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Alternative Global Transition Pathways to 2050: Prospects for the Bioeconomy

An application of the MAGNET model with SDG insights

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MAGNET

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Contents

Abstract

The role of the bioeconomy is a key building block within the EU vision for a modern, competitive and climate neutral model of prosperity. To understand the role that this diverse collective of activities plays within the circular economy requires a systems-wide approach, complete with loops and feedbacks with the broader macroeconomy.

In this context, a global economy-wide simulation model – MAGNET – is employed to quantify different medium- to long-term market outlooks for the European and global bioeconomy, with a focus on sustainability as a cross-cutting issue. Model outcomes are also framed within the international language of the United Nations Sustainable Development Goal (SDG) indicators.

To examine differing degrees of climate action, three different transition pathways to 2050 are designed and simulated, two of which are based on the EU long-term climate strategy.

Of the five European Bioeconomy Strategy objectives, the transition to a more resource-responsible and sustainable pathway, with ambitious emissions reductions and deep transformations within the energy markets, contributes towards both climate action and reduction in fossil-based energy use. Nevertheless, important investments in innovation are a precondition to realising these fundamental changes in the economy.

With regard to the natural resource management objective, the scenarios indicate the presence of land substitution effects, both from pastureland to more intensive cropland production, and the rapidly increasing use of non-food biomass for advanced bioenergy technologies.

Moreover, sustainability pathways reveal that efficiency gains, both from energy usage and from land yield improvements arising from lower temperature increases, reduce demand for agricultural land and irrigation water, compared to the reference scenario. The potential usage of this released land must be carefully evaluated, given the increasing trend for agricultural land use in the reference scenario.

In terms of food security, climate policies aligned with achieving the Paris Agreement lead to higher average food prices and slight reductions in calorie intake. Importantly, these 'average' effects are highly prevalent in sub-Saharan Africa, which could have notable implications for the most vulnerable members of society.

Turning to the objective of growth and job creation in Europe, the turnover of the bioeconomy increases over time. Depending on how the innovative biobased industry evolves, additional growth could be envisaged. The expected downward trend in job creation in the primary bioeconomy sectors, which undergo a structural change, could be mitigated subject to expectations for growth in the aforementioned innovative biobased activities.

Within the sustainability pathways, the circular bioeconomy has adequate macroeconomic conditions to evolve, as the high carbon price levels the playing field between conventional fossil-based and nascent biobased technologies. As a result, biobased liquid energy and biochemical transformation could witness significant increases, with feedstocks coming mainly from more sustainable solutions such as lignocellulosic non-food crops (e.g. switchgrass, miscanthus) and agricultural and forestry residues.

A follow-up report planned in 2020 will examine the extent to which technological and behavioural market measures and policies can be used to mitigate some of the social, environmental and biophysical trade-offs which arise when comparing sustainable pathways with the reference scenario.

Acknowledgements

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1 Introduction

Circular Bioeconomy as a driver towards a sustainable future

Current global resource assessments (IPCC, 2018; IRP, 2019; IPBES, 2019; IPCC, 2019) signal the unsustainability of the present economic system and resource use. Indeed, today's economic system is confronted with the need to decarbonise energy markets and lower greenhouse gas emissions, responsibly manage our natural resources, reduce social inequalities, and meet the food security demands of an increasing global population, whilst continuing to deliver on the 'traditional' metrics of economic growth and living standards.

The updated European Bioeconomy Strategy (EC, 2018a) signals the transformative potential of the bioeconomy to address these multiple policy aims. As the bioeconomy incorporates a range of diverse economic activities, the Bioeconomy Strategy inevitably encompasses a broad array of public policies and initiatives, which heightens the need for a coherent approach to their design and implementation to minimise the risk of potential trade-offs or conflicts. This same ethos of interconnectivity is also embedded within the United Nations Sustainable Development Goals (SDGs) (UN, 2015).

The bioeconomy has been identified as one of the building blocks of the European Commission Communication *A Clean Planet for all: A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy* (Long-term strategy – LTS) (EC, 2018b), and as an important part of the Common Agricultural Policy strategic plans.

The role of the bioeconomy as a strategy connecting and leading policies towards more coherence is also emphasised within the agenda of the forthcoming Commission (EC, 2019). The proposed European Green Deal encompasses a New Circular Economy Action Plan focusing on sustainable resource use, a Sustainable Europe Investment Plan, a Biodiversity Strategy for 2030 and a new 'Farm to Fork Strategy' on sustainable food throughout the value chain.

This technical report presents results of a medium- to long-run modelling exercise, analysing how the bioeconomy and its key objectives could evolve over a medium- to long-term time horizon.

Background to this study

The study presented in this report builds on earlier modelling exercises, mainly the JRC report *Drivers of the European Bioeconomy in Transition (BioEconomy2030)* (Philippidis et al., 2016), the JRC report *The MAGNET model framework for assessing policy coherence and SDGs* (Philippidis et al., 2018a), and a number of scientific articles.

The research aimed to develop a policy-coherent approach for assessing the bioeconomy, with a focus on sustainability as a cross-cutting issue for the bioeconomy.

The current work also contributes to the JRC Biomass Assessment Study which provides the EC services, on a long-term basis, with data, models and analyses of EU and global biomass potential, supply, demand and related sustainability.

This study does not set out to give conclusive answers to the key questions of the bioeconomy. However, it illustrates the usefulness of a state-of-the-art systems-wide global simulation tool for providing insight into the key drivers motivating global market trends affecting this broad collective of sectors. Key assumptions of the LTS were implemented to enumerate different global transition pathways with a 2030/2050 time horizon. More specifically, world-wide trends are presented through an array of metrics encompassing market, environmental and biophysical considerations. Moreover, to reach a broader audience, the emphasis is on the presentation of digestible visual representations, whilst technical information underlying the approach is reserved for the annex.

In a follow-up report planned in 2020, a set of additional measures and policies to mitigate, in particular, social and environmental impacts, will be analysed.

2 A model of the global bioeconomy

Simulating the global and EU bioeconomy

- The complexity and interdisciplinarity of the bioeconomy requires systems-wide modelling tools, which capture the input-output linkages between the different biobased sectors and their links with the broader macroeconomy.
- The latest developments in including SDGs in the MAGNET model employed in this work are quoted in the updated Bioeconomy Strategy COM(2018) 673 and SWD(2018) 431 *A sustainable bioeconomy for Europe: strengthening the connection between economy, society and the environment* as a model framework for assessing policy coherence and SDGs.

MAGNET model in a nutshell

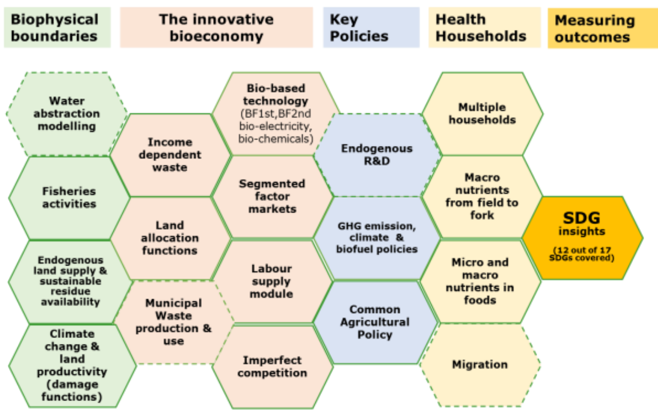
- MAGNET (Modular Applied General Equilibrium Tool; Woltjer, 2014) is an economy-wide global tool. For this class of modelling framework, the accompanying model database delivers an unparalleled coverage of traditional (agriculture, forestry, food, fishing/aquaculture, etc.) and contemporary (bioenergy, biomaterials) biobased activities, and their underlying sources of biomass (crops, residues, pellets, waste).
- MAGNET has garnered considerable attention within the natural resource economics literature on topics relating to land use change (Schmitz et al., 2014); EU domestic agricultural support (Boulanger and Philippidis, 2015); agricultural trade (Philippidis et al., 2018b); biofuels policy (Banse et al., 2011); food security (Rutten et al., 2013); food waste (Philippidis et al., 2019); climate change (Nelson et al., 2014); and bioeconomy (Philippidis et al., 2016; van Meijl et al., 2018).
- MAGNET includes a comprehensive SDG insights framework (Philippidis et al., 2018).
- As a key insight into understanding the role of public policy, the underlying modelling software permits a detailed decomposition analysis to identify and quantify the relative contribution of key exogenous market drivers (demographics, macroeconomics, technology change, market interventions) over several discrete time periods towards 2050 (Figure 2).

  Technical details on the modelling approach can be found in the annex.

Figure 1. Key documents for the global and EU (bioeconomy) scenario analyses

Sources: EC, 2018a; Philippidis et al., 2018a; Keramidas et al., 2018

Figure 2. A modular approach to policy coherence modelling



Reference scenario and transition pathways

- The enumerations of three different pathways to 2050 are largely based on the European Commission's Global Energy and Climate Outlook, which constitutes a central element of the EU's vision for a prosperous, modern, competitive and climate neutral economy (LTS) (Keramidas et al., 2018).
- Each of the pathways involves different assumptions regarding region-specific economic drivers (real GDP, labour force, capital accumulation), expectations of global energy and carbon price forecasts, detailed energy market balances describing decarbonisation and renewables uptake, land productivity forecasts and emissions cuts.
- Exogenous productivity changes to physical input-output ratios are calculated (i.e. calibrated) to track forecast real GDP growth targets and energy-specific (i.e. fossil, renewable) usage by four broad industrial classifications. Final usage of energy is captured through household budget shifters.
- These drivers characterise three scenarios: a business as usual reference scenario (REF) and two sustainable pathways, consistent with temperature rises no greater than 2 °C (SUS) and 1.5 °C (SUS+) above pre-industrial levels by 2100 (see also Figure 3).
- Figure 4 and Figure 5 show the assumed global changes in emissions and fossil energy markets, respectively. Whereas in the REF an increase in both drivers is projected, both sustainable pathways show strong decreases over the time horizon towards 2050.

Figure 3. Key assumptions

The **REF scenario** assumes that human development is purely driven by market forces and technological progress, with no explicit recognition of additional climate agreements beyond 2017.

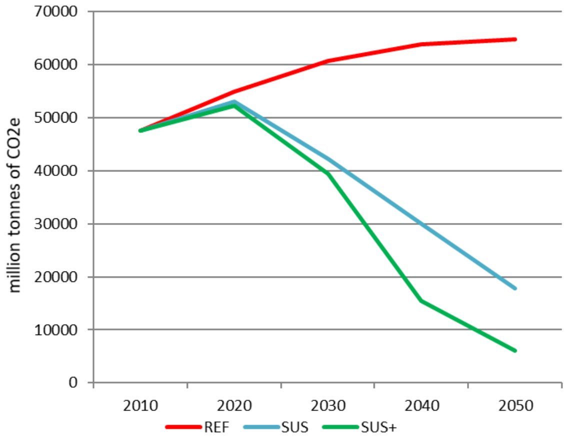
The more profound **energy balance transition pathways** in the SUS and SUS+ scenarios are motivated by:

(i) further increases in energy efficiency (i.e. decoupling economic growth from energy consumption);

(ii) additional transformation of energy carriers towards electrification;

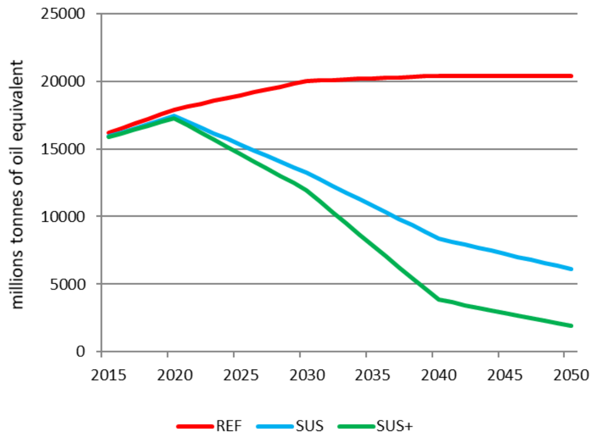
(iii) deeper decarbonisation of energy through the

Figure 4. Assumed global changes in emissions



Source: based on Keramidas et al. (2018)

Figure 5. Assumed global changes in fossil energy markets



Source: based on Keramidas et al. (2018)

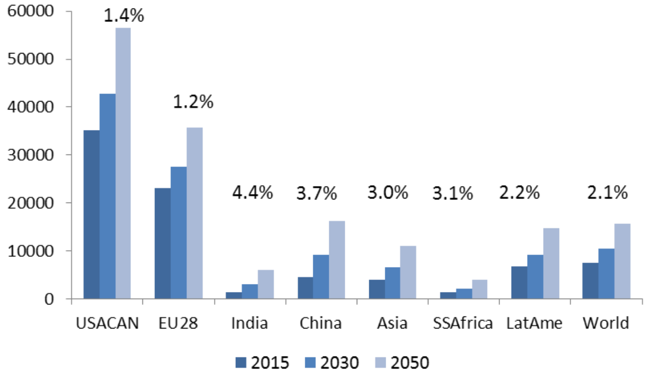
3 The reference pathway (1):

Towards a more energy-efficient economy

Unfettered economic growth towards 2050

- Globally, annual income per capita doubles by 2050 to reach €15,600 Figure 6).
- Asian countries have the highest annual average growth rate (3.0-4.4%), with China surpassing the global average income level by 2040.
- Whereas sub-Saharan Africa (SSAfrica) is also projected to grow rapidly, corresponding rates of aggressive population growth in this region result in an average annual growth rate in income per capita of 3.1%.
- The EU, growing at a moderate pace of 1.2%, keeps its place among the high income regions.
- There is evidence of global income convergence, although it is slow.

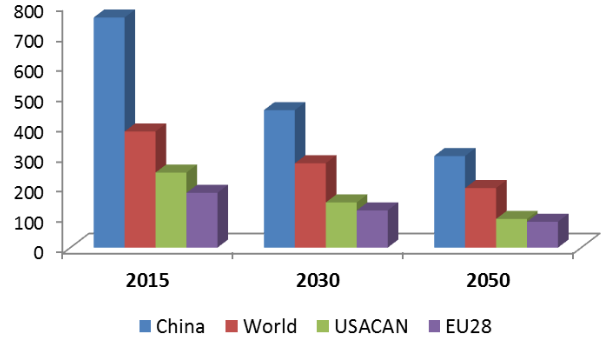
Figure 6. Income per capita in € and average annual growth rate from 2015-2050



More energy-efficient economy

- Over time, the global economy is projected to become more efficient and to reduce greenhouse gas (GHG) emissions per € million GDP (Figure 7).
- This is caused by a mix of energy saving, energy efficiency and decarbonisation (i.e. greater uptake of renewables, especially electrification).
- The EU currently has the lowest values at about 180 tonnes CO_2 equivalent (CO_2e) per € million GDP, being halved by 2050 (85 tonnes CO_2e per € million GDP).
- Significant improvements are expected, especially in China, with an absolute reduction of 450 tonnes CO_2e per € million GDP (from 758 to 302).

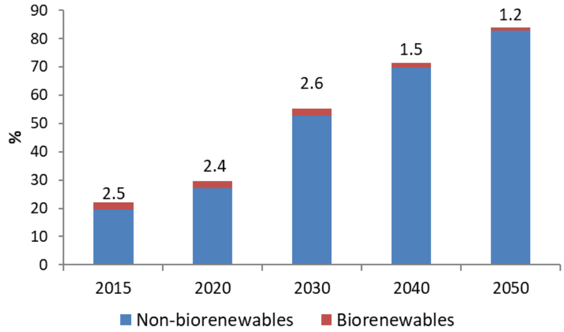
Figure 7. Greenhouse Gas Emissions (tonnes CO_2 equivalent per € million GDP)



Renewables key for electricity

- Energy carriers are shifting into electrification.
- Figure 8 shows the share of renewables increasing strongly over the time period to 2050.
- The share of biorenewables shrinks over time.
- World average for the share of renewables in the total energy mix is catching up to EU levels by 2050 (65% vs. 83%).
- Global output of conventional biofuels rises from 80 million tonnes of oil equivalent (Mtoe) in 2015 (not shown), to 291 Mtoe by 2050.

Figure 8. Share of renewable energies* (%) in electricity generation in the EU



*includes solar, hydroelectric, wind and biomass, but not biogas, liquid biofuels or industrial waste.

4 The reference pathway (2):
Beyond planetary boundaries

More biomass needed to feed the planet

- Overall, global food production increases by about 60% from 2015 to 2050; which amounts to an increase of 6 billion metric tonnes over the period.
- The biggest growth in absolute terms takes place in Asia (2.5 billion metric tonnes). The highest growth in percentage takes place in Africa (165%) to feed a rapidly growing population (Figure 9).
- The EU28 increases its annual food production by about 10%, reaching 1 billion metric tonnes by 2050.

Land use increase

- Regional income and population pressures fuel global increases in agricultural land use of 8%, which is equivalent to 80% of current agricultural land in the USA and Canada combined (Figure 10).
- Demand factors drive considerable land use increases in Africa (26%) and Latin America (10%), which are met by biophysical estimates of potentially available land.
- There is ample evidence that agricultural land use impacts biodiversity (see e.g. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services — IPBES, 2019). Hence, assuming moderate improvements in production practices, the pressure on the planet's resources would still increase.
- With rising land use, a similar rise in irrigated abstracted water is observed.

Global emissions increasing

- In the REF scenario, compared with 2015 global emissions could rise by 15 gigatonnes CO_2e by 2050 without action; that is about one third higher than in 2015.
- Rapid growth in developing regions (e.g. Africa: 175% higher emissions) and emerging regions (e.g. India: 80% higher) are the main drivers.
- The EU (-18%) as well as USA/Canada (-11%) reduce emissions toward 2050.
- In the REF scenario, CO_2 emissions remain the largest contributor to total global emissions (around 62% in 2050), although methane (CH_4) and nitrous oxide (N_2O) are growing much quicker, owing partly to continued growth in livestock numbers and agriculture and also because CO_2 emission growth is much slower due to some degree of decarbonisation within the energy market.

Figure 9. Domestic agricultural food production (millions of metric tonnes)

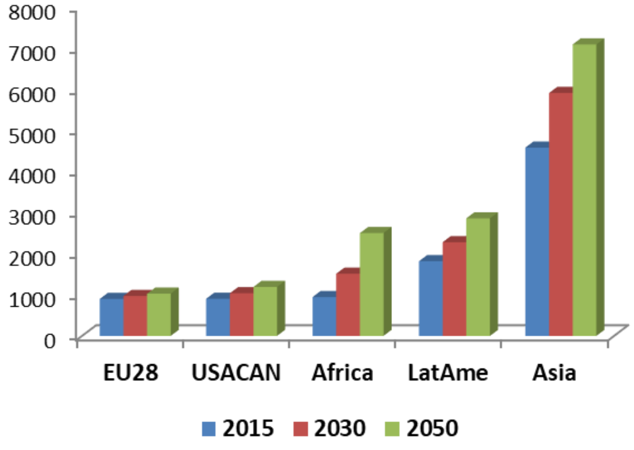


Figure 10. Agricultural land share in 2050 and change in % from 2015 to 2050

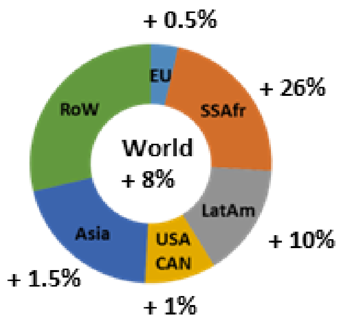
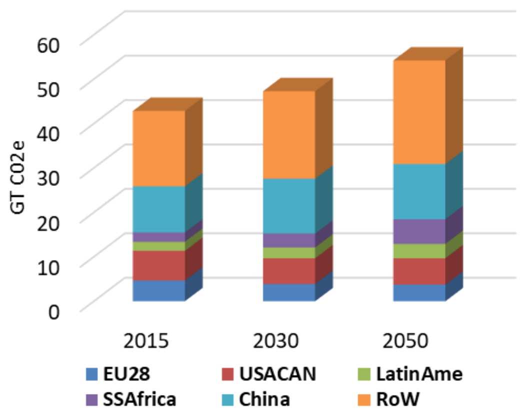


Figure 11. GHG emissions in CO_2e (gigatonnes)



5 Sustainability scenarios

EU's vision for a climate neutral future

- Europe's vision for a climate neutral future (EC, 2018b) is aligned with the Paris Agreement goals to keep the global temperature increase below 2 °C while pursuing more ambitious efforts to restrain it to 1.5 °C.
- The required reduction in GHG emissions could be achieved through decarbonisation of energy markets (including bioenergy), energy efficiency and electrification of energy carriers.

Strong decrease in global emissions

- Global emissions decrease sharply in both SUS and SUS+ scenarios. This manifests itself through the expected improvements in energy balance (i.e. less fossil fuel dependency, greater renewables capacity, greater electrification) over the time period (Figure 13).
- In all three pathways, there are also upward trends in support of the electrification of global final consumption energy needs, in particular in the transport sector. This is made possible through a reorientation in the portfolio of electricity generation technologies toward non-biological renewables (i.e. wind, solar, hydroelectric) in all three transition pathways, with in the SUS and SUS+ narratives (from a low base) a considerably greater reliance on solid biomass for electricity generation.

Economy more energy efficient

- The decoupling of economic growth from energy usage and its related environmental degradation is a key objective for global resource efficiency in consumption and production.
- Calculating the average global economic value in euro per tonne of CO_2e (€/tCO_2e) shows in Figure 14 a fivefold increase in efficiency when comparing SUS+ with REF (27,000 €/tCO_2e vs. 5,100 €/tCO_2e). For the EU, the corresponding statistic by 2050 in the SUS+ scenario is 54,000 €/tCO_2e.

Trade-off between biosphere and economy

- In both sustainability scenarios the per capita real income for the world falls, showing a trade-off between progress on the biosphere and the economy (decoupling of growth remains a challenge). Market driver part worths (Figure 15), i.e. the weight attached to each driver in determining the outcome from a given indicator, highlight the synergies and trade-offs.
- Technology-driven (green bar) efficiency gains, driven by investment in energy innovation and savings, lead to increasing incomes. Higher carbon taxes (red bar) on emitting activities raise input and product prices, which depress real incomes. The resulting macroeconomic impacts (blue bar) are negative, as higher green taxes act as a brake on economic activity.

Figure 12. Scenarios

REF: Reference Scenario
SUS: Sustainability pathway limiting global temperature rises to 2 °C above pre-industrial levels by 2100
SUS+: Sustainability pathway limiting global temperature rises to 1.5 °C degrees above pre-industrial levels by 2100

Figure 13. Global emissions assumptions, % change in years 2030 and 2050 compared to 2015

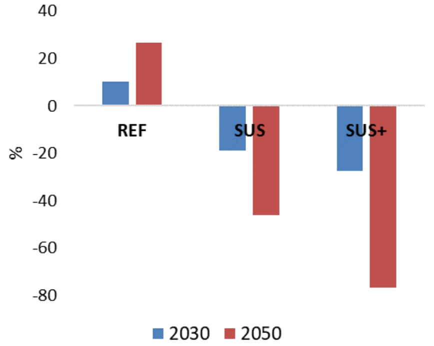


Figure 14. Global economic value (€/tCO_2e), 2050

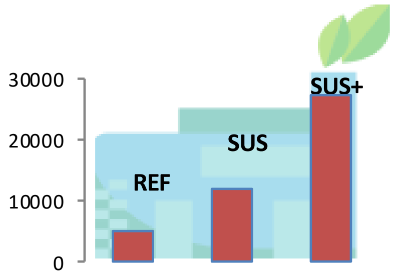
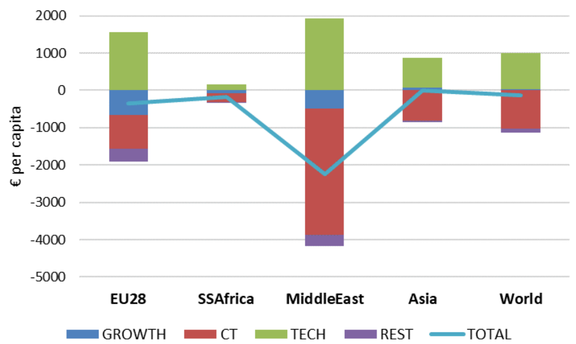


Figure 15. Real income per capita and drivers (SUS+ vs REF)



GROWTH=macroeconomic growth; CT=carbon tax; LANDPRO=Land Productivity; TECH=technology changes in the energy markets arising from energy saving initiatives and energy efficiency; REST=other drivers; TOTAL=net impact of all drivers

6 Food security: Limited impact, but climate action costs the poorest most because of food security

Food first

- Food and nutrition security is also a key priority for the bioeconomy.
- However, in recent years, the number of malnourished people has grown, reaching 820 million (FAO, 2019).
- The FAO report also states that no region is exempt from problems of obesity.
- In the REF, a much steeper calorie intake growth can be observed in SSAfrica (Engel's Law), but it remains well below the global average (World) (Figure 16).
- The overall improvement in available calories must be accompanied by reliable access to food and balanced nutrition.

Planetary responsibility comes with (limited) costs for the poor

- Carbon tax rises (red bar) and slower economic growth (blue bar) in SUS+ vs. REF constrains growth in per capita calorie intake, due to price transmission effects on food (Figure 17).
- Reported income benefits arising from energy efficiency gains drive increases in demand for food, thereby increasing per capita calorific intake (green bar).
- The overall impact on calorie intake is negative, albeit limited.

Food prices

- Overall, the temporal trend line shows that food prices are expected to remain stable over the whole period, in line with recent projections (see e.g. OECD/FAO, 2019).
- For the year 2050, the bar on Figure 18 shows how different drivers combine to impact on global food prices. The expectations of population growth (orange bar), particularly in poorer regions, are a strong driver of food price rises. In contrast, improvements in land productivity are expected to remain vital for ensuring lower food prices and food security.
- In the SUS and SUS+ scenarios, world food prices rise by 1.2% and 3.6% respectively compared to the REF 2050 scenario.
- Regional differences are accentuated, with relative price increases of 8-10% in SSAfrica and India in the SUS+ vs. REF, which worsens food accessibility for the poorer populations.
- Similar to calorie intake, the key driver behind this result is the rise in carbon tax, which has the most impact on more emissions-intensive agricultural sectors in developing regions.

Figure 16. Regional consumption of calories per capita per day: Reference Scenario 2015-2050

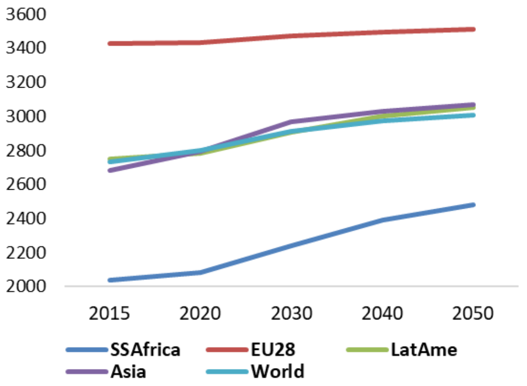


Figure 17. Total change and drivers of calories per capita per day, SUS+ vs. REF (2050)

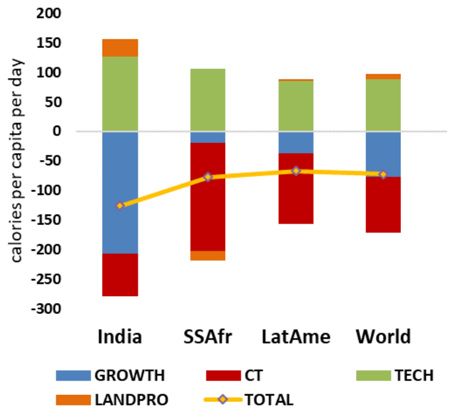
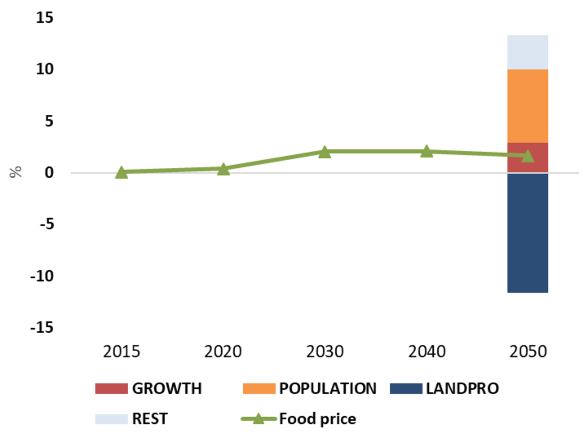


Figure 18. % change in global food prices in REF scenario and key drivers (2015 – 2050)



7 Resources: Sustainable pathways and planetary responsibility

Agricultural land use

- Compared with the REF, marginal savings in land usage across all regions are observed in both sustainable transition pathways (see Figure 19, SUS+).
- At the global level, by 2050 this ranges from 15 million hectares (ha) (SUS) to 74 million ha (SUS+). This is equivalent to approximately 8% and 42%, respectively, of the EU's current agricultural land area.
- The global area of cropland increases by 1.8%, whereas pastureland is reduced by 2.9% (SUS+). The increase in cropland is driven by converting pastureland and rising bioenergy feedstock requirements.
- In the SUS+ vs. REF for the EU (see Figure 20), oilseed crops are reduced; wheat, sugar beet and energy crops increase, responding to the demand for biobased liquids from ethanol.

Land saving through lower temperature rises

- Investigating the market drivers SUS+ vs. REF (see Figure 21), the negative impact on agricultural production resulting from the carbon tax reduces agricultural land usage worldwide by up to 99 million ha.
- Land productivity improvements, due to reduced radiative forcing resulting from lower temperature increases, are responsible for an agricultural land saving effect of up to 35 million ha worldwide.
- In global terms, an agricultural land saving effect of 75 million ha globally by 2050 can be observed comparing SUS+ vs. REF. This corresponds to -1.4% of land use or 20% of current EU agricultural land area.
- EU agricultural land saving is observed, although relatively minor at 565,000 ha.
- With lower emissions reductions commitments, the land saving effect in scenario SUS (compared to REF) is approximately 15 million ha.

Water

- Irrigated abstracted water volumes calculated in the model are closely related to agricultural land area. Therefore, the SUS and SUS+ scenarios also lead to marginal savings when compared with the REF. At the global level, the savings by 2050 are 7.9 billion m^3 and 37.6 billion m^3 for SUS and SUS+, respectively, with between 65% and 70% of these totals from Asia.
- Interestingly, the SUS+ result at the global level is equivalent to 87% of the EU's total irrigated abstracted water usage.
- Finally, land productivity gains owing to reduced temperature rises generate between 9.0 billion m^3 and 15.8 billion m^3 of global abstracted irrigated water savings by 2050 for SUS and SUS+, respectively.

Figure 19. Change in cropland and pastureland use (%) in 2050, SUS+ vs. REF 2050, global level

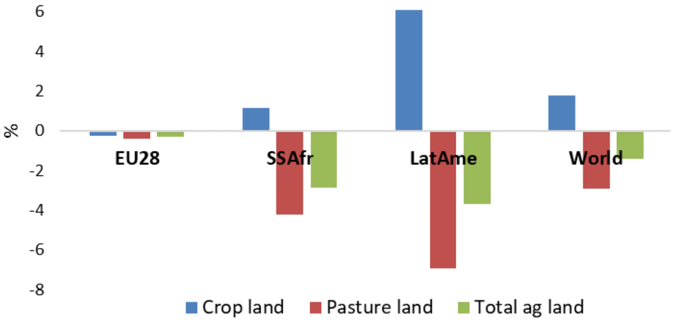
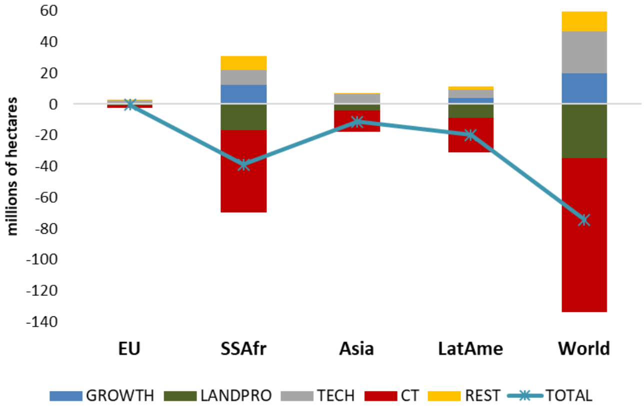


Figure 20. EU land use changes by selected crops in SUS+ vs. REF, 2030 and 2050, % change and 1,000 ha

	2030	2030	2050	2050
	%	in 1,000 ha	%	in 1,000 ha
Wheat	0.4	11,151	2.4	6,843
Other grains	-0.2	2,853	-1.8	-5,894
Oilseeds	-1.6	-1,931	-7.2	-8,745
Sugar beet	1.4	672	3.4	578
Energy crops	88.3	5,812	769.9	6,275
Total	0.0	8,283	-0.3	-5,530

NB: 'Total' is not the sum of the selected crops; total land use change also includes pastureland.

Figure 21. Land use in million ha, SUS+ vs. REF 2050



8 Growth in bioeconomy sectors

Bioeconomy in the global economy

- Real economic growth in the overall economy in the REF is above that in the bioeconomy, following a long-term trend (note the difference in scales in Figure 22). Therefore, the share of the bioeconomy in the total economy is slightly reduced.
- The SUS and SUS+ scenarios reverse this trend slightly for the bioeconomy.
  Percentage share of bioeconomy in total economy in 2050 [middle growth scenario]

	REF	SUS	SUS+
World	9.3	9.9	10.3
EU	7.0	7.4	7.6

- The scenarios SUS and SUS+ increase the value share of the bioeconomy, thus underlining in particular the economic importance of the innovative bioeconomy sectors within the transformation towards a decarbonised economy.
- The growth in the innovative biobased sectors is however highly uncertain, and this determines to a large extent overall bioeconomy growth rates in each of the transition pathways. Annex 15.5 describes the assumptions for three different growth scenarios for the biobased chemical, pharmaceutical and rubber/plastics sectors (low, middle and high growth rates).

Figure 22. Growth of whole world economy and bioeconomy, in trillion euro (2011 constant prices)

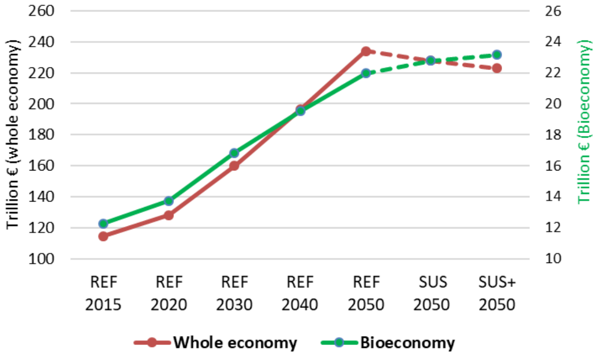
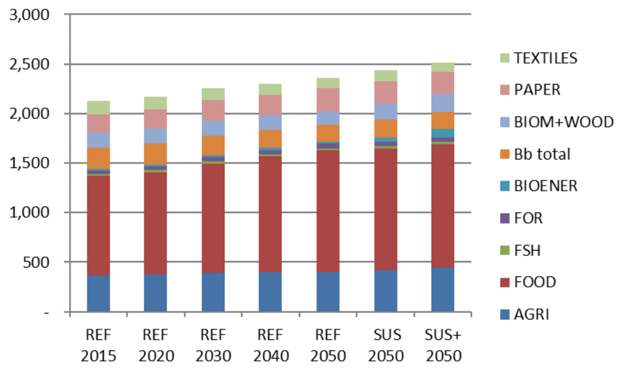


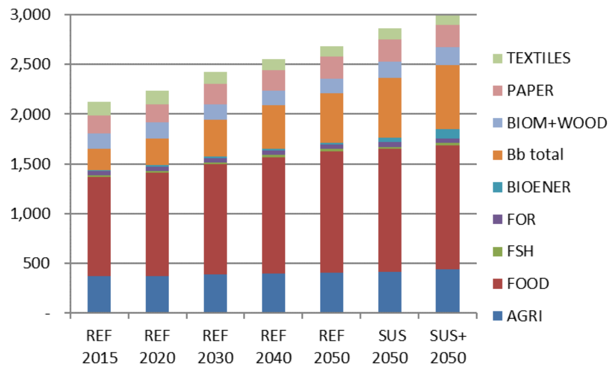
Figure 23. Bioeconomy sectors turnover/value in EU – *low* growth scenario for biobased (chemical) industry, € billion in constant prices (2011)



EU bioeconomy turnover trends by sectors

- Figures 23 and 24 show the turnover trends at market prices under the assumption of, respectively, a low and high growth scenario for biobased chemical activity (i.e. chemical, pharmaceutical and rubber/plastics).
- The primary production sectors (agriculture, forestry, fisheries) show a stable evolution over time. The food industry is also growing steadily.
- Other traditional biobased sectors (paper, wood production, textiles) continue their decreasing trends in the EU, mainly due to increasing imports from more cost-competitive regions such as China.
- In the REF 2050, the overall value of the bioeconomy is estimated to be between €2.33 trillion and €2.66 trillion, for the low and high biobased share calculations, respectively.
- In the SUS+ pathway, by 2050 the total turnover could reach up to €3 trillion.

Figure 24. Bioeconomy sectors turnover/value in EU – *high* growth scenario for biobased (chemical) industry, € billion in constant prices (2011)



9 Jobs: Specific biobased sectors create new jobs. Agricultural jobs in developing countries under pressure.

Worldwide agricultural jobs over time:

- Regional agricultural employment shares in total economy (Figure 25) show downward trends (REF 2015 and REF 2050), due to economic restructuring.
- Worldwide, a decrease of 12% between 2015 and 2050 could be expected; in the EU, approximately 14%.
- Africa shows a strong decrease in the share, from 38% to 25%. However, the agricultural workforce rises in absolute numbers by 18% because of the rapid calorie intake rises, largely met by 'internal' production.
- The scenarios SUS and SUS+ have only slightly different shares compared with the REF 2050.

Scenario impacts on agricultural jobs

- Looking at the different drivers in SUS+ (see Figure 26), carbon taxes impact negatively on agricultural production, especially livestock, and consequently reduce agricultural employment (red bar).
- Energy market innovation (grey bar) is beneficial for macroeconomic growth (i.e. induces productivity gains in activities), thus it also promotes agricultural activity.
- The relative contraction in income growth slows down structural change in agriculture and the rural exodus to urban areas (blue bar).
- As a result, the global share of employment in industry and manufacturing rises slightly (20.8% in REF, 21.0% in SUS, 21.6% in SUS+).

Scenario impacts on bioeconomy jobs in EU

- It should be noted that the job numbers for 2015 in Figure 27 are partly different from the ones referred to in the Bioeconomy Strategy. This is due to a different approach and usage of the Global Trade Analysis Project (GTAP) database with extensions.
- The 'traditional' bioeconomy sectors experience a decrease in jobs over time in REF. The sustainability scenarios increase the number of jobs compared to REF. The percentage changes (not calculated) vary depending on the size of the sector.
- A notable increase in job numbers in the scenarios could come from the biobased chemical, pharmaceutical and plastics/rubber sectors (see also Annex 15.6). However, it should be kept in mind that the composite fossil-based/biobased chemical sector is declining because of the high carbon tax and increased global competition.
- In the REF, the structural change in the economy is accompanied by wage improvements for skilled workers (vs. unskilled) and non-agricultural workers (vs. agricultural). The marginal wage impact in the SUS and SUS+ pathways is negligible.

Figure 25. Share of agricultural employment in economy

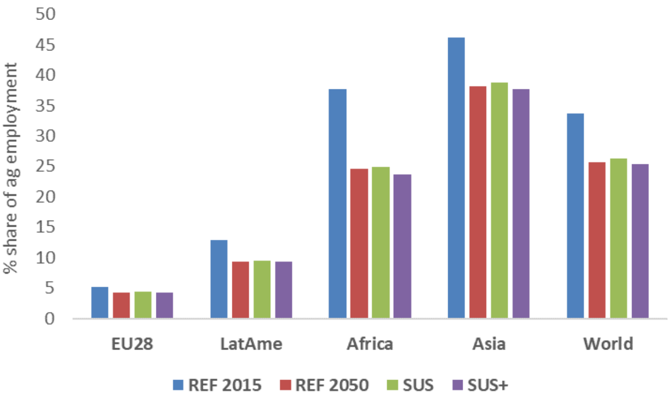


Figure 26. Changes in number of agricultural jobs by 2050 and drivers of change, SUS+ vs. REF

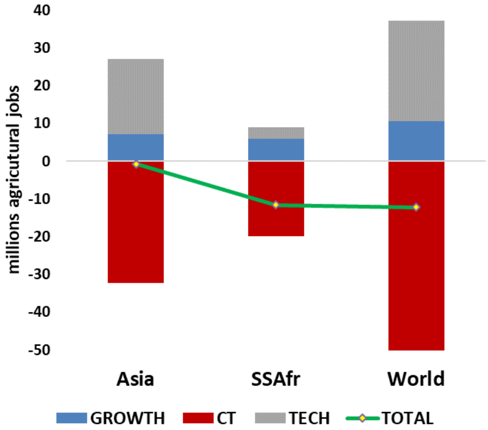


Figure 27. EU Jobs in 000s, for 2015 and 2050

	2015	REF 2030 vs 2015	REF 2050 vs 2015	2050 SUS vs REF	2050 SUS+ vs REF
Agriculture	12,990	-232	-1,771	317	-114
Food industry	4,984	-234	-1,019	162	191
Fishery	309	14	-14	39	57
Forestry	995	-37	-157	41	8
Bioenergy	14	11	5	39	115
Wood manufacture	1,083	-119	-350	21	-56
Paper	1,136	-6	-101	31	17
Textiles	1,323	-209	-544	66	-4
Bioeconomy (traditional)	22,833	-813	-3,952	716	214
Bioeconomy*	23,324	-431	-3,337	960	497

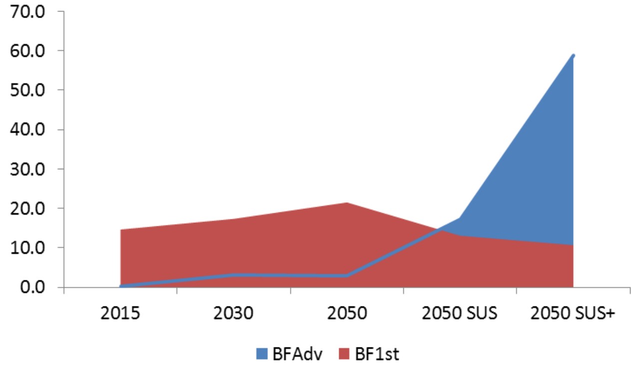
NB: The 'traditional' definition of bioeconomy in Figure 27 is the sum of all sectors in the rows above, but does not include the sectors biochemical, biopharmaceutical and bioplastics/rubber.
The 'bioeconomy*' totals also includes a mid-range scenario estimate of (bio)chemical, (bio)pharmaceutical and (bio)plastics/rubber sector employment. Owing to data limitations, the calculations behind these sectors are driven by stylised assumptions and further explained in Annex 15.6.

10 Biofuel markets

Biofuels in the reference scenario

- Rising fossil fuel prices in the REF scenario close the cost-disadvantage gap between fossil-based and biobased alternatives, increasing the global capacity of conventional biofuels from 80 Mtoe in 2015 to 291 Mtoe by 2050.
- Brazil's role as a key producer and exporter of conventional biofuels (particularly bioethanol) is strengthened, with a share of 30% by 2050. China and India also become major players.
- By 2050, a limited but marked shift from conventional first generation (BF1st) to advanced generation (BFAdv) biofuels is observed, rising from 2 Mtoe in 2015 to 51 Mtoe in the EU (see Figure 28).

Figure 28. Evolution of first and advanced biofuels in the EU; REF; Mtoe



Biofuels in the sustainability scenarios

- With a drive towards sustainable energy, by 2050 the global liquid biofuels market grows from 342 Mtoe in REF to 450 Mtoe in SUS and 908 Mtoe in SUS+.
- The global volume of conventional biofuels remains relatively stable across the three transition pathways in 2050: 291 Mtoe in REF, 236 Mtoe in SUS and 261 Mtoe in SUS+ (see Figure 29).
- Brazil further cements its position as a principle supplier in the conventional biofuels market.
- More sustainable (i.e. less land-intensive) advanced biofuels, based on non-food lignocellulosic feedstocks (e.g. miscanthus, switchgrass) and residues, are promoted heavily in the SUS and SUS+ scenarios. As Figure 30 shows, by 2050 the global advanced biofuels market is twelve-fold higher in SUS+ than in REF.
- The share of biomass-based fuels (conventional and advanced) in total fuels/petrol could reach almost 20% in the EU in 2050 in the SUS+ scenario.

Figure 29. Volume of conventional biofuel production in 2015 and 2050 for REF, SUS, SUS+, Mtoe

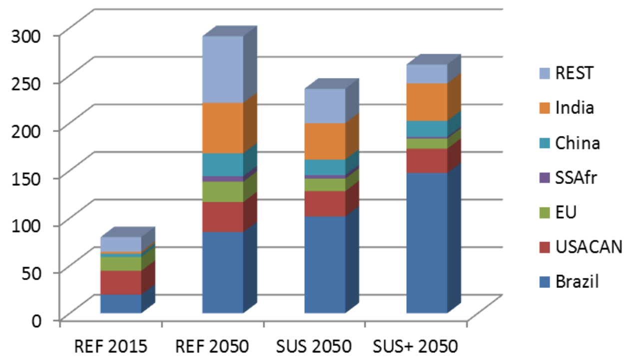
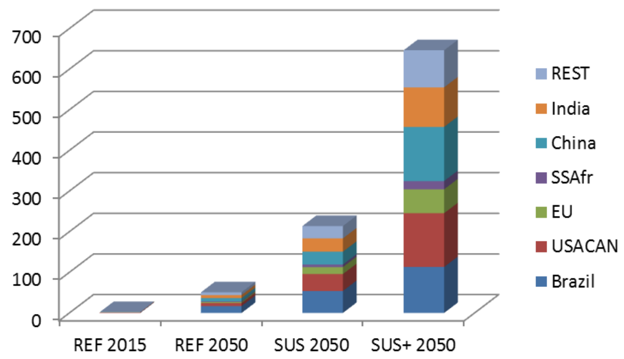


Figure 30. Volume of advanced biofuel production in 2050 for REF, SUS, SUS+, Mtoe

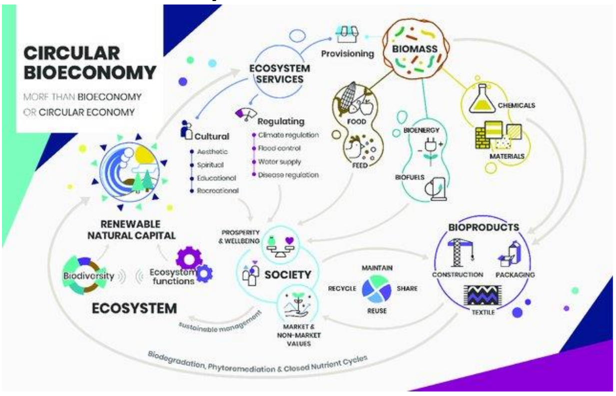


11 Capturing the circularity of the bioeconomy

Towards a European Green Deal

- With the European Green Deal, the EU aims to put climate neutrality into practice, as outlined in the Political Guidelines for the next European Commission 2019-2024 (EC, 2019).
- A New Circular Economy Action Plan aims to foster sustainable resource use, very much in line with the Bioeconomy Strategy (EC, 2019).
- Several versions of graphical representations of the circular bioeconomy exist, showing the linkages between the different drivers and sectors (see e.g. Martinez de Arano et al., 2018). The MAGNET model has been developed to explicitly treat key elements of the circular economy.
- This section provides insights into the transformation from a fossil-based to a biobased economy, and elements of circularity, mainly related to waste. It should be noted that further model improvements, including ones related to waste treatment and usage, and bioheat, are ongoing.

Figure 31. Example of graphical representation of circular bioeconomy

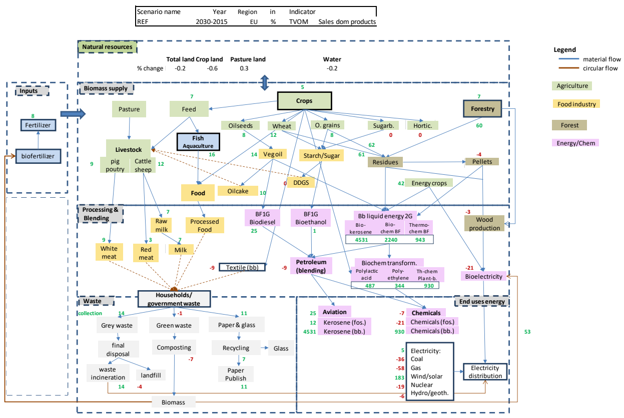


Source: Martínez de Arano, 2018.

Modelling the circular bioeconomy

- To understand the modelling outcome in a holistic and circular way, some results are shown in flow diagrams.
- As most appropriate for the bioeconomy from the economic model, the domestic sales for different scenario comparisons are shown either in € million or in % change, for different years.
- These diagrams are organised according to the material flow in the bioeconomy: 'biomass supply' requires 'inputs' and 'natural resources', which in turn undergo 'processing and blending' prior to end usage (e.g. food, 'end use energy and material') and reach their end of life ('waste'). Part of the waste is reintroduced into the economy.
- The numbers shown are the changes (in sales value) of the individual sectors, either in percentage or absolute terms.
- Given the focus of the transition pathways on energy transformation, there is a strong drive towards advanced generation biotechnologies (both materials and energy), which becomes the major driver of the big percentage rises in lignocellulosic-related biomass and processing activities.

Figure 32. Example of graphical representation of circular bioeconomy with MAGNET results (full-size example in following pages)



 M'barek, Philippidis, Ronzon (2019). Alternative Global Transition Pathways to 2050: Prospects for the Bioeconomy - An application of the MAGNET model with SDG insights | JRC Technical Report.

How to read the flow diagrams

For illustration, some guidance is provided here to the flowchart Figure 33, which shows the percentage change in sales of domestic products, comparing REF 2030 with REF 2015. The focus is on the relationship between biomass supply and non-food usage.

- Biomass supply 'Crops' and 'Livestock'
  - Most subsectors in the crop sector increase their sales.
  - In the meat sector, the impact of the carbon tax can be observed. The sales value increases because of the higher prices, not because of higher production.

- Biomass supply 'Forestry'
  - Residues use from forestry is increasing, supplying feedstock for advanced biobased liquid energy and bioelectricity generation.
  - The reduction in wood production is mainly related to greater competition from third countries (higher imports mainly from China).

- Conventional biofuels and their feedstocks
  - EU biodiesel production increases by 25%. This means a need for more vegetable oil (14%), and higher oilseed production (8%); oilcake as a by-product increases by 10%. The changes are not linear, as vegetable oil is also used in food production, and trade influences changes in production and usage.
  - Bioethanol production remains stable and does not trigger changes in starch/sugar or the feed by-product of ethanol distillers' dried grains with solubles (DDGS).

- Advanced liquid biofuels and their feedstocks
  - A strong growth can be seen in advanced liquid biofuels, which are becoming more competitive and replace fossil-based input to the petroleum blending, aviation and chemicals industries.
  - The feedstocks are coming mainly from residues (agriculture, forestry) directly and via pellets, from energy crops, and partly from vegetable oils.
  - Biobased liquid energy and biochemical transformation increases strongly, starting from a very low level.

- Waste (households/governments)
  - The allocation of waste collection services is driven by a fixed budget share of household expenditure. This expenditure is allocated over the three waste types, based on relative prices of each (and the respective substitution elasticity).
  - For green waste in the REF scenario, there are very small changes between 2015 and 2030, as no policy is supporting its development. The small rise in food prices is probably also making the resulting waste more expensive.
  - Grey waste treatment becomes more efficient: with more incineration, which goes to electricity.
  - Waste paper and glass increase significantly, concomitant with their recycling levels.
  - Note to the reader: the waste module is still under development.

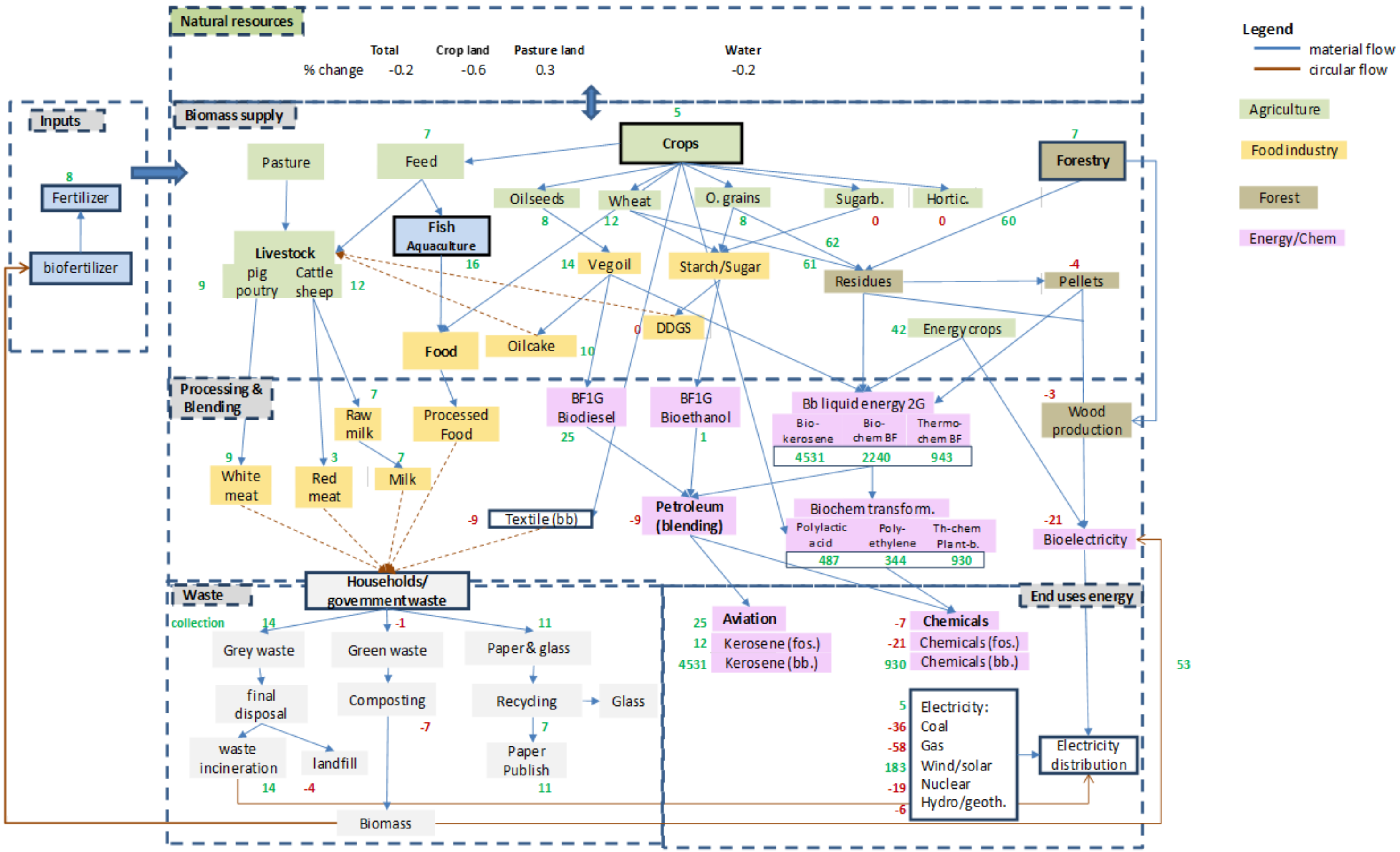
- End use of energy (of relevance to bioeconomy) is changing
  - Chemical sector sales in the EU fall by 7%, with fossil-based chemicals being replaced to a large extent by biobased chemicals.
  - The aviation sector increases overall, with biobased kerosene showing much higher growth rates than fossil-based kerosene.
  - Electricity shows an important transformation, with wind and solar energy almost tripling at the expense of fossil-sourced energy.
  - The decrease in bioelectricity, although accompanied by an increased use of waste-generated biomass, can be explained by the relatively higher profitability of using biomass in the biobased liquid.

- Input (here fertiliser) sales for agriculture increase by 8%, due to the higher price of fertiliser.

- Use of natural resources, i.e. agricultural land (and abstracted irrigated water), is slightly reduced.

Figure 33. Bioeconomy sector flow diagram – Reference 2030 vs 2015, % change, EU, domestic sales

Scenario name	Year	Region	in	Indicator	
REF	2030-2015	EU	%	TVOM	Sales dom products



M'barek, Philippidis, Ronzon (2019). Alternative Global Transition Pathways to 2050: Prospects for the Bioeconomy - An application of the MAGNET model with SDG insights | JRC Technical Report.

12 Trade

EU bioeconomy trade balance towards 2050

- The trade balance is defined as total value of exports minus imports of goods, expressed in € million.
- With trade liberalisation, the EU agri-food trade balance improves in the REF towards 2050 (Figure 34). Although imports of primary agricultural goods increase stronger than exports, EU processed food exports gain markets, as to a lesser extent do forestry products.
- The traditional sectors of wood processing, paper and textiles continue to lose relative competitiveness over time.
- The biobased chemical sector is not included in these calculations because of the uncertainty.
- The reader should also keep in mind the different absolute sizes of the individual sectors.

Sustainability scenarios

- Compared to the REF in 2050, the overall European trade balance in SUS is slightly less negative. The food and textile sectors benefit most from this scenario.
- In the SUS+ scenario, almost all sectors, apart from the food industry, experience a stronger increase in imports than in exports (or a reduction in the latter).
- Main reasons for these market shifts are increased competitiveness in other world regions, partly due to comparative advantage in non-EU bioenergy markets, and greater marginal land productivity improvements in non-EU regions arising from lower temperature increases.

EU market impacts from a multilateral trade liberalisation scenario

- To illustrate the possibilities in analysing potential policy measures, multilateral trade liberalisation of 50% on merchandise trade is assumed on top of the scenarios.
- As an example, results are shown for the SUS+ scenario, which again reveals trade-offs.
- Food prices decrease as expected, up to 1% for SSA, and food consumption improves slightly.
- Food imports (exports not shown) also rise, and there is improved access to third markets. It could be debated whether a higher food import quota has advantages for certain world regions.
- Overall per capita GDP would rise; however, for SSAfrica a slight decrease of almost 1% is observed. Nevertheless, it should not be concluded that no developing countries benefit from trade liberalisation.

Figure 34. Change in EU trade balance, in € million

	REF 2050 vs 2015	2050 SUS vs REF	2050 SUS+ vs REF
AGRI	-10,528	-847	-3,261
FOOD	24,873	8,850	4,863
FISH	-43	6	20
FOREST	2,027	-30	-234
BIOENER	530	-242	-1,973
WOOD	-13,702	263	-9,885
PAPER	-11,101	595	-5,586
TEXTILES	-94,676	5,142	-8,131
Total	-102,619	13,738	-24,186

Figure 35. Change in EU trade balance, in € million

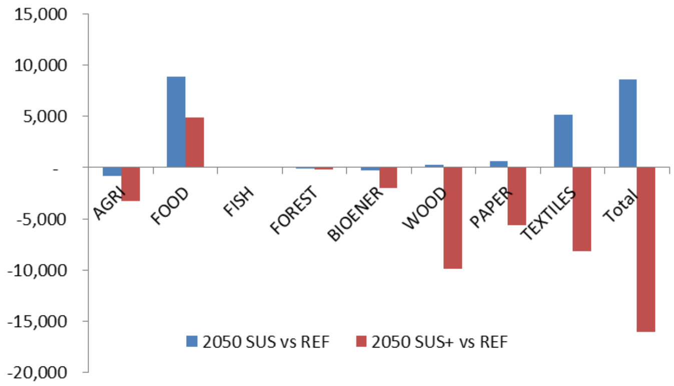
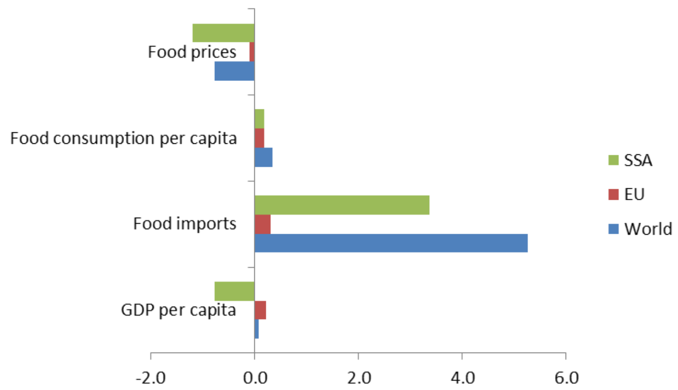


Figure 36. Change (%) in selected indicators, 2050 SUS+liberalisation vs SUS+, in SSAfrica, EU and globally



13 Bioeconomy and SDGs

Contribution of bioeconomy to SDGs

- The Bioeconomy Strategy mirrors many features of the SDGs. As outlined in the Staff Working Document on the Bioeconomy Strategy (EC 2018a), sustainable bioeconomy activities are deemed central to meeting the SDGs, from food and nutrition security to ensuring energy access and health.
- The Reflection Paper *Towards a Sustainable Europe by 2030* (European Commission, 2019) features the bioeconomy very prominently in the context of the SDGs. For example, it mentions the bioeconomy as 'one example where an important contribution can be made to decarbonising our economy while creating rural jobs.'
- The Political Guidelines for the next European Commission 2019-2024 plan to refocus the European Semester into an instrument that integrates the SDGs.
- The complexity of the SDGs, with their comprehensive list of targets and indicators, has been stated in many reports and articles. Whereas *ex post* analysis is available, the literature on forward-looking SDG analysis (for targets and/or indicators) is relatively thin. The present approach with the MAGNET modelling tool seeks to fill this gap.
- In this report, the scenarios performed do not include specific SDG or bioeconomy targets/actions/ measures. However, the sustainability scenarios SUS and SUS+ incorporate two important elements of both the SDGs and the Bioeconomy Strategy: the reduction of greenhouse gases and the transformation of the energy system.
- In the following figures, key results of the study are summarised in the context of the five bioeconomy objectives and the respective SDGs.
- The colour coding indicates the direction (green = more desirable, red = less desirable) with respect to the objectives (see also Heimann, 2019).
- On a global basis, resource usage in the REF negatively impacts environmental sustainability (see bioeconomy objective 2 and partly objective 4).
- The scenarios improve the use of land and water resources, and in particular objective 4. Regionally, food security (objective 1), but also objective 2 and 5, may increase in distance from the targets (see sub-Saharan Africa).

Figure 37. Key results in the context of the Bioeconomy objectives and SDGs for the world, 2015, 2030, 2050

			World						
Bioeconomy objectives	**SDGs**	**Description of indicator**	REF 2015	REF 2030 vs 2015	REF 2050 vs 2015	SUS vs REF 2030	SUS+ vs REF 2030	SUS vs REF 2050	SUS+ vs REF 2050
1 Food Security	2.1	Food prices index (2011=100)	100.1	2.0	1.6	0.7	0.8	1.1	3.5
1 Food Security	2.2	Calories per capita per day	2729.8	6.7	10.1	-0.2	-0.7	0.0	-0.8
1 Food Security	2	Food production (million metric tons)	11235.3	27.9	58.2	0.4	0.0	0.4	-0.4
1 Food Security	2	Food production per ha	2.3	22.9	47.2	0.5	0.3	0.6	1.0
2 Sust Resources	15.2	Brazil crop land (ha)	818107.0	3.1	-1.2	1.9	3.0	2.3	7.9
2 Sust Resources	15.2	Land use (million ha)	4853.2	4.1	7.4	-0.1	-0.3	-0.3	-1.4
2 Sust Resources	6.4	Abstracted irrigated water use (billion m^3)	2996.9	3.0	4.3	0.0	-0.1	-0.3	-1.2
3 Renewable Energy	17	Change of imports crude oil and gas in %						-43.4	-71.7
3 Renewable Energy	8.4	Advanced biofuels (Mtoe)	2.0	1327.3	2398.2	200.2	240.2	319.8	1169.4
3 Renewable Energy	8.4	Conventional biofuels (Mtoe)	80.0	58.9	264.0	-2.7	-2.3	-19.0	-10.2
3 Renewable Energy	7.2	Share renewable energy (change in %)	14.2	150.2	219.1	-8.6	0.0	66.4	90.4
4 Climate Change	13.2	Climate emissions reductions (Mtoe)	42807.0	10.3	26.0	-26.0	-33.7	-59.5	-79.1
4 Climate Change	13.2	tCO_2e per million € of economic activity	532.1	-27.4	-48.8	-26.2	-33.6	-57.0	-81.3
5 Jobs&growth	8.1	Per capita growth (€/person/year)	7481.0	38.7	108.8	-0.2	-0.8	-1.1	-0.8
5 Jobs&growth	8.5	Employment agriculture (million persons)	1144.9	-0.3	-12.4	-0.1	-1.2	2.8	-1.7
5 Jobs&growth	9.2	Industry's share of employment (change in%)	20.4	2.1	2.1	1.5	0.1	0.8	3.5
5 Jobs&growth	17.1	Food import quantity index (change in%)	107.0	26.2	56.1	0.0	-1.5	2.4	0.0

NB: 'REF 2015' ('Reference 2015') are absolute values, index or shares for the initial values in the year 2015.

'REF 2030 vs. 2015' and 'REF 2050 vs. REF 2015' depict the % change under the Reference scenario in 2030 and 2050 versus the initial year (Reference) 2015.

The third block of results shows the % change under the two scenarios SUS and SUS+ in the year 2030 compared with the Reference scenario in the year 2030.

The fourth block of results shows the % change under the two scenarios SUS and SUS+ in the year 2050 compared with the Reference scenario in the year 2050.

Figure 38. Key results in the context of the bioeconomy objectives and SDGs for the EU, 2015, 2030, 2050

			EU						
Bioeconomy objectives	**SDGs**	**Description of indicator**	REF 2015	REF 2030 vs 2015	REF 2050 vs 2015	SUS vs REF 2030	SUS+ vs REF 2030	SUS vs REF 2050	SUS+ vs REF 2050
1 Food Security	2.1	Food prices index (2011=100)	99.0	-0.2	0.8	0.5	1.2	-0.5	1.7
1 Food Security	2.2	Calories per capita per day	3424.2	1.5	2.6	0.1	-0.2	0.2	-0.1
1 Food Security	2	Food production (million metric tons)	1185.2	8.2	14.6	0.6	0.0	1.3	1.2
1 Food Security	2	Food production per ha	6.7	8.4	15.2	0.6	0.0	1.3	1.6
2 Sust Resources	15.2	Brazil crop land (ha)	818107.0	3.1	-1.2	1.9	3.0	2.3	7.9
2 Sust Resources	15.2	Land use (million ha)	178.1	-0.2	-0.5	0.1	0.0	0.0	-0.3
2 Sust Resources	6.4	Abstracted irrigated water use (billion m^3)	56.0	-0.2	-0.2	0.1	0.0	-0.3	0.0
3 Renewable Energy	8.4	Advanced biofuels (Mtoe)	0.2	1661.0	1484.9	255.3	315.7	506.3	1957.4
3 Renewable Energy	8.4	Conventional biofuels (Mtoe)	14.7	18.4	46.8	-5.0	-5.4	-39.2	-50.3
3 Renewable Energy	7.2	Share renewable energy (change in %)	22.1	149.3	279.5	13.7	11.7	6.7	5.2
4 Climate Change	13.2	Climate emissions reductions (Mtoe)	4672.0	-15.6	-17.6			-60.1	-78.9
4 Climate Change	13.2	tCO_2e per million € of economic activity	250.9	-32.1	-52.7	-20.0	-24.4	-49.3	-78.5
5 Jobs&growth	8.1	Per capita growth (€/person/year)	23167.3	18.6	54.1	0.0	-0.2	-1.0	-1.0
5 Jobs&growth	8.5	Employment agriculture (million persons)	12.9	-1.8	-13.6	-0.3	-2.2	10.8	-0.8
5 Jobs&growth	9.2	Industry's share of employment (change in%)	24.3	-7.6	-20.4	0.9	-11.0	-1.4	-3.8
5 Jobs&growth	17.1	Food import quantity index (change in%)	102.0	10.8	22.5	0.0	-0.9	0.8	0.8

Figure 39. Key results in the context of the bioeconomy objectives and SDGs for sub-Saharan Africa, 2015, 2030, 2050

			Subsaharan Africa						
Bioeconomy objectives	**SDGs**	**Description of indicator**	REF 2015	REF 2030 vs 2015	REF 2050 vs 2015	SUS vs REF 2030	SUS+ vs REF 2030	SUS vs REF 2050	SUS+ vs REF 2050
1 Food Security	2.1	Food prices index (2011=100)	97.2	-5.8	-13.0	0.6	0.6	2.8	9.9
1 Food Security	2.2	Calories per capita per day	2036.9	9.9	21.6	-0.2	-0.7	0.0	-2.9
1 Food Security	2	Food production (million metric tons)	844.2	64.7	183.1	0.0	0.0	-0.7	-3.2
1 Food Security	2	Food production per ha	0.8	45.5	126.7	0.4	0.9	-0.1	-0.3
2 Sust Resources	15.2	Land use (million ha)	1077.2	13.2	24.9	-0.4	-0.9	-0.6	-2.9
2 Sust Resources	6.4	Abstracted irrigated water use (billion m^3)	100.4	13.2	24.9	-0.4	-0.9	-0.6	-2.9
3 Renewable Energy	8.4	Advanced biofuels (Mtoe)	0.03	1725.7	5057.1	162.0	192.0	329.3	1334.6
3 Renewable Energy	8.4	Conventional biofuels (Mtoe)	0.04	6670.9	12397.1	-4.6	-5.9	-33.6	-66.3
4 Climate Change	13.2	Climate emissions reductions (Mtoe)	2914.0	59.4	175.3			-67.0	-81.5
4 Climate Change	13.2	tCO_2e per million € of economic activity	1219.5	-24.9	-50.1	-29.8	-40.1	-58.6	-79.7
5 Jobs&growth	8.1	Per capita growth (€/person/year)	1343.5	50.7	191.3	-0.4	-1.9	-2.2	-4.3
5 Jobs&growth	8.5	Employment agriculture (million persons)	154.5	22.6	17.5	-0.5	-1.0	1.3	-5.1
5 Jobs&growth	9.2	Industry's share of employment (change in%)	15.9	10.1	22.5	3.0	10.2	2.9	9.5
5 Jobs&growth	17.1	Food import quantity index (change in%)	113.0	48.7	134.5	1.8	1.8	5.3	15.1

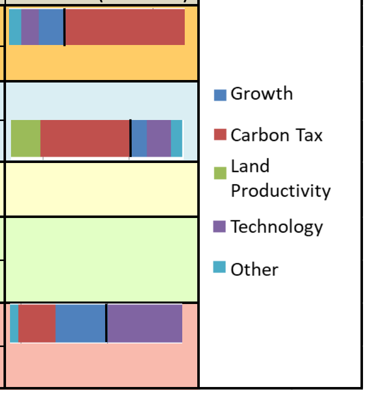
An alternative way of describing the results is shown below.

Comparing the SUS+ to the REF pathway, the size of colour-coded horizontal bars shows the relative strengths of selected market drivers in reaching the result for each of the metrics identified in the figure, where diagonal indicates less severe change than vertical. In terms of the signs, the black line separates positive (right side) and negative (left side) impacts for each metric. For example, in the first row, in terms of the marginal impact on food prices, the carbon tax (red bar) is the largest absolute driver and has a price-increasing impact (i.e. positive) on the outcome.

The direction of the arrow could be debated in some cases. For example, is higher food consumption a positive evolution, taking into account high obesity rates?

Figure 40. Key results in the context of the bioeconomy objectives and SDGs for the world, 2015, 2050

Bioeconomy objectives	SDGs	REF 2050 vs 2015	SUS 2050 vs REF 2050	SUS+ 2050 vs REF 2050	Examples for main drivers in scenarios (SUS+ vs REF)
Ensuring food and nutrition security	SDG 2.1 Food prices	↘	↘	↓	
	SDG 2.2 Food consumption	↗	↗	↘	
Managing natural resources sustainably	SDG 6.4 Agric water use	↓	↗	↗	
	SDG 15.2 Land demand	↓	↗	↗	
Reducing dependence on non-renewable, unsustainable resources	SDG 7.2 Renewable energy share	↑	↑	↑	
Mitigating and adapting to climate change	TOTAL CO2 emissions	↓	↗	↑	
	SDG 13.2 tCO2 emissions /GDP	↗	↑	↑	
Strengthening European competitiveness and creating jobs	SDG 1.1 Income /8.1	↑	↘	↘	
	SDG 8.5 Agric employment	↘	↗	↘	



14 Conclusions and outlook

Business as usual is not sustainable

- Latest global resource assessments (IPCC, 2018; IPBES, 2019; IPCC, 2019) signal the **unsustainability of the present economic system and resource use**.
- In this study we build **model-based scenarios** following the European Commission's Global Energy and Climate Outlook to 2050, which constitutes a central element of the EU vision for a prosperous, modern, competitive and climate neutral economy.
- Results of this study indicate that in the reference scenario (REF), **economic growth** in developing and emerging countries remains **strong towards 2050**, while **global income disparities persist**.
- Over time, the economy is projected to become **more energy-efficient**, creating more wealth per GHG emissions. However, in absolute terms, **GHG emissions continue to grow** by one third.
- **Global food production** increases by about 60% to feed the growing and richer world population, requiring **8% more land** and related resources.

Synergies between climate change and energy policies and the Bioeconomy Strategy

- Starting the transition to a more sustainable economic system, with ambitious climate change and energy policies, is fundamental.
- The two Bioeconomy Strategy objectives on **climate change** and reduction in **fossil-based energy use** are largely reached.
- Significant **investments in innovation** are a precondition for making these fundamental changes to the economy.
- They are also accompanied by benefits to resource usage, e.g. **less land** is used due to overall efficiency improvements and reduced climate change induced yield reductions. The potential usage of this land must be carefully evaluated, given the expected increase in land use over time.
- The **circular bioeconomy** has adequate macroeconomic conditions to evolve, as the high carbon price makes **innovative biobased industries** more competitive in replacing conventional fossil-based inputs to petroleum blending, aviation and chemicals sectors.
- **Biobased liquid energy** and **biochemical transformation** could increase six- to ten-fold, with feedstocks coming mainly from agricultural and forest residues and energy crops.
- The **value of the bioeconomy** increases continuously (in 2011 prices). Depending on how the biobased industry evolves (biobased production shares), additional growth could be expected.
- The **job market**, which in general terms faces more efficient technologies and structural change in the primary sectors, does not necessarily favour the net creation of new jobs.
- The **carbon tax** also gives price signals to food consumption, making **carbon-intensive meat** production, and thus consumption, more expensive.
- From an **environmental perspective,** substitution effects need further investigation, e.g. more cropland with potentially more intensive production, and the strong growth in use of non-food biomass for advanced bioenergy pathways.

Specific focus on socioeconomic aspects for the global South

- The alternative sustainable transition pathways do not produce a noticeable change in real **income inequalities**.
- The key driver within these transition pathways is the rise in the **carbon tax**, which delivers a cleaner global economy. However, for the traditional part of the bioeconomy, there are negative repercussions for production and employment in more emissions-intensive agricultural sectors in developing regions.
- **World food prices** in the scenarios rise only slightly, but regionally and for more vulnerable parts of the population, this could be problematic.
- **Food security concerns** also arise, through reduced growth in per capita calorie intake for the poor.

Global responses to global challenges

- The present analysis, in line with other studies, underlines the need for **globally coordinated responses**. It shows that the EU vision for a climate neutral economy is also a key transition path from a bioeconomy perspective.
- The **SDGs** are the **appropriate international framework** to address the broadness of the challenges and identify the required **policy mix** to address the complexity.
- The **part worth analysis** employed in this study signals which **drivers/policies** are important.
- **Lower population growth**, and its supporting factors such as **reduced inequalities** and **better education**, are obvious worldwide responses.
- **Burden sharing**, including through the provision of modern systems and technologies (leapfrogging), is necessary to ensure that living conditions improve for the poorest or most vulnerable regions.
- **Sustainable and sustained investments** are needed to deliver potential growth. In order to foster thriving competitive rural communities, where available biomass feedstock is close to processing plants, we require reliable and convenient infrastructure.

- Responsible and environmentally **sustainable production**, with higher productivity, is crucial to provide the additional food and biomass needed for other purposes.
- **Sustainable consumption**, including the **change in diets** towards a more plant-based diet, can alleviate pressure on agricultural production and resource usage, and lower greenhouse gases (see e.g. IPCC, 2019).
- Reductions in **food waste** (SDG target 12.3) also reduce greenhouse gas emissions, and improve food security and biodiversity due to the shrinking demand for agri-food products.

An EU bioeconomy view

- Looking at the results, the challenges identified and the options for solutions from an EU perspective, the importance of appropriate framework conditions and incentives becomes evident.
- The EU Bioeconomy Strategy's contribution to optimising the sustainable supply and use of biomass lies in the **policy-coherent approach** to **identify synergies and limit unwanted trade-offs**. The agri-food sector plays a key role here.
- The EU Bioeconomy Strategy Action Plan foresees the deployment of innovative biobased solutions, often in the form of biorefineries. **Production of alternative biobased liquid energy** (also for chemistry) could grow more than ten-fold in the SUS+ scenario, compared with today's production. The **industrial capacity and infrastructure** needs to be in place.
- **Research and innovation** is critical, as only through improvements in land productivity and resource use management could a sustainable transition become reality. It should be stressed again that the technological change in the scenarios is exogenous; its extent is a reflection of the necessary investments to be accomplished, subject to a degree of uncertainty.
- The EU is already today a **major importer of biomass raw materials**. The reliance on imports would increase over time in the reference and sustainability scenarios. In an era where mercantilist sentiment may threaten the goal of free and unfettered access to third country markets, the results highlight once again the importance of trade, in meeting domestic energy requirements and food security needs, and providing consumers with unprecedented access to choice.
- It should be recognised, however, that **non-market costs to trade**, in the form of environmental footprints and leakage, should take high priority when seeking to strike new trade deals. This is clearly in line with EU pledges to factor sustainability concerns into the legislature for future preferential trading arrangements.
- **Ecosystem services** are represented in an indirect way through the carbon price (tax), which can be interpreted as a shadow price on the cost of (non-market) environmental benefits (cleaner air, biodiversity, etc.), represented in the model in terms of national income cost.

Outlook: analysis of specific measures for a sustainable bioeconomy in Europe

- The study presented is subject to the general limits of all model-based assessments (Philippidis et al, 2018). With a time horizon of 2050, assumptions lead to a higher degree of **uncertainty**. For the very purpose of delivering a specific analysis of the bioeconomy sectors, assumptions had to be made on biobased shares over time.
- In parallel to this study, the MAGNET model is being further developed to include for instance bioheat, the carbon sink of forests, and details on the fishery and aquaculture sector.
- A follow-up report planned in 2020 will analyse a limited set of additional **potential measures and policies**, to mitigate in particular social and environmental impacts, mainly concerning food waste reduction and diets.
- Furthermore, there is a clear need to analyse key measures in a **systematic and simultaneous way** and to rank them according to sustainability impacts.
- Whereas the MAGNET model can provide a broad picture of the whole economy, with recourse to specific biophysical model inputs, other model types, such as sectorial or land use models, can provide additional granularity to furnish policymakers with detail on specific sectors or biophysical interactions. As a result, there is a clear strategic gain in seeking out **coherent model linkages** between the economic and biophysical modelling communities, which can further enrich the analysis.

15 Annex

15.1 Further information on the approach

15.1.1 Computable general equilibrium (CGE) models – overview

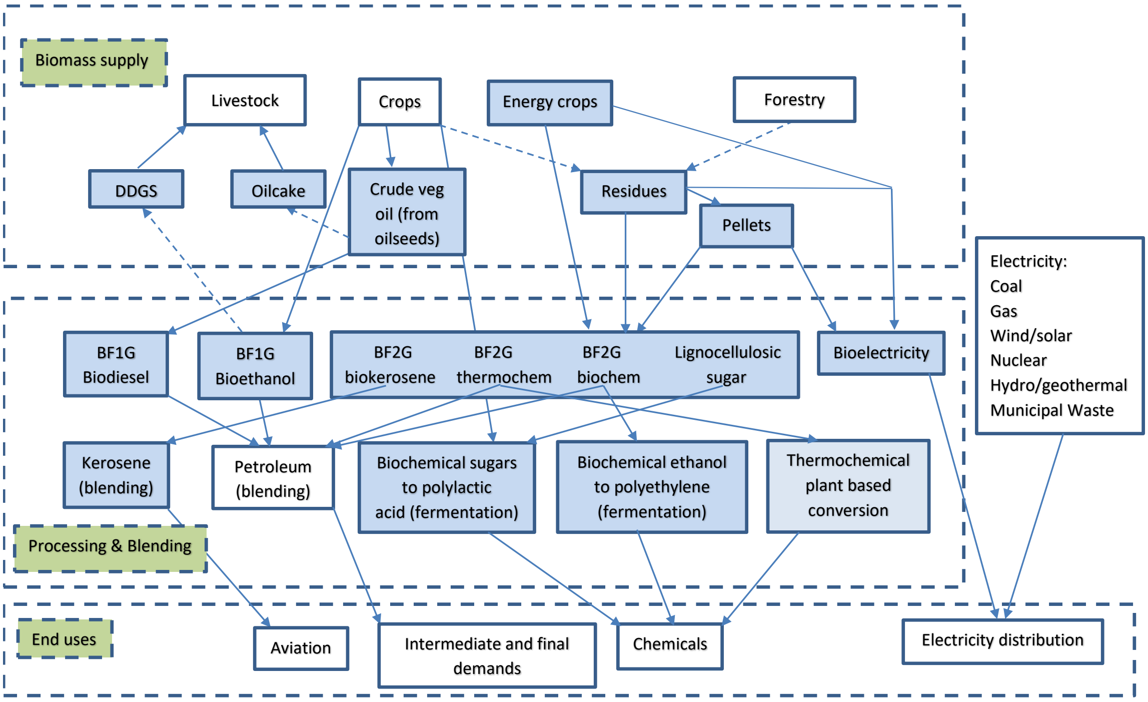
MAGNET is a class of multiregion, multicommodity computable general equilibrium (CGE) economic simulation model. The model employs the typical tenets of neoclassical economic behaviour, to derive the behaviour of agents. Input demands are subject to minimisation of costs subject to constant returns to scale production technologies, whilst the regional household optimises its utility subject to a budget constraint. Employing linearly homogeneous functional forms and weak separability conditions, multistage budgeting allows for cost minimising optimisation across a series of sub-nests, permitting parsimonious yet flexible treatment of production technologies. Additional market clearing and accounting equations enforce the underlying conditions of the model database, namely that supply equals demand in each market; economic profits remains zero; and the values of output, income and expenditure within the macro circular flow remain equal. Furthermore, the movement of transactions of goods and services around the circular flow is supported by price transmission equations with tax/subsidy rates.

To ensure a model solution, the number of equations and endogenous variables (typically prices and quantities) in the model system must be equal – known as the model 'closure'. Remaining variables (i.e. tax rates, technology changes, endowment changes) are held to be exogenous. Neoclassical closure is assumed where savings rates are fixed shares of regional income; interregional investment is allocated with movements in relative regional rates of return; and capital account imbalances (i.e. savings minus investment) are matched by current account movements (i.e. exports minus imports) such that the balance of payments nets to zero. The closure is therefore not only a mathematical requirement for guaranteeing a model solution; it also serves as a maintained hypothesis regarding the macroeconomic behavioural mechanisms driving the model. Once the modeller successfully replicates the equilibrium conditions inherent within the underlying database (known as 'calibration'), a simulation run consists of imposing a series of targeted exogenous shocks. These could cover projections on macroeconomic variables to characterise a certain time period, and/or shocks to specific market variables. In response, the model arrives at a new matrix of equilibrium prices and quantities to satisfy the market clearing and accounting conditions discussed above. In the case of recursive dynamic models which run over multiple time periods (such as MAGNET), the equilibrium solution from the end of the previous simulation period forms the starting point for the next period.

15.1.2 MAGNET database

An illustration of the linkages between the existing GTAP activities and the new biobased sector and commodity splits, is presented in Figure S.1. The non-standard data additions are highlighted in blue and the standard GTAP sectors appear in white. The arrows indicate the directional flows of biomass, whilst the dashed lines show by-products of biomass processing. A detailed discussion of these sectors and the accompanying data sources is available online in Philippidis et al. (2018a).

Overview of biobased sectors and linkages in MAGNET



Source: Philippidis et al., 2018)

15.1.3 MAGNET SDG Insights Module

To achieve a more holistic and coherent approach to policy implementation, the representation of the SDG indicators/metrics within an *ex ante* global market simulation model provides a unique insight into the synergies or trade-offs in scenarios where several policy instruments and other drivers are operating simultaneously.

The MAGNET SDG Insights Module (MAGNET SIM) embeds 60 official and supporting indicators, covering 12 of the 17 SDGs for each of the 140 regions in the database (see Table). The aim is that complex model output is made more accessible through translation into a series of SDG metrics, which is increasingly becoming part of the common language of global impact assessment. In many cases, the generation of index- and share-based SDG indicators directly follows from the existing price, quantity and value indicators within the MAGNET database (e.g. food price indices, rural wages, import and export changes, value added shares by industrial classification). Moreover, access to additional non-standard modules, and their associated satellite databases, further enriches the suite of available MAGNET SDG metrics to encapsulate levels indicators (e.g. employment head, land areas, calorie intake, water volume abstraction, energy production and consumption in million tonnes of oil equivalent).

Detailed list of SDG indicators in the MAGNET SDG Insights Module

Goal 1: No poverty
Per capita utility from private expenditure
Ratio of rural wage to cereal price (food access measure)
Goal 2: Zero hunger
Total factor productivity
Average import tariffs on agricultural food products (*ad valorem* rate)
Average export subsidies on agricultural food products (*ad valorem* rate)
Index of import tariffs on agricultural food products
Index of export subsidies on agricultural food products
Food availability:
Domestic food production (primary agriculture)
Domestic food production (primary agriculture including fish)
Food imports (primary agriculture including fish)

Food exports (primary agriculture including fish)
Calories per capita per day (excluding fish)
Calories per capita per day (including fish)
Share of calories from cereals
Protein (grams per person per day) from livestock and fish products
Protein (grams per person per day) from livestock products
Food access:
Average household income per capita in thousand USD
Food prices
Share of food expenditure in total income
Food consumption and food consumption per capita
Food utilisation: share of calories from fruit and vegetables
Goal 4: Quality education
Share of skilled labour
Goal 6: Water and sanitation
Percentage change in water use over time (in arable sectors)
Goal 7: Sustainable energy
Primary energy
Renewable energy share in total energy input consumption
Final energy
Relative competitiveness of fossil fuel to renewables
Energy security: self-sufficiency (value)
Energy security: price per energy unit
Energy security: value-added contribution of energy
Land devoted to bioenergy
Ratio of value added to net domestic energy use by industry
Energy intensity measured in terms of primary energy and GDP
Share of household spending on energy
Goal 8: Sustainable economic growth
Annual growth rate of GDP per capita
Net trade position
Share of fossil fuels in GDP
Revealed Comparative Advantage
Diversification index
Net trade position
Annual growth rate in real GDP per employed person (Indicator 8.2.1)
Goal 9: Resilient infrastructure
Manufacturing value added as a percentage of total value added
Manufacturing value added per capita
Manufacturing employment as a percentage of total employment
CO_2 emissions (tonnes per unit of value added)
Combustion emissions (tonnes per unit of value added)
Non-combustion emissions (tonnes per unit of value added)
Trade levels
Trade openness
Goal 10: Reduced inequalities
Labour share of GDP comprising wages
Skills composition

Wage differential skilled/unskilled
Wage differential agriculture/non-agriculture
Change in agricultural employment
Agricultural employment as a percentage of total employment
Goal 12: Responsible consumption and production patterns
Share of renewables (biobased and non-biobased) in total energy production
Amount of fossil fuel subsidies per unit of GDP
Amount of fossil fuel subsidies as a share of national expenditure on fossil fuels
Goal 13: Climate action
Share of renewables in total energy production
Factor intensities:
Sectoral value-added share in total value added
Share of value added in total costs by sector
Number of countries using a biofuel directive
Emissions per unit of GDP/output
Emissions per calorie
Goal 14: Conserve and sustainably use marine resources
Fisheries as a value share of GDP
Goal 15: Sustainable use of terrestrial ecosystems, including forests
Share of non-agricultural land
Goal 17: Strengthen the Global Partnership for Sustainable Development
GDP
Total government revenue (by source) as a percentage of GDP
Developing countries' and least developed countries' share of global exports
Average tariffs faced by trading partners
Worldwide weighted tariff average

15.1.4 Recent applications of MAGNET relevant to this study

In their review of scenario modelling tools, Allen et al. (2016) evaluated 80 models addressing SDG thematic issues. Out of the eight models meeting the two screening criteria of 'policy relevant' and 'integrated', MAGNET was identified as addressing the three dimensions of sustainable development (see also JRC report on interlinkages and policy coherence 2019, p. 12).

This model has been used for many different research and policy studies geared towards the food-energy-climate-water-health nexus (see below for published articles). It is also used in various JRC projects (including AgFUTURE, Water-Energy-Food-Ecosystems Nexus - WEFE) and H2020 projects.

It has recently been referenced in the impact assessment for the legal proposal related to 'Modernising and Simplifying the Common Agricultural Policy'.

In the academic literature in the field of sustainability, MAGNET has featured prominently as an impact assessment tool within a broad variety of areas including: land use change (e.g. Schmitz et al., 2014); EU domestic support (e.g. Boulanger and Philippidis, 2015); biofuels (e.g. Smeets et al., 2014; Philippidis et al., 2018); food security (Rutten et al., 2013); climate change (van Meijl et al., 2018) and EU bioeconomy (Philippidis et al., 2018).

The MAGNET model has been used for many different research and policy analyses in the food-energy-climate-water-health nexus. The latest scientific publications involving the JRC are in *Nature Climate Change* (2018a; 2018b), *Energies* (2018), *Ecological Economics* (2018), *Environmental Research Letters* (2018), *Economic Systems Research* (2019), *Resources, Conservation & Recycling* (2019).

Technical documentation including the SDG concept is available in the JRC report *The MAGNET model framework for assessing policy coherence and SDGs* (Philippidis et al., 2018a); a JRC brief, *SDGs in the global MAGNET model for policy coherent analysis,* outlines the main features of the new module for SDGs.
The latest developments in including SDGs in MAGNET are quoted in the updated Bioeconomy Strategy COM(2018) 673 and SWD(2018) 431 *A sustainable Bioeconomy for Europe: Strengthening the connection between economy, society and the environment* as a model framework approach to assessing policy coherence and SDGs.

15.2 Disaggregation of commodities and regions

(used in various aggregations)

Commodity disaggregation (59 commodities):

Arable and horticulture (9): paddy rice (pdr); wheat (wht); other grains (grain); oilseeds (oilsd); raw sugar (sug); vegetables, fruits and nuts (hort); other crops (crops); crude vegetable oil (cvol).
Livestock and meat (7): cattle and sheep (cattle); pigs and poultry (pigpoul); raw milk (milk); cattle meat (meat); other meat (omeat); dairy (dairy).
Fertiliser (1): fertiliser (fert).
Other food and beverages (2): sugar processing (sugar); other food and beverages (ofdbv).
Other 'traditional' biobased (2): fishing (fish); forestry (frs); wood products (woodpro); paper products (paperpro); textiles & clothing (textcloth).
Biomass supply (12): energy crops (energy); residue processing (res); pellets (pel); by-product residues from rice (r_pdr); by-product residues from wheat (r_wht); by-product residues from other grains (r_grain); by-product residues from oilseeds (r_oilsd); by-product residues from horticulture (r_hort); by-product residues from other crops (r_crops); by-product residues from forestry (r_frs); municipal waste (waste).
Biobased liquid energy (5): 1st generation biodiesel (biod); 1st generation bioethanol (biog); 2nd generation thermochemical technology biofuel (ft_fuel); 2nd generation biochemical technology biofuel (eth); bio-kerosene (bkero).
Biobased and non-biobased animal feeds (3): 1st generation bioethanol by-product distillers dried grains and solubles (ddgs); crude vegetable oil by-product oilcake (oilcake); animal feed (feed).
Renewable electricity generation (3): bioelectricity (bioe); hydroelectric (ely_h); solar and wind (ely_w).
Fossil fuels and other energy markets (10): crude oil (c_oil); petroleum (petro); gas (gas); gas distribution (gas_dist); coal (coa); coal-fired electricity (ely_c); gas-fired electricity (ely_g); nuclear electricity (ely_n); electricity distribution (ely); kerosene (kero).
Other sectors (5): chemicals, rubbers and plastics (crp); other manufacturing (manu); aviation (avi); other transport (trans); services (svcs).

Regional disaggregation (13 regions):

USA and Canada (USACan); Brazil (Bra); Rest of Latin America (RestLatAme); Northern Africa (NoAfrica); Sub Saharan Africa (SSAfrica); European Union (EU); Rest of Europe (REurope); Russia (Rus); Middle East (MidEast); India (Ind); China (Chn); Rest of Asia (RAsia); Oceania (Oce).

15.3 Overview on indicators covered by the whole-economy approach, compared to the most suitable key indicators for the EU Bioeconomy Strategy objectives

EU bioeconomy strategy objective	Identified most suitable key indicators	
Creating jobs and maintaining competitiveness	Number of employed persons in rural and urban areas	☑
	Value added	☑
	Contribution to the GDP	☑
	Investment in research and innovation	☑
	Exports	☑
	+ Import (identified by the correspondents after the online-survey)	☑
Reducing dependence on non-renewable resources	Production of renewable energy *and* Production of biofuels and biogas *combined*	☑
	Material and waste recycling and recovery rates	partial
	Material replacing non-renewable resources	partial
	Public financial support and private	partial
	Investment in research and innovation	☑
Mitigating and adapting climate change	Carbon sequestration	no
	Forest carbon emissions/sinks	no
	Greenhouse gas emissions from agriculture	☑
	Water area carbon emissions/sinks	partial
	Public financial support and private investments	partial
	Investment in research and innovation	
Ensuring food security	Domestic food supply of food commodities in terms of production, import/ stock change	☑
	Agricultural products	☑
	Fish products	☑
	Non-wood forest products	☑
	New food products	?
	Public financial support and private	partial
	Investment in research and innovation	☑
Managing natural resources sustainably	Land cover	☑
	Resource availability	partial
	Sustainable resource use	partial
	Environmental protection	no
	Public financial support and private investments for ecosystem services	no
	+ Investment in research and innovation (identified by the correspondents after the online-survey)	partial

Source: Lier et al. (2018). Synthesis on bioeconomy monitoring systems in the EU Member States - indicators for monitoring the

15.5 Assumptions on biobased shares

Aggregation for value added and job calculation

Agriculture	Paddy rice; wheat; other grains; oilseeds; sugar beet; vegetables, fruits and nuts; other crops; cattle and sheep; pigs and poultry; raw milk; feed
Food industry	Other food and beverages: sugar processing; crude vegetable oil; cattle meat; other meat; dairy
Fishing	Idem
Forestry	Idem
Bioenergy	1st generation biodiesel; 1st generation bioethanol; 2nd generation thermochemical technology biofuel; 2nd generation biochemical technology biofuel; bio-kerosene
Wood manufacture	Idem
Paper	Paper and publication (40%)
Textiles	Textiles and clothes (50%)

The biobased shares for 2015, by industrial activity, are taken from Ronzon (2018).

Biobased shares in (%) 2015

		Bio-based share
AGRI	Agriculture	100
FOREST	Forestry	100
FISH	Fishing and aquaculture	100
FOOD	Food, Beverages and other agromanufacturing	100
BIOMASS	Biomass for second generation	100
WOOD	Wood products	100
PAPER	Biobased paper product	40
TEXTILES	Biobased textiles	50
BIOENERGY	Biobased energy	100
BIOCHEM	Biobased chemical and pharmaceuticals, plastics and rubber	18

For a **lower threshold, or 'pessimistic' outlook for biobased shares,** we assume the share remaining as in 2015 over the whole period and across all scenarios.

Estimates for expected future changes in biobased shares, by industrial classification, are scarce. For biobased chemicals, the Bio-based Industry Consortium sets an objective of 25% by 2030 (see Road2Bio project). From this value, we derive a compound annual increase in the share of about 1% in the REF for all three biobased sub-sectors.

For a **middle-of-the-road biobased shares outlook**, we assume the share following the high assumptions over the whole period and remaining at the 2050 value.

Biobased shares in (%) of the chemical sector for a middle-of-the-road biobased share outlook

	REF	REF	REF	REF	REF	SUS	SUS+
	2015	2020	2030	2040	2050	2050	2050
Biobased chemicals	9	15	25	35	45	45	45
Biobased pharmaceuticals	50	55	65	75	85	85	85
Biobased plastics and rubber	6	10	20	30	40	40	40

Biobased shares in (%) of the chemical sector for an 'optimistic' biobased share outlook

		REF	REF	REF	REF	REF	SUS	SUS+
		2015	2020	2030	2040	2050	2050	2050
Biobased chemicals		9	15	25	35	45	60	75
Biobased pharmaceuticals		50	55	65	75	85	90	95
Biobased plastics and rubber		6	10	20	30	40	50	60

The current GTAP 9 database does not provide a split of the chemical sector into the categories above (fossil-based and biobased together). We use the split in the recently released GTAP 10 database to calculate the share of the three subsectors (chemicals: 54%; pharmaceuticals: 23%; rubber and plastics: 23%) in the current aggregate 'chemicals, rubbers and plastics'. To these values, we apply biobased shares from Ronzon (2018).

15.6 Alternative ways on job calculation in the chemical sector

Job numbers for the chemical sector in MAGNET (GTAP) for the EU are higher than in EUROSTAT. In order to follow the trends and model results, the % changes for the whole chemical sector are extracted.

Job calculation for the chemical sector

	2015	2030	2050	SUS	SUS+
Chemical sector (GTAP), in million	4,597	4,033	3,037	3,039	2,649
		REF 2030 vs. REF 2015	REF 2050 vs. REF 2015	SUS 2050 vs. REF 2050	SUS+ 2050 vs. REF 2050
Change in %		-12.3	-33.9	0.1	-12.8

Using the EUROSTAT data for the three subsectors and applying both the overall change in the chemical sector and the biobased share evolution as in 15.5, the following job numbers are generated.

low bio-based share			**REF**	**REF**	**REF**	**SUS**	**SUS+**
NACE_R2/TIME	2015		2015	2030	2050	2050	2050
Manufacture of chemicals and chemical products	1,150,000	Bb chem	103,500	90,811	68,386	68,426	59,639
Manufacture of basic pharmaceutical products and pharmaceutical preparations	572,976	Bb pharma	286,488	251,365	189,292	189,404	165,080
Manufacture of rubber and plastic products	1,671,757	Bb rub plast	100,305	88,008	66,275	66,314	57,798
Total	3,394,733		490,293	430,184	323,953	324,144	282,517

mid bio-based share			**REF**	**REF**	**REF**	**SUS**	**SUS+**
NACE_R2/TIME	2015		2015	2030	2050	2050	2050
Manufacture of chemicals and chemical products	1,150,000	Bb chem	103,500	252,253	341,929	342,131	298,194
Manufacture of basic pharmaceutical products and pharmaceutical preparations	572,976	Bb pharma	286,488	326,774	321,797	321,986	280,636
Manufacture of rubber and plastic products	1,671,757	Bb rub plast	100,305	293,360	441,834	442,094	385,320
Total	3,394,733		490,293	872,387	1,105,560	1,106,211	964,149

high bio-based share			**REF**	**REF**	**REF**	**SUS**	**SUS+**
NACE_R2/TIME	2015		2015	2030	2050	2050	2050
Manufacture of chemicals and chemical products	1,150,000	Bb chem	103,500	252,253	341,929	456,174	496,989
Manufacture of basic pharmaceutical products and pharmaceutical preparations	572,976	Bb pharma	286,488	326,774	321,797	340,926	313,652
Manufacture of rubber and plastic products	1,671,757	Bb rub plast	100,305	293,360	441,834	552,618	577,979
Total	3,394,733		490,293	872,387	1,105,560	1,349,718	1,388,621

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List of abbreviations and definitions

BF1st	first generation biofuels
BFAdv	advanced generation
CT	Carbon tax
FAO	Food and Agriculture Organization of the United nations
GDP	Gross domestic product
GHG	Greenhouse gas
GROWTH	Macroeconomic growth
GTAP	Global Trade Analysis Project
ha	Hectare
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
LANDPRO	Land Productivity
LatAme	Latin America
LTS	Long-term strategy
MAGNET	Modular Applied General Equilibrium Tool
Mtoe	million tonnes of oil equivalent
OECD	Organisation for Economic Cooperation and Development
REF	Reference scenario
REST	Other drivers
RoW	Rest of World
SDGs	Sustainable Development Goals
SSAfrica	Sub-Saharan Africa
SUS	Sustainable pathway, consistent with temperature rises no greater than 2 °C
SUS+	Sustainable pathway, consistent with temperature rises no greater than 1.5 °C
TECH	Technology changes
TOTAL	Net impact of all drivers
UN	United Nations
USACAN	USA and Canada

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