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Creating global scenarios of environmental impacts with structural economic models

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Summary

One of the important contributions of environmental sciences to policy making is to analyse how future economic development might impact our environment. The influence of the economy on the environment at present is larger than ever before. As a result the environment is changing and this changing environment can threaten the resource basis of our economy. A particular area where the effect of economy on the environment has already global economic repercussions is climate change. To limit the effects of climate change, global average temperature since pre-industrial measurements are to be kept well below 2 °C preferably even at 1.5 °C. The 2 °C limit and certainly the 1.5 °C target means that substantial GHG emission reductions should be realized already by 2050. How these emission reductions should be achieved is unclear. At least it is clear that the use of fossil fuels should be reduced.

It is important to know if indeed the introduction of the renewable energy technologies can achieve the deep GHG emission reduction that are required in 30 years' time against a backdrop of population growth and economic growth. Therefore we investigate in this thesis the effects of the introduction of renewable technologies on GHG emissions and resource use until 2050.

The principal global economy-environment model used in this investigation is based on a global multi-regional environmentally extended input-output (EIOA) framework. It is in principle a static model. A model that is mostly used to analyse inter-industry relationships and effects of (marginal) changes in the demand for products. It is not often used for long-term scenario analysis as is required in this research.

The first research question to be answered was therefore how an in principle static EIO framework can be turned into a long term global quantitative scenario model that allows us to investigate environmental interventions and their effect on environment and economy?

Current global scenario models used in climate change research are either very simple regression models, macro-economic models and integrated assessment models. The scenario model developed in this thesis uses another modelling approach. A second question to be investigated is how the EIOA framework based scenario tool compares to the other types of global scenario models used in climate change research. Especially what are the strengths and weaknesses of the different modelling approaches?

The number of sectors and countries distinguished in the EIOA framework determine how specific technology developments can be included in which regions in the scenario model. It was therefore investigated what the appropriate spatial and economic sector resolution has to be for a successful implementation of scenarios in the developed scenario model?

Having created a scenario model we used this model to investigate two cases. 1) If the introduction of renewable energy technologies can reduce GHG emissions in 2050 to a level in line with the 2 °C limit? And 2) if the introduction of these renewable energy technologies might be constrained by the supply of metals until 2050?

Finally given the experience gained using the EIOA framework based scenario tool in the case studies and comparing it with other types of global scenario models how can the EIOA framework based model be adapted to overcome certain weaknesses it has, compared with other quantitative scenario methods?

A long term global quantitative scenario model was developed based on global multiregional supply-use tables that distinguish 129 different commodities and sectors for the year 2000. The year 2000 is the base year for our scenario studies. Implementation of scenarios for the year 2050 in these supply-use tables is done in several consecutive steps:

- 1) Supply-use tables are seen as the production recipes of products.
- 2) The production has to increase to provide products for a growing population.
- 3) While the efficiency of the production improves especially in developing countries.
- 4) 2 & 3 lead to a growth in GDP

- 5) On top of that the production recipes are changed due to the implementation of low carbon technologies or the production of some sectors is increased at the expense of other while maintaining the same output.
- 6) Energy use for combustion and hence CO₂ emissions are kept in synchronized with the size of the energy inputs of the sectors as influenced by requested sector output, general efficiency changes and specific low carbon technologies.
- 7) CO₂ emissions can father be cut back by the use of carbon-capture and storage.
- 8) The resulting balanced supply-use table containing a would-be global world is subsequently transformed into an input-output table for further analysis.

Using this framework multiple scenarios that assume different use of low-carbon technologies in 2050 into the global economy can be made.

The developed global EIOA framework based scenario tool was used in the field of climate change scenario studies, a research field that typically uses computable general equilibrium (CGE) models, macro-econometric models or integrated assessment models (IAM). These models have a long development history and it is rightfully to ask what the contribution of the global EIOA framework based scenario tool can be in this mature research area. To be able to answer this question an evaluation was made of current global climate change scenario models. The models were evaluated in terms of their description of the economic system, environmental system, the solution mechanism used to calculate the GHG emissions for a particular scenario and how accessible the models (results) are to external researchers. The evaluation shows the strength and weaknesses of the global EIOA framework based scenario tool and where the application of the framework might be useful. A weakness of all models evaluated is the reliance on extrapolation of past trends. Sometimes this extrapolation is obvious as for instance in IOA based scenario tool where it is assumed that observed general efficiency changes can be extrapolated into the future. Sometimes it is less obvious when observed elasticities are assumed to remain constant over time. Another weakness of all modelling approaches is the very limited or absence of process descriptions where climate change can affect the economy. With the current prospect that the 1.5 °C limit will be breached it might be expected that such repercussive effects become more pronounced. There are no global scenario models that can take these effect reasonably into account. A strength of the EIO based scenario tool is its consistent and comprehensive description of 129 economic

activities in a country. A weakness and a strength of the EIO based scenario model is its simple description of the economy. It is not possible to analyse effects of economic policy measure such as subsidies or taxation but the model is easy to understand and to couple to other models. The linearity of the EIO based scenario model cannot be seen as a drawback of these types of models compared to CGE models. The widely used CGE models are in practice also often linearized. The IAMs are currently the only models with a detailed description of processes happening in the environment such as land use changes and biodiversity impacts.

When developing a global EIOA framework based scenario tool, the question of which sector resolution and spatial resolution has to be used in the model is important. Therefore the effect of aggregation on calculated material footprints was investigated. The investigation showed that spatial aggregation is preferred above sector aggregation. The rationale is that the production recipes in different countries does not differ as strongly as production recipes in between sectors. Of course this statement depends on the countries or the sectors that are being aggregated. An example might be illustrative here. A coal power plant in the Netherlands will operate very similarly to a coal power plant in Germany or Belgium. Spatial aggregation will not lead to large aggregation errors. An aggregation of different types of electricity production e.g. gas, coal and nuclear power plants might introduce larger aggregation errors because the production recipes are quite different. But spatial aggregation of countries where technology is very different is not advisable either. In the global EIOA framework based scenario tool spatial aggregation was carried out, but sectoral and product detail was maintained. Spatial aggregation was done on the basis of economic development status. As such the structural scenario model balanced the theoretical best approach and practicalities in the best way possible.

In a first case study, the scenario tool was used to investigate if the introduction of feasible renewable energy technologies can reduce GHG emissions in 2050 to a level in line with the 2 °C limit against a backdrop of population and economic growth. Three different scenarios were developed. From a business-as-usual (BAU) scenario to a scenario which complies to the 2 °C limit. The BAU scenario was in close agreement with other BAU scenarios that have been created with integrate assessment models and brings us on RCP8.5 which means that the

global temperature will rise by about 5-6 °C in 2100. The other two scenarios developed indicate that only with a reduced economic growth the 2 °C limit can be met.

A second case study carried out with the developed scenario model looked at the possibilities or impossibilities of supplying resources for the low carbon technologies until 2050. Possible resource bottlenecks for eleven different metals were investigated ranging from bulk metals such as iron and aluminium mostly used in general infrastructure to specific low carbon technology metals such as lithium and neodymium. While most studies try to forecast or even predict supply and demand of metals until 2050, our methodology started from the notion that development of supply and demand cannot be predicted but that it is better to determine a viable operating space where it is likely that supply and demand can be matched. It is also important to look at global demand. It might be that the implementation of renewable energy technologies leads to a tenfold increase of that metal in that specific application. However there is already a large application of the metal in other applications that is not expected to grow so much, the overall expected increase of that metal is not so dramatic.

In this case study, again the same low carbon scenarios were investigated plus two other scenarios that investigated the possibilities of equipping every electric car with neodymium magnets or having an electricity production mix with a higher use of renewable energy technologies. The result of this case study shows that the overall annual supply increase needed to satisfy future metal demands in low-carbon scenarios is not extreme and in line with or even lower than supply increases observed in the past. However demand-supply imbalances and price hikes may still occur, particularly if there is a faster transition to low-carbon technologies and electric vehicles than assumed in our scenarios. There is another reason why the result is not just a positive message. Extracting metals from ore bodies with lower metal concentrations means that more energy, water, and auxiliary materials are needed to extract the metal, with possibly higher environmental impacts.

To be able to further develop the EIO based scenario model first an important weakness of this model approach must be tackled. It has not been validated. Recently a time series of global multi-regional supply-use tables have become available that can be used for that.

Furthermore a side-by-side comparison of the global scenario models using the same scenario starting points should be carried out to fully inform us about the behaviour of the models.

Coupling the EIO based scenario model with environmental process models might be a promising direction of research because a full integration might give us the possibilities to analyse scenarios where repercussion from climate change on the economy might be taken into account.

When the EIO based scenario model is indeed going to be used to investigate possible repercussions of climate change on the economy, the sectoral and spatial differentiation question has to be revisited again and likely spatial disaggregation has to be increased. If the introduction of renewable energy technologies and associated resource use are to be analysed in more detail, the EIOA framework the description of waste and recycling flows and stocks should be improved. This likely call for further improvement of the creation of hybrid unit or physical input-output tables. Special attention has to be given to the occurrence of interlinkages between degrading resources, food and feed production, energy use, water use and environmental impacts. In an ever tightening safe operating space, it must be prevented that one of such an interlinkage spirals out of the safe operating space.