OPTIMISATION OF THE BIOECONOMY – COST-EFFECTIVE SWEDISH BIOENERGY PATHWAYS

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Overview

Use of bioenergy could contribute to reduction of greenhouse gases (GHGs) and increased energy security, but to what extent depends on the cost and potential availability of biomass resources. While bioenergy today is primarily used in the stationary energy sector for electricity and heat production, there is a strong interest in options for biofuels for transport and the use has in recent years increased significantly albeit from very low levels. Declared policy targets on both national and international levels also aim at increasing its future share while also targeting lower GHG emissions.

Biomass can be used for a number of applications, e.g., as for biofuel production and/or heat/power production or as feedstock in the forest product industry. Changes in biomass demand in any of these sectors will affect biomass markets and, thus, imply altered conditions for other biomass use. A wide systems approach in the analysis of efficient bioenergy utilization and ways of meeting climate targets is therefore imperative.

This study aims at exploring system interactions related to future bioenergy utilization and robust cost-efficient bioenergy technology strategies for the case of Sweden and, from a systems perspective, identify bio-based fuel and technology scenarios cost-efficiently meeting demand for energy services and environmental objectives, assess utilization options of biomass, analyze costs and effects of different energy policy strategies. The main research questions include:

- How will implementation of stringent CO_2 reduction and road transport fossil fuel phase-out polices affect future utilization of biomass and its price?
- Under stringent CO_2 constraints, how can integration of second generation biofuel production with existing industry or district heating systems influence future cost-efficient biomass utilization?

The research questions are explored using a variety of scenarios in which effects of potential development paths for the factors of importance for the national energy system are tested. Examples of such key factors include CO_2 reduction levels and technology development.

Methods

To address the complex dynamic relationships between sub-sectors of national energy systems, a system modeling approach is applied. A model structure of the Swedish energy system, the so-called MARKAL_Sweden model, based on the internationally well-established, dynamic, bottom-up modeling framework MARKAL, is further developed and applied. The result of a model run represents the overall cost-optimal system solution meeting the defined model constraints (e.g., regarding energy service demands and emission restrictions).

MARKAL_Sweden applies a long-term time horizon reaching from 1995 to 2050. The model applies a comprehensive view of the Swedish energy system and represents all relevant sectors including electricity, district heating, industry, transport, premises and services. The system is represented as a network of energy technologies and flows of energy carriers, covering fuel extraction and import, via energy conversion technologies and distribution systems to end-use energy demands, such as for transportation, space heat and industrial process heat. Technology input data to the model include technology properties such as current capacities, investment costs, operation costs and conversion efficiencies for energy technologies in all parts of the national energy system.

In the study, the MARKAL_Sweden model is improved in several respects, e.g., in regard to the biomass supply representation. Potentially available quantities of biomass from forestry are based on data from the Swedish Forest Inventory. The forest development is simulated using HUGIN, a calculation system that enables the calculation of potential outcomes of stemwood, logging residues and stumps from harvesting operations. Supply data from the forest potential modeling are then used to construct detailed biomass supply curves which are integrated into the MARKAL_Sweden model.

Significant model developments are also carried out for the representation of conversion routes for bioenergy, in particular, regarding the model description of integration opportunities for second generation biofuel production, which often have a relatively large net surplus of heat. Thus, heat integration with heat sinks can further increase system efficiency and lower the costs. A number of options for biorefinery heat integration with district heating systems and existing industry are added to the model. Black liquor gasification in the paper and pulp industry can be seen as a special case of industry integration and is treated as a separate alternative.

Results

The results indicate a potential for significantly increased use of bioenergy in the energy system. The high demand and strong competition for biomass significantly increases biomass prices and leads to utilization of higher-cost biomass sources such as stumps and cultivated energy forest. To some extent, pulpwood is also used for energy purposes.

The allocation of bioenergy between sectors differs over the studied time horizon and depends on the energy policies applied. For CO_2 reductions of 80% over the studied period, the largest increase in biomass utilization occurs in production of transport biofuels, which by 2050 accounts for 41% of total primary biomass use. The scenario shows a required annual growth rate for road transport biofuels of about 6% from 2010 to 2050. Due to the limited amount of biomass resources available, and the strong demand for transport biofuels, biomass use for heat and power generation declines in the second half of the studied period.

If a sector specific fossil fuel phase-out policy is implemented in the road transport sector, aiming at close to fossil-free road transports already by 2030 (defined as -80% until 2030), while keeping the system-wide CO_2 reduction of 80% to 2050, a doubling of the annual growth rate of transport biofuel (to 12%) until 2030 is required. A large part of the biomass resources is then allocated to biofuel production in the middle of the studied period. Compared to the situation without a fossil fuel phase-out policy, the total system-wide use of bioenergy is about 5% higher, while the use for heat and power is about 20% lower in 2030. However, the difference between the two situations is small in 2050.

Results imply that second generation biofuels are an integral part of optimized system solutions meeting stringent climate targets. However, even in a biomass endowed country like Sweden, the utilization of biomass resources will be constrained, and transport energy efficiency measures constitute a highly important part of a carbon-free transport sector in order to reduce fuel demand (e.g., by use of energy-efficient vehicle technologies, such as plug-in hybrids).

Integration of biofuel production with heat demands in industry or district heating systems can be a cost-efficient option for meeting of stringent CO_2 constraints. Under the assumed conditions, such technology solutions increase system efficiency, lower the production cost of biofuels and the overall system cost. In the model results, integrated alternatives are chosen over stand-alone options in all cases such options are available. However, the level of cost saving from integration differs from comparably large in some cases to small in other. Under the assumed conditions, biofuel production through black liquor gasification shows high cost-competitiveness while biofuel production with heat integration shows somewhat lower.

The integration options available are of large significance for which biofuel option shows the highest cost-competitiveness. Regarding second generation biofuels, SNG is chosen to a comparably large extent in all cases. In cases with only stand-alone second generation biorefinery plant configurations available, SNG gets a dominating position. Due to its high production conversion efficiency, SNG is an advantageous option despite comparably high distribution and vehicle costs. However, when black liquor gasification is available, this option is utilized for methanol production. Benefits of methanol include low distribution and end-use costs compared to gaseous fuels. Heat integration cases have primarily a positive impact on ethanol production, for which available polygeneration plant configurations show high efficiency.

Stringent CO_2 constraints will induce a strong biomass competition, which in turn is likely to significantly increase future biomass prices compared to today's levels; substantial increases in biomass prices are seen across all modeled scenarios applying CO_2 emission constraints. Increased stress on the system in the form of additional policy measures, such as early fossil fuel phase-out in road transport or a nuclear power phase-out, or other factors such as slower than anticipated development and cost reduction of electric vehicles further pushes up biomass prices.

The CO_2 shadow prices (marginal costs) generated by the model suggest that significant penalties (e.g., taxes) on fossil fuels are required to achieve stringent CO_2 reductions to 2050. Under the assumed conditions, the results suggest that gasoline taxes in the long run needs to at least be doubled while keeping biofuels tax exempt if the modelled emission reductions and technology transition should occur. Other sectors than transport show lower marginal CO_2 reduction costs.

Conclusions

The study concludes that in an optimised carbon neutral energy and transport system the use of bioenergy increases significantly and results in considerable utilization of higher-cost biomass sources such as stumps and cultivated energy forest. It also leads to strongly increased production of transport biofuels and that biomass use for heat and power generation declines in the second half of the studied time period. If a sector specific fossil fuel phase-out policy is implemented in the road transport sector this results in a small additional bioenergy use in 2030 but it has only minor impacts in 2050. The optimized bioeconomy implies a strong increase in marginal biomass costs and high CO2 prices are required to attain a carbon neutral system.