Techno-economic assessment of regional biomass use

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An approach for techno-economic optimisation and for the analysis of industrial biomass use is proposed in this paper. The ARGUS model (German acronym for: allocation module for a computer-aided generation of environmental strategies for emissions), based on linear programming, has been implemented as one of the few models that investigates VOC emissions from approximately 40 industrial sectors. Its approach can be transferred for an integrated assessment for biomass use.

1 Introduction

In order to achieve sustainable economic growth, the use of bio-energy, bio-fuels and bio-based products (cf. Table 1) is recently stipulated by various legislative initiatives worldwide. Increasing the use of biomass offers significant opportunities to reduce greenhouse gas emissions and securing raw material supply. Whereas for energy production, a variety of alternative resources (like wind, sun, water, or biomass) can be established, industry based on conversion of materials has to change from fossil to biological raw materials. Today's biorefinery technologies are based on the utilisation of the whole plant and on the integration of traditional and modern processes for the exploitation of biological raw materials [1]. However, the substantial rise in the use of biomass from agriculture, forestry and waste may potentially counteract other environmental and economic policies and objectives [2]. Thus, suitable approaches for the estimation of the longer term effects of biomass use are needed. In this paper, first current models for biomass generation and use are reviewed, before a techno-economic assessment approach for regional biomass use is outlined.

Table 1: Overview on biobased products (following [1])

Biomaterials	**Fuels & Energy**	**Biochemicals**
• Oils and Inks • Dyes and Pigments • Paints and Varnishes • Detergents and Cleaners • Industrial Adhesives • Biopolymers and Films • Composite Materials	Solid: Coke, Lignin, Bagasse Liquid: Ethanol, Methanol, Fuel Oil Gaseous: Syngas, Methane, Hydrogen	• Activated Carbon • Oxy fuel Additives • Pheonls and Furfural • Speciality Chemicals • Fatty and Acetic Acids • Industrial Surfactants • Agricultural Chemicals

2 Modelling of biomass generation and use

The amount of available biomass primarily depends on the available land area and the yields of the cultivated crops. Land use models are being developed for regional and global scale simulation experiments in order to simulate the interactions of various drivers determining land use. Recently, the effects of bioenergy production on competing land use sectors like food production and on the extent of natural land as well as on ecosystem services are of major interest. One exemplar model is LandSHIFT (Land Simulation to Harmonize and Integrate Freshwater Availability and the Terrestrial Environment), which aims to simulate the interactions of socio-economic drivers and the biophysical environment [3]. Thus, it allows investigating the effects of an increasing demand for food on the spatial extent and intensity of agriculture and on competing land use sectors such as forestry versus the urban/industrial sector under climate change conditions.

Due to the importance of sustainable energy supply, numerous research projects and models cover the whole value-added chain, from primary energy generation, energy conversion, transmission as well as distribution and use of energy. For instance, the model AVALANCHE (Environmental Balances for the Use of Regenerative Energies) aims at the assessment of the cost-effectiveness and environmental impacts of wind energy-, photo-voltaic-, bio-gas-, and small hydro-electrical technologies [4]. Other research concentrates on efficient trading of biomass fuels and analysis of fuel supply chains and business models for market actors by networking (cf. www.eubionet.net, [5]). Current and future biomass fuel market trends and biomass fuel prices are analysed, and the techno-economic potential of the biomass is estimated until 2010.

When it comes to biomass use in industry, non-food crops are in the centre of research. In Asian countries, typical biomass crops include sugarcane, cassava residues, and palm oil and residues. Their mass flows for long term simulation periods can be described using constraint formulas in linear programming (LP), with supply, demand, and conversion efficiencies as exogenous parameters. Alternatively, system dynamics approaches are being suggested [6]. In Europe, besides switchgrass, hemp, corn, willow and sugarcane, species are being rediscovered such as kenaf as a fibre to manufacture rope, twine, coarse cloth, and paper (cf. http://www.cres.gr/biokenaf/). Dynamic crop-growth simulation models can predict yields, evaluate the effect of harvest timing and storage methods on the quality of the raw material and assess the feasibility of the specific biomass use for industrial and energy applications.

More emphasis on agricultural development and a microeconomic basis is put on in CAPSIM, a partial equilibrium modelling tool with behavioural functions for activity levels, input demand, consumer demand and processing [7]. It is designed for policy relevant analysis of the Common Agricultural Policy (CAP). Its moduls are coded in GAMS (General Algebraic Modeling System), a high-level modeling system for mathematical programming and optimization for complex, large scale applications. For the consideration of more regional aspects, Geographical Information Systems (GIS) are being employed, in combination with system dynamics and indicator modelling, in order to integrate rural areas, natural and human capital and sectors like agriculture, energy, fisheries, forestry, industry, small business, tourism and transport [8].

It can be concluded, that the models developed so far concentrate on conventional agriculture (aiming at an integrated development of agricultural and rural areas) and mainly on bio-energy production. As regards biomass use for industrial purposes, mainly feasibility studies, especially for non-food crops, have been performed. Here, especially the logistics of biomass has to take into account various peculiarities. Like other agricultural products, biomass may have losses during storage, resulting in positive effects (as moisture loss and thus reduced transportation costs) or in negative effects (as dry matter losses, reducing the value of the material) [9]. A suitable approach for a techno-economic assessment of industrial biomass use has to take into account the following aspects:

- amount of available biomass and its temporal variations
- competing demand of bio-energy, bio-fuels and bio-based products (not forgetting the food demand)
- stage of development of production processes (including experience curve effects and economies of scale)

3 Dynamic Mass Flow Optimisation Models

In a theoretical system view, national and regional energy and material flow models represent systems whose elements consist of energy transformation or production technologies, which undergo a transformation from energy, to materials to emissions. The elements are interrelated via material and emissions flows. The intent is to derive strategic and normative recommendations for future system configurations. For estimating the economic consequences of environmental measures in a region, techno-economic optimisation models have been developed (for an overview, cf. [10,11]). They provide the 'cost optimal' evolution of the production system over a given planning horizon, ensuring the supply of demand for products or services specified exogenously on the sectoral level. One example is the ARGUS model (German acronym for: allocation module for computer-aided generation of environmental strategies for emissions), based on linear programming, which has been implemented as one of the few models that investigates VOC emissions from approximately 40 industrial sectors [12]. What follows is a discussion if this approach can be transferred for a techno-economic assessment for biomass use.

ARGUS is based on a detailed representation of all relevant production processes and the corresponding applicable emission reduction options, which are structured according to a reference installation approach [13]. It takes into account the mass flows that are generated by the considered industrial sectors. The objective function for the linear optimisation describes the minimisation of the expenditures (operating costs and investments for production processes and their retrofit for biomass use) in the considered time periods on the net present value basis. By means of further sensitivity analyses, alternative strategies for biomass use can be examined comprehensively. In summary, it can be characterised as follows:

- *Flexible choice of the aggregations level*: Due to their variable nature energy and production systems can be represented on a national, regional and plant level.
- *Bottom-Up-Approach*: Modelling on a technology level allows the detailed representation of production systems.

- *Consideration of dynamic effects:* Energy and material flow models allow the representation of different possible development paths over varying periods. Especially changes in the future demand for biomass or replacement investments in new techniques due to end of lifetime can be considered. Dynamic investment calculation procedures allow, through discounted expenditures based on the net present value method, a comparison between future expenditures.

3.1 Uncertainty Observations

Any modelling is subject to various sources of uncertainty. The occurring uncertainties can be classified in several ways (see for instance [14,15]). According to their respective source, a distinction can be made between “data uncertainties”, “parameter uncertainties” and “model uncertainties” (resulting from the fact that models are ultimately only simplifications/approximations of reality). Especially the modelling of biomass use is subject to the following variabilities:

- *Spatial variability*, such as regional differences in the local environment, e.g. the geographical and climatic conditions, influencing the amount and quality of bio-mass and consequently the subsequent production processes;
- *Temporal variability*, e.g. differences in yearly harvests or effects caused by storage;
- *Variability between sources*, e.g. different techno-economic characteristics of the relevant production plants (e.g. depending on the used input materials and the mode of plant operation).

Derived quantitative statements only have limited information value because uncertainties in the primary data are known only with minimal statistical confidence, or in individual cases are not known directly but must be estimated from other studies.

In the strategic planning of complex systems the scenario technique is employed in order to account for uncertainty and to play through various future development possibilities. By comparing assorted exploratory scenarios the effects of decisions can be analysed [16]. For the definition of model scenarios the start and target years can be varied; various transition periods can be defined, or changes in subsidy practices can be explored. In addition, a high technological and temporal resolution within the model enables the consideration of dynamic effects, for instance new technology developments (and experience curve effects), outdated technologies, or variations in product demand, which can occur during the planning period.

3.2 Consequences for production planning

The problem of planning the future production capacity of a company can be addressed in numerous ways and has been extensively discussed in literature. When companies face a seasonal demand, the problem of capacity adaptation can become even more challenging, as there may be a constant need for capacity adaptations. In contrast to conventional chemical processes, the use of biomass has several distinct characteristics: Raw materials differ in quality, have a time dependent availability, come from decentralised sources and require adjusted logistics operations.

Consequently, the analysis of biomass use with its special characteristics requires suitable planning tools that take into account the dynamics of the production system (for example by following the seasons and the yearly changes). Furthermore, the control of the single unit operations in the context of renewables with respect to the overall systems performance is more complex than in classical mass and energy flow management systems.

3.3 Possible goal conflicts

New aspects in the planning process must be considered, such as the opportunity to reduce CO_2 emissions, the decentralised structure within the process chain (requiring low transport distances) and the economic development of urban areas. However, the biomass potential is limited by forest and agricultural crop land and the plant size (due to the transport costs) limiting the economies of scale. This tends to result in a competition between acreage and biomass (food production, material use of biomass, different energetic biomass paths) requiring a multi-criteria assessment identifying the best utilisation of a given area.

Ideally, a monetarisation of the environmental effects of production activities would allow fully integrated assessments. Approaches for the internalisation of external costs (and benefits) for the use of the environment are being discussed, but they are afflicted by numerous drawbacks, since the monetary evaluation of nature is the subject of an ongoing scientific debate [17].

Thus, the formal methods for multi-criteria analysis (MCA) seem to be more appropriate, considering multiple, and to some extent conflicting dimensions [18,19] . Both quantitative and qualitative information can be taken into account because the aggregation is based on a transformation using value functions or preference functions. The basic question for the choice of an appropriate MCA method for the techno-economic assessment of regional biomass use is the degree of integration. The most advanced solution would be the integration of multiple objective functions into a combined model. However, due to the increase of computational effort (which is already immense with the current mass and energy flow models), this approach seems less feasible for the time being. In particular, sensitivity analyses would become impossible because of the size of the mathematical problem.

The alternative approach would use the calculated emission reduction strategies for the one-dimensional goal functions (with regard to the single media) as the input for a multidimensional decision table. Model runs and combinations of model runs are then treated as discrete alternatives. This approach, based on simulations of various scenarios, would yet require more model runs and more iterative steps. As an advantage, hardly quantifiable information could also be taken into consideration [20].

4 Conclusions and recommendations

The techno-economic optimisation model ARGUS has been implemented as one of the few models that investigates VOC emissions from approximately 40 very heterogeneous industrial sectors. Its approach can be transferred for an integrated assessment for biomass use, because it offers a flexible choice of the aggregation level, the bottom-up approach based on representative reference installations and the consideration of dynamic effects. Special emphasis is necessary for the consideration of the enormous uncertainties in future biomass use. Additionally, multi criteria analysis is suggested for the investigation of the numerous goal conflicts.

5 References

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