Is project scale the key to sustainable modern bioenergy systems?

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Abstract: Availability of energy sources is the main driver for societies. Bioenergy is increasingly seen as a part in the puzzle to fill the gap that dwindling fossil fuel reserves create. However, its huge potential benefits to human societies comes with a price tag attached; bioenergy projects competing with food production, locally crashing social cohesion by export orientated production, and large-scale production threatening biodiversity and productivity of pristine and fragile tropical ecosystems put a shady light on it. Bioenergy can reveal dependencies of social to ecological systems as ruthlessly as it can be. Bioenergy production does not necessarily have to be to the disadvantage to societies. Bioenergy can deliver cost, resource and time efficient energy on a long-term sustainable base to societies outcompeting other sources of energy by far. Disadvantages as mentioned above come often with increasing scale of projects. For instance, with increasing scale, there is an increasing pool of stakeholders making it harder to apply participatory approaches and decisions tend to be centralized. However, sustainability is based on individual risk perceptions and normative values therefore demanding participatory planning. This paper describes the problem of scale by drawing from on-the-ground experience from Uganda, East Africa. By means of one large-scale and one small-scale bioenergy example both producing electricity, we show how bioenergy can unfold its manifold benefits in a distributed, small-scale infrastructure. It can be in the interest of the poor, strengthen social cohesion, and can contribute to improved natural resource management. We conclude with tools and policies we need to make small-scale projects to be the norm rather than the exception. We need policies fostering distributed energy infrastructure, and participatory tools to assess sustainability of bioenergy systems stepping beyond traditional cost benefit analysis.

Keywords: Bioenergy, scale, distributed energy, sustainability, Africa

1 INTRODUCTION

Availability of energy sources is the main driver for societies. Modern bioenergy, like electricity produced from woodchips, is increasingly seen as a part in the puzzle to fill the gap between dwindling fossil fuel reserves and increasing global demand: The absolute quantity of biomass contribution to human energy needs rose by 80 % in the last three decades (Sagar and Kartha 2007). Bioenergy production can contribute to human well being delivering cost, resource and time efficient energy on a long-term sustainable base to societies outcompeting other sources of energy. However, its huge potential benefits to human societies come with a price tag attached; bioenergy projects competing with food production, locally crashing social cohesion by export orientated production, and large-scale production threatening biodiversity and productivity of pristine and fragile tropical ecosystems put a shady light on it (Reijnders 2006, Sims 2003, Hall 2000). Bioenergy can reveal the dependency of social systems on ecological systems as ruthlessly as it can be. The question is how to design bioenergy systems in a sustainable way: how can we get the maximum social and economic benefits from the biomass used while staying within ecological limits?

A bias to large-scale bioenergy projects?

As the influence of bioenergy is increasing, so are projects based on the "economy of scale" principle. But do these large-scale projects actually contribute to a societies' overall sustainable development goals just as small-scale systems do? For instance, does a 350 MW project, as suggested for Wales, UK, (Prenergy 2008) put the same stress on the planet while providing given benefits to society as 350 distributed one MW projects? Does it make more sense for a state like Vermont, USA, to support development of two 50 MW biopower systems or to encourage small-scale heating systems for buildings utilizing the same amount of biomass?

Despite the potential small-scale bioenergy systems offer, there is still a tendency to large-scale projects. Presumably, the reason for this might be that bioenergy projects in the scale of several tens of MW are familiar to international investment firms, technology developers, and project managers therefore benefiting from a greater pool of information and access to capital. Moreover, traditional cost-benefit analysis puts emphasize on those aspects that fare better in large-scale projects like financial profits or total direct jobs created. Large-scale projects are easier to steer for both public authorities and project managers as they are easier to

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control (e.g. environmental impacts, job regulations, etc.), they are more likely to attract tax breaks, have easier access to carbon markets, can produce more visible side benefits (e.g. active community development), and are more likely to attract attention in the media.

Comparing large- with small-scale

There is no generally acknowledged methodology and only little practical evidence dealing with the sustainability of bioenergy systems depending on scale. Burton and Hubacek (2007) suggest that small-scale renewable energy projects offer most value in ecological and social terms (local trade, job creation, etc.) compared to large-scale projects while large-scale projects fare better in economic terms measured through cost-benefit analysis. Impacts on the social and ecological impacts were measured on purely normative scales. Bird (2007) proposes the use of different criteria sets for bioenergy systems at different scales. Transport distances (e.g. Bernesson et al. 2006) and supply logistics (Maker, personal communication, 2007) seem to play an exponentially increasing negative impact on both, economics and ecosystems with increasing project scale. However, Gwehenberger and Narodoslawsky (2007) modeling different scales of cellulosic ethanol plants, suggest that scale can be increased to improve economic and ecological efficiency i) if more elaborate processes producing many different products are applicable (which is difficult for small-scale projects) and ii) when more agricultural byproducts become available. If this is not the case, small-scale projects with one product and powered by bioenergy from crops grown only for this purpose, are a better trade off between ecological impact and economical gains.

A systems approach can greatly contribute to this discussion. A detailed integrated and quantified sustainability assessment of large vs. small-scale bioenergy projects is beyond the scope of this paper (see e.g. Odum 1996). The goal of this paper is rather to point out that current decision approaches to assess economic, ecological and/or social sustainability tend to prefer large-scale projects. However, using a systems approach and drawing on systems theory, we show how a systems approach can introduce new perspectives and reveal advantages of small-scale systems which are often neglected or even assumed to be disadvantages. To support our line of thinking, we draw on a Ugandan case study.

2 LARGE- AND SMALL-SCALE – A CASE STUDY IN UGANDA

The case study used in this paper to demonstrate some few representative aspects of sustainability assessments is situated in Uganda and consists of one 50 MW power plant and a 200 kW combined heat and power plant both fired by wood chips from a dedicated fuelwood plantation. So far, there is only a feasibility study for the 50 MW plant while the 200 kW plant has been in operation for the last two years. As the 50 MW plant is not realized to date, Figure 1 shows a biopower system using a similar technology for a better understanding of the scale. Table 1 shows some descriptive facts on the two projects as it is often used in conventional feasibility studies. Although the small-scale project depicted here does supply power and heat to an industry only such applications are not restricted to industry but can easily deployed for household consumption as well (Nouni et al. 2007).

Figure 1: 50 $MW_{el.}$ wood powered steam turbine McNeil Station, Vermont, USA. Source: Burlingtonelectric 2008

Figure 2: 200 $kW_{el.}$ wood gasifier (red circle) at Muzizi Tea Estate, Uganda

Table 1: Overview on the two Ugandan bio-electricity case studies presented. Note that the 50 MW project creates a considerable amount of jobs and that it would include active community development such as building schools and a hospital. No such direct support for the local community comes from the small-scale project.

NET CAPACITY (ELECTRIC)	UNITS	50 MW[A]	200 KW[B]
Owner		International investment firm	National industry owner
Business concept		Power production only, selling electricity to the grid	Combined heat and power (CHP), internal energy demand of a tea factory
Applied technology		Bubbling fluidized bed boiler with steam turbine	Wood gasifier with gas engine
Implementation status		Feasibility study	Operating since May 2006
Efficiency	% electric efficiency (including heat)	30 % (no heat application)	15 % (75 %)
Project lifetime	years	28	13
Electricity production costs	US$/kWh	0.1 - 0.13	~0.14
Power plant investment costs	US$ (US$/kW)	165 m (3,300)	0.45 (2,087)
Biomass production area	ha	30,000 ha (15 % native species)	51 ha
Biomass productivity	m^3/ha/yr	25	15
Direct jobs created	Total (jobs per MW)	>1,000 (20) including fuelwood supply chain	12 (60) excluding fuelwood supply chain
Other measurable social impacts		Active community development (schools, hospital, etc.)	No active community development

[A] Source: Buchholz et al. 2007a
[B] Source: Buchholz and Volk 2007

3 SCALE AND SUSTAINABILITY – IMPLICATIONS FROM SYSTEMS THEORY

Systems theory has been suggested in a number of applications to help frame sustainability measurements (e.g., Abel 2004, Hjorth and Bagheri 2006). Bioenergy can easily be described as a complex, adaptive system with the coevolving sub-systems feedstock supply, conversion technology and energy allocation. These sub-systems are further embedded into an environmental, economic and social context unique to each system. These systems involve agents who adapt and learn, thereby changing the systems from within (Luzadis et al. 2008, Buchholz et al. 2007b). Systems are sustainable when they are resilient to change coming from inside and outside the system and therefore survive. Failure of addressing one sub-system can lead to failure of the whole system (Karekezi 2001).

Biopower systems nested in larger socio-ecological systems

To provide a systems view on the information to Table 1, Figure 3 andFigure 4 show the two bioenergy systems embedded in their surrounding socio-ecological super-systems or levels. For the 50 MW project, electricity consumers are not local, the electricity is delivered to the near town of Gulu. The financing entity and the owners have an international background. The conversion technology is provided from abroad, white collar jobs are advertised internationally. The plant is expected to draw blue collar workforce from a regional level. In contrast, the 200 kW project provides electricity and heat to a local customer, is mostly financed and owned by a national entity, white collar jobs are advertised nationally and no migration of blue collar workers occurs. The environmental impacts – although possibly differing in quantity – do not change scales with changing plant size. For instance, in both cases, greenhouse gases are a global issue while noise is a local impact.

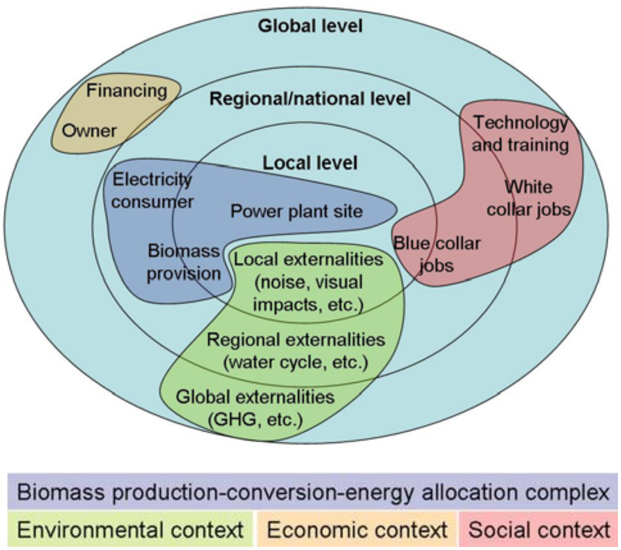

Figure 3: Socio-ecological levels affected by the 50 MW plant.

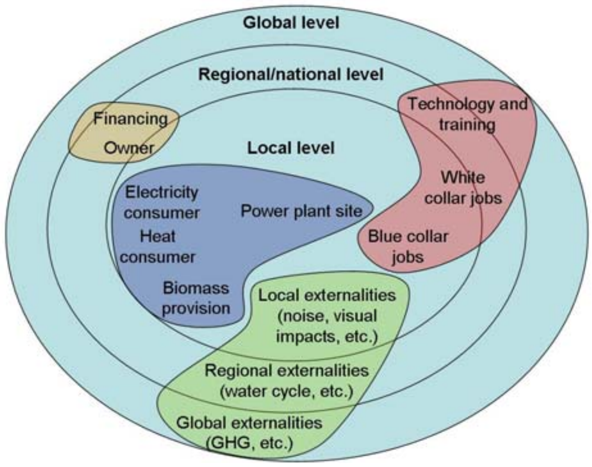

Figure 4: Socio-ecological levels affected by the 200 kW plant.

Increasing complexity with increasing scale

With increasing spatial scale, higher socio-ecological levels are involved to a greater extend (see Figure 3 and Figure 4) and techniques have to be adapted to reduce associated uncertainties and risks of failure; ‘‘the bigger the project, the better the techniques [have to be] to respond to anticipated impact growing with scale’’ (Pétry, 1990). The long planning and implementation phases of larger scale projects and the more stringent regulations they might have to obey to can be seen as an evidence of this relationship of complexity and scale. While the 200 kW biopower system took 2 years from planning to implementation and required only one permit from the national level – namely the environmental impact assessment - the 50 MW project is still not beyond the feasibility stage after 2 years. It might be more sustainable to support many small and fast renewing systems instead of one big one.

Time and scale - resilience through diversification

Another important aspect is increasing longevity of systems with increasing scale (Buchholz et al. 2007b). A small system can fulfill its purpose, i.e. be sustainable, in shorter time scales than larger systems in which it might be nested (Costanza and Patten, 1995; Holling, 2001; Odum, 1988). While the 200 kW biopower system is considered economically sustainable with a project life of 13 years, the 50 MW project succumbs longer time expectations. Assuming that several small power plants would be assessed against one large plant, the accepted shorter lifespan of smaller systems, their lower associated impacts in case of failure, and their spatial distribution also promotes evolution and innovation of different technologies and approaches while hedging each others risks. These facts further contribute to the system’s overall resilience. Against this, the high investments necessary for the 50 MW project rely on proven rather than innovative technologies. This implies that for small-scale bioenergy systems higher risks and less stringent sustainability criteria could be accepted in assessing its sustainability compared to large-scale projects (see Voinov and Farley 2007 for general systems, Norgaard 1994 for socio-ecological scales).

Efficiency and financial aspects

Efficiency measures are often used as technical, expert-based, and objective criteria for system assessments. However, efficiency depends heavily on where systems boundaries are drawn, can relate to many subjects like resources, energy, investment/finances, or human labor, and can obscure discussions. For instance, looking only at electrical efficiency, the high tech 50 MW technology fares better (see Table 1). However, while the 200 kW system utilizes the waste heat and generates an overall efficiency of 75 %, the heat of the 50 MW plant would not be used. Moreover, the electricity of the 200 kW system is used on site and little transmission losses occur. The 50 MW plant would rely on grid transmission with losses between 10 % (global average, WADE 2008) and over 30 % in Uganda (UIA 2003) significantly lowering the overall efficiency of the system. Besides discussing efficiency for different scales, both examples – inclusion of heat use and transmission losses- demonstrate well the role boundaries play when assessing systems and the importance of a systems approach in general. Moreover, energy efficiency rates often dramatically fall at partial loads (e.g. Nouni et al 2007 for biopower). Large units are more prone to such efficiency losses as, for instance, two small systems in which case one unit can be shut down while the other runs at full capacity delivering

50 % of the total output (Lovins 2002). There are many tools to assess investment efficiency, most notably Internal Rate of Return (IRR) or a payback period. While these figures are proprietary for the 50 MW project, they compete with a 30 % IRR, and a payback period of only 4 years for the 200 kW system.

Social aspects

Figure 3 and Figure 4 show on which level the financial decisions were made in the both case studies. With increasing scale, the decision makers are less likely to be local. Participation of stakeholders is key to sustainability (Reed et al. 2006). However, the increasing complexity of large-scale bioenergy projects involving increasing numbers of stakeholders implies a shift to centralized decisions as participation is seen as too complicated and therefore ignored completely. The risk of a disrupted social cohesion or even project failure can be considerable (Upreti and Horst 2004, Upreti 2004). The Ugandan 50 MW large-scale project depended on negotiations with those few individuals owning the largest estates to acquire sufficient acreage for the fuelwood plantation with little to none participation of other local residents. Considerable job migration would occur in the 50 MW project. While the large system creates only 20 direct jobs per MW including the fuelwood supply chain, the small system would create 60 per MW only at the plant excluding the fuelwood supply chain. Large-scale power production has an urban bias as it depends on large-scale consumption while keeping transmission costs down. The 50 MW plant site was chosen close to the second largest Ugandan town with around 120,000 inhabitants to provide it with additional electricity. Rural electrification with its intended development benefits to scattered settlements is more likely to be pursued with small-scale distributed power production. These small-scale systems do often not add additional power to a region but extend electricity services to formerly non-electrified regions being more likely to address subsistence rather than urban luxury consumption – a distribution problem (see also Gowdy and Erickson 2005 for such 'welfare efficiency'). The small-scale plant at Muzizi Estate was precisely chosen because of the rural (off-grid) setting.

Impacts on the ecosystem

Although both scales discussed affect the same socio-ecological levels in terms of ecological impacts, the extent of the respective impacts is difficult to compare between the two systems. While there are no imminent indications that the several small patches of fuelwood plantations for the 200 kW system destabilize the larger ecosystem they are nested in, the large-scale plantations required for the 50 MW plant would convert current grass land and stirred discussions about its negative impact on wildlife corridors, groundwater levels, fire risks, and impacts associated with monocultures and exotic tree species applications. Similarly, while the cooling water supply and discharge for the 50 MW plant would seriously affect (and rely on) the local Aswa river, the low water demand for the 200 kW does not have a major impact on hydrological cycles (James Finlay Uganda 2007). However, most of the ecological impacts need to be quantified more in detail to allow meaningful comparisons of large vs. small-scale.

4 CONCLUSIONS

There lies an advantage in small-scale bioenergy systems from an environmental, economic, and social perspective. This potential becomes more obvious when using a systems approach that goes beyond traditional cost-benefit analysis or environmental and social impact assessments. Small-scale bioenergy systems promise an efficient use of resources, reduce environmental impacts from power production, are more likely to engage stakeholders, are predestined for rural development, and offer manifold opportunities to innovate and learn while at the same time offering affordable power, being implemented in comparably short timeframes and with potentially low investments. To tap into this potential the following steps might be valuable:

- To deploy small-scale bioenergy beyond industrial use, there is a need to create awareness amongst public authorities, investors, and project developers about the benefits of small-scale bioenergy systems in order to access capital and to tap into their expert knowledge.
- Elaborate quantification methodology allowing direct comparison of the impacts of many small-scale bioenergy systems (a 'virtual power plant') vs. a few large-scale ones needs to become standard such as emergy analysis (Peng et al. 2007).
- Based on insights from quantification, Criteria & Indicator frameworks to assess sustainability need to be developed for bioenergy systems to allow quick assessments. Such frameworks would include development of criteria lists, rules how criteria need to perform to indicate sustainability, and which political level would be responsible for implementation. Such frameworks are known and tested in forestry (e.g. Forest Stewardship Council 2008a), carbon markets (Clean Development Mechanism 2008), or fair trade (Transfair 2008) and are capable to deal with a comparable entanglement of social, environmental, and economic contexts like bioenergy.
- When applying such Criteria & Indicator frameworks, system's theory suggests that small-scale bioenergy systems should be subjected to less stringent and elaborated assessments and rules than large-scale systems not only to allow innovation,

and evolution of these systems but also due to the lower risks and negative impacts associated with each. This is already acknowledged for bioenergy production in general (e.g. Ecological Society of America 2008) and put to practice in other systems: cluster certification schemes for small projects are subject to less stringent rules for fair-trade (Fairtrade 2008), sustainable forestry (Forest Stewardship Council 2008b) or carbon credit schemes under the Kyoto protocol (ENCOFOR 2008).

- There might be valuable insights from other bioenergy systems (e.g. the Roundtable on Sustainable Biofuels 2008) that could contribute to the discussion outlined in this paper focusing on power and heat production from bioenergy.

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