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Transformation scenarios towards a low-carbon bioeconomy in Austria

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A B S T R A C T

The transformation towards a low-carbon bioeconomy until 2050 is one of the main strategic long-term targets of the European Union. This work presents transformation scenarios for the case of Austria with GHG reduction to about 20% of Kyoto baseline. The scenarios are developed with an optimization model integrating the energy sector, land use and biomass flows. Focus is on investigating possible developments in domestic biomass supply and use. Biomass is crucial for (largely) decarbonising the energy system and replacing fossil-based and energyintensive materials. Domestic biomass use (dry mass) increases by 32% in an 'intensive' and 11% in an 'alternative' transformation scenario, while total energy consumption decreases by 40%. Transformation to a low-carbon bioeconomy could be accomplished without additional biomass imports.

1. Introduction

1.1. Background

With its 2011 ‘Low Carbon Roadmap’ [1], the European Union has committed itself to establish a low-carbon economy until 2050. Starting with 1990 as base year, the roadmap shows a pathway towards an 80% reduction in domestic greenhouse gas (GHG) emissions by 2050. Furthermore, in February 2012 the EU launched a strategy for “A Bioeconomy for Europe” [2], which aims at driving the transition from a fossil-based economy to a sustainable bioeconomy. This strategy addresses crucial societal challenges such as food security, natural resource scarcity, dependence on fossil resources, climate change and sustainable economic growth. The ‘bioeconomy’, according to the strategy, encompasses ‘the production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, bio-based products and bioenergy’ [2].

Biomass will be of crucial importance for reducing GHG emissions and the dependence on fossil resources; not only in energy supply – as the EU's ‘Energy Roadmap 2050’ [3] and the National Renewable Energy Action Plans indicate (cf [3,4]) – but also with regard to the replacement of energy- and carbon-intensive products. Already today forestry and the wood processing industries are key elements of Austria's economy. Biomass is currently the most important renewable energy source [5] and is usually considered to be of high importance for the establishment of a sustainable energy system (cf [6,7]).

A transformation towards a bioeconomy might lead to rising demand for biogenic resources and increasing pressure on land; it might promote land use change and result in environmentally harmful intensification of agriculture, possibly resulting in an increase in non-energy related GHG emissions and a decline of natural carbon stocks (cf [8]). It is therefore essential to apply a model

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with full carbon accounting (cf. [9] [10–12]) and consider all relevant GHG sources and sinks, namely emissions from agriculture, land use, land use change and forestry (LULUCF) as well as artificial carbon stocks like wood products.

1.2. Research question

While EU documents and accompanying studies provide some insight into transformation pathways for the EU, there is currently little knowledge on the feasibility and implications of transformation on a smaller scale (i.e. on national level) and the possible contribution of locally available biomass resources. This work aims at contributing to fill this research gap by answering the following core question: To what extent can domestic biomass contribute to the establishment of a low-carbon bioeconomy in Austria until 2050?

To this end, it is investigated whether pathways leading to a reduction of GHG emissions by at least 80% are feasible without an increase in biomass net imports. Austria's base year emissions under the Kyoto Protocol, which correspond to the historical GHG emissions in 1990 without consideration of LULUCF, are considered as the reference level. Apart from an 80% reduction of GHG emissions, a significant increase in biomass use as material as well as enhanced cascading utilization chains are envisaged, in order to justify the term 'bioeconomy transformation' (cf [2]).

2. Methodology

2.1. Modelling environment and approach

The model is implemented in the programming environment of 'TIMES-VEDA' (cf [13–15]). The TIMES model generator (The Integrated MARKAL-EFOM System) was developed for deriving long term energy scenarios and conduct energy and environmental analyses. It uses linear programming to generate a least-cost energy system, optimized according to certain constraints, in order to explore possible energy futures based on scenarios [13].

The optimization target of the presented modelling approach is to minimize GHG emissions, while economics are ignored. This approach is appropriate for deriving scenarios with maximum emission reduction without the necessity to assume concrete policy measures and highly uncertain parameters like fuel and raw material prices or cost developments for conversion technologies. The resulting scenario are, on the other hand, not cost-optimal; they might, for example, result in vast employment of high-cost bioenergy technologies (cf. section 5).

In the resulting scenarios, biomass is utilized in a way that is most efficient in reducing GHG emissions under the given constraints. Certain constraints are equal in all scenarios, such as dynamic constraints on technology diffusion, on fuel switch and market diffusion of individual bio-based products. Others are scenario-specific parameters (see Section 3.2).

The time resolution of the model is 5 years, with three time slices for the seasonal and two for the day-night level (cf [15]). These 'sub-annual' time slices are, however, only implemented in the electricity and the district heat sector, where generation profiles (especially from fluctuating renewable energy sources) and consumption patterns (load profiles) are relevant for capacity utilization and plant deployment.

Agricultural biomass supply and use in the scenarios is to a large extent determined by food and feed requirements. Yield development and dietary habits are the main factors determining the agricultural land resources available for growing crops for bioenergy and material uses. How the remaining land and biomass resources are utilized is determined endogenously based on GHG balances of the value chains and their fossil-based counterparts.

2.2. Data sources and model calibration

The model comprises two main elements: An 'energy module', which is a representation of the Austrian energy system, and a 'biomass module', which includes all relevant aspects of biomass supply, processing and consumption. The two modules are interlinked in several ways: through biomass being used in the energy sector (i.e. being converted from mass to energy flows), through biofuel plants producing animal feedstuff as by-product or industrial energy demand depending on developments in wood processing industries.

The scope of the biomass module goes beyond technical uses of biomass (i.e. for energy or materials) but also considers biomass flows induced by food consumption. For this purpose, specific per capita diets, such as vegetarian or reduced meat diet have been defined according to dietary guidelines [16] as well as their relative shares within the population (cf. supplementary material). As for other categories this final demand is converted into a corresponding demand for primary biomass, based on different conversion factors, in particular feed balance sheets. Primary biomass supply is linked to representations of agricultural land use, land use change and forest management.

The base year is 2010. Biomass flows and foreign trade streams, energy supply and consumption, installed plant capacities, land use structure etc. are calibrated to statistical data. The main data sources for the energy module include the national energy balance [5], the 'useful energy analysis' [17] and statistical data provided by the Austrian energy regulator [18]. Data used for calibration of the biomass module are from foreign trade statistics [19], commodity balances [20] statistics on agricultural production [21], on wood supply and consumption [22] and many more. Sources regarding biomass flows are to a large extent identical to the data used to map biomass flows in Austria in Ref. [23]. A complete list of data sources is provided in this publication.

Data for 2015 have not been available at the time the simulations were carried out. However, certain developments from 2010 to 2015 have been defined exogenously based on projections derived from developments until 2014. This approach ensures that relevant trends which took place after 2010 are represented in a realistic way. The following sectors and flow data are predetermined until 2015: the bioenergy sector (generation capacities and utilization), wood flows (production and consumption of the wood processing industries), bio-based product supply and consumption (biopolymers, bio-based insulation material etc.) as well as individual parameters in other sectors. Data on life-cycle emissions of conventional and bio-based products have been adopted from publicly available databases ([24,25]), scientific publications ([26,27]) and environmental product declarations ([28,29]). Energy technology data (like typical conversion efficiencies and utilization factors) and assumptions regarding future developments are based on previous studies [30,31] and literature [24,25,32–35]; and are calibrated to statistical data [5,18]. Assumed technology development in bioenergy is characterized by moderate efficiency increases for well-established technologies and large-scale commercial availability of 'second generation' biofuel technologies and thermochemical biomass gasification after 2020. Relatively immature technologies like algae-based pathways are disregarded.

Forest management scenarios are calculated with the dynamic forest succession simulator PICUS v1.4 [36,37]. The simulation results – time series for wood removals (differentiated by wood qualities) and forest stock development (and corresponding net