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Research paper

Advanced biomaterials scenarios for the EU28 up to 2050 and their respective biomass demand

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A B S T R A C T

In order to reach sustainable development, the EU plans to expand the production of renewable resources and their conversion into food, feed, biobased products and bioenergy. Therefore also advanced biobased products like e.g. polymers are discussed to substitute their fossil based counterparts which are highly relevant commodities in terms of volumes. The present paper aims to assess the magnitudes of possible substitution shares as well as their implications on biomass demand in the EU28. Therefore scenarios are calculated based on a top-down estimation of current fossil based- and a literature analysis on biobased capacities, respective expectations and targets. Demands for biogenic building blocks are derived using conversion efficiencies and finally energy contents of underlying biogenic carbon carriers are calculated which could be deployed either for energy or material utilisation. We find lowest substitution potentials for biobased surfactants and highest for biodegradable polymers as well as potentials in a same order of magnitude for more durable polymers and biobased bitumen. Compared to average literature estimates for moderate and ambitious bioenergy scenarios, material utilisation could reach up to 4% and 11% shares in 2050 in a joint biobased subsector respectively. However, our scenarios are based on relatively poor data availability. Clearer definitions of products and feedstocks are needed, official monitoring has to be implemented, EU wide substitution targets must be set and pre-treatment and conversion technologies have to be introduced and diffused if we want to discuss and trigger climate change mitigation effects of this bioeconomy subsector in the upcoming decades.

1. Introduction

The consumption of fossil resources largely contributes to destabilise the Earth's climate [1] and our large dependency on such resources for material and energy supply is a main obstacle to a more sustainable development as defined by the Sustainable Development Goals [2] and the Paris agreement [3]. While the subsidies to fossil fuel resource use currently about four times higher than that of renewable resource use, or than the amount invested in improving energy efficiency [4], a large transformation of our economy is required. Such a transformation needs to be anticipated and efficiently as well as quickly incentivized to meet the Paris agreement. Two broad levels of intervention allowing reducing the fossil carbon intensity of our economy can be investigated: i) reducing the material and energy intensity of the economy through efficiency increases and ii) the substitution of fossil resources with alternatives for material and energy supply. The present paper focuses on the latter.

On the one hand, the utilisation of oil, gas and coal as energy carriers is gradually substituted to reach a more sustainable portfolio including wind, solar, tidal, geothermal and biomass based technologies [5]. In this sector bioenergy leads over other renewable technologies and is expected to keep this position in the upcoming decades [6]. In this sector bioenergy leads over other renewable technologies and is expected to keep this position in the upcoming decades [6]. On the other hand, in the materials sector, the potential substitution of fossil carbon-based products will be mainly based on biomass, using different conversion technologies such as fermentation, gasification and lignin processing [7]. A second alternative is the recycling of carbon contained in existing and future materials, without making use of carbon synthesised through photosynthesis. As described in e.g. Tahir and Amin [8],

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recycling technologies are in an early research phase and will not be part of the scope of this paper.

In several position papers [9–12], the European Commission (EC) and the European Union (EU) Member States (MS) outlined strategies and recommendations to develop a knowledge based bioeconomy (KBBE) in the coming decades. The bioeconomy sectors can be defined as those dealing with "the production of renewable biological resources and their conversion into food, feed, bio-based products and bioenergy." [12] Beside traditional biobased products like e.g. from the pulp and panel industry also more advanced biobased materials like biobased polymers fall in this category [13]. Furthermore the 'Cologne Paper' [9] defines knowledge based by "transforming life sciences knowledge into new, sustainable, eco-efficient and competitive products."

Despite such a pro-active policy environment in the EU, the literature on potential pathways for the European bioeconomy on a medium or long term (up to 2030 or 2050 respectively) is incomplete. A large literature discussed possible developments of the production and consumption of bioenergy, food and feed, and traditional wood products (e.g. Refs. [14–18], etc). On the contrary, the literature on possible developments in advanced biomaterial production and consumption stands out as relatively scarce. [19–23]. While [20] discuss several advanced biobased material product groups and outline short term expectations which are updated in Refs. [21,22], focuses on biobased polymers and short term expectations only [19]. and [23] outline long term expectations and scenarios, however in Ref. [19] on a highly aggregated level and in Ref. [23] with the focus on the global development. No detailed medium to long term European advanced biobased material scenarios exist so far. In the light of such a gap, we propose an appraisal of the potential for substituting fossil based materials by advanced biomaterials in the EU on a medium (2030) to long (2050) term. We more specifically address the following research questions:

- Which advanced bio-based materials hold the potential to substitute substantial amounts of fossil based materials?
- How much of these advanced biobased materials are currently produced and what are plausible magnitudes in 2030 and 2050 respectively?
- At which rate the production of such products should grow to allow the EU phasing out fossil based counterparts?
- What are possible underlying biomass needs and how do they compare to existing biomass for bioenergy scenarios?
- How will the additional biomass demand be distributed within the EU28 and what are possible implications for international biomass trade?

2. Methodology

In order to address our research questions we scanned the existing literature for advanced biobased materials that exhibited strong growth rates respectively hold the potential for substituting substantial amounts of fossil fuels. Current biobased capacity estimations are collected and the fossil based counterpart calculated. The following subsection describes how the fossil based production in the 28 MS are estimated and projected up to 2050. We define two substitution storylines and calculate their advanced biobased material production capacities for the upcoming decades. Based on the calculated capacity scenarios we estimated biogenic building block demands for further comparison with existing bioenergy scenarios. The calculation steps and their assumptions are explained and justified in the following subsections; the code for reproducing the results can be downloaded as supplementary material (see Appendix D).

2.1. Fossil based non-energy consumption estimation — now and up to 2050

The first step is to list and assess final products which could be subject to substitution: The world energy statistics and balances database from the IEA and OSCE [24] informs the production of bitumen, lubricants and waxes, further denoted as heavy refinery products. The balance further outlines the non-energy consumption of various types of primary energy carriers (see Appendix A) for the production of other materials through steam cracking - referred to as High Value Chemicals (HVC) according to Ren et al., 2006 in Ref. [25]-. Yearly quantities for the non-energy consumption of primary energy carriers for the 28 MS and the years 2008, 2009 and 2010 are further processed to estimate production of various HVCs. According to the EC [20] non-energy use of fossil based HVCs can be further split into polymers, solvents and surfactants with 89.6%, 8.2% and 2.2% respectively. We divide the group of polymers in Polyethylene terephthalate (PET) with 7%, Polyethylene (PE) and Polypropylene (PP) with 48.5% and Polyvinylchloride (PVC), Polyurethane (PUR), Polystyrene (PS) and others with 44.5% [26]. For the matter of simplification we neglect losses in the mass balance of the conversion process and assume the same non-energy utilisation shares for all MS and the three years as well as for the scenario time span.

The second step is to estimate the evolution of the production of these fossil resource based final products: The EU Energy, Transport and GHG Emissions Trends to 2050 from Capros et al. [15] contain scenarios for the fossil-, nuclear- and renewable energy consumption of the EU28 up to 2050 on a member state. The resulting secondary products of the corresponding petrochemical industry are also calculated on the member state level and documented as "non-energy uses … such as chemical feed-stocks, lubricants and asphalt …" level (see Appendix B). The 2013 reference scenario of [15] is used to project the historic fossil based materials production estimations derived from the database of OECD and IEA [24] for the 28 MS up to 2050 in five years' time steps.

2.2. Advanced biobased materials — status quo

For the European Union four of the five discussed fossil based product groups were identified to hold possible high substitution potentials already in the beginning of this century between the Directory General (DG) Enterprise and the European Renewable Resources & Materials Association (ERRMA) [27]. In the final report of the BIOCHEM project [20] the same products were discussed again as promising product segments and their market shares in 2008 and potentials have been analysed. Estimated production capacities in million tonnes per annum (Mt) and kilo tonnes per annum (kt) are adapted for this paper.

Surfactants based on biogenic feedstocks represent the highest biobased share of the selected materials today. Surfactants or surface acting agents are blends that lower the surface tension of a medium in which they are dissolved in. This property makes it applicable for example for soaps, herbicides, wetting agents, cosmetics, fabric softeners and "… virtually any other application where two dissimilar types of compounds are brought together" [28] The biodegradability and lower toxicity can outweigh the higher costs for naturally derived surfactants compared to their mineral oil based complement for certain applications. The EU biobased consumption for this product grew from 1.18 Mt in 1998 to 1.52 Mt in 2008 compared to 1.2 Mt fossil based surfactants ([27] and [29] respectively). It is the only case of the here presented materials where biobased production already overtook fossil based production in the past decade.