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Bioenergy villages in Germany: Bringing a low carbon energy supply for rural areas into practice

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ABSTRACT

An increasing number of rural municipalities wants to meet their entire energy demand with biomass. This article gives a system analytic view on these "bioenergy villages" by balancing pros (reduction of CO_2 emissions) and cons (increasing costs, land use) using the example of a model municipality in Germany. The results indicate that a 100% energy supply based on biomass from within the boundaries of a rural municipality is technically possible but less reasonable with respect to land use competition and costs of energy supply. Whereas heat and power demand in bioenergy villages can be covered with relatively little land use and to relatively low costs, the production of transport fuel based on energy crops (rape seed) leads to significant negative impacts. For a cost-efficient decarbonization of rural areas it can therefore be recommended to particularly expand the utilization of biomass for heat and power production and to reconsider the transport fuel production.

1. Introduction: concept and status of bioenergy villages

Numerous bioenergy villages have been realized in rural areas of Central Europe over the last decade, for instance in Güssing (Austria), Jühnde (northern Germany) or Mauenheim (southern Germany). In Germany alone, 55 additional bioenergy villages are already completed and 14 additional ones are in planning/implementation-stage [1]. Besides, more than 100 regions in Germany intend to cover 100% of their future energy demand with renewable energy [2].

Bioenergy villages aim to maximize coverage of energy demand with biomass and to operate the bioenergy infrastructure independently [3,4]. The German Agency for Renewable Resources (FNR) emphasizes that using fossil technologies for covering peak load demand can be compatible with the concept of bioenergy villages and specifies that – while balancing economic and environmental impacts – at least 50% of heating demand and 100% of the yearly electricity demand should be met with biomass [5]. To fulfill the requirements of the concept, energy autarky (within the territory of a municipality) can be aimed but is not a mandatory goal [6]. It is rather emphasized that biomass provision should be "regional" or "decentral".

Table 1 highlights some pros and cons of bioenergy villages. Looking at the realized villages, it is interesting to see that they do not restrict themselves to biomass utilization only and some even underline the implementation of additional renewable energy such as solar or geothermal energy. Moreover, it is noticeable that despite a relatively low energy demand density all bioenergy villages trust in district heating systems instead of using separate technologies for each building (such as split log or pellet boilers). This apparently is because district heating systems offer the opportunity to gain economies of scale, to switch over to renewable energy fast and collectively as well as to keep the added value completely within the region (by using regional energy sources as well as operating the plant and marketing the energy by local stakeholders). Additionally, rollout of district heating systems in rural areas often benefits from the lack of competing grid bound systems (e.g. pipelines distributing natural gas) [7]. And in fact, using renewable energy in rural areas seems to have advantages compared to urban areas, e.g. with respect to resource base and market penetration. A case study of Baden-Württemberg, Germany, for instance points out that in rural areas seven times more biomass (per capita) is available compared to large cities [8]. Moreover, 60% of Germany's installed bioenergy capacity is located in rural areas [9] although only 18% of the entire German population lives in such areas [10].

But as bioenergy villages are usually initiated in existing residential areas, still there are some kind of existing supply technologies (often individual boilers fueled with heating oil). Hence,

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Table 1
Pros and cons of bioenergy villages.

Pros	Cons
Low fuel costs and therefore low operating costs	High up-front costs (investments)
Stimulation of regional and rural economy	Transport of biomass (traffic)
Reduction of energy related "global" greenhouse gas emissions	Increase of "local/regional" emissions (particulate emissions)
Shifting away from finite energy resources	Increase of land use competition
Reaching (to a large extent) independency from price development of fossil energy carriers	
Image building and strengthening of tourism	Acceptance of residents is an important pre-condition for economic feasibility

acceptance is inevitable for successful project implementation as the exemplary case study of Mauenheim shows [11]: In Mauenheim (Baden-Württemberg, Germany) – a village of 400 people – the entire electricity and heat demand is met by using a combined heat and power (CHP) unit with biogas (for base load) and a woodchip-heating-station (for peak load). The project was initiated by a newly found enterprise of two local farmers, an external consulting agency, and an engineering company. In order to reduce barriers for acceptance and to improve the willingness of residents to connect to the district heating network, all costs over the entire lifetime of the project are covered by a specific price per kilowatt-hour. Whereas operators usually charge up to 10,000 EUR for tubes and house installations in similar cases, no one-time-payments were required. As one of the farmers was district mayor and both farmers are local villagers, trustful relations existed and good starting conditions were set. In a personal interview a resident stated: "Integrating people we trust paved the way for implementation". First steps of implementation included two public discussion rounds, offering personal dialogs to each household and a weekly consultation hour for discussing the contracts. It was clearly communicated that implementation would only take part if at least 50 percent of the households agreed on using the heat supply within the next two months. Self-dynamics and multiplication effects developed: residents showed their own initiative by contacting indecisive neighbors and encouraging them to connect to the district heating network. Within the time limit, two-thirds of the households (66 households) signed contracts for the heat supply with a duration of 20 years.

2. Material and method: a system analysis of bioenergy villages

Against the background of the rapid development of bioenergy villages, this survey investigates the technical prospects of bioenergy villages in rural areas and offers economic-environmental balances for typical bioenergy supply systems. This includes quite a huge bandwidth of bioenergy technologies such as fermentation biogas plants, district heating plants and CHP[1]-plants (combustion and gasification) as well as biodiesel plants and BTL[2] plants.

Specifically, we look at the following research questions: What prospects do bioenergy villages offer with regard to decarbonization of rural energy supply and economic competitiveness? What does the potential for CO_2 reduction of different technology combinations for bioenergy villages look like in comparison to each other? Is it possible to cover the entire energy demand of the village by using regional biomass potentials and is this reasonable when looking at the consumption of agricultural and forest area? Are the renewable options economic competitive to conventional supply options? What are pros and cons of bioenergy villages?

To answer these questions, we first considered to conduct a case study analysis of a few villages which in fact have switched over to energy supply with biomass. This approach promised to give us in depth insight on the pros and cons of bioenergy villages and to better address the challenges during practical implementation. But in turn, this course of analysis poses great challenges with regard to data-acquisition, even more as operators and municipalities apply different methods for their balances. Moreover, such approach would refer to villages with good frame conditions (best practice examples) only, instead of picturing the general prospects of bioenergy villages in Germany. Thus, to ensure a better quality of data and to allow a better transferability of results to other places, the balances are carried out using the example of a rural "model municipality". This methodological approach is inspired by the pioneer of urban ecology Abel Wolman, who applied a similar approach in the 1960s to analyze the material flows of an US-American City [12]. The assessment follows a methodology which is illustrated in Fig. 1.

First of all, a rural model municipality is identified and described with regard to its central characteristics (e.g. inhabitants, land use, energy demand, forest and agricultural area) with help of public statistics and a comprehensive literature review.

Following, a technology analysis is carried out to define the specific CO_2 emissions (g/kWh) and specific energy generation costs (EUR-cent/kWh) of eleven biomass technologies, one fossil technology (heat peak load) as well as fossil reference technologies for the provision of heat, electricity and transport fuel. The basic data regarding emissions and costs are taken from König and were adapted to the specific technologies in this survey [13]. The analysis is devoted to the principle of life cycle assessments (LCA) and includes direct and indirect emissions (up- and downstream processes, such as transport-diesel, fertilizer or deconstruction of facilities) as well as generating costs.

Based on the technology assessment, technologies are combined to 6 distinct technology systems which are capable of serving the entire energy demand of the model municipality. These combinations are balanced with regard to CO_2 emissions, costs and land use.

A holistic overview on methodology and assumptions for the environmental and economic balancing is given in Table 2.

The system assessment is based on the technical status quo (base year 2010) and does not refer to possible future technology

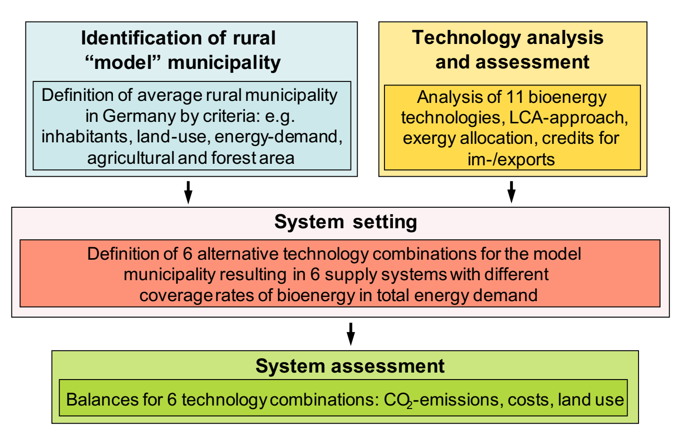

Fig. 1. The methodological design.

[1] CHP = Combined Heat and Power.
[2] BTL = Biomass to Liquid.