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Assessing the economic efficiency of bioenergy technologies in climate mitigation and fossil fuel replacement in Austria using a techno-economic approach

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ABSTRACT

The core issues of the Austrian energy policy agenda include reducing greenhouse gas (GHG) emissions and dependence on fossil fuels. Within this study, the costs of GHG mitigation and fossil fuel replacement (abatement costs) of established and upcoming bioenergy technologies for heat, electricity and transport fuel production are assessed. Sensitivity analyses and projections up to 2030 illustrate the effect of dynamic parameters on specific abatement costs.

The results show that the abatement costs of wood-based heat generation technologies substituting oil-fired boilers and gas-fired heating plants, respectively, are in the range of −45 € per ton CO_2-equivalent (€/t CO_2-eq.) and −11 € per MW h higher heating value (€/MW h_{HHV}) to 93 €/t CO_2-eq. and 24 €/MW h_{HHV}. Heating systems around 50 kW show the lowest abatement costs. For combined heat and power (CHP) plants, two different cases with regard to heat utilization are assumed. In an optimal mode (100% of generated heat displaces fossil fuel-based heat production), abatement costs of wood-based technologies, substituting electricity from modern combined cycle gas turbines, range from 5 €/t CO_2-eq. and 1 €/MW h_{HHV} to 201 €/t CO_2-eq. and 38 €/MW h_{HHV}. Representative values of typical CHP plants with a capacity of 1 MW_{el} and more are in the magnitude of 50 €/t CO_2-eq. and 10 €/MW h_{HHV}. Under less favorable conditions (3000 heat full load hours per year), abatement costs of typical plants are around 100 €/t CO_2-eq. and 17 €/MW h_{HHV} higher. The costs of GHG mitigation and fossil fuel saving with established transport fuels (biodiesel and ethanol) range from 71 €/t CO_2-eq. and 8 €/MW h_{HHV} to 200 €/t CO_2-eq. and 82 €/MW h_{HHV}. For liquid fuels from lignocellulosis, abatement costs are estimated 147 €/t CO_2-eq. and 38 €/MW h_{HHV} to 240 €/t CO_2-eq. and 59 €/MW h_{HHV}. The abatement costs of synthetic natural gas are found to be significantly lower: 75 €/t CO_2-eq. and 14 €/MW h_{HHV} to 128 €/t CO_2-eq. and 23 €/MW h_{HHV}. The results suggest that heat generation and – given favorable conditions – CHP generation are the most cost-efficient options for reducing GHG emissions and fossil fuel dependence in Austria. A core advantage of CHP is higher quantities of abatement per unit of biomass used. In contrast, this is found to be the main drawback of synthetic transport fuels from wood.

1. Introduction

Two of the major challenges of the European Union's and Austria's energy policy are to reduce greenhouse gas (GHG) emissions and dependence on fossil fuels [1]. Bioenergy is generally expected to make a significant contribution to these energy policy targets (see [2] or [3]). Not only because it currently (2008) has the highest share of all renewable energy sources in Austria (and the EU), but also due to its vast potentials and the fact that it can be used in all energy sectors: for heat-only production or combined heat and power (CHP) generation as well as for the production of biofuels.[2] Furthermore, there is a wide variety of biomass fractions, technologies and plant sizes. Hence, there are numerous pathways for energy conversion from biogenic energy carriers, each of which has specific properties with regard to GHG mitigation, fossil fuel replacement and economics.

1.1. Biomass and fossil fuel consumption in Austria

Biomass currently accounts for about 15% of the total primary energy consumption in Austria (all data about the current energy use stated here are based on [4,5], and refer to 2008 unless

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[2] The term "biofuel" is used for liquid and gaseous fuels produced from biomass and usually used for mobility, such as biodiesel, ethanol, Fischer–Tropsch-Diesel or biomethane (cleaned and conditioned biogas from anaerobic digestion).

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otherwise stated). Until the end of the 20th century, the use of bioenergy was virtually limited to heat generation (residential heating and process heat generation). Today biomass accounts for about 30% of the total energy demand for space and water heating. Despite the growing importance of renewable energy sources, fossil fuels account for more than 50% (heating oil: 74 PJ, natural gas: 76 PJ). Therefore, the use of biomass in the heat sector still holds the opportunity for substituting significant amounts of fossil fuels.

Biomass has also become increasingly important for district heating, power generation and in the transport sector due to support schemes in recent years. About 38% of the district heat supply is currently based on biomass (25.5 PJ), with 17% coming from heating plants and 21% from CHP plants.[3] The non-renewable production of district heat is dominated by natural gas: 32% of the total supply originate from natural gas CHP and 10% from heating plants.

In the electricity sector the biomass share has increased from 3% in the late 1990s to 6.5% in 2008. Fossil-based electricity generation accounts for about 30% (with more than half of this coming from natural gas-fired power plants), the rest is primarily hydropower.

As a consequence of obligatory quotas and tax incentives, the share of biofuels in road transport fuel consumption has increased from less than 1% in 2005 to 7% in 2009 [6]. The fossil fuel consumption in the transport sector accounts for about 300 PJ/a (about 75% diesel and 25% gasoline).

1.2. Objective

Comparing GHG mitigation costs of different technologies is a commonly used approach for identifying efficient strategies for achieving climate policy targets (e.g. [7,8]). However, there is scarce literature comparing GHG mitigation costs of different bioenergy technologies, taking into account the wide range of plant sizes and variable operational characteristics, such as annual full load hours or heat utilization rates of CHP plants.

The objective of this work is to assess GHG mitigation costs as well as costs arising from replacing fossil fuels with bioenergy technologies for the situation in Austria. Biomass and fossil fuel prices are based on specific data for Austria. Costs data were also preferably taken from studies referring to the situation in Austria (e.g. [9]) and the selection of technologies is based on which plant types and sizes are common in Austria. In addition, technologies which are likely to become more important in the future are taken into account. The results are to provide insight into the question of how limited biomass resources can be utilized in a most efficient way, and how bioenergy can contribute to the achievement of energy policy targets in a cost-efficient way for the specific case of Austria.

In contrast to these and other publications on this topic (see Section 4), a core objective of this study is to highlight the influence of plant sizes and other (country-specific) parameters on the efficiency of bioenergy technologies for GHG mitigation and fossil fuel replacement. Furthermore, projections for technological developments, plant costs and fuel prices are used to assess trends up to 2030.

2. Methodology and data

2.1. Methodological approach

The methodological approach consists of the following steps:

First, default reference systems are defined for each cluster of bioenergy technologies. The selection of reference technologies is based on the current supply structure in the according energy sector (see Section 1.1); those fossil-based energy systems which are most likely to be replaced with bioenergy technologies are defined as default reference system. Table 1 gives an overview of the technology clusters and their fossil fuel-based reference systems in the default case and sensitivity analyses (alternative cases). Since oil-fired boilers are still very common in Austria, they are considered as reference technologies for biomass systems. Oil-fired stoves are the reference system for biomass stoves. Due to the increasing electricity demand in Austria and the fact that natural gas-fired combined cycle gas turbines (CCGT) are assumed to constitute the price setting technology, modern CCGT are considered as reference technology in the default case. The production costs of liquid and gaseous biofuels are directly compared with wholesale prices of the fuel they displace (i.e. fossil diesel, gasoline or natural gas).[4] The alternative reference systems are discussed in Section 3.6.

Next, a default set of technology data, representative fuel prices, etc. is compiled. These data are summarized in Section 2.2 and the Appendix, respectively. Third, the costs of bioenergy and reference technologies are calculated and compared on the basis of the total energy generation costs (long run marginal costs, LRMC), i.e. heat, electricity or fuel production costs, depending on the technology type. The production of waste heat in CHP plants as well as byproducts of fuel production plants are taken into account in the form of revenues (see formulas in Appendix).

Finally, greenhouse gas mitigation costs of bioenergy technologies (subscript "x") are calculated as the incremental generation costs ΔC_x per unit decrease in GHG emissions ΔE_x, following [12,13]:

$$C_{mit} = \frac{\Delta C_x}{\Delta E_x} = \frac{C_x - C_r}{E_r - E_x} \quad (1)$$

C_x (C_r) denote the specific LRMC and E_x (E_r) the specific GHG emissions resulting from energy generation with the bioenergy technology (the reference system).[5] The mitigation cost can be interpreted as the minimum incentive in the form of a carbon tax which is required to equal the additional cost of a bioenergy system with the cost of the reference system. Tax incentives and other subsidies which are currently in place are not considered in this calculation. Possible carbon stock changes related to biomass use are also not taken into account, as it is assumed that the considered utilization paths do not result in land use change.

When E_x and E_r in Eq. (1) are replaced by the specific cumulated fossil fuel demand of the bioenergy technology D_x and of the reference technology D_r, Eq. (1) defines the cost of fossil fuel replacement. Auxiliary energy consumption (fossil fuel-based), peak load coverage in biomass heating and CHP plants, energy consumed in the fuel supply chain and the related GHG emissions are taken into account for bioenergy and reference technologies.

2.2. Data

The default technology data, including capacities, efficiencies, default full load hours per year, specific GHG emissions, cost data as well as explanations to the technology data are stated in Appendix A. The specific GHG emissions used in this work are based on datasets of the GEMIS model [14] which have been adopted according to the assumed technology data (e.g. efficiencies). The specific GHG emissions related to the production of biofuels are partly based on the "typical greenhouse gas emission saving" stated in Annex V of [1] (see Table A3). The default fuel prices and byproduct credits are given in Table 2. Calculations based on these data are referred to as "default case" for the base year 2010. All monetary data are real prices/costs with the base

[3] The biogenic fraction of waste is not included in these shares.

[4] Engine modifications and additional costs which might arise from the displacement of fossil fuels with biofuels are not taken into account.

[5] Only systems with $(E_r - E_x) > 0$ are assessed, i.e. technologies which have lower specific GHG emissions than the reference system.