefacts as complex as the Linux operating system, the integrated assessment models might be build and maintained using similar methods. That is to say, from a software engineering perspective at least, it would seem perfectly feasible.

According to Schweik, the adoption of open source practices as model for a knowledge commons in the sciences requires two things. First of all, it requires that the full model implementation, and not just a high level description, is available for inspection to participants in the commons. Secondly, it requires that people be acknowledged for their contributions. Specifically, Schweik imagines the establishment of a kind of e-journal in which such contributions could be published as a way to marry the activities of the computer programmer with the recognition system in place for scientists and academics.

Schweik's suggestion to take inspiration from open source practices has not been left unheeded by people in the field, but not without difficulties.

In what follows, I will describe two examples of ongoing research activities centred on the development of integrated assessment models. In particular, I will describe the activities as a "socio-ecological system" using the framework that was proposed by Ostrom in 2009. The framework helps to get an inkling of the viability of the socio-ecological system as a commons and I will argue that the two examples of integrate assessment research I give are examples of different types of knowledge commons. The commons are of a different type because they are aimed at different users. Roughly speaking, the users in the first example are stakeholders while the users in the second example are scientific peers. Crucially, neither address academic model implementers as users. There are some hopeful signs that a commons addressing their needs might develop in future as well and active support of such developments would surely precipitate its arrival.

METHODS

In order to structure the description of integrated assessment modelling activities, I follow the suggestion of Ostrom (2009) to analyze commons as socio-ecological systems. Specifically, I will map actors and elements of integrated assessment modelling to the components distinguished by Ostrom based on information obtained from interviews I have carried out with practitioners at the International Institute of Applied Systems Analysis (IIASA) complemented by desktop research.

Following Ostrom, a socio-ecological system (SES) consists of a resource system (RS) made up of resource units (RU) which interact with users (U) subject to a governance system (GS) yielding certain outcomes (O); the system is subject to outside pressures from related ecosystems (ECO) and is dependent on social, economic, and political settings as well (S). In the classical commons the pasture is the resource system, the cows are the resource units, grazing is an interaction, farmers are users, and the outcome is overexploitation or sustainability depending on the norm and rules, the governance system, that the farmers adhere to. Ostrom (2007) uses this framework to make apparent the assumptions that Hardin made to establish the commons as an inevitable tragedy. Ostrom (2009) uses the framework to discuss in which circumstances commons are likely to appear and when they are less likely to appear.

Knowledge commons are a peculiar kind of commons, given that knowledge is a non-rivalrous good. Nevertheless, one can imagine situations in which the collective sharing of infrastructure enables the accumulation of knowledge, where collective governance rules need to be established and participation needs to be limited to some extent in order to maintain quality standards. A good example of this is Wikipedia.

The types of knowledge commons of interest in the context of integrated assessment modelling are those that focus on sharing information. In this context, the resource system is interpreted as the technical infrastructure that allows for the sharing of information, the resource units consists of the types of information that are shared, and the desired outcome is for the aggregated information to be reliable.

RESULTS

IIASA was founded in 1972 and has a focus on interdisciplinary policy oriented research. In particular, it has a long tradition in the development of integrated assessment models.

The Greenhouse gas and Air pollution Interactions and Synergies model (GAINS)

One of these models is GAINS. GAINS, the Greenhouse gas and Air pollution Interactions and Synergies model, is an integrated assessment model that is developed and maintained by the Mitigation of Air pollution and Greenhouse gases program at IIASA together with a network of collaborators. GAINS is an extension to RAINS (Regional Air pollution Information and Simulation), which was developed by the Acid Rain project from 1986 onwards and has been used as aid to the negotiation process of the second sulphur protocol of the convention of long-range trans-boundary air pollution in 1994 and the European Commissions' clean air for Europe program launched in 2001. The GAINS model is similarly policy oriented. Amongst others it is used by the European Union for the analysis of burden sharing schemes for the implementation of the EU decision to reduce EU greenhouse emissions by 20% (IIASA web site).

GAINS is a data-centric model. That is, its main purpose is to aggregate data from multiple sources and to translate them into information that can help decisions of policymakers. For instance, from household surveys GAINS estimates the number and types of woodstoves that are in place in regions in Europe. It then combines this information with data on the quantities of wood that have been sold and information to estimate the total amount of greenhouse gases that result from the burning of the wood in the stoves given their technical characteristics. Finally it extrapolates from EMAP estimates to assess the environmental impact of these emissions.

Thus GAINS is basically a database with an aggregation method. In the SES framework one could say that it also serves as resource system. The resource units are the sources of data that GAINS uses as inputs and the users are the model stakeholders, that is, the modellers and the policy makers, but also the domain experts, who vouch for the quality of the inputs. The interactions consist of amendments to the input data or to the assumptions guiding the data-extrapolation in reaction to comments by domain experts. RAINS used workshops to involve experts in the data-vetting processes (Tuinstra et al., 1999) and GAINS continues this tradition. The governance system is dominated by the consultancy contracts that fund GAINS. Related ecosystems are organizations like Eurostat, with which GAINS cooperates and competes at times as they are also in the business of collecting and curating data. Finally, the socio-economic setting consists of the set of values and norms that determine the priority that determine the amount of effort that users are willing to put in the maintenance of GAINS as common resource. For instance, certain regions have a reputation for being exceedingly lax in the specification of meta-data such as an indicating whether sensor-measurements are taken close to a road. Also the political capital that European politicians want to invest in meeting emissions targets may vary over time and affects the attention that GAINS will get.

The Model for Energy Supply Strategy Alternatives and their General Environmental impact (MESSAGE)

MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environmental Impact) is another integrated assessment model that is developed at IIASA. MESSAGE adopts a systems engineering approach and determines the minimum total systems cost subject to given constraints. This approach is computationally intensive and requires access to specialized optimization software. Like GAINS, MESSAGE has a long history. In this case it is even longer and can be traced back to the 1970s. A key characteristic of MESSAGE is the complexity of the model, which has grown over time as the model as grown more complete and features were added. The high level description of the model is available in a report consisting of over 50 pages of equations (Messner and Strubegger, 1996). Using and contributing to MESSAGE requires weeks of training to obtain familiarity with the subtleties involved. The intricacy of the model makes peer review very difficult. Given that MESSAGE is one of the reference models employed by the IPCC working group on mitigation strategies, peer review is crucial. In light of this, efforts are being undertaken to make MESSAGE more transparent. In particular, MESSAGE developers participate in various consortia such as the Integrated Assessment Modelling Consortium (IAMC), which aim to compare model outputs. Besides, there are efforts underway to rewrite MESSAGE in GAMS, a proprietary modelling language, which was originally developed for the World Bank in the 1970s and that is widely used in the discipline (Bussieck and Meeraus 2006). Consequently, one could say that MESSAGE participates in two kinds of socio-ecological systems that are or could become a knowledge commons.

The first SES centres on the consortium. The resource units of the consortium are the common scenarios that serve as inputs for the models and the standards for model outputs. The resource system as made up of the database of and web-interface to these resource units. The users are modelling groups and the interactions consist of the definition of scenarios and standards and the application of the scenarios to the models to produce comparable model outputs. The desired outcome of the consortium is to be able to compare a variety of models on common criteria. The governance system consists of the rules and methods that the consortium has adopted to achieve consensus about scenarios and output standard and to decide which models are included. There exist several consortia for integrated assessment model comparison, some of which are concerned about the compatibility with other climate modelling sub-disciplines as well. These consortia can be thought of as related ecosystems. Finally the socio-economic setting consists of the importance that agencies give to providing funds for this kind of activity.

The second SES centres on the modelling environment in which the model is implemented. In this context, the modelling environment makes up the resource system. In the case of MESSAGE this used to be Unix and efforts are now underway to move to GAMS. The resource units in such an environment are the components from which models can be constructed (the interaction). Models themselves could serve as components to other models, but in the context of Mathematics Programming environments like GAMS the most important components from a modeller's perspective are the solver routines that carry out the system's optimization. Hence there are two groups of users of GAMS, modellers and solver developers. The governance system of GAMS has two-layers. First users need to acquire a licence for GAMS and after that users need to acquire a licence for access to the solver routines. Models like MESSAGE employ solvers that can handle a large amount of data and typically those solvers are expensive to acquire. Several environments for mathematical programming similar to GAMS have been developed (Kallrath, 2012). They constitute closely related ecosystems in the sense that they provide access to more or less the same set of solver routines. Modellers tend to have a harder time to switch from one environment to the other as this involves familiarizing oneself with the idiosyncrasies of the target environment. If GAMS would reinforce its position as de facto standard language for integrated assessment modelling and as repository for state-of-the-art solvers as well as models that would probably be a desirable outcome for most actors involved. The socio-economic setting that influences this is the leeway that is given to developers to dedicate time and effort to this activity rather than other pressing needs such as the providing policy advice or publishing scientific articles.

DISCUSSION

To recapitulate, we can distinguish between three types of information linked to integrated assessment models for which a knowledge commons could be constructed: the model inputs, the model interface, and the internal workings of the model. A lot of progress has already been made with respect to the former two less with respect to the latter. In extremis, this might reflect a conception of integrated assessment models primarily as consulting effort or scientific exercise, respectively and less as software development activity. With respect to inputs, we have seen that stakeholders have an incentive to make sure that the model is based

information that is accurate, at least from their perspective, when there is something at stake. Besides, in the wake of RAINS a whole sub-discipline, called participatory integrated assessment (van Asselt et al., 2002) has developed amassing experiences with this type of modelling. With respects to interfaces, we have seen that scientists have an incentive to make sure that their models can be compared to the models of their peers. The peer review remains rather shallow however, as peers have only a limited inclination to familiarize themselves with their colleagues' models due to the intellectual and computational resources that would be required to comprehend all its subtleties. Even when a high level description is available in the form of a set of differential equations, in a model like MESSAGE the size of this set is so large that it is unlikely that anyone would be able to fully understand the system they describe without the help of experiments with the actual model implementation.
Efforts are made to make the internal workings of the models transparent. To start, the raw data, the SQL trace in case of GAINS and a code dump from the SVN version control system in case of MESSAGE, are available to whoever is interested. Yet, without proper documentation, these raw data are of limited use to outsiders. Also, developers of MESSAGE try to externalize as much as possible of the internal workings of the model through parameters in the interface and developers of GAINS try to simplify the inner workings by standardizing the format of the input data. The result of this may be that relative importance of access to a model's inner workings to understand the model will decline over time. Nevertheless, the establishment of a knowledge commons with respect to information about the internal workings of a model remains a worthwhile pursuit.

An important step contributing to the establishment of such a commons is the attempt that is undertaken at IIASA to rewrite MESSAGE in GAMS. GAMS is a dedicated declarative language that is closer to the high-level descriptions of the model in reports and publications than the generic languages C and FORTRAN in which MESSAGE is implemented right now. Besides, and partially because of this, GAMS is very popular among modellers involved in integrated assessment. It is unlikely, however, that the move to GAMS is sufficient for the creation of a knowledge commons of this kind. As the analysis of the socio-ecological setting of GAMS of the previous section illustrates, the environment lacks characteristics that would lead to self-organization: GAMS has many users spanning many disciplines and while the two main groups of users, the modellers and the solver developers, share GAMS as a common platform, they do not necessarily value each other's contributions very much given that the interaction between both groups is purely monetary as modellers pay for access to solver tools and solvers need modellers as client, while as scientists few members of the group are likely to be active in both disciplines and so only few of the solvers are likely to care about access to the modellers' code. Nor is it necessarily the case that modellers would value access to the code of their colleagues tremendously: it takes a lot of effort to write code that is self-documenting or well documented. So, unless special effort is made, most code will be hard to understand. Consequently, the modeller needs to trust the code before reuse, which will be hard for code that is "not invented here."

What is needed for GAMS to become a platform for the sharing of information on the implementation of integrated assessment models is that the publication and documentation of the models has a clear benefit to the modellers themselves. As Schweik (2007) remarked, the main benefit to be had is acknowledgement of reuse. That is why the publication of the model on the GAMS platform should ideally be automatically accompanied by a publication in a journal with a high impact factor. On the cost side, GAMS management could help by making publication easy, that is, by providing tools to integrate code with documentation and establishing an inventory of contributed code much in the way that the R environment for statistical computing has done for statistics packages. Besides, the modellers should be reassured that they won't be spending time on maintenance and customer support to the detriment of their own research interests. One of the reasons that the physical sciences sub-disciplines of climate science have been more successful in adopting an open source framework (Janetos et al. 2009) might be that these sub-disciplines are traditionally more used to employing support personnel to take care of the infrastructure (Whitley, 2003). A complicating factor in climate science is that due to what's at stake it is less likely than usual that all actors in the debate are going to adhere to the Mertonian standard of disinterestedness. Specifically modellers who publish their model code expose themselves to the possibility of detailed attacks from which they will have to spend time defending themselves.

The R environment for statistical computing is an example of what could be achieved. Originally a clone from the proprietary language S, its developers have adopted practices pioneered by the TeX user group such as the establishment of a conference series and a journal, the journal of statistical software, in which academics can describe their contributions, the development of a repository in which the contributions can be deposited and from which they can be retrieved easily, as well as integration with tools that support the provision of documentation (See ScienceWatch.com). While focused on statistical computing, over the years the scope of R has been enlarged considerably. Contributions to the journal of statistical software now span virtually any kind of data analysis (e.g. bayesTFR by Ševčíková et al. (2011)). A priori, there is no reason, it seems, why a similar system should not develop in the field of Mathematical Programming, which is the field on which integrated assessment modelling depends.

CONCLUSION

In this paper, we looked at efforts to make integrated assessment models more transparent. We described two complementary research programs, both at the International Institute for Applied Systems Analysis, and tried to interpret the institutional settings in which they operate as socio-economical systems. It appears that there are different types of information that can be shared about integrated assessment models and that not every type of information elicits the same amount of interest among the users of the models. Domain experts are mainly interested in an accurate representation of their domain, policy makers are mainly interested in the extraction of unequivocal indicators that can guide actions, and scientific peers, meanwhile, are mainly interested in making sure that the model output is comparable to their own. The paucity of information about the actual implementation of the models can be explained at least partially as a reflection of the limited role that model developers have traditionally had in ensuring that the model is seen as relevant. If integrated assessment models or their components could be reused more easily, then they might derive part of their relevance from the extent in which they were being reused, which in turn would incite model developers to provide better documentation on the implementation and use of the model. The statistical computing environment R is a good example of what the integrated assessment community might want to emulate. Statisticians from around the world contribute to a growing library of tools for this platform. Similarly, the algebraic modelling community could gather around GAMS and turn it into a platform for exchange, or perhaps it might need to create a clone of GAMS (say, CAMS), just like R was cloned from S, to make the platform viable, but that is a subject for future research.

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