The CLEW Model – Developing an integrated tool for modeling the interrelated effects between **C**limate, **L**and use, **E**nergy, and **W**ater (CLEW)

Long Abstract

JEL Classification: Q41 (Agricultural and Natural Resource Economics; Environmental and Ecological Economics – Energy – Demand and Supply)

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This paper applies a prototype of a new tool which analyses the Climate-, Land-, Energy- and Water- (CLEW) interactions and implications associated with socio-economic development. It builds on previous efforts[1] in that it develops a generic methodology based on detailed analysis of each CLEW resource. The new methodology integrates different modeling approaches for different resources into one final tool which demonstrates trade-offs associated with interventions aimed at meeting development goals (specifically food, fuel and water supply). The CLEW model is demonstrated in the context of a specific case study–namely the small island state of Mauritius.

The motivation for this study follows a review of existing integrated resource assessmentand modeling literature[2].This research has shown that the analysis of individual systems (such as energy or water systems) are undertaken routinely, but are often focused only on a single resource or have often been applied on an aggregated scale for use at regional or global levels and, typically, over long time periods. Those approaches are only of limited use for short or medium term national policy analysis[3]. The CLEW model aims to overcome this gap in the modeling sphere.

Given continuously growing human demands for the world's natural resources, especially water, land and energy are coming under increasing pressure.The use of each of these resources affects demand for the others and has an impact on the environment and climate. These interlinkages are most prominently visible in the agricultural sector: The production of food, cash and energy crops strongly depends on water and energy for irrigation and transport and often needs input of (energy intensive) fertilizers. A change in agricultural production methods new and different crops produced in turn may have considerable impact on the local energy system (e.g. in the case of fuel crops) or may induce land use changes by forcing traditional farming practices to formerly marginalized land and forest areas. There are many more such interlinkages between the different CLEW resources, and understanding these interdependencies is of key importance for decision makers worldwide. Isolated approaches to adjust energy, water or agricultural policies without investigating their impacts on other resources will not be sufficient in the future as evidence shows that adverse effects on the other CLEW resources are often very likely.

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[1]The research builds on and significantly extends Howells, M. And Rogner, H."Seeking CLEWS – a case study (Transport biofuel in Mauritius)" International Energy Workshop, 2010, Venice.(Howells et al(2009)).

[2](CE2010) gives a detailed overview about a great number of modelling approaches and their options for (and current lack of) integration. IAEA (2009) gives a specific and detailed review of various approached to CLEW modelling.

[3]Examples of models which tackle some of the integrated nature of the CLEW system, but are impractical for local short-to-medium term policy making include, amongst others:MINICAM (PNL 2009), IMAGE (MNP 2009), and TIAM (Loulou and Labriet, 2008)

Using anexemplarycase study, this paper introduces the prototype of a new tool which analyses the Climate-, Land-, Energy- and Water- (CLEW) resources and their interactions and implications associated with socio-economic development. The analytical tool presented and applied in this paper includes all CLEW aspects in a manner that may be made easily accessible and useful to policy analysts and planners.The CLEW tool is designed to be easy to operate and manage and will provide options to be integrated with elements from more resource specific and complex approaches and methodologies. Ideally in its application, the tool will (1) help to identify potential and specific CLEW issuesat the country-level, (2) be used to illustrate the need for detailed resource planning and (3) help to integrate aspects of detailed resource assessments of countries into one combined resource plan. Importantly, the model is not limited to internal (national) effects but can also be set up to estimate external changes (in other countries) induced through energy and fertilizer imports or exports and induced land use change.

Given that CLEW modeling addresses four core interlinked areas (climate, land use, energy, water) - all affecting socio-economic development - the case study scope could potentially be very complicated. Bringing climate, water, energy, and land-use systems together into one model implies a large number of trade-off effects and interactions which are complex in nature. Therefore, in this early phase of the CLEW development, the focus has been deliberately put on a small country with clearly defined boundaries and good data availability.The small developing island nation of Mauritius was chosen as it fulfills the above mentioned criteria to a large extent.Mauritius is a producer and exporter of food (sugarcane) and depends on local biomass and imports for almost all of its energy needs.

The case studyexplicitly investigates sugarcane growing in Mauritius and a change in production from sugar for export (the currently dominant pattern) to bio-ethanol for local use in the transport sector and for electricity generation. First CLEW calculations show very strong implications for the amount of produced GHG emissions under the investigated scenarios, with induced land-use changes (e.g. usage of marginal and or forest for agriculture) being of critical importance. Moreover, significant changes in water use, electricity generation dynamics and external effects, such as fuel and fertilizer imports are calculated. It goes on to investigate scenarios of low rainfall assessing related mitigation strategies, costs and effects.

Methodologically, different resource and climate-related aspects of the study area in question (Mauritius)arepresented in cells of a predefined geographical grid. After collecting a number of different data sets, a “Master Map” is created which contains data on topography, climate, water availability, land cover and soil structure. Consequently, for each cell in the grid a stylized and normalized (1) energy and (2) water balance “response function”, a (3) cropping “production function” and (4) a carbon balance will be modeled.

The “balances” in the response functions (1) and (2) include supply, use, transformation and imports from or exports to neighboring grid cells. The cropping production function (3) estimates crop yields as a function of various inputs (water and fertilizer) as well as accounting simplified internal dynamics of nutrients and input (such as water use) efficiency, resulting from changes in land uses and land use cover. The carbon balance (4) extracts information from (1), (2) and (3) to determine soil carbon contents as well as information relating to the carbon intensity of activities or inputs (e.g. energy and fertilizer) to each grid cell that emits or sequesters carbon.

To develop (1) energy and (2) water balance functions, (3) crop production function and (4) carbon balance, a number of existing analytical methods and tools were employed, including:

(1) MAWD (Model for the Analysis of Water Demand) for the demand for water by each grid cell taking into account water quality,

(2) MAED[4] and LEAP[5] for investigating the demand for energy services by each grid cell taking into account fuel type,

(3) LEAP and MESSAGE[6] for investigating the energy chain supply options to meet the demand estimated in (2),

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[4] MAED (Model for Analysis of Energy Demand) of the International Atomic Energy Agency (IAEA), (IAEA2006)

[5] LEAP (Long Range Energy Alternatives Planning) model of the Stockholm Environmental Institute (SEI) (http://www.energycommunity.org/)

(4) WEAP[7] for developing the water supply balances and response functions by sub-region and grid cell,

(5) AEZ[8], Aquastat[9] and AQUACROP[10]to estimate crop potential, yield and water requirement by region and grid cell,

These analyses – each undertaken with as detailed granularity as possible for a desktop study, using existing statistics and data –were harmonized in terms of assumptions and units. This was done to deliver comparable inputs to (and outputs from) the CLEW tool. In the last step response functions and other information from the separate tools are incorporated into one integrated analysis of the whole target area. The new tool is developed using the mathematical programming language GNU-Mathprog[11], with the code is referenced in the appendix of the paper. While no graphical user interface is yet developed, the overall analysis can be used to produce overall accounting and benchmark figures for the CLEW region investigated. Those figures may include overall energy and water balances (including fuel and water production, supply and use), and GHG balances, as well as overall costs and other economic indicators.

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[6] MESSAGE (Model of Energy Supply Strategy Alternatives and their General Environmental Impacts) is a systems engineering optimization model which can be used for medium to long term energy system planning, energy policy analysis and scenario development. The model provides a framework for representing an energy system with its internal interdependencies. (IIASA 2001)

[7] The WEAP energy model is maintained and supported by the Stockholm Environmental Institute: http://www.weap21.org

[8] AEZ (Agro-ecological Zones) Methodology, The Food and Agriculture Organization of the United Nations (FAO) with the collaboration of the International Institute for Applied Systems Analysis (IIASA), has developed this system, which enables rational land-use planning on the basis of an inventory of land resources and evaluation of biophysical limitations and potentials.(http://www.iiasa.ac.at/Research/LUC/GAEZ/)

[9] AQUASTAT is FAO's global information system on water and agriculture (http://www.fao.org/nr/water/aquastat/main/index.stm)

[10]AquaCrop is FAO's crop water productivity simulation model (http://www.fao.org/nr/water/index.html) and (FAOa)

[11]http://www.gnu.org/software/glpk/