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Sustainable Bioenergy Systems: Experiences from Sweden

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Abstract

Many aspects of present energy systems and the direction towards future energy systems are incompatible with sustainable development. Sustainable bioenergy systems contribute to combating climate change and improving energy security. Expanding bioenergy decreases carbon dioxide emissions if replacing fossil fuels, establishing energy crops, or integrating with carbon capture and storage, and increases the resilience of energy systems because of the range of viable biomass inputs (agriculture residues, forest residues, energy crops, and organic waste), the different conversion technologies, and the options for energy outputs (heat, electricity, and fuels for transport). What is overlooked in many studies and assessments of bioenergy is that establishing sustainable bioenergy systems promotes regional development and results in multiple benefits across environmental, social, and economic spheres. Both industrialised countries and developing countries can exploit the potential of bioenergy. However, stimulating the development and diffusion of sustainable bioenergy systems requires supportive policies and measures to overcome constraints. This paper investigates the experiences of bioenergy in Sweden. Both the national perspective and local examples of bioenergy systems are presented in this paper.

Keywords

Bioenergy, Biomass, Sustainable Development, Climate Change, Energy Security, Regional Development, Multiple Benefits

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1. Introduction

Bioenergy is often perceived by the public and politicians as a fuel of the past rather than a fuel of the present and future. This paper therefore investigates how bioenergy systems in Sweden contribute to sustainable development through combating climate change, improving energy security, and promoting regional development. There are several sections in this paper. First, an introduction to bioenergy generally, and more specifically bioenergy in Sweden. Second, an outline of the methods applied in the research for this paper. Third, a discussion of bioenergy in Sweden both from the national perspective and local examples of bioenergy systems. The case studies presented in this paper are examples of innovative and sustainable bioenergy systems.

2. Context

Bioenergy provides more than 10 percent of global energy demands, which represents 75 percent of renewable energy (Goldemberg & Johansson, 2004). Bioenergy is important in developing countries where some 35 percent of the energy supply is based on traditional biomass. Over 2 billion people depend almost exclusively on traditional biomass in local energy applications (Johansson & Goldemberg, 2002). The challenge facing developing countries is to shift towards sustainable bioenergy systems, which requires the sustainable utilisation of biomass resources and the diffusion of more efficient, safe, and clean conversion technologies.

Bioenergy is decreasing in the energy supply of many industrialised countries (Sims, 2002). Some exceptions are Sweden, Austria, Denmark, Finland, Germany, and Brazil where supportive policies and measures are increasing bioenergy. In Sweden, 378 PJ or 20 percent of primary energy is supplied from bioenergy. In the short-term, estimates for bioenergy in 2010 are 576 PJ or 26 percent of primary energy (SEA, 2004). In the long-term, projections suggest 792 PJ is feasible depending on supportive policies and measures (SVEBIO, 2004).

The experiences from Sweden demonstrate the considerable potential of bioenergy to contribute to energy supply. There are opportunities for sharing know-how and exporting technologies from Sweden to both industrialised countries and developing countries (Kåberger, 2004). The bioenergy industry in Sweden has acquired experience with many types of biomass, different conversion technologies, and the enabling and constraining factors that influence the development and diffusion of sustainable bioenergy systems.

There are 4 foremost reasons why bioenergy is so developed in Sweden. First, there are considerable forest resources and an established forest industry with the knowledge and skills to collect, transport, and utilise biomass (Ericsson *et al.*, 2004). Second, there are demands for heat in Sweden, especially for district heating systems (Helby *et al.*, 2004). Third, there are supportive policies and measures, particularly the carbon tax. The introduction of the carbon tax, which only applies to heat, has stimulated the shift from fossil fuels to biomass in district heating systems (Johansson *et al.*, 2002). Fourth, local and regional initiatives on climate change and environmental protection often provide foundations and justifications for exploiting bioenergy (McCormick & Kåberger, 2005).

3. Methods

This paper is based on research conducted by the Bioenergy Network of Excellence (NoE), which is a collaboration of research institutes in the European Union (EU).[1] The Bioenergy NoE is engaged in the case study approach to identify and analyse barriers to expanding bioenergy.[2] However, the findings are relevant beyond the industrialised countries of the EU, particularly for developing countries that are modernising energy systems and expanding renewable energy. The case study approach provides insights into the development and diffusion of bioenergy systems.

This paper presents research on bioenergy in Sweden from the national perspective and local examples of bioenergy systems. The methods applied to gather data at the national level included discussions with experts from academia, government, and industry, and a literature review, mainly national reports and articles. For the local level, the methods utilised in the case studies included observations of the bioenergy systems, interviews with stakeholders, and a literature review, mainly local documents and brochures. The case studies are examples of innovative and sustainable bioenergy systems (see table 1).

Table 1: Case Studies of Sustainable Bioenergy Systems in Sweden

Location	Input	Technology	Output	Comment
Enköping[a]	Forest residues, energy crops	CHP plant, biomass boilers	Heat, electricity	Waste water is utilised as fertiliser on energy crops, and there are investments to expand energy crops.
Vansbro[b]	Forest residues	Wood pellets plant, CHP plant	Wood pellets, heat, electricity	Condensate from the wood pellets plant is utilised in the CHP plant.
Kristianstad[c]	Forest residues, agriculture residues, organic waste	CHP plant, biomass boilers, biogas plant	Heat, electricity, fuels for transport	Public buildings use biomass boilers and public buses use biogas.
Växjö[d]	Forest residues	CHP plant, biomass boilers, DME (di-methyl-ether) plant	Heat, electricity, fuels for transport	There is research, development, and demonstration on biomass and DME (di-methyl-ether).

[a] Read McCormick & Kåberger (2005) for more information.

[b] Read Mirata *et al.* (2005) for more information.

[c] Read Johansson & Johnsson (2002) for more information.

[d] Read Erfors (2003) for more information.

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[1] Visit http://www.bioenergynoe.org/ for more information on the Bioenergy NoE and the research institutes involved in the collaboration.

[2] See Yin (2003) and Stake (1995) for more information on the case study approach.

Bioenergy is defined as energy from biomass. However, exploiting biomass for energy purposes is rather more complicated. When conducting research on bioenergy it is constructive to apply systems thinking.[3] Bioenergy systems comprise biomass resources, supply systems, conversion technologies, and energy services (McCormick, 2005). Furthermore, there are many influences on the development and diffusion of bioenergy systems from national policy to local actors. Identifying the elements in bioenergy systems and the relationships between elements is valuable. The research presented in this paper therefore utilised systems thinking to explore the case studies.

4. Discussion

The impacts (both positive and negative) of bioenergy systems are shaped by the location and management. Establishing sustainable bioenergy systems requires attention on several issues, including the design of bioenergy systems that are carbon neutral, the implementation of sustainable practices when utilising agriculture residues and forest residues, and the control of emissions. Many studies and assessments of bioenergy identify combating climate change and improving energy security as positive impacts from bioenergy. However, what is striking about sustainable bioenergy systems in Sweden is the observed regional development and multiple benefits across environmental, social, and economic spheres (see table 2).

Table 2: Perspectives on Sustainable Bioenergy Systems in Sweden

Level	Impact	Comment
Global	Combating Climate Change	Bioenergy systems can decrease carbon dioxide emissions if replacing fossil fuels, establishing energy crops, or integrating with carbon capture and storage.
National	Improving Energy Security	Bioenergy systems can increase the resilience of energy systems because of the range of viable biomass inputs, the different conversion technologies, and the options for energy outputs.
Local	Promoting Regional Development	Bioenergy systems can contribute to regional development in several ways.
	- Distribution and Diversification	Bioenergy systems can promote distributed and diversified energy systems.
	- Partnerships and Synergies	Bioenergy systems can stimulate partnerships to exploit synergies.
	- Business and Employment	Bioenergy systems can generate (direct and indirect) employment and business.
	- Environment and Landscape	Bioenergy systems can support environment and landscape goals.

Acceptance of bioenergy systems by the public and politicians is hindered by several perceived constraints or negative impacts. Hall & Scrase (1998) refute the perceived constraints, including health concerns, environmental impacts, energy balances, and

[3] See Meadows (1999) and Olsson & Sjöstedt (2004) for more information on systems thinking.

transport issues. A real challenge is the cost of bioenergy compared to fossil fuels or nuclear power. Johansson & Goldemberg (2002) argues that fossil fuels and nuclear power receive energy subsidies, which distort energy markets. Furthermore, the external costs associated with fossil fuels and nuclear power are excluded from calculations. The cost of bioenergy is therefore competitive on energy markets when supportive policies and measures are implemented.

4.1. Climate Change

Sustainable bioenergy systems are essentially carbon neutral and therefore address the challenge of combating climate change.[4] The flows of carbon dioxide in bioenergy systems are simple in general and complicated in detail. Biomass absorbs carbon dioxide from the atmosphere. When biomass is harvested and combusted for energy purposes there are carbon dioxide emissions. However, no more carbon dioxide is released than is re-absorbed by growing biomass. Bioenergy is therefore carbon neutral if all biomass that is combusted is replaced (Börjesson *et al.*, 1997).

When considering carbon dioxide emissions and energy sources it is important to recognise the effects across the complete life cycle (Sims, 2002). All stages of the life cycle can result in carbon dioxide emissions. Bioenergy systems involve many elements, including processing, transporting, and storing the biomass resources, constructing the conversion technologies, and combusting the biomass for energy purposes. The different elements in bioenergy systems can produce carbon dioxide emissions, so it is important to evaluate more than only the production and combustion of biomass resources (Sims, 2002).

Expanding bioenergy decreases carbon dioxide emissions if replacing fossil fuels, establishing energy crops, or integrating with carbon capture and storage. In Sweden, bioenergy acts as a carbon offset by substituting fossil fuels (especially in district heating systems) and acts as a carbon sink by sequestering carbon dioxide through the planting and harvesting of energy crops.[5] Interestingly, the development and investments by the coal industry in carbon capture and storage is expected to support the bioenergy industry. If bioenergy systems can be coupled with carbon capture and storage, then carbon dioxide can be removed from the atmosphere (Kåberger, 2004).

4.2. Energy Security

Bioenergy systems contribute to improving energy security in several ways. Expanding bioenergy in Sweden has diversified energy sources and improved the resilience of energy systems because of the range of viable biomass inputs (agriculture residues, forest residues, energy crops, and organic waste), the different conversion technologies, and the options for energy outputs (heat, electricity, and fuels for transport). Put simply,

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[4] Traditional biomass results in carbon dioxide emissions (Johansson & Goldemberg, 2002). The challenge facing developing countries is to shift towards sustainable bioenergy systems, which requires the sustainable utilisation of biomass resources and the diffusion of more efficient, safe, and clean conversion technologies.

[5] When land is utilised for energy crops carbon dioxide is sequestered in both the plants and soils (Sims, 2002).

the flexibility and diversity of bioenergy systems enhances energy security (Helby *et al.*, 2004).

The distinctive features of bioenergy are displayed in Sweden (Hall & Scrase, 1998). In many ways, bioenergy shares more features with fossil fuels than renewable energy. It can be based on agricultural residues, forest residues, energy crops, or organic waste; it can be produced as solid, liquid, and gaseous fuels; it can be stored and transported; it can be used for heat, electricity, and fuels for transport; and it can be used to substitute fossil fuels (Sims, 2002).

Biomass resources are abundant and available for energy purposes in many countries. Compared to oil where reserves are concentrated in only a few countries. Energy security is improved with bioenergy because of the many possibilities for importing and exporting biomass. In Sweden, allowing unrestricted imports of biomass has helped to support investments in bioenergy (Kåberger, 2004). Imports of biomass to Sweden are negligible. However, access to markets beyond Sweden has diminished the risks associated with establishing conversion technologies that rely on biomass resources.

4.3. Regional Development

The concept of Distributed Economies (DE) is a strategy to guide industrial development towards sustainable development (Johansson *et al.*, 2005). Bioenergy systems often support the fundamentals of DE and illustrate the advantages of distributed and diversified energy systems (Mirata *et al.*, 2005). The emergence of DE is based on the perceived disadvantages of large scale and centralised systems. What DE promotes is a transition in industrial development to small scale and distributed systems. However, the emphasis is on finding a balance rather than abolishing centralised systems or marginalising distributed systems.[6] The concept of DE is constructive when analysing sustainable bioenergy systems.

In Sweden, bioenergy systems are predominantly distributed and diversified energy systems, and therefore connected with regional development. The range of viable biomass inputs (agriculture residues, forest residues, energy crops, and organic waste), the different conversion technologies, and the options for energy outputs (heat, electricity, and fuels for transport) illustrate the diversity and flexibility in bioenergy systems, which are key attributes of DE. Furthermore, the utilisation of residues and waste stimulates partnerships to exploit synergies. When bioenergy systems are implemented, residues and waste are transformed into resources creating opportunities for partnerships, thereby stimulating DE.

4.3.1. Distribution and Diversification

In the 1970s there was an interest in Sweden to diminish the reliance on imported oil. The options suggested were energy efficiency, renewable energy, coal, and nuclear power. In a referendum in the 1980s it was decided to shift away from nuclear power (Kåberger, 2004). The concerns with imported oil and nuclear power have helped to

[6] Visit http://www.delabs.org/ for more information on DE and the establishment of DElabs (Learning Labs for DE).

promote energy efficiency and renewable energy in Sweden. Furthermore, the introduction of the carbon tax in the 1990s, which only applies to heat, has stimulated the shift from fossil fuels to biomass in district heating systems (Johansson *et al.*, 2002). Put simply, there are several factors in Sweden stimulating distributed and diversified energy systems.

In the Växjö Case and Kristianstad Case the local governments have committed to become Fossil Fuel Free (FFF). The objective is to replace all fossil fuels for electricity, heat, and fuels for transport with renewable energy and improved energy efficiency. The commitment to become FFF is based on concerns over climate change and energy security. What FFF stimulates is distributed and diversified energy systems often based on bioenergy. In the town of Kristianstad the local government has established a CHP plant based on biomass and a biogas plant, converted boilers in public buildings from oil to biomass, and started to utilise biogas in public buses.

Agriculture residues and organic waste will be utilised predominantly in regional systems. In contrast, energy crops and forest residues can be transformed into internationally tradable products (Börjesson, 1998). When looking at bioenergy in Sweden there are many examples of regional systems. The Enköping Case is based on a range of biomass resources collected in the region and utilised to supply heat and electricity to the town of Enköping. The Vansbro Case illustrates the development of internationally tradable products. In the town of Vansbro there is production of wood pellets from forest residues (in the region) with expected markets both nationally and internationally.

4.3.2. Partnerships and Synergies

Most bioenergy systems in Sweden are integrated or linked to industries that produce by-products, which are transformed into co-products when coupled with bioenergy (Roos *et al.*, 1999). The development of a biogas plant in the town of Kristianstad illustrates how wastes are utilised in bioenergy systems. The Kristianstad Case involves waste from households, manure from agriculture, and waste from the food industry to produce both energy and fertiliser. The biogas plant therefore transforms wastes into resources by developing partnerships between several sectors.

When bioenergy systems are initiated the actors involved are often stimulated to look for synergies and possibilities for collaboration. In the Enköping Case the local government decided to apply the nitrogen rich water from the Waste Water Treatment Facility on energy crops to meet the Baltic Sea Agreement, which requires each local government in Sweden reducing nitrogen leakage to the Baltic Sea by 50 percent. The collaboration helped several actors by stimulating the development of energy crops and reducing nitrogen leakage to the Baltic Sea.

Sustainable bioenergy systems often involve partnerships between urban and rural populations. With rural populations providing the biomass resources, and urban populations investing in conversion technologies. There are some 15,000 ha of energy crops in Sweden, which represents only a minor contribution to bioenergy at present (SVEBIO, 2004). Energy crops are expected to play a major role in the future

(Goldemberg & Johansson, 2004). However, the challenges of building partnerships between energy companies and farmers are evident in the Enköping Case. The energy companies have leased land from the farmers to plant and harvest energy crops because the farmers are concerned about the viability of energy crops.

4.3.3. Business and Employment

Bioenergy systems involve many activities that generate employment opportunities and business partnerships. The production and utilisation of biomass requires harvesting, transporting, and distributing. Equipment and technology is manufactured and contracts are signed to provide the biomass resources, maintain the supply systems, establish the conversion technologies, and generate the energy services. Put simply, business is stimulated across several sectors.

When a tree is felled for the purpose of providing wood products or paper, only about 50 percent is utilised. The remaining 50 percent is available as by-products for energy utilisation (Kåberger, 2004). After the wood products or paper have served the intended purposes and the opportunities for recycling are exhausted, most of the energy content is recoverable. Bioenergy is not competing with the forest industry. On the contrary, the by-products are considered co-products by the forest industry (Kåberger, 2004). In Sweden, bioenergy is important to the viability of the forest industry in general and sawmills in particular.

Bioenergy systems generate both direct and indirect employment. In the Vansbro Case the local employment associated with the production of wood pellets supported investments in bioenergy. The utilisation of local biomass resources implies that expenditure on energy provision is retained in the local community and re-circulated. The employment generated through bioenergy systems therefore stimulates regional development (SVEBIO, 2004).

4.3.4. Environment and Landscape

Utilising forest residues, agricultural residues, energy crops, and organic waste as biomass resources for energy purposes requires management and planning to meet the goals of sustainable development. In Sweden, forestry practices have improved in terms of preserving habitats and biodiversity in combination with expanding demands for bioenergy (Kåberger, 2004). Collecting forest residues appears to have no negative effects. On the contrary, the health and productivity of forests relies on thinning and managing the forests. In the Vansbro Case the need for thinning forests was linked with the development of a wood pellets plant.

When biomass resources are harvested from forests for energy purposes the nutrients and minerals are diminished in the forest soils. It is therefore important that the nutrients and minerals in the ash are returned to the forest soils. Ash recycling after stabilisation is feasible with almost 100 percent of all nutrients and minerals contained in the ash, except nitrogen (Kåberger, 2004). In the Växjö Case it is recognised that ash recycling is necessary in a sustainable bioenergy system, which has resulted in trials with ash recycling. In the Enköping Case the ash is returned to the forests.

When establishing energy crops there are several opportunities to combine environment and landscape goals. Energy crops are able to act as visual or wind barriers on the landscape, prevent erosion and degradation, and create habitats for birds and mammals thereby supporting biodiversity on agricultural land (Kåberger, 2004). Cadmium in fertilisers has resulted in undesired levels of cadmium in agricultural land. Willow has the capacity to absorb cadmium, so planting willow and storing the ash after combustion contributes to diminishing levels of cadmium in agricultural land.

5. Conclusion

Expanding bioenergy contributes to sustainable development by combating climate change, improving energy security, and promoting regional development. This paper has highlighted how sustainable bioenergy systems in Sweden stimulate regional development and produce multiple benefits across environmental, social, and economic spheres. However, measuring and incorporating regional development and the multiple benefits associated with sustainable bioenergy systems into evaluations and decisions is often difficult (Helby *et al.*, 2004). Supportive policies and measures are therefore imperative to overcome constraints and exploit the potential of bioenergy in both industrialised countries and developing countries.

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