Considering the Energy, Water, and Food Security Nexus

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Abstract: The areas of energy, water and food all have critical security issues ranging from lack of access, to environmental damages during production, to reliability of supply, and associated potential economic and social impacts and susceptibility to climate change. While these impacts appear to be very different between the three "spheres", many of the effects are direct results of Energy, Water and Food (EWF) interrelations. Identifing useful overlaps between them is of great importance to target synergies and potential tensions.

After briefly describing the linkages and security aspects of the three areas, we consider the case of a new modeling framework being developed to address this specific nexus. Then, we focus on cases that allow for a close examination of concrete aspects of their interaction. Given the unique attributes of renewable energy in relation to food, energy and water security, we then view each of the cases from a renewable energy lens.

Security of supply and its close ties with human well-being and economic stability, appears as a more powerful impetus from which to guide and motivate international cooperation in these areas than environmental concerns, although both local and coordinated regional and international action on environmental issues are intricately tied to security goals. We discuss the attributes of a unifying framework from which to formulate more effective national policies and regulations.

1. Introduction

Global human society must now attempt to solve a set of complex, interrelated problems that Diamond (2005) characterizes as fundamental threats to human civilization. Many of these issues are directly related to the areas of energy, water and food production, distribution, and use – especially in developing countries. But due to the vastness of the individual areas and the complexity of considering all three together, there is little work focusing on how to support decision-making at the nexus. As a result, policies and regulations can often inadvertently create sub-optimal signals to national security or environment concerns. As an example, even when policy is designed by considering more than one area, it is normally done with a focus on food-water, food-energy, or water-energy (see e.g. (Winpenny, 1992)), and few approaches have comprehensively addressed the broader complexities and the interdependencies when considering climate change mitigation or adaptation.

The approach to the energy, water, and food (EFW) nexus normally depends on the perspective of the policy-maker. If it is a water perspective, then food and energy systems are users of the resource (See Hellegers, et al., 2008); from a food perspective (See e.g. (Mushtaq et al., 2009), (Khan and Hanjra, 2009)) energy and water are inputs. From an energy perspective, water as well as bio-resources (e.g. biomass in form of organic oils or energy crops) are generally an input or resource requirement and food, end-user fuels or power is generally the output. Of course, areas such as food as fuels (biofuels or bioenergy) tend to complicate these descriptions (see e.g. (Nonhebel, 2005)) due to additional complexities associated with land use, land use change and use of the available biomass resource. The perspective taken will affect the policy formation. This is due to the specific priorities of the institution or ministry, as well as the data, knowledge and analytic breadth of the tools of the associated experts and support staff. Thus, one of the key first identifiable steps in moving to more holistic policy making is capacity development of people and institutions towards understanding all three areas and their inherent interlinkages – at least basic vocabularies and context.

Some of the descriptive elements of the EFW nexus that are readily identifiable include:

- All areas have rapidly growing global demand
- All have resource constraints
    - Those constraints can be managed, to certain degrees, by technology, regulation, financing, etc.
- All have different regional variations in supply and demand
- All are "global goods" and involve international trade and have gloabal implications
- All have many millions of people without access (quantity or quality or both)
- All have strong interdependencies with climate mitigation and adaptation / affect and are affected by climate change
- All require more efficient management, innovation and possibly new business models in order to improve availability and security
- All have deep security issues as they are fundamental to the functioning of society
- Many operate in heavily regulated markets
- When viewed together, it is normally from an environmental perspective
- Each is normally handled under a different Government department or fall under multiple jurisdictions
- There are very few experts in all three areas
- All prone to public discourse by cliché

As noted, all of the elements have critical security issues ranging from lack of access to pollution to reliability of supply[1]. Still, we can find useful overlaps between them to consider synergies and tensions. Security may be a more powerful impetus from which to guide and motivate international cooperation in these areas than environmental concerns or even development (see e.g. Bazilian, 2010). It is also a useful unifying framework from which to formulate more effective and holistic (inter)-national policies and regulations. Still security aspects not only attract enormous subsidies; but the focus on energy security, for example, often adversely affects water and food security as well as the environment.

2. Strong interactions

While energy, food and water systems are often analyzed in isolation, the literature clearly indicates that their interaction is strong. We briefly look at several from a (mainly) energy lens. Examples abound, such as:

- In the power sector, thermal power plants[2] use large amounts of water for cooling, a small amount of which is lost to evaporation (see US DOE (2005 and 2009) for a comprehensive treatment of this subject). Hydropower plants use significant quantities of land[3] and interfere

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[1] The World Economic Forum outlines several of these interrelated risks from government, societal and business perspectives (WEF, 2011).

[2] Some 50% of US fresh water consumption first runs through turbines for electricity production before being piped to the end-user (USGS 2004); a barrel of oil equivalent from tar sands requires three barrels of water; one kWh of coal-based electricity involves the use - on average - 95 litres of water.

3 The large land requirements of hydropower can require the relocation of activities and people. Over a million people, for example, had to be relocatedbecause of the Three Gorges Dam Project (Chaudhuri, 2003).

with existing water flows, changing silting patterns in river basins[4] , and in fact lose a considerable amount of water to evaporation (Torcellini et al, 2003). Significant quantities of water are also required for other energy processing activities, such as refining oil products or manufacturing synthetic fuels[5]. Land-use, especially cultivation of biofuel crops, is water-intensive[6] (See IEA (2010) for a useful comparison of land use requirements for power generation).

  - About 7% of commercial energy production is used globally for managing the world's fresh water supply. Before use it can be extracted, purified and distributed. After use, it can be treated and recycled; all of which requires energy[7]

- In the water sector, "Energy is used in the conveyance, treatment, and distribution of water…The California Energy Commission has estimated that the water use cycle accounts for 19 percent of all electricity consumed in the state and 30 percent of non-power plant-related natural gas use." (CEC, 2011).
- Water combined with energy has a particularly important role to play in agriculture (see e.g. (Gerbens-Leenes et al., 2009). In arid developing countries, irrigation can account for as much as 90% of total water use[8]. Irrigation can be gravity driven but increasingly requires energy for pumping as water tables decline. For example, in India between 15-20%[9] of electricity use is attributed to irrigation.
- Hussey (2010) graphically depicted the interrelationships between some energy-water interactions (with food as a "knock-on sector" using a qualitative framework (Figure 1):

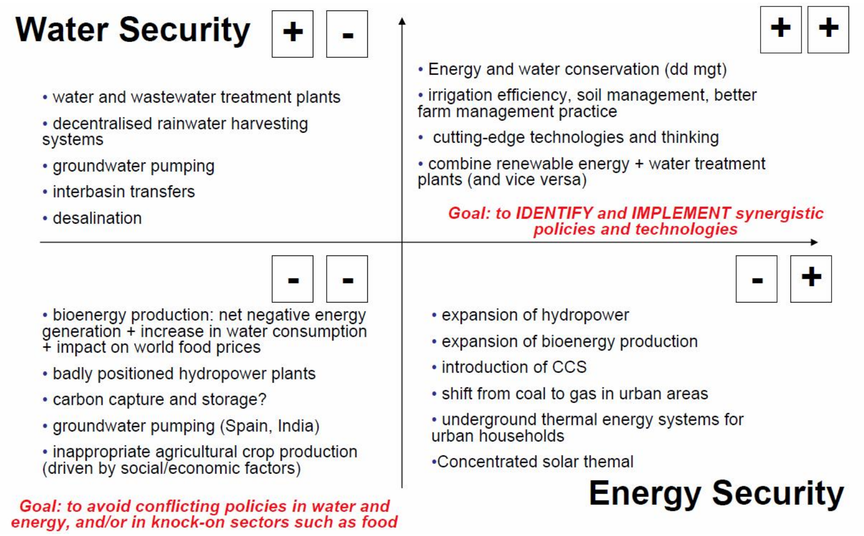

Figure 1: Energy-Water interactions positive and negative implications (Hussey, 2010)

- The majority of global anthropogenic water use, in the range of 60-80%, is for irrigation. If significant areas of energy crops are added, this could raise the water needs significantly. It is estimated that about 60-80% of the technical potential for bioenergy in 2050 would be accounted for by dedicated energy crops, although options may be developed to significantly reduce the water requirements of these crops. As an example, it is known that maize in North

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[4] Damming the Nile River, for example, caused the silt - which was deposited in the yearly floods and made the Nile floodplain fertile - to be depositedbehind the dam. This lowered the water storage capacity of Lake Nasser. Poor irrigation practices further waterlog soils and bring the silt to the surface.

[5] In New Mexico, for example, refineries currently use 50–180 litres of water per barrel of crude oil and generate 30–120litres of wastewater (Timm, 1985).

[6] A barrel of ethanol from corn requires 73,000 to 132,000 litres of water.

[7] For example, the energy required in California to treat waste water for reuse ranges between 0.1 and 4.0 kWhr per 1000 litres (CEC, 2005).

[8] GDI(1998)

[9] Shah et al (2004)

America requires significant irrigation. In 2010, 40% of all corn harvested in the US was used for production of ethanol. This implies that a very significant share of US water use can be attributed to biofuel production. Additonally, effects of climate change are likely to have a significant effect on rainfall patterns around the globe. While some regions might benefits from more rainfall other regions will suffer from prolonged drought periods as well as more uneven distribution of rainfall. Extreme weather events with large amounts of rainfall over a short time period are another likely scenario.

  - However the water and water situations cannot easily be extrapolated to the global level. Different, less irrigation dependent crops are used in different regions, for example, sugar cane in Brazil requires usually no irrigation. Also rainfall regimes differ historically with some societies having developed elaborate techniques to deal with reoccurring rainfall shortages. Also, genetically modified crops that are drought resistant will likely be available soon. Experts claim that new varieties can increase yield by 40% when the plants are most water-stressed (REF?). Finally, a more simple approach is to switch from water intensive crops such as maize to drought resistant crops such as cassava, sorghum, millet or jatropha, depending on the soil and hydro-geological conditions.
  - It should be unmentioned that changing agricultural practices and land-use patterns may have strong impacts on socioeconomic structure of a region. Agricultural practices (including irrigation techniques, crop selection and cropping cycles) have often developed over generations and in many instances present optimal solutions for small scale labour intensive farming with relatively high yields per hectare. (REF)

- Another interesting example of close interactions is the very close correlation between food price indexes (from the UN Food and Agriculture Organization (FAO)) and oil price indexes (from the US Energy Information Administration (EIA)), which generally reflects the importance of petroleum on food production thru both fuels (e.g in transport and cooling facilities) and products such as fertilizer. Figure 2 depicts this correlation:

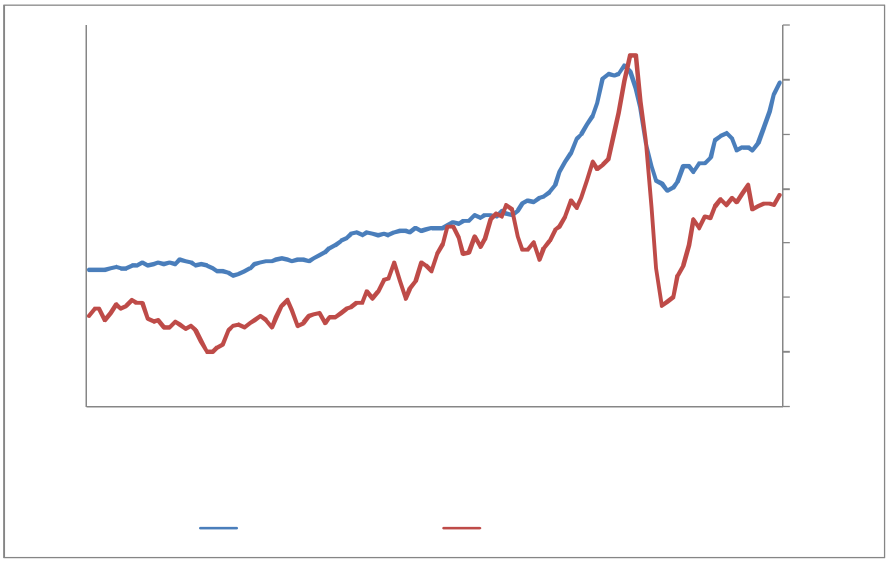

Figure 2: Food and Oil price correlation over time (FAO and EIA data)

There is a wide literature on the topic of life-cycle emissions. This ranges from product cycles to industrial processes and cleaner production to value-chain accounting. All of these areas normally consider energy and water at a minimum and often food production or land-use (see e.g. Abiola et al., 2010, Allen et al., 2010, Amigun et al., 2011, Azzopardi and Mutale, 2010, Berkhout and Howes, 1997, Byrne et al., 2007, Cerutti et al., 2010, Chaurey and Kandpal, 2010, Cherubini and Strømman, 2011, Dismukes et al., 2009, El-Fadel et al., 2010, Finnveden et al., 2009, Fthenakis and Kim, 2010, Grossmann, 2003, Hertwich et al., 1997, Ito et al., 1997, Kaldellis et al., 2009, Lee and Koh, 2002, Ou et al., 2009, Perz and Bergmann, 2007, Rubio Rodríguez et al., 2011, Sørensen, 1994, Tan et al., 2010, Unsihuay-Vila et al., 2011, Wang et al., 2011, Weisser, 2007).

It is clear that each of the three "resource spheres" (EFW) affects the other in substantive ways. Ignoring effects in one can have significant impacts on another. Thus, the need for a systematic, coordinated planning approach is obvious. The three areas, while likely to have numerous powerful synergies and co-benefits if treated with sensitive policy, also have natural tensions. Recognizing these issues, an international conference on sustainable water, energy and food security is now being planned by the German Government for 2011 (Government of Germany, 2011). Likewise, the World Economic Forum (WEF) has been working in this area for some time (see WEF, 2008). Figure 3 is a schematic of the interactions.

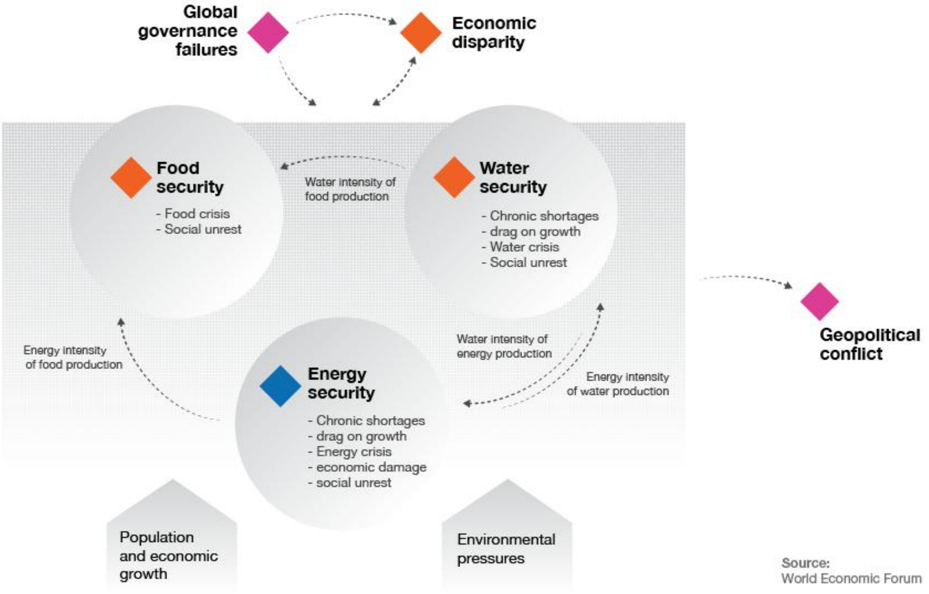

Figure 3: Schematic of nexus (WEF, 2011)

Lee (2010) notes, "The anticipated bottlenecks and constraints – in energy, water and other critical natural resources and infrastructure – are bringing new political and economic challenges, as well as new and hard-to-manage instabilities." Allan (2011) notes that the already significant complexity at this nexus is being compounded. To this end, he describes a "mega" nexus of Water/Food/Trade/Energy/Climate Change/Finance. Still, decisions have to be made by governments and business without full understanding of all possible interactions and consequences; tools are being designed that inform possible options.

3. Systems Thinking – Developing a new modeling framework

The motivation for the development of this new modeling framework follows a review of existing integrated resource assessment and modeling literature[10].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. As Rogner (2009) notes, "…most water, energy and land-use planning, decision and policy making occurs in separate and disconnected institutional entities." Likewise, the analytical tools used to support decision-making are equally fragmented.

Common tools used for energy system analysis include, for example, the MESSAGE[11], MARKAL[12] and LEAP[13] models. A commonly used model for water system planning is the Water Evaluation and Planning system (WEAP[14]), and for water scarcity and food security planning, the Global Policy Dialogue Model (PODIUM) model is well established[15]. However, these and other models, in one way or another, lack the data and methodological components required to conduct an integrated policy assessment especially where these may be needed in a developing country policy context. Generally, they focus on one resource and ignore the interconnections with other resources; have overly simplified spatial representations; are grand policy "*research*" rather than short term applied "*policy*"/decision support models, or analyse scenarios which are impractically long term[16].

The development of the Climate, Land, Energy and Water (CLEW) modeling framework is a response to these shortcommings (IAEA, 2009[17]). Key improvements over existing approaches should include: finer geographical coverage, minimised data requirements for easy applicability in regions with limited data availability, a medium term temporal scope, multi-resource representation (including their interlinkages) and software accessible to developing country analysts. Also, it should use a systems approach, which refers to physical accounting of resources, technology and other requirements and constrains to meet certain needs and services, with the accounting extended far upstream and including externally induced effects (e.g. induced land use change).

Historically, the most famous systems analysis to address some of the ELUW issues was the study *The Limits to Growth* in the early 1970s (Meadows et al., 1972). While providing important insights, the analysis was of little use to national policy makers. A second approach, developed around the same time to analyse the provision of energy services, focused on five connected resources: water, energy, land, materials and manpower (WELMM) (Grenon and Lapillonne, 1976). However, this approach was never developed into a manageable software package that could be used by national analysts. Integrated assessment models[18] attempt to include more aspects of the ELUW nexus.

The CLEW modeling framework in addition to mapping key relationships aims to support:

- Decision making: A well formulated integrated CLEWS tool would help decision and policy makers assess their options in terms of their likely effects on the broad CLEW system. The tool should be able to transparently evaluate the trade-offs reflected in different options.
- Policy assessments: Given limited resources, it is important for policy makers to ensure that policies are as cost-effective as possible. If multiple objectives can be achieved by a single policy, it may advance development more than policies focussed separately on single

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[11] 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)

[12] MARKAL (Market Allocation) model of the ETSAP implementing agreement of the International Energy Agency (ETSAP 2009).

[13] LEAP (Long Range Energy Alternatives Planning) model of the Stockholm Environmental Institute (SEI 2009).

[14] The WEAP energy model is maintained and supported by the Stockholm Environmental Institute: http://www.seib.org/software/weap.html

[15] The Podium model is maintained and supported by the International Water Management Institute http://podium.iwmi.org/podium/

[16] 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, 2011), IMAGE (EMN 2011), and TIAM (Loulou and Labriet, 2008).

[17] A full case study using CLEWS can be found in Rogner et al. (Submitted).

[18] Tol (2006) gives a full discussion of IAMs. They are considerably wider in scope than individual sectoral models, not usually focused on security constraints, and often only focused on climate change and environmental issues.

objectives[20]. A CLEWS tool should therefore provide a more complete, multi-system policy assessment.

- Facilitating policy harmonization and integration: There are instances of very contradictory policies, e.g. electricity subsidies that accelerate aquifer depletion – that in turn lead to greater electricity use and subsidy requirements. A CLEWS tool should help harmonize potentially conflicting policies.
- Technology assessments: Some technology options can affect multiple resources, e.g. nuclear power could reduce GHG emissions, reduce the exposure to volatile fossil fuel markets, but may increase water withdrawals and use. Although it would use water for cooling and uranium mining, nuclear power can generate electricity for freshwater processing and seawater desalination. As with other policies, a CLEWS tool should allow a more inclusive assessment of technological options.
- Scenario development: Another goal is to elaborate consistent scenarios of possible socio-economic development trajectories with the purpose of identifying future development opportunities as well as of understanding the implications of different policies. This is important for understanding whether current development is sustainable, and for exploring possible alternative development scenarios and the kinds of technology improvements that might significantly change development trajectories.

IAEA(2009) shows a schematic diagram of some of the interacting issues used as inputs and parameters to a modeling exercise using the CLEWS tool (Fig. 4).

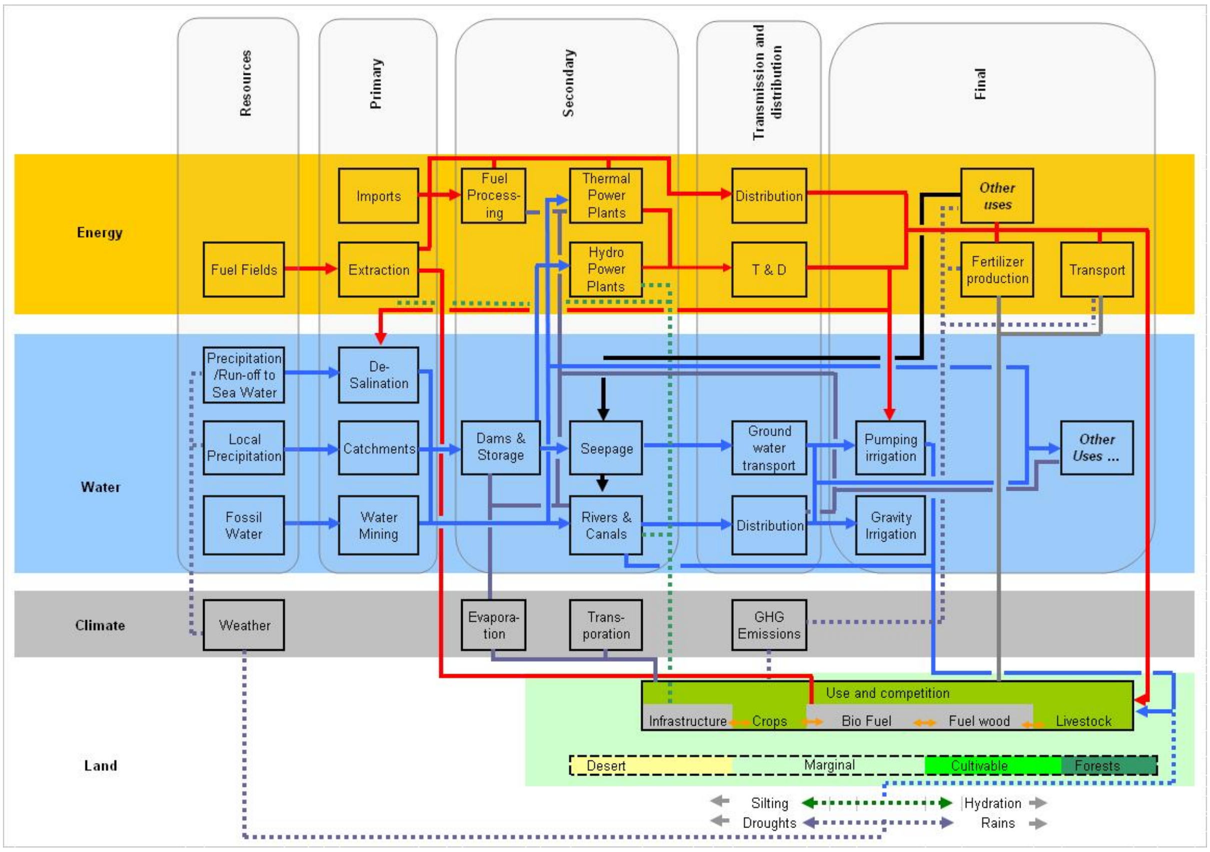

Figure 4: Schematic of Ethanol production and energy/water/food interactions (IAEA, 2009)

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[20] See, for example (Howells, 2003), which shows how different industrial energy efficiency options could affect water use, employment, GHG emissions and energy investment requirements. Analyses that consider the multiple benefits of each option will yield better estimates of the overall development potential of each.

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4. Perspectives for Renewable Energy

It is very difficult to come to grips with the enormity of all three issues without resorting to a restatement of common statistics on growth or lack of access, etc. or to somewhat diffuse guidance[21]. We briefly outline several specific areas where the EWF nexus is apparent, but currently not benefiting from systems thinking in most projects or programmes. These are not full case studies, but highlighted as areas with distinguishable system boundaries for the EFW nexus that future, more detailed research could focus. Examples include:

1. Drip irrigation using photovoltaics (PV)
2. Energy Access and deforestation
3. Biofuels production
4. Desalinisation

- **PV to reduce CO2 emissions of electricy used for irrigation:** As an example, Punjab has only 1.5% of India's land, but its output of rice and wheat accounts for 50% of the grain the government purchases and distributes to feed more than 400 million poor Indians. The problem is that farmers are pumping ('mining') aquifers faster than they can be replenished, and, as water levels drop, increased pumping is sapping an already fragile and overtaxed electricity grid. Moreover, because farmers in Punjab pay nothing for electricity, they run their pumps with abandon. This both further depletes the water table and, as water is pumped from ever increasing depths, requires ever more electricity to maintain a constant level of irrigation water. Overall, irrigation accounts for about 15-20% of India's total electricity use. The Government recognizes that all these issues are interconnected. But the planning and decision making is constrained to address the nexus comprehensively. One option involves the use of distributed photovoltaic powered water pumps which introduces both economic signals but also has positive economic benefits compared to grid based power. Under the appropriate conditions, PV irrigation systems are becoming utilised in this area to great success (Sallem et al., 2009) (Purohit, 2007) (Hussain et al., 2010).

- **Energy Access and deforestation:** As an example, uncoordinated development efforts in Uganda have slowed development and increased environmental stresses, particularly on rapidly decreasing forest lands. Limited access to electricity (only 9% of Ugandans have electricity access) is a major drag on development, and major environmental problems include overgrazing, deforestation, and (often) low productivity agricultural methods, all of which lead to soil erosion. 93% of the country's energy needs are supplied by wood. The resulting deforestation is a severe problem, although its pace has slowed significantly, from a 67% loss of forests and woodlands between 1962 and 1977 to a 7.7% (total or per annum?) loss between 1983 and 1993. Alternative energy sources, including solar energy, biomass gasification, and mini-hydro have all proven to be excellent choices for rural electrification (See e.g. (Biswas et al., 2001, Liu et al., 2008, Viswanathan and Kavi Kumar, 2005, Zahnd and Kimber, 2009).

- **Biofuels production:** Global grain prices are volatile. Recent spikes were caused by many factors, including increased prices for fertilizer and fuel and thus transport, increased demand for bio-fuels driven by energy security and climate change concerns[22], as well as changing

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[21] See e.g. Wong (2010): "Holistic approaches that weigh trade-offs among the three resource systems are the future of natural resource management and, indeed, any sustainable economic or national security policy." Or see WEF (2011): "The key challenge is to incorporate the complex interconnections of this nexus of risks into response strategies that are integrated and take into account the many relevant stakeholders".

[22] The actual impact of bio-fuels on climate change can be negative as well as positive, depending on the resulting land-use changes, and production, harvest and conversion methods. The need to analyze all these factors together reinforces the need for better methods and models that consider all the linkages among ELUW factors.

diets in populous fast growing developing countries. Both fertilizer and irrigation (pumping) require energy. Moreover, as the demand for food, feed and biofuel grows, and as food requirements grow, so does the competition between the two for land. Similarly, there is competition between bio-fuels and food for fresh water and for fertilizers, especially as more marginal land is cultivated. Important positive impacts of increased bio-fuel production might include much needed economic opportunities for farmers and countries trapped by economic barriers. On the negative side, it may cause short term opportunism, such as unsustainable clearing of forests for extra farmland, which may have long term consequences (See e.g. UN-Energy, 2007), (Elena and Esther, 2010),(Kaphengst et al., 2009, Lange, 2011, Méjean and Hope, 2010, Peters and Thielmann, 2008, Schut et al., 2010)).

- **Desalinisation:** As an example, many island populations and large populations in the Middle East and North Africa depend on water desalination as a source of potable water and irrigation. As underground water reservoirs are rapidly depleted and population expands, it is projected that the need for desalination will rapidly rise. The dominant desalination processes; Multi Stage Flash (MSF) and reverse osmosis (RO) constitute 44 % and 42 % of the worldwide capacity, respectively. Thermal desalination technologies, which under the appropriate conditions can be "fueled" by solar energy, rely on the distillation processes to remove fresh water from salty water. Saline feed water is heated to vaporize, causing fresh water to evaporate as steam leaving behind a highly saline solution namely, the brine. A feature of the MSF technology is that it can utilize excess thermal energy. Thus, it is possible to combine the production of large amounts of power and water in one station, thereby satisfying the demand for both of them. Energy needs for desalination are projected to grow rapidly. Water desalination in the MENA region alone is projected to grow from 8 million m^3 today to around 15 million m^3 in 2030. Depending on the country, 33-67% of power capacity additions will be combined electricity and water plant (IEA, 2005). See also (Othmer, 1975), (Blanco et al.) (Peñate and García-Rodríguez, 2011).

There are, of course, numerous other possible examples. The key will be to draw system boundaries wide enough to encompass the enormity of the interacting vectors, while maintaining it small enough to be able to conduct useful analysis.

5. Conclusions and next steps

One clear area that could improve decision-making at the EFW nexus is capacity building. The different vocabularies, competing priorities, institutional capabilities, and regulatory regimes between the three areas all encourage "silo thinking"' in decision-making bodies. In some cases, this will lead to sub-optimal policy and regulatory decisions, in others it will lead to large communication failures and negatively impact on development goals. Another vital step is to develop robust analytical tools and appropriate and validated data sets that can supply information on the present and future concurrent and related use of energy, water and food.

As each jurisdiction will have different levels of resource "constraints" in regards to EFW, case studies with clear system boundaries are required in order to build the evidence-base. To this end, an extension of Rogner et al. (submitted) is being undertaken that develops links between a detailed water, energy and crop production model for Mauritius. It tests the roles of key technologies and processes, such as ethanol production, desalination and renewable electricity generation, key policies such as food, water and energy security and does this in the context of climate change-constrained futures.

Regulatory practices that encourage systems thinking will also be essential. The idea of "water exchanges", where water is traded like other commodities (whate, corn, oil, gas, etc.) is one such notion. The price discovery that might occur in such markets will lend clear insights about the relative demand and importance between, say, food producers, upstream oil and gas exploration and processing, and power generation (See e.g. Reuters, 2011, (Stern, 2010)).

Finally, while it is useful that there is a growing acknowledgment of the need to consider the EFW nexus holistically, the tools and expertise is lagging far behind the political rhetoric. We must also acknowledge that undertaking the kind of inclusive policy-processes required to consider the vast array of interacting issues is difficult to transact in current government and regulatory structures and cultures. As an example, even within the energy ministries of many countries, those responsible for upstream oil and gas issues are often far removed from their colleagues working on the details of electricity market regulation, as well as those that consider water and agriculture. To actually form constructive linkages across the boundaries that exist between the three areas will require strong political leadership, compelling visions, and significant cooperation and humility.

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