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Report on the linking of EXIOMOD and LPJmL

WP 3 - Scenarios and modeling of policy implementation for resource efficiency

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Key word list

CGE model, water demand, land use

Definitions and acronyms

Acronyms	Definitions
CGEM	Computational General Equilibrium model
IO	Input-output

1. Introduction

Resource use is intrinsically related to human economic activities, in particular since the industrial revolution. The development of a detailed input-output (IO) database extended with an environmental account such as GTAP database (www.gtap.agecon.purdue.edu) or EXIOBASE – www.exiobase.eu, Tukker et al. (2009) – helps better understanding and quantifying the link between resource use and economic activity – see Tukker and Dietzenbacher (2013). In particular, these regional databases can be used to develop Computational General Equilibrium Model (CGEM) able to cover most regions of the world economy. Examples of these models are GTAP, EXIOMOD, GINFORS, NEMESIS.

However, the way the resource constraints is taken into account is often unsatisfactory. In CGEM, resource use is generally demand driven because of the assumption that the supply of the resource will be able to follow the demand. In this case, the effect of the deterioration of the resource stock does not have any impact on the economic choices of agents. This is at odds with reality where certain resource constraints have been observed to affect economic variables. One typical example is the increase in the price of agricultural food products with the rise of use of land for biofuel production. Although attempts have been made to take better account of these constraints in economic models (See Section 2.2), they often raise technical and theoretical issues, in particular when implemented in large scale CGEMs.

This report describes the approach we will use to take better account of water and land constraints in EXIOMOD. This approach consists in linking the CGEM EXIOMOD with the biophysical model LPJmL. Here we justify this choice and explain how it will be implemented. We do not describe the technical solution used since it will be the same as the one retained to link GINFORS with LPJmL. This solution is described in detail in deliverable D3.4 (Report about the linking of GINFORS and LPJmL- see Section 2). We also skip the description of EXIOMOD and the details on the modelling of water demand and land use in EXIOMOD already reported in deliverable D3.1 (Report about the modelling of water demand and land use in EXIOMOD).

Section 2 describes the methodological approach as follows:

- Sub-section 2.1 reviews the different approaches used in the literature to account for resource constraints in economic models. It points the advantages and drawbacks of each of them. It also justifies the choice we have made on how to incorporate these constraints in EXIOMOD;
- Sub-section 2.2 explains the interaction between LPJmL and EXIOMOD;
- Section 3 gives specificity of the technical solution with regard of EXIOMOD. Section 4 concludes and describes the future steps;
- Section 5 gives the publications plan resulting from the work described.

2. Methodological approach

2.1. Resource constraints in economic models

Using the technical coefficients derived from the IO databases and eventually assuming some technical efficiency, CGEM can directly derive the impact of each economic activity on the use of various resources such water, land, mineral, etc[1]. This representation has, however, the drawback of being demand driven in the sense that the limit of the resource is often not or imperfectly taken into account into the economic model. Often scenarios implicitly assume that the supply of the resource will be able to follow the demand. At the most, the modeler controls a posteriori if the resource stock is not exceeded within the time frame of the simulation. But the deterioration of the stock does not have any impact on the economy. If the simulation horizon is sufficiently short, one could argue that this approach provides a good approximation, since the negative economic impacts of the overuse of the resources may not be perceived or anticipated by agents. However, for a long horizon, it is unlikely that economic agents do not react to the deterioration of the resource stock, especially if physical effects (such as resource constraint, damages, pollution, etc.) become directly perceivable.

Certain CGEMs incorporate the resource constraint by assuming that the resource is an input of the production function – Calzadilla et al. (2010), Calzadilla et al. (2010). The supply of the resource is exogenous and the assumption of perfect flexibility of prices ensure that the demand for the resource is equal to the supply at every period. This approach interprets the resource constraint as an exogenous productivity shock. When the resource is lacking, the productivity of the other production factors is lower. This property can be modelled with the assumption that production function is homogenous of decree 1 (constant returns-to-scale). When the input “resource” is limited, increasing production requires a more than proportional increase of the other inputs (capital, labor, energy, intermediaries) to compensate for the resource scarcity. In other words, the limitation of the resource leads to increasing marginal costs. In the event of a decrease in the resource availability, the average cost of production increases because the producer needs to use a more capital intensive technology. The main drawback of this approach is that the supply of the resource is exogenous and that demand is set to this level because prices are perfectly flexible. The possibility that the demand for the resource is lower than the resource constraint is a priori excluded. In many cases of resource constraint including land or water, this assumption is not satisfactory since it is completely possible for the demand at a given point in time to be lower than the supply constraint.

This weakness of most CGEMs comes from their difficulties to model consistently the effect of the degradation of the resource stock on prices and the role for anticipation and rational economic behavior in a context of large uncertainty about the future. One important issue is that the taking into account of these dimensions hugely increase the complexity of the algebraic and computational resolution since it requires the use of intertemporal maximization resolution techniques. Examples of these approaches can be found in the literature related to the neoclassical model of (non-)renewable resources. But these are often in partial equilibrium concentrating on one resource (e.g. Okullo and Reynès (2011) for oil market)). The

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[1] An alternative approach to CGEM is the use of partial equilibrium model: e.g. Mannaerts (2000) for references. The main drawback of these models is that they only consider the material markets and do not account for feedback effects on the rest of the economy. There are therefore not reviewed in the present study.

transposition into a general equilibrium framework with a large number of sectors and economic regions would be very tedious, and therefore (to the best of our knowledge) has not been attempted so far. Other examples are the neoclassical models involving a social planner such as the DICE model which can account for uncertainty (e.g. Hwang et al. (2013). Unfortunately there is no social planner in reality and these models provide an analysis at a very aggregate level. This makes them poorly suited for practical purposes at country and sectorial levels.

It should be noted that the complexity of this transposition may not be the main factor preventing modelers from incorporating these approaches into a CGEM. Another important issue is that inter-temporal neoclassical approaches are far from being exempt from critics and weaknesses. Indeed, methods using inter-temporal maximization approaches rely on bold assumptions relative to the agents' knowledge of the future, the length of their inter-temporal horizon, their risk aversion, the level of the discount rate. This makes them have properties largely at odds with reality. For these reasons, modelers are reluctant to use these approaches to better account for the impact of supply in CGEM.

2.2. General approach used to link LPJmL and EXIOMOD

We use here an intermediary approach by modelling the shadow price of the resource, that is the price someone would have to charge so that consumers do not overuse the resource. This approach allows two cases: (1) the case where the resource constraint is inactive because the limit of the supply is not reached; (2) the case where the resource constraint is active, that is when the supply limit is reached. Technically, this means that 2 simulations of EXIOMOD may need to be carried out. The first one assumes the absence of a resource constraint. If the implied demand is lower than the actual supply (case 1), the algorithm is stopped and there is no need to conduct a second simulation. But if the implied demand is higher than the actual supply, we conduct a second simulation where the shadow price of the resource adjusts to ensure that the demand is equal to the supply (case 2).

In order to increase the realism of the model, EXIOMOD will be linked to the biophysical model LPJmL – see BONDEAU et al. (2007) – that will model the resource supply constraint for water and land use. The consistency between the two models will be ensured through an iterative process. EXIOMOD will define the demand relative to water and land use that will be used as an input for LPJmL. LPJmL will define the supply constraint for water and land use. An adjustment in the (shadow) prices of water and land use in EXIOMOD will insure the consistency between supply and demand.

The output of EXIOMOD simulations will provide the economic demand for water and land use to LPJmL. It corresponds to the resource demand that the economic sector would like to achieve at the current prices if the resource was unlimited. In other word, it defines how demand may constrain the supply. Of course, regarding resource use, the opposite is more likely to happen at least in the long run since we expect that the supply will restrict the demand. The output of LPJmL allows for considering this case too. The resource supply constraint computed by LPJmL will be used by EXIOMOD to calculate the set of (shadow and commodities) prices that allows the economy to respect the limit of the resource. Environmental policies could eventually be used to reach this sustainable equilibrium.

3. Specificity of the technical solution with regard of EXIOMOD

Since the aim of the project is to compare the results of the linking of LPJmL with two economic models (GINFORS and EXIOMOD), it is very useful if the same software controller is applied to both linkages. This software controller is described in deliverable D3.4. Although we aim to use the same technical solution as the one retained to link GINFORS with LPJmL, it is important to note that this solution may have to be slightly adapted because of the specificity of the EXIOMOD model. This section point out the main specificities with regard to EXIOMOD.

3.1. Possible algorithms to link LPJmL and EXIOMOD

The size and complexity of both EXIOMOD and LPJmL do not allow for a simultaneous solution that would require a full integration of both models. This would raise technical issues which go largely beyond the scope of this project. Instead, the choice has been made to rely on a soft linking where the output of one model serves as input for the other. The technical solution retained here is an automation of this process though the development of an algorithm.

The main challenge is to make sure that both models provide a consistent story, that is the constraints the two models impose on each other are well taken into account at every period of time. To do so, an algorithm of simulation that iterates between the two models has to be defined. As a starting point, the step of the simulations would be as follows:

1. Simulation of EXIOMOD without resource constraint
   Output: data for the biophysical model LPJmL
2. Simulation of LPJmL
   - Output: data relative to water and land use constraint
3. Simulation of EXIOMOD with resource constraint
   - Output: data for the biophysical model LPJmL
4. Simulation of LPJmL
   - Output: data relative to water and land use constraint
   - If resource constraint (4) = resource constraint (3), STOP
   - If not, GO TO step 3.

The above algorithm gives the general picture of the linkage. In practice, some technicalities have to be considered. In particular, two approaches relative to the time frame are possible. The first one would consist in making the two models perfectly consistent at every period. For instance, so that the demand and the supply perfectly match at every period. This implies that the iteration process running both models takes place until a convergence is found in every time period. This may lead to very long computational time. A second approach will be to consider that the solution reached by one model at time t affects the other model at t+1. This has the advantage of reducing computational time and will therefore be tested first. But it may lead to unstable results over time which may require the need to find a solution close to the first approach.

3.2. Detail of the data exchange between LPJmL and EXIOMOD

In order to facilitate the comparison with GINFORS, EXIOMOD will reduce its country representation from 43 to 38 (as in GINFORS). This has also the advantage that both economic models can use the same land use allocation module. The latter has to be developed to bridge the high resolution of LPJmL (0.5°x0.5°/10*10 km spatial resolution) to the low resolution of economic models (country level).

The timescales of LPJmL differ also from the one of EXIOMOD. EXIOMOD has a period of one year whereas LPJmL uses a monthly step. Therefore the transfer of data from LPJmL to EXIOMOD will require an annual aggregation of monthly data whereas the output of EXIOMOD will have to be converted into monthly data.

LPJmL distinguishes 13 different type of crops whereas EXIOMOD distinguishes 8 of them. A mapping from EXIOMOD to LPJmL or the other way around will involve both aggregation and disaggregation of crop types (see Table 1). This disaggregation can be supported with crop output data from Faostat.

Table 1. Mapping of crops between LPJmL and EXIOMOD

	Crops in EXIOMOD							
Crops in LPLmL	Paddy rice	Wheat	Cereal grains not elsewhere classified	Vegetables, fruit, nuts	Oil seeds	Sugar cane, sugar beet	Plant-based fibers	Crops not elsewhere classified
Temperate cereals (barley, rye, wheat)		X	X					
Rice	X							
Maize			X					
Tropical cereals (millet, sorghum)			X					
Pulses								X
Temperate roots (sugar beet)						X		
Tropical roots (cassava)								X
Sunflower					X			
Soybeans					X			
Groundnuts				X				
Rapeseed					X			
Sugarcane						X		
Others (e.g. fruits, vegetables, cotton, cocoa, coffee, potatoes, palm oil)				X	X		X	X

Table 2 shows the data that will be exchanged between EXIOMOD and LPJmL. These are the same as the ones that will be exchanged between GINFORS and LPJmL (see section 3.1 of deliverable D3.4). This exchange takes the following steps:

1. The aggregate water supply per country for period t is given by LPJmL to EXIOMOD.
2. EXIOMOD calculates, for period t and for each country, the water use for non-agricultural purposes (water abstraction by public water supply, by industry and by production of electricity). Subtracting it to the water supply, EXIOMOD provides to LPJmL the water available for agricultural purposes at period t.
3. EXIOMOD provides to LPJmL the land use decisions of the farmers for period t. Given the price of each crop, the farmers decides the land use allocation for each crop.
4. Based on the water availability for agriculture and the land use decisions of the farmers, LPJmL calculates the amount of crops which are harvested at period t on a grid-cell basis. After aggregation of these results to the 39 countries level, this information is sent to EXIOMOD.
5. EXIOMOD matches these productions to the demand of consumer and can therefore derive the market clearing price for each crop. This new price defines the land use decisions of the farmers but also the water abstraction for non-agricultural use for period t+1 (step 2 and 3).

Table 2. Data exchange between LPJmL and EXIOMOD

Data exchanged	Direction
Water abstraction (in cubic metres) by public water supply, by industry and by production of electricity [for cooling purposes] in 38 countries and Rest of World for the actual year	EXIOMOD to LPJmL
Agricultural land use (in hectares) for 13 crop types and pastures in 38 countries and Rest of World for the successive year	EXIOMOD to LPJmL
Land scarcity factor for 38 countries and Rest of World for the successive year	EXIOMOD to LPJmL
Production quantities (in tonnes) for 13 crop types in 38 countries and Rest of World for the actual year	LPJmL to EXIOMOD
Total irrigated area (in hectares) for 38 countries and Rest of World for the actual year	LPJmL to EXIOMOD

This algorithm is repeated until all the periods are solved. It has the advantage that the linking between the two models is recursive. LPJmL is solved at period t based on data from EXIOMOD at t. But EXIOMOD is solved at period t based on data from LPJmL at t-1. Compared to a simultaneous solution, there is no need to iterate for each period until convergence is found between the two models. Therefore this approach saves a lot of computation time, is potentially more stable and relatively easy to implement.

The drawback of the approach is it may lead to instability across time. The change in price that will guarantee the consistency between supply and demand for the resource (price clearing hypothesis) may lead to erratic behavior of agents across time in particular in relation with land use allocation. We may see prices jumping up and down in every period. We have to have additional constraints or change our algorithm to avoid this problem.

A first test will be made on a simplified version of EXIOMOD that uses only the number of sectors required for the linking with LPJmL. EXIOMOD being a generic model, the numbers of sectors can be defined by the user. This will reduce the computation time and make it easier to control the consistency of the results.

4. Conclusions and future steps

This report presents the approach we will use to better account for water and land constraints in EXIOMOD. It also describes the modelling improvement this brings compared to the existing approaches published in the literature. Our approach consists in linking EXIOMOD with the biophysical model LPJmL. We have presented the algorithm that we will use for this link and justified this choice compared to other alternatives.

The next step is to implement and test this procedure and see if it provides the expected outcome using a simplified version of EXIOMOD. When successful, the approach will be used with the complete version of EXIOMOD. Then the result obtained with EXIOMOD will be compared with the one obtained with GINFORS by GWS. In particular, a comparison of key indicators, such as land footprint and water footprint, could be performed.

5. Publications resulting from the work described

- Technical paper on the modelling approach implemented in the project to be submitted in an international peer-reviewed computational journal such as Economic Modelling, Environmental Modelling & Software or Environmental and Resource Economics.
- A policy paper on the results obtained with that modeling approach to be submitted for international peer-review in a policy journal such as Environmental Science & Policy or Ecological Economics

We intend to present the drafts of these papers in international conferences such as the conference on Water resource and environmental research or of the European Association of Environmental and Resource Economists (EAERE).

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