Understanding Modelling Tools for Sustainable Development

MODULE: CLEWS COUNTRY MODEL: A READER

Assessing Climate, Land, Energy and Water Strategies OR SYSTEMS – INCONSISTENT USAGE…

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PRESENTATION

SUMMARY

Food, energy and water are basic elements for human survival that are greatly interdependent. The development of the climate, land, energy and water systems (CLEWS) modelling framework can contribute to understanding these interlinkages. The CLEWS approach takes advantage of existing well-tested assessment methodologies for each of the three resources and their integrated aspects. It can shed light on connections across policies for the Sustainable Development Goals (SDGs) and nationally determined contributions under the Paris Agreement on climate change.

The modular structure of the CLEWS model encourages experts from relevant disciplines to work together.

LEARNING OBJECTIVES

- Understand why food, energy and water should be assessed in an integrated way.
- Understand how to integrate climate, land, energy and water modelling tools into the CLEWS framework.
- Assess the strengths and weaknesses of the CLEWS model in terms of integrated analysis.
- Use the online CLEWS interface to inform debates on sustainable development policies, and the interlinkages among climate, land, energy and water systems.

OUTLINE

1. Sustainable development and the food-energy-water nexus
2. The CLEWS framework
3. Some modelling tools to perform CLEWS analysis

QUESTIONS TO ACTIVATE RELATED KNOWLEDGE

- What is a model?
- What are the interlinkages among:
    - Climate and land use?
    - Energy and water?
    - Climate, land use, energy and water?

1. SUSTAINABLE DEVELOPMENT AND THE FOOD-ENERGY-WATER NEXUS

Links among the various dimensions of sustainable development have long been recognized—their nature and magnitude, impacts on each other, and the need for integrated planning and quantification of interdependencies in mathematical models.

These interdependencies imply that the manner and extent of progress in one area can have ramifications in other areas. This can be positive and reinforcing (e.g., improved access to education will tend to support progress in almost all other areas) or negative and detrimental (e.g., economic growth at the expense of environmental sustainability). Among a myriad of interlinkages, those among food, energy and water (often termed the food-energy-water nexus) have received much attention.

Links across the SDGs pose difficult challenges to policymakers. These interactions can be:

1. **Synergistic, reinforcing each other**
2. **Symbiotic, depending on each other**
3. **Antagonistic, obstructing each other**

Food, energy and water security are at the heart of sustainable development because they are the basis for human survival. Connections among the three are particularly strong, underscoring the need for cross-sectoral approaches based on integrated assessments. Further, billions of people lack access to modern energy sources, food and water. The bottom billion people in developing countries lack subsistence-level access; lower middle-income people find themselves spending large proportions of their incomes

Global challenges are great:

- **1.1 billion people without access to electricity**
- **Almost 3 billion people without access to modern fuels or technologies for cooking/heating**
- **900 million people lack access to safe water**
- **2.6 billion do not have adequate sanitation**
- **900 million people are chronically hungry due to extreme poverty**
- **2 billion people lack food security**

Source: Bazilian et al. (2011).

to gain access. Upper-middle and high-income people overuse these services with substantial waste.

Addressing secure access to these resources quickly reveals their interdependence. Improvement in one area, say energy, often challenges food or water security or both. Action addressing any one of these concerns not only has implications for the climate and, more generally, the environment, but also affects numerous socioeconomic development aspects.

The 2030 Agenda for Sustainable Development explicitly affirms the integral nature and indivisibility of its 17 SDGs and 169 targets. Still, planners and policymakers will face situations where the SDGs and targets may be synergistic and reinforce each other. They may be symbiotic and dependent on each other. Or they may be antagonistic, such as where targets impose constraints on each other to the point of being mutually exclusive, which implies making important trade-offs.

Land use, water, energy and climate are all fundamental for human survival. They all share the following common characteristics:

- Rapidly growing global demand
- Important constraints
- Defined as “global goods” with some relation to international trade, and transboundary implications
- Supply and demand varies by region
- Strong interdependencies with climate change

DESCRIPTIVE ELEMENTS OF THE FOOD-ENERGY-WATER NEXUS

- Globally, agriculture accounts for 71 per cent of current water withdrawals, and up to 90 per cent in arid developing countries. Water stress already burdens many parts of the world. Unabated water stress could cause annual productivity losses of up to 30 per cent by 2050, even as food production is supposed to increase by 70 per cent to 100 per cent to sustain a world population of some 9 billion people (World Economic Forum, 2011). Without substantial productivity growth in agriculture, i.e., crop yield per hectare and year, also known as “sustainable intensification” (Elferink and Schierhor, 2016), arable land availability might seriously constrain future food security.
- About one-third of the world’s land cover is devoted to agriculture, one-third to forests and one-fifth to savannas, grasslands and shrub lands. The remainder is either barren or low-productivity land, with urban areas comprising about 1 per cent of the world’s land cover (Hertel, 2010).
- By 2050, global arable land increases will probably be limited to around 70 million hectares (or less than 5 per cent of current arable land) with expansion in developing countries, predominantly in sub-Saharan Africa and Latin America, of about 120 million hectares (12 per cent) offset by a decline of some 50 million hectares (8 per cent) in the developed countries (Food and Agriculture Organization, 2012). The 5 per cent potential for expansion will be determined by land requirements for urbanization, demand for lands for preserving biodiversity (protected areas), and climate change (Hertel, 2010).
- Freshwater supplies require energy for conveyance, treatment and distribution. About 7 per cent of commercial electricity is used globally for meeting the world’s freshwater demand. In California, the water cycle accounts for 19 per cent of the state’s electricity consumption and 30 per cent of non-electricity generation related to natural gas use (California Energy Commission, 2011). In India, between 15 per cent and 20 per cent of electricity use is attributed to irrigation.
- In the energy sector, thermal power plants use large amounts of water for cooling. Depending on the type of cooling system, some or most of this water may be returned to a water body. The rest is lost to evaporation. Hydropower plants can use significant quantities of land and interfere with existing water flows, changing silting patterns in river basins, and lose a considerable amount of water to evaporation from reservoirs. The construction of large hydrodams has led to the dislocation and resettlement of millions of people. Significant quantities of water are also required for other energy-processing activities, such as refining oil products or manufacturing synthetic fuels (e.g., one barrel of oil equivalent derived from tar sands requires three barrels of water).
- Biofuels have been advanced for energy security in countries highly dependent on imports of fossil fuels and as an effective greenhouse gas mitigation option. They can be a more profitable use of crops than in the food market where the same agricultural products would often be less valued. This diversion of land and crops for energy purposes may therefore compromise food security (i.e., less food at higher prices).
- Biofuels require water and land resources that could otherwise be used to produce food and to preserve ecosystems. Biofuel production can be quite water intensive and thus may compete for already stressed water resources. Depending on location, feedstock and kind of water supply, i.e., rain-fed or irrigated, water requirements can range from 90 litres to 3,500 liters per litre of ethanol (International Water Management Institute, 2008). Clearing land and forests for biofuel crops releases greenhouse gases and reduces biodiversity.
- A back-of-the-envelope calculation shows that in 2013, global biofuel production (essentially ethanol and biodiesel) accounted for 2 per cent to 3 per cent of global water demand and use of agricultural land. The same amount of land and water, if used for food production, could feed about 30 per cent of malnourished people (Rulli et al., 2016).

QUESTIONS

- Why is it important to study the food-energy-water nexus?
- What is the main challenge of a sustainable land management strategy?
- Why is the management of water becoming an urgent political issue?
- What are the interlinkages between land and water management?
- What are the interlinkages among land, energy and water management?

2. THE CLEWS FRAMEWORK

The rationale behind the development of the CLEWs framework is based on two basic observations. First, many of the key development challenges are closely tied to land, water, energy and climate change. Second, the interlinkages among the challenges related to these resources are particularly strong. A set of methodologies to assess the nexus of food, energy and water in an integrated manner could provide important insights for development policy.

A set of methodologies to assess the nexus of food, energy and water in an integrated manner could provide important insights for development policy.

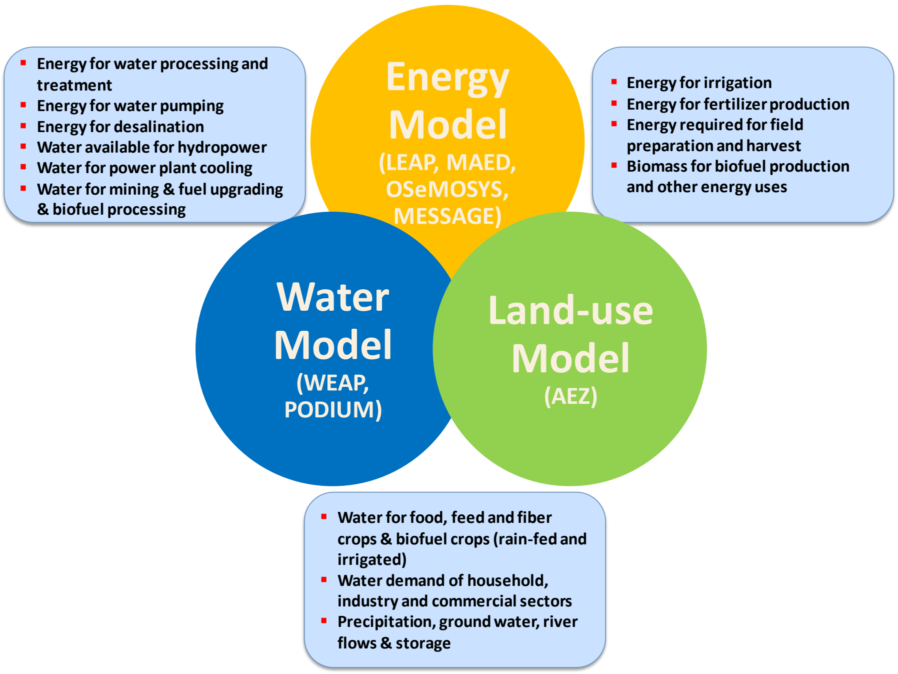
The CLEWS framework can be applied through two different approaches:

1. A tandem approach where land, energy and water models are run in parallel to assess sectoral development strategies and their interdependencies. The models are soft-linked (i.e. modelling results are exchanged between sectoral models), and an iterative process is used to derive scenarios that are consistent across sectors.
2. A fully integrated approach where land, energy and water systems and their interaction with climate is modelled in a single model.

The key to these two approaches is to identify the points at which the resource systems interact (e.g., water requirements in land-use and energy systems, energy needs for water supply and land use, and land requirements for food, energy and water infrastructure).

For the tandem approach, a protocol needs to be established where data for intersection points are exchanged between models. The output from one model forms the input for the two others; models are then solved sequentially, and each model feeds results to the two other models. This process is repeated through a series of iterations until a convergent solution is found. Figure 1 shows a schematic example.

FIGURE 1. A SCHEMATIC CLEWS EXAMPLE



Note: The framework integrates the Long-range Energy Alternatives Planning tool (LEAP),[1] the Open Source Energy Modelling System (OSeMOSYS),[2] the Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE),[3] the Model for Analysis of Energy Demand (MAED),[3] the Water Evaluation and Planning tool (WEAP),[4] the Global Policy Dialogue Model (PODIUM)[5] and agro-ecological zoning (AEZ)[6] models with climate change scenarios.

[1] Stockholm Environment Institute.
[2] Royal Institute of Technology, Stockholm.
[3] International Atomic Energy Agency.
[4] Stockholm Environment Institute.
[5] International Water Management Institute.
[6] International Institute for Applied Systems Analysis and Food and Agriculture Organization.

The CLEWS approach takes advantage of existing well-tested assessment methodologies for each of the three resources and their integrated aspects.

An advantage of the tandem approach is that it can rely on previously established modelling methodologies. This reduces time and resource needs, and lowers the effort and cost of introducing the framework compared with developing a fully integrated model. The module structure encourages experts from the relevant CLEWS disciplines to work together. Departments, ministries or institutions can participate in collaborative work, with each participant contributing with their already established tools and expertise.

CLEWS´ module structure encourages experts from relevant disciplines to work together.

In countries where there is already national capacity for using specific sectoral models, the advice is to make best use of these tools separately. Learning curves are greatly reduced, and this allows for the application of already acquired local knowledge and experience. An extra benefit of modularity is that individual components can still be run individually. Updates or enhancements to individual modules can be applied in parallel to an ongoing CLEWS study. Running modules separately allows users to check the impact of adding them or dropping them from the integrated analysis, facilitating, for example, the comparison of model behaviour in integrated mode vis-a-vis stand-alone mode.

In the fully integrated approach, a single algorithm is used for all systems simultaneously. The advantage of this approach is that it forms a true partial equilibrium representation that allows for efficient resource allocation and consistent price signals across systems.

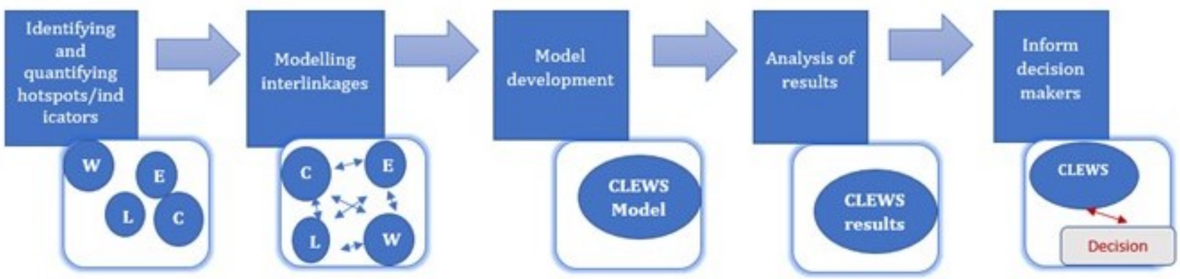
The two approaches need not be mutually exclusive. They can be pursued in parallel or in sequence, thereby drawing on the strengths of both, potentially enriching insights from the analysis.

The CLEWS approach allows for use of already acquired local knowledge and experience; learning curves are greatly reduced.

IMPLEMENTING THE CLEWS APPROACH

Regardless of the approach taken, there are a few key steps to apply CLEWS analysis in decision-making, as shown in Figure 2.

FIGURE 2: KEY STEPS IN THE CLEWS APPROACH

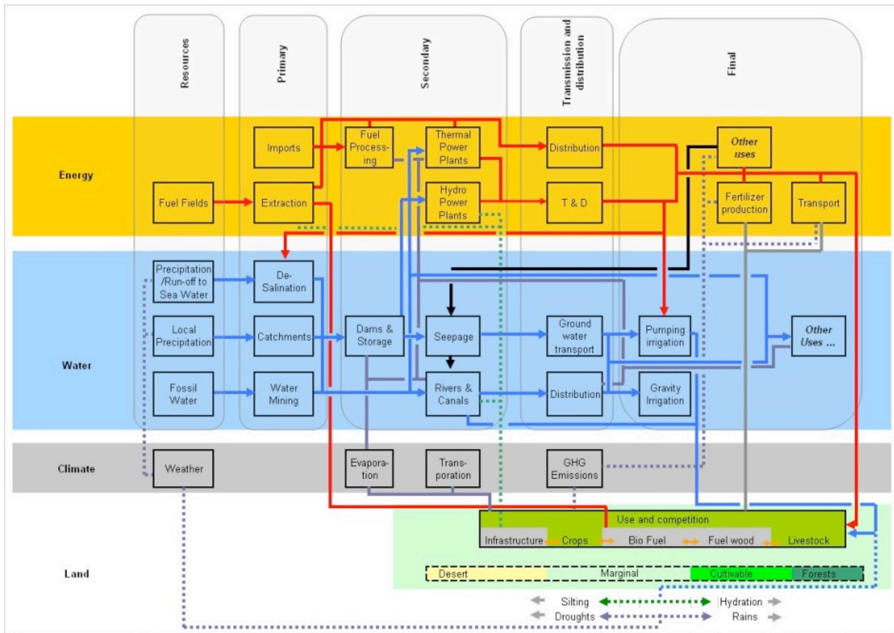


FIRST STEP: SYSTEM PROFILING

The first step is to undertake a survey of the current situation. This involves an assessment of the present state, challenges and outlook for each of the sectors, and the identification of the main interlinkages or “hot spots” among them. These also need to be evaluated in the broader context of national development policies and strategies. Figure 2 shows the structure, components and interlinkages of a generic CLEWS model.

The CLEWS approach is based on a bottom-up methodology that includes a description of the physical systems. Each component of land, water and energy systems is described by its technical and economic characteristics. These could, for instance, involve the capacity, efficiency and running costs of a power station, the storage capacity of a water reservoir, or the production potential and costs associated with a given land resource. These are linked together in value chains as depicted in Figure 3. This type of diagram is useful for illustrating the structure of a CLEWS model. Each box represents a technology or transformation process while each line represents a flow (e.g., a land, water or agricultural commodity) linked together to represent a value chain (e.g., well-to-wheel or field-to-fork). Given that these value chains are highly interlinked, a CLEWS model is thus a web of interconnected value chains.

FIGURE 3: SIMPLIFIED GENERIC AGGREGATE CLEWS REFERENCE DIAGRAM



Note: The lines in the diagram represent flows between activities or technologies aligned in columns. Technologies or activities convert input flows into outputs. Together they represent the reference energy system.

At the end of each value chain is a final demand that represents the wants and needs of people. This could be demand for food (e.g., rice, wheat, potatoes, etc.), water (e.g., drinking water, irrigation water, cooling water, etc.), energy services (e.g., home appliances, industrial equipment, water pumps, etc.), or other relevant services or commodities. These demands are effectively the drivers of the model.

A model solution is a configuration of the value chains that meets specified demands. This configuration involves the acquisition and operation of assets in a way that converts natural resources into meeting demands for commodities and services. In simulation and accounting models, this configuration is based on user-specified allocation rules and mechanisms, while in optimization models, the configuration is done in such a way as to meet demands in the most cost-effective manner.

Once the problem has been assessed, and the priorities and policy goals have been agreed, the development of the model can begin. The first step towards building a CLEWS model is data collection. CLEWS models are highly data intensive. Data on the relevant natural and physical capital including stocks, capacities, technical characteristics and cost information are needed. A base year is selected, usually representing the latest year in which a reasonably complete dataset can be assembled. Data collection and analysis are usually the most time- and labour-intensive components of the model development process.

Five key steps to build a CLEWS model:

1. **System profiling (identifying hotspots/data collection)**
2. **Model development**
3. **Model execution**
4. **Analysis of results**
5. **Informing policymaking**

The process is sequential, but some overlap is expected, e.g., model building and data collection can be done in parallel. Early scenarios might reveal shortcomings in the model.

SECOND STEP: MODEL DEVELOPMENT

The next step is model development. This involves building a model structure, which includes the definition and specification of the interlinked value chains described above. This structure is then populated with the data collected during the previous step. The model structure needs to be adapted to the scope and needs of the study. The type of policy questions to be answered and the issues to be explored determine the model design suitable for each assessment.

THIRD STEP: MODEL EXECUTION

The third step is model execution and analysis of results. During this phase, the model users will run the model and review model outputs. This is a highly iterative process where the model is gradually refined and adjusted during repeated steps until analysts are confident that results are reasonable, robust and consistent. It is dependent on expert judgement and review, which introduces a level of subjectivity to the analysis.

FOURTH STEP: ANALYSIS OF RESULTS

Once the model has reached a state where analysts have confidence in the results it produces, a broader set of stakeholders is often invited to review and suggest changes. A range of scenarios and extensive sensitivity analysis to explore options, risks and uncertainties is usually required to draw robust conclusions and provide useful insights.

While the process here is described as sequential, there will often be significant overlap between the different stages. Model building and data collection will usually be done in parallel, and the model will be populated with data as they become available. Likewise, early scenario tests might reveal shortcomings in model structure, and analysts might have to revisit the model development phase and make appropriate adjustments.

FIFTH STEP: INFORMING POLICYMAKING

The model architecture has been designed to serve planners and decision makers in developing countries. Once properly calibrated and tested, a national or regional CLEWS model calculates the resource and service requirements to meet socioeconomic goals—such as national sustainable development and SDG priorities—in a growing economy. Thus, the tool should simulate important interactions to meet food, energy and water service demands, within the constraints imposed by physical and economic environments. Examples of possible applications include, but are not limited to:

Integrated assessment: Assist decision and policymakers in assessing options in terms of their likely impacts on food, energy, water and climate—the broad CLEWS system—and transparently evaluate trade-offs associated with different options.

Cost-effectiveness: It is important for policymakers to ensure that policies are as cost-effective as possible. If multiple objectives can be achieved by a comprehensive policy, it may advance development more effectively than policies focused separately on single objectives.

Facilitating policy harmonization and integration: A CLEWS assessment can help identify potentially conflicting policies, such as electricity subsidies that accelerate aquifer depletion, which in turns leads to greater electricity use and subsidy requirements.

Technology assessment: Some technology options can affect multiple resources. For instance, a rapid expansion of solar and wind-based electricity generation to replace fossil fuel generation could reduce greenhouse gas emissions, local pollution and cooling water requirements; improve energy security; and reduce exposure to volatile fossil fuel markets. Nuclear power could do the same, while avoiding the intermittency of wind and solar generation. Although it would use water for cooling, nuclear power can generate electricity for seawater desalination during times of off-peak demand. Unlike electricity, water is easily storable. As with policy choices, a CLEWS analysis allows a more inclusive assessment of technological options.

Scenario development: By building consistent scenarios of possible socioeconomic development trajectories, future development opportunities can be identified and insights gained on the implications of different policies and strategies. This is important for understanding whether current development is sustainable, and for exploring alternative development scenarios and technology improvements that might significantly change development trajectories.

3. SOME MODELLING TOOLS TO PERFORM A CLEWS ANALYSIS

CLEWS simultaneously uses several models, such as OSeMOSYS, MESSAGE, WEAP and AEZ. Figure 4 summarizes some of their main features.

FIGURE 4. EXAMPLES OF MODELLING TOOLS TO PERFORM A CLEWS ANALYSIS

	Energy	Water	Land-use
Model	**MESSAGE OSeMOSYS LEAP MAED**	**WEAP MIKE BASIN**	**AEZ LEAM**
Scale of Operation	From small island systems to large country analysis	Local water based on geographical data	Small scale to country analysis (flexible grid cells sizes)
Input	• Demand (current/future, load curves) • Existing + planned power plants • Imports and exports, and resource availability • GNG emissions factors	• Climatic data • Land cover data • Soil data and water availability • Water consumption • Desalination and hydropower	• Climatic data (plus projection) • Land cover data • Soil data
Output & Results	• Future optimal energy mix under different conditions • Future GNG emissions • Costs	• Water availability under different scenarios (CC and/or water demand change) for all points in a modelled system	• Crop map (most suitable crops per area) • Crop calendar • Future water demand • Fertilizer demand

ENERGY MODELLING TOOLS

Energy system models can generally be categorized into bottom-up techno-economic models and top-down macroeconomic models. The former employ a high degree of detail in terms of technologies, but cannot provide any insights on net impacts across the economy. The latter consider aggregated sector-specific energy demand and supply, and assess effects on the entire economy, but are not suitable for analysing potential technology deployment, due to insufficient detail.

The bottom-up models are used to represent physical flows and energy balances through an energy system, and can be classified into three sub-categories: optimization, simulation and accounting.

1. **Optimization models** help to analyse the potential for replacing existing technologies with low-carbon, more efficient or cost effective alternatives. Examples are:
    - MESSAGE
    - OSeMOSYS
    - MARKAL (MARKet Allocation)[7]
2. **Accounting models** can be used to assess the impact of predetermined pathways for development, like the following:
    - LEAP
    - MAED
3. **Simulation models** represent decisions of actors within the system.

[7] International Energy Agency.

Energy system models: critical questions

- **What investments are needed in generation and network infrastructure to meet electricity demand and when?**
- **What is the cost for expanding the system to offer a certain level of modern energy services? What technologies achieve the least-cost and most reliable energy mix?**
- **What are the associated impacts on land-use? For example, from growing biofuels or from large-scale solar parks?**
- **What are the associated water requirements for a specific energy mix? For example, water for cooling, hydropower or irrigation of biofuels?**
- **What pollutants are emitted and at what level?**

WATER MODELLING TOOLS

Water management tools essentially aim to achieve balance in the water system. Considering precipitation patterns, and surface and groundwater body resources, we can estimate water availability and addition into the system at each given (spatial) point. Different processes in the economy consume (such as agriculture, electricity generation or industrial processes) or require (such as navigation) water. Water modelling tools help prioritize the use of water across these resources.

In other words, water management models assist in the assessment of optimal water resource allocation for a range of climate scenarios. Water is not an infinite source. Arid and semi-arid regions need careful planning by authorities to manage their water resources, while even countries with high levels of precipitation can suffer from periods of unexpected drought. In a changing climate, the vulnerability of infrastructure (e.g., hydropower or industrial plants) or important economic processes (e.g., agriculture or residential water demand) to a lack of water must be assessed.

Examples of tools to match water balance with specific water demands are:

- WEAP
- MIKE BASIN[8]

Water management models: critical questions

- **How should water be allocated to various uses in times of shortage?**
- **How should infrastructure in the system (e.g., dams, diversion works) be operated to achieve maximum benefit?**
- **How will allocation, operations and operating constraints change if new management strategies are introduced into the system?**
- **What is the demand for irrigated water, and what are the associated energy requirements?**

AGRO-ECOLOGICAL MODELLING TOOLS

Agriculture provides one of humanity's key necessities: access to food. At the same time, crops can be grown for energy purposes, for instance, for use as biofuels in transport. A greater agricultural yield could potentially improve the trade balance of a country, be it for food or for energy. Intensive agricultural practices can stress natural resources, however. Land may need to be converted for agricultural purposes, additional water may be needed

[8] DHI. See http://dssplanning.dhigroup.com/links/MIKEBASIN_UserManual.pdf. LINK DOES NOT SEEM TO BE CURRENT

for irrigation, energy might be required for water pumping and operation of machinery, and fertilizers and pesticides might be applied to improve yield.

Agricultural yield can be affected by factors outside of human control (e.g., precipitation, temperature or extreme weather events). Since agriculture is such an important aspect of the economy, it should be carefully managed.

The Land-use Evolution and Impact Assessment Model (LEAM)[9] is an accounting tool intended to enable users to capture stochastic influences and view the reported probable consequences of intended events in a scenario-based format that is readily comprehended by local experts, decision makers and stakeholders.

Agro-ecological modelling: critical questions

- **What is the potential yield of a range of crops in each region?**
- **What are the water requirements for each crop in each modelled sector?**
- **How do different climate scenarios affect crop yield?**
- **Which are the input requirements to achieve a certain level of yield?**

CLIMATE REPRESENTATION

In CLEWS work, no actual climate modelling takes place, but the different components of the methodology (land, energy and water modelling) get their inputs from existing climate models. These provide information such as temperature, precipitation patterns, etc., which are required as inputs in the aforementioned models.

[9] University of Illinois at Urbana-Champaign.

QUESTIONS

- What are the main advantages of using the CLEWS approach to study food, energy and water interlinkages? List three.
- What are the key steps in the CLEWS approach?
- Why is it useful to design a reference energy system to start the CLEWS analysis?
- Why is the “land block” of the CLEWS approach a main reference of the model?
- Why is it important to supplement data from the calibrated modules with data and assumptions about the future?
- What are some possible applications of CLEWS for policymaking? List three.

BOX 3

MAURITIUS: SAMPLE STUDY AND RESULTS

The sugar industry has been an important source of export revenue for Mauritius. Yet revenues have collapsed after a favourable agreement with the European Union expired, and prices declined by more than 30 per cent. The supply of bagasse from the refining process, used for cogeneration of heat and electricity supplied to the national grid, declined, prompting higher fuel imports. At the same time, international energy prices skyrocketed. The country imports more than 80 per cent of its primary energy needs.

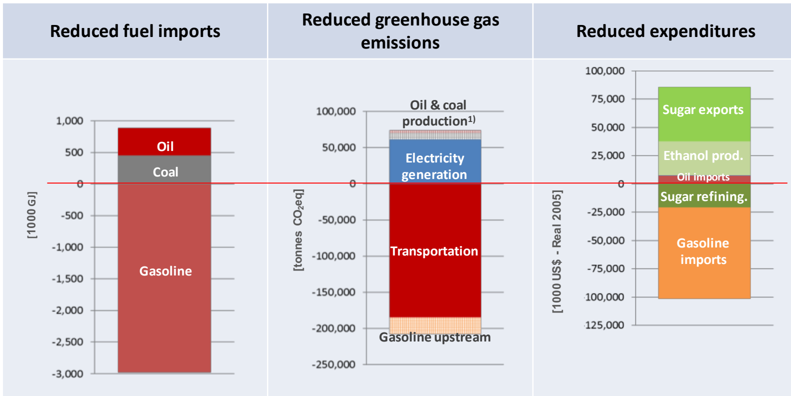
Many sugarcane farmers with access to irrigation have diversified to more water-intensive food crops and vegetables to supply the local market. Water demand has risen. In areas with a water deficit, agricultural production is jeopardized by recent recurrent droughts, however. Seven out of the last 12 years have been declared drought years in the northern part of the country. Consequently, even sugarcane, which is known to be relatively drought tolerant, suffered reduced yields. Not only does the northern region supply 20 per cent of the national sugar cane yield, but also 25 per cent of the national food crop.

Against this background, the Government contemplated introducing policies that would utilize domestic resources and substitute energy imports while alleviating water stress. One policy was to introduce a fuel standard mandating the blending of ethanol into gasoline. This would improve the income of sugarcane growers at lower water use, displace imported liquid fuels, and improve self-sufficiency in fuel supply, hence energy security. The intention was to base ethanol production on future second-generation technologies.

The other policy was a target for renewable electricity generation. A 35 per cent share of renewable electricity generation in the total electricity mix by 2025 is part of the current sustainability strategy. The policy has aimed at both reducing energy import dependency and curbing carbon emissions.

A CLEWS analysis showed that the intended policies would generate several economic and environmental benefits, as shown in Figure 5. But it also showed that the policies would not mitigate the overall water situation (see Figure 6).

FIGURE 5: IMPACT OF SHIFTING TWO MAJOR SUGAR REFINERIES TO PRODUCE SECOND-GENERATION ETHANOL

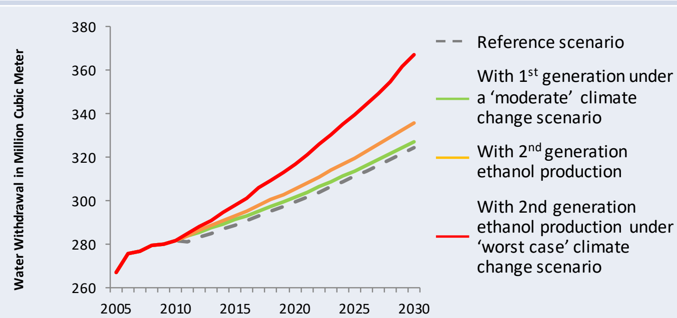


Overall energy import dependence decreases: Gasoline imports are reduced as ethanol replaces gasoline as a motor fuel. Some bagasse is diverted from electricity generation to ethanol production and needs to be substituted by higher imports of coal and distillate oil.

Total greenhouse gas emissions are reduced: Tailpipe and upstream emissions are reduced as gasoline is replaced by ethanol. The increased use of coal and distillate oil (in place of bagasse) for electricity generation results in smaller additional emissions.
[1] Indirect emissions

Domestic ethanol production has economic benefits: As some of the sugar is converted to ethanol, the expenditures for sugar refining and gasoline imports are reduced. This outweighs the reduced sugar export earnings and the costs associated with ethanol production and the increases in oil and coal imports.

FIGURE 6: TOTAL WATER WITHDRAWALS UNDER DIFFERENT INTEGRATED CLEWS SCENARIOS



Water withdrawals increase under climate change scenarios:

To compensate for reduced rainfall, irrigation will have to be expanded to previously rain-fed sugar plantations and farms. This leads to higher withdrawals of surface and ground water.

CLOSING REMARKS

Although CLEWS provides a step forward for practical integrated analysis, many issues remain unaddressed. For example, without quantification and valuation of ecosystem services, it is difficult to assess issues such as the impact of cropping practice on loss of biodiversity. The expansion of agriculture into natural habitats and the adoption of monoculture, along with other management practices, have had a detrimental impact on biodiversity and ecosystem services which, in turn, may have adverse effects on freshwater resources, soil health and climate variability.

Further, while CLEWS models help integrated planning at the local and national levels, they cannot foretell the future. Decisions must still be made by governments and businesses without full knowledge of all relevant connections and possible consequences. The CLEWS methodology provides a sound starting point, however, by yielding important insights on interlinkages.

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