Can the evolution of the European bioeconomy contribute to the Sustainable Development Goals?

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Abstract

Launched and adopted on 13 February 2012, Europe's Bioeconomy Strategy addresses the production of renewable biological resources and their conversion into vital products and bio-energy. The Strategy proposes answers to the challenges Europe and the world are facing, in particular the increasing populations that must be fed, depletion of natural resources, impacts of ever increasing environmental pressures and climate change. The Strategy is also needed to ensure that carbon based technologies are replaced with sustainable natural alternatives as part of the shift to a post-petroleum society. In addition, on 25 September 2015, the United Nations General Assembly formally adopted the universal, integrated and transformative 2030 Agenda for Sustainable Development, along with a set of 17 Sustainable Development Goals and 169 associated targets, and the EU has committed to implement the SDGs both in its internal and external policies.

A newly developed MAGNET SDG module evaluates the impact of policy on SDG indicators in an ex-ante framework. It carries the advantage of translating often complex modelling results into the impact on SDG indicators which are fast becoming the common language of global impact assessment. Evaluating the impact on SDG metrics within GTAP-style ex-ante global market simulation models provides a unique insight into the synergies or trade-offs in scenarios where several market instruments are operating simultaneously and allows for a more coherent approach to policy implementation.

This paper evaluates three scenarios based on Europe's Bioeconomy Strategy and evaluates the impacts on the Sustainable Development Goals, using the newly developed MAGNET SDG module. We examine the impact on biomass usage arising from (1) a 'no mandate level playing field' in which RED 1 first and second generation biomass mandate support is removed (2) an EU-wide biofuels mandate exploring a greater role for second generation biofuels, and (3) a 'Bio high tech' scenario in which an aggressive R&D led policy is implemented into the emerging second generation biobased sectors. All scenarios impacts are evaluated relative to a 'business as usual' baseline 2011-2030 using SDG indicators.

We conduct the analysis using the Modular Applied GeNeral Equilibrium Tool (MAGNET), a GTAP-based global economic simulation model based on version 9.2 of the GTAP database, benchmarked to 2011. The database and model are extended to include second generation biofuels, bioelectricity and waste, biochemicals and a suite of SDG indicators. Specifically, the MAGNET Sustainable Development Goals module includes 60 official and supporting indicators, covering 12 of the 17 SDGs for each region of the world.

These extensions ensure that MAGNET represents the complexities of the supply chain from the sources of biomass (e.g., agricultural crops, crop and forestry residues, energy crops, pellets), through different technological biomass processes, to end uses (e.g. food, feed, first and second generation biofuels, bioelectricity and a representative sample of biochemical technological pathways). Combining the abovementioned data and modelling developments with additional secondary data on Greenhouse gas (GHG) emissions, the MAGNET model is able to provide unique insights relating to specific policy issues such as the impacts of energy prices on biomass use and fertiliser inputs for agricultural activities; the effect of competing land uses (food, feed, energy) for agricultural crop prices; or in broader terms, the economy-wide implications and feedback effects arising from the broad collection of diverse activities identified with the concept of the bioeconomy.

The results of the scenarios show the contribution of the policy changes to societal challenges in 2030, both in terms of synergies and trade-offs. Using the results, we will show the impact on energy usage for biofuels using SDG7 indicators, job creation using SDG10 indicators and food and nutrition security within and outside of Europe using SDG2 indicators.

1 Introduction

Launched and adopted on 13 February 2012, Europe's Bioeconomy Strategy addresses the production of renewable biological resources, or biomass, and its conversion into high-value material products and bio-energy. In broad terms, the core principles behind this strategy are to provide "a long-term balance of social, environmental and economic gains by linking the sustainable use of renewable resources for food, feed, bio-based products and bioenergy, with the protection and restoration of biodiversity, ecosystems and natural capital across land and water"(1). Under the lead of DG Research and Innovation, the Strategy was co-signed by several other Commission departments, namely DG Agriculture and Rural Development, DG Environment, DG Maritime Affairs, and DG Industry and Entrepreneurship, with a view to greater harmonisation between existing policy approaches in this area.

The Bioeconomy Strategy therefore represents a coordinated response to the key societal challenges faced both in Europe and throughout the world. In particular, it proposes solutions to alleviate the pressures of increasing food demand from a growing population; circumvent environmentally unfriendly industrial practises and climate change through technological innovation and present sustainable energy alternatives which aid the transition toward a post-petroleum society. In 2017 a review(2) of the Strategy was undertaken to provide a major opportunity for a new political impetus and orientation.

Early 2018, the roadmap(3) "Update of the 2012 Bioeconomy Strategy" was published, outlining the main purpose of the strategy and providing an updated plan for concrete actions. While delineating, as a key objective, the balance of all three sustainability dimensions, it re-emphasises the need for a system-wide approach, which encompasses pan-European and globally interconnected challenges such as climate change; biodiversity loss; unsustainable production and consumption patterns; demographic growth and migration; urbanisation; the double burden of malnutrition and undernutrition and the evolving attitude and behaviour of European consumers.

In tandem with the development of the Bioeconomy Roadmap, the actions as outlined in the Roadmap are concomitant to the Sustainable Development Goals (SDGs), which the EU, along with other key world players, is committed to implementing within its portfolio of domestic and foreign policy initiatives. Inaugurated under the auspices of the '2030 Agenda for Sustainable Development', a set of 17 SDGs and 169 associated targets were formally adopted in September 2015. On 22 November 2016, the European Commission published a Communication on the 'Next steps for a sustainable European future', encompassing the economic, social, environmental dimensions of sustainable development, as well as governance, within the EU and globally. The related staff working document (SWD(2016) 390 final) outlines the "Key European action supporting the 2030 Agenda and the Sustainable Development Goals" and links the different policy areas to specific SDGs.

Looking forward, as a broad sector of highly diverse economic activities, the bioeconomy provides an ideal platform for mobilising a system-wide framework balancing the social, environmental and economic dimensions of these European and international initiatives. Inevitably, a flagship initiative with multiple policy goals inevitably leads to potential trade-offs and even potential policy incoherence. Through its very definition, the discipline of economics is rooted to the principle of efficient scarce resource allocation in a world of unlimited wants. Accordingly, applied forward-looking, or *ex-ante*, economic analysis is an essential component of the policy prescription process by employing impartial tools of assessment to examine 'second-best' alternative market outcomes.

1 Ref. Ares(2018)975361 - 20/02/2018; https://ec.europa.eu/research/Bioeconomy/index.cfm?pg=policy&lib=strategy

2 https://ec.europa.eu/research/bioeconomy/pdf/review_of_2012_eu_bes.pdf

3 Ref. Ares(2018)975361 - 20/02/2018; https://ec.europa.eu/research/Bioeconomy/index.cfm?pg=policy&lib=strategy

One attractive option for such a task is the use of theoretically consistent economy-wide global market simulation models, known as computable general equilibrium (CGE). This class of research tool is well geared toward the explicit representation of multiple bioeconomic activities with numerous input- and output interlinkages with the broader macroeconomy. Thus, CGE models recognise trade-offs between diverging uses and applications of available biomass, as well as the competition that exists between bio-based and non-bio-based activities for primary resources such as labour and capital. Moreover, with an explicit representation of gross bilateral trade flows, CGE models directly consider the essential access to third country sources for vital supplies of both biomass and energy to meet internal market requirements. Finally, a key strength of this approach is the ability to explicitly treat a range of economic policies simultaneously (albeit as an approximation of existing, or expected, real-world market intervention) or other market shocks, with a view to isolating the marginal impact of any specific market driver on a set of targeted indicators.

As a vehicle for operationalising this CGE analysis, the Modular Applied GeNeral Equilibrium Tool (MAGNET) is employed. In the peer-reviewed literature, the model has featured as an impact assessment tool within a broad variety of areas including: land-use change (e.g., Verburg et al. 2009, Schmitz et al., 2014); agricultural trade and policy (e.g., Boulanger and Philippidis, 2015, M'barek et al. 2017); Biofuels (e.g., Banse et al, 2011; Kavallari and Tabeau, 2014, Smeets et al., 2014); Food Security (Rutten et al., 2013) and Climate change (Nelson et al., 2014).

Over the last few years, MAGNET has been further developed with a focus on the bioeconomy and the climate-energy-water-food nexus (Philippidis et al., 2018b; van Meijl et al., 2018). As a fundamentally economic tool of analysis, the representation of biophysical limits are restricted at the current time to sustainable land and biomass availability, whilst further modelling to capture other natural resource availability is still to be done. Nevertheless, as a system-wide overview of economy-wide bio-based activity, from the perspective of the Joint Research Centre (JRC), the MAGNET model is an ideal complement to narrower, more highly detailed sector-specific partial equilibrium (PE) models of the agricultural and forestry sectors. Indeed, as part of an integrated assessment of biomass usage consisting of links with specialist energy and land-use model representations, the aim is to provide more in-depth insights on developments on biomass availability, production, consumption and trade trends (Camia et al, 2018).

With a view to conducting rigorous scientific assessment of different medium-term scenarios, the current technical report serves as a point of reference. Thus, the rest of this report is structured as follows. In Section 2, a detailed description is given of the MAGNET bio-based database and medium-term baseline to 2030. In Section 3, a commentary of the main market outcomes from the baseline is provided along with a selection of output from the launch of a new module, known as the MAGNET SDG Insights Module (MAGNET SIM). This module is still under development, although it is envisaged that a more detailed description of the modelling and the accompanying results in scenario analysis will be forthcoming. A final section concludes.

2 Methodology

2.1 Database Overview and New Sectors

With its unrivalled global coverage of countries (140 regions) and activities (57 sectors), the Global Trade Analysis Project (GTAP) database has become a *de facto* source of data for conducting economic impact assessments. In its latest incarnation (version 10), the database includes detailed information on production, gross bilateral trade flows, transport costs and trade protection data for a 2011 benchmark year. As a principal secondary data source for characterising the technology and final demand structures within each country or region, input-output national accounts data adhere to broad industry classifications. Importantly, efforts by the GTAP centre to disaggregate certain bio-based activities (i.e., primary agriculture and food processing) are undertaken, although inevitably, more contemporary uses of biomass for feed, fuel and even material applications remain subsumed within their parent industry classifications.

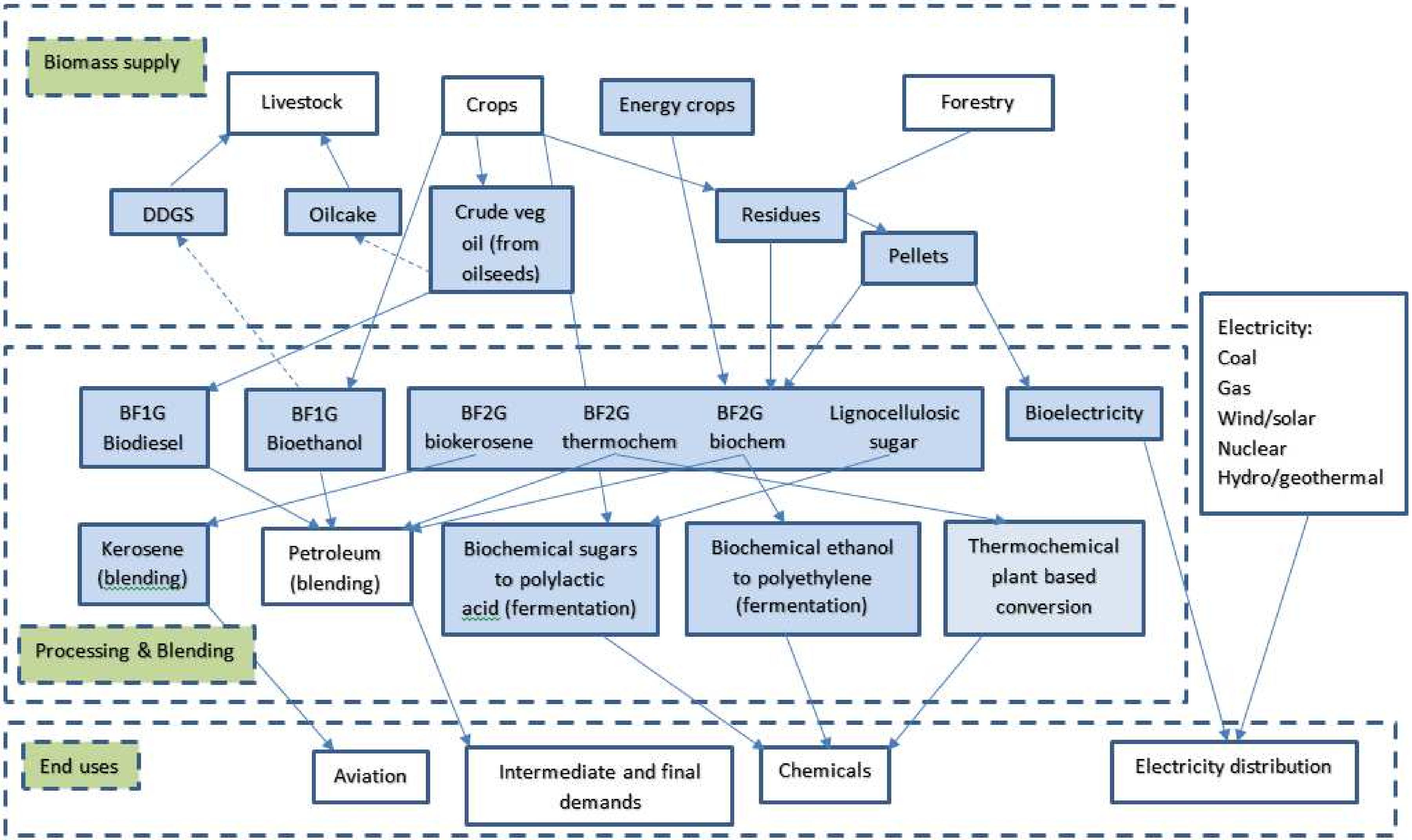
Thus, a clear challenge for modelling in detail the sources of biomass and the interrelationships and potential conflicts that arise between competing uses, requires an explicit representation of established and emerging bio-based activities within the GTAP database. The Modular Agricultural GeNeral Equilibrium Tool (MAGNET) (Woltjer & Kuiper, 2014) is a multi-region computable general equilibrium model which is a derivative of the above mentioned Global Trade Analysis Project (GTAP) model and database. As a reaction to the challenge for more detailed modelling of sources of biomass, MAGNET contains a significant number of bio-based activities and sectors. MAGNET represents the complexities of the supply chain from sources of biomass (e.g., agricultural crops, residues, energy crops, pellets), to different technological biomass processes, to end uses e.g. food, feed, biofuels (first and second generation), bioelectricity and biochemicals (e.g. PLA, PE, etc.). With this database combined with a GHG emission database, at its disposal, the MAGNET model provides unique insights on (*inter alia*) the impacts of energy prices on e.g. biomass use, fertiliser inputs for agricultural activities, etc.; the effect of competing land uses (food, feed, energy) for agricultural crop prices. Or more generally speaking the economy-wide implications and feedback effects arising from the broad collection of diverse activities identified with the concept of the bioeconomy.

An overview of the new bio-based sectors in MAGNET and their linkages with the existing GTAP database is provided in Figure 1. The new bio-based sectors are highlighted in blue, and the standard GTAP sectors in white. The arrows indicate the direction of biomass and bio-based energy and chemicals flows. Furthermore, the dashed lines indicate where production processes produce secondary by-products.

Biomass: Aside from primary agricultural activities, an additional three activities and one by-product commodity in MAGNET represent the supply and trade of raw biomass; namely energy crops, residues, pellets and municipal solid waste, respectively. The energy crop sector produces biomass for energy production using dedicated woody or grassy energy crops. Residues are modelled as by-products from the activities of the existing GTAP database crop and forestry sectors. Crop residues include residues from harvesting and processing of wheat, other grains, rice, horticulture, oilseeds and other crops. The latter includes residues from forest management and logging that are usually left in the field, and residues from the wood processing industry, such as bark, shavings, sawdust, etc. A separate residue processing sector collects and transports both crop and forest residues (including waste).

Biofuels: Following previous work by Banse et al. (2008, 2011), first generation biofuels are split out from the parent 'chemicals, rubbers and plastics' industry in the GTAP database. Thus, bioethanol production relies on substitutable first-generation feedstocks such as sugar cane/beet, wheat, and maize, whilst for biodiesel, (crude) vegetable oil and oilseeds are used as inputs. The production of ethanol allows for by-products like distiller's dried grains with soluble (DDGS) that can be used for animal feeding. For biodiesel vegetable oil is used, where the (crude) vegetable oil sector has oilcake as a by-product. The animal feed sector and the animal sectors themselves are able to substitute between different types of feed through a nested CES structure. In this manner also the indirect effects of biofuel production through its by-products is taken into account. In addition, production and use of first generation bio-fuels in the petroleum (blending) sector were taken from IEA (2010) and WEC (2014).

Figure 1. Overview of bio-based sectors and linkages in MAGNET.



The identification of two promising second-generation biofuel technologies and associated cost shares in MAGNET is based on a cost-minimising linear programming energy model of the Netherlands (MARKAL-NL-UU). Firstly, a thermochemical biomass conversion process[(4)] based on the gasification of solid lignocellulose biomass and synthesis to Fischer-Tropsch fuels is considered. Secondly, a biochemical conversion[(5)] technology employs hydrolysis of lignocellulose biomass and fermentation of sugars to ethanol. Data on current and future conversion costs (exc. feedstock costs) and conversion efficiencies were taken from the Dutch variant of the market allocation model (MARKAL-NL-UU) platform. Given the choice of benchmark year (2011), blending rates in the downstream petroleum sector for second-generation biofuels assume very small (non-zero) values. On the other hand, the cost-disadvantage of biofuels (first- and second-generation) compared with conventional fossil technologies is reflected in the subsidy rates to end-users based on differences between crude oil and biofuel (actual and assumed) prices per litre.

Kerosene: The MAGNET database is extended to include both conventional (fossil based) kerosene and bio-kerosene production from lignocellulose sources of biomass from agriculture and forestry. The conventional kerosene produced from oil, is assumed to have the same cost structure as the original GTAP sector P_C (Petroleum & Coke: coke oven products, refined petroleum products, processing of nuclear fuel). Bio-kerosene is 'blended' in the kerosene, which is subsequently sold to the aviation sector. The cost of bio-kerosene is assumed equal to the cost of 2nd generation thermal technology biofuel (ft_fuel). This is the cheapest technology according to a review of the future costs of bio-kerosene production pathways by De Jong (2015).

Electricity: In the MAGNET model, the generation of electricity is split into fossil based (gas-fired, coal-fired), nuclear and renewable (wind and solar, hydroelectric and geothermal, bioelectricity). In addition, an electricity transport and grid distribution sector is subsequently included which meets electricity demand for final and intermediate uses.

Data on the production and consumption of electricity are taken from energy statistics from the International Energy Agency (IEA) and the Energy Information Administration (EIA). Secondary data on the total production of electricity from biomass and waste in billion kWh per country in 2011 are taken from the Energy Information Administration International Energy Statistics (EIA 2017). In these statistics, the production of bioelectricity is split into bioelectricity from biomass (residues from agriculture and forestry, biomass from lignocellulose energy crop plantations and pellets) and bioelectricity from the organic fraction of municipal solid waste.

Chemicals: In the absence of any detailed cost structures, a collection of promising technologies and cost shares were selected using estimates from the biophysical MARKAL-UU-NL model. Each of these sectors are split out from the parent 'chemicals rubber and plastics' sector in the GTAP database. In short, three promising representative technologies (two biochemical conversion and one thermochemical conversion) are selected as bio-alternative processes into plastics production; (i) a biochemical fermentation conversion process of direct sugar to chemicals or polylactic acid (pla) polymers which employs conventional (i.e., first-generation) sugar from sugar beet and cane and/or second-generation lignocellulosic fermentable sugars (see Figure 1); (ii) as a proxy for ethanol usage in the chemical industry, a biochemical fermentation conversion process of first- and\or second-generation ethanol into a bio-polyethylene (pe) polymer, and (iii) a thermochemical conversion of plant based feedstocks to produce biochemicals for plastics (b_chem).

A full discussion of these sectors is provided in Philippidis et al. along with the principal data sources uses to capture the additional sectors (2018a).

[4] Thermochemical conversion technologies include combustion, gasification or pyrolysis
[5] Biochemical conversion technologies include fermentation or anaerobic digestion.

2.2 Model framework, closure and aggregation

To carry out the analysis, an advanced multi-sector, multi-region recursive-dynamic global market model known as the Modular Agricultural GeNeral Equilibrium Tool (MAGNET - Woltjer and Kuiper, 2014) is employed. This class of model employs constrained optimisation to characterise agent behaviour (i.e., intermediate-, final- and investment demands), whilst homothetic separability and consistent aggregation permit a parsimonious 'nested' representation of consumer and producer behaviour. Producers are assumed to operate under conditions of perfect competition and constant returns to scale, whilst a series of market clearing and accounting equations ensure that all markets clear and national-income, -expenditure and -output are equal. A series of price linkage equations with exogenous *ad valorem* tax (or tariff) variables capture the market distortions on domestic and imported markets. It is assumed that savings rates are a fixed share of changes in regional income, whilst investment to each region is allocated as a function of relative changes in regional rates of return. A neoclassical closure rule is assumed such that imbalances on the capital account (i.e., regional savings less investment) are compensated by the current account (exports minus imports), such that the balance of payments nets to zero.

A key strength of the model is its modular structure which allows the user to easily activate those modules of most relevance to the study at hand. With a focus on biomass sources and usage, the model follows the same structure as in Philippidis et al. (2018b). Thus, as a key producer of biomass for food, feed and energy, the agricultural sector is fully disaggregated into cropping and livestock activities. An agriculture specific module is included which covers production function nesting structures for cropping and livestock production technologies, rigidities in agricultural labour and capital markets and agricultural policy modelling (Boulanger and Philippidis, 2015). A further significant area where public policy influences the use of biomass is in the liquid biofuels market, where a fiscal neutral approach is taken (Banse et al., 2008). Thus, a further module exogenously imposes mandates by the (blending) petroleum sector on purchases of biofuels, where taxes on demand finance the subsidy to biomass providers for energy to meet said targets. An environmental module akin to the work in GTAP-E (Burniaux and Truong, 2008) captures carbon taxes and physical limits on all greenhouse gas (GHG) emitting activities. This work is supported by further production nests to capture the capital-energy substitution possibilities inherent within the refining and power generation sectors (e.g., electricity, petroleum) based on Golub, 2013).

Further modelling of biomass markets is captured through the modelling of joint (i.e., Leontief) production technologies which acknowledge the important role of by-products as additional sources of raw biomass inputs in other production technologies (i.e., energy, animal feed, bioindustry). More specifically, agricultural and forestry sectors produce 'residues'; first-generation bioethanol produces distiller's dried grains with soluble (*DDGS*) animal feed, and crude vegetable oil, largely employed in first generation biodiesel production, produces an oilcake animal feed.

To capture the sustainable limits on the usage of residues, an asymptotic supply function is modelled (**Error! Reference source not found.**), where the equilibrium market price change (P*) reflects the usage position on the supply curve up to a maximum 'sustainable potential'. This available maximum excludes residues for fibre board and animal feed, whilst also acknowledging that a fraction of residues must be left on the field to maintain soil quality and avoid degradation. Both the residue asymptote and the ratio of the equilibrium supply of residues to the maximum sustainable potential is provided as a input from the IMAGE biophysical model (Daioglou et al., 2015). With changes in residue demands by using sectors, adjustments in equilibrium prices and quantities are a function of the point supply elasticity which in MAGNET is a function of changes in the ratio of total derived residue demand in biomass applications to residue supply and the residue market price.

Finally, to improve the tracking of final demand patterns over medium- to long-term time frames, particularly in relation to food biomass demand in regions with rapidly increasing per capita real incomes, calibrated income elasticity parameters are endogenously adjusted downwards in successive time periods with rises in real (PPP corrected) GDP per capita (Woltjer and Kuiper, 2014)[(6)].

The choice of EU regions captures geographical diversity whilst identifying some of the individual larger players on EU bio-based markets (

6 As a result, in regions/countries where real incomes are rising rapidly (i.e., China, India, Mercosur), a more realistic rise in food demands (vs. the standard GTAP treatment) moderates pressure on food prices, and by extension biomass prices and land rents.

Annex

Table 2 in the Annex). In the same way, the non-EU region choices includes a European residual region of EU neighbours including Russia) and 'large' third-country distributors of raw and processed biomass products on world markets.

At the current time, the coverage of the bioeconomy commodities in the MAGNET model remains an ongoing work-in-progress, although it goes far beyond the typical classification of sectors commonly found in the standard classification of national accounts which underlies the GTAP database.

Annex

Table 2 in the Annex presents the classification of commodities employed in the current study. As expected, the emphasis is on the disaggregation of the different sources of supply and uses (i.e., food, feed, bioenergy and bio-industrial) of biomass. To enhance the model treatment, additional agricultural inputs are also explicitly split out, whilst the disaggregation of sectors also encompasses the representation of energy markets in terms of supply (fossil and renewable) and usage (i.e., transport, chemicals, industry, services etc.).

3 The MAGNET SDG Insights Module (MAGNET SIM)

The use of the MAGNET global neoclassical computable general equilibrium (CGE) model has emerged as a useful framework for providing insights on future trends in the Sustainable Development Goals (SDGs). With a multi-sector, multi-region coverage, these simulation models have the flexibility to provide market impact assessments arising from one or more policy shocks simultaneously, which serves as an ideal complement for the enumeration of policy coherence analysis.

A key area of development is the implementation of a MAGNET SDG module which can provide a series of metrics (i.e., levels, shares, indices) for an array of indicators covering, as far as feasibly possible, the spirit of the 17 SDG definitions. As the scope of the MAGNET model is clearly centred on economic indicators, it was deemed implausible to attempt a full coverage of all SDG indicator groupings. Indeed, a mathematical simulation model is found wanting when one is interested to examining concepts of ensuring healthy lives, educational quality, gender equality, or the promotion of peaceful societies. As a result, the ambition of this first step was to narrow the model's interpretation of the SDG indicators to those relating principally to energy usage, consumption, competitiveness, employment and growth, climate and land usage.

In line with the ethos of the model´s modularity, the MAGNET SDG Insights Module (MAGNET SIM) is an add-on to the core model's behavioural equations, and employs market variables based on value flows, and where possible, some use of physical units (i.e., land use hectares, calorie consumption), to enumerate the descriptors of the SDG indicators. In large part, these indicators have been calculated using the model's underlying database on production, consumption and trade flows. Given the law of one-price which typically underlines the benchmarking of data for this class of simulation model, it is recognised that over time, "value" based flows do not track aggregated physical quantity changes which underlies many of the SDGs. This point has particular pertinence when one considers issues of energy efficiency or employment changes between sectors.

Accordingly, this caveat should be understood when interpreting the MAGNET SDG indicators which emerge from the medium-term baseline scenario presented in this report. Indeed, a key priority for the further development of this module is to remedy this methodological shortcoming through recourse to actual physical data quantities accompanied by some form of validation method. The selection of indicators is deliberately spread across different SDGs as an illustration of the potential variety of indicators covered in MAGNET.

It should be noted that the results section is purely descriptive in nature. There is no attempt to target SDG indicators or evaluate in depth the desirability of said outcomes based on our baseline assumptions. As noted above, all results are presented as levels (i.e., values, calories per capita per day), shares or indices for the time period 2015-2030. Notwithstanding, the selection of SDG indicator results presented serves as a useful precursor of what can be achieved using this modelling framework in the coming months and years.

4 Baseline

From the benchmark year of 2011, and examining available sources of historical and projections data, a *baseline scenario* is developed distinguishing three different periods covering the time horizon of the SDGs: namely 2011-2015, 2015-2020 and 2020-2030. The first time period is an update to capture, as faithfully and feasibly as possible, the structural economic and political trends. To this end, shocks to agricultural spending and agricultural policies (Boulanger and Philippidis, 2015) as well as biofuel mandates and global GHG emissions reductions capture relevant policy developments (see next sections). The implementation of EU bioenergy policy developments also has implications for fossil based and non-biological renewable energy markets. For this reason, macroeconomic, energy market and GHG emissions trends are from a single consistent source (European Commission, 2016). The shocks employed are summarised in

Table **1** and discussed in more detail in Philippidis et al. (2018a).

5 Looking at the baseline scenario from an SDG perspective

5.1 Baseline trends 2015-2030

In the baseline, the general trend for the market price effects is downward due to land and output productivity gains in the EU28, a finding consistent with other studies (e.g., Baldos and Hertel, 2014, OECD FAO 2015). As expected, the dominant price drivers are the technical-change assumptions on output and land; capital accumulation and labour force growth. In bio-based activities, market trends are also strongly driven by EU policy. Aggregate first-generation biofuel (BF1G) output volume increases 38.9% in the period 2015-2020, which in turn, drives upstream output increases in crude vegetable oil and oilseeds (used in biodiesel), as well as wheat, grains and sugar beet (used in bioethanol). As a result, the production of by-product animal feeds also rises 9.1% in this period. As the blending mandate reaches a plateau in the 2020-2030 period, first generation biofuel production falls slightly as rising oil prices in this period reduce the scale of the EU's petroleum (blending) activity. Oilseeds and crude vegetable oil production also drops off slightly, whilst cereals production remains strong due to population growth and rising real incomes which drive food demand.

Second-generation biofuels (BF2G) output volumes increase aggressively to 2030 with a ratcheting up of the blending mandate to 1.5%. As a result, strong production volume growth in associated upstream biomass cellulosic feedstock sectors is observed (an average of 70% increase). The assumed blending mandates for EU biofuels therefore indicate the potential importance of such market interventions for the promotion of EU biofuels activities. In the absence of any concrete EU support policies; standard rates of technological growth; and a continued decline in the oil price over the 2015-2020 period, bio-industrial output volumes (i.e., nascent biochemical- and thermochemical biomass-conversion technologies) contract from a small base. In the 2020-2030 period, strong output volume growth in these bio-based sectors (approximately 30%) is the result of a substitution effect due to the declining competitiveness of conventional carbon technologies from assumed rises in fossil fuel prices.

Table 1. Baseline assumptions over the three time periods disaggregation of commodities and regions.

Periods: (2011-2015; 2015-2020; 2020-2030)

- **Real GDP** and **population growth** projections from European Commission (2016) for each period
- **Land productivity growth:** projections from von Lampe et al., (2014).
- **Global fossil fuel price projections** for coal, crude oil and gas (World Bank, 2017) for each period
- **Greenhouse gas emissions** reductions from European Commission (2016) for each period

(2011-2015 period)

Trade Policy (Trade)

- EU28 Enlargement elimination of border protection between incumbent EU27 members and Croatia
- Extension to Croatia of an EU common external tariff (CET) on third country trade and reciprocal third country CETs extended to Croatia as an EU28 member

Agricultural Policy

- Continued phasing in of decoupled payments for 2004 and 2007 accession members
- Targeted removal of specific pillar 1 coupled support payments: Seeds, beef and veal payments (except the suckler cow premium) decoupled by 2012, Protein crops, rice and nuts decoupled by 1 January 2012
- Re-coupling of support under the article 68 provision
- Greening of 30% of first pillar payments
- Pillar 2 payments to the EU Member States under the financial framework
- Abolition of raw milk (2015) quota

Biofuels Policy (BF)

- EU-wide 1st generation EU average bio-fuel mandate of 5.75%

(2015-2020 period)

Trade Policy (Trade)

- EU-Canada trade shocks with HS6 product exceptions tariffs
- EU-Vietnam trade shocks with HS6 product exceptions tariffs

Agricultural Policy (CAP)

- First and second pillar payments follow financial framework budget envelopes.
- Abolition of raw sugar (2017) quotas

Biofuels Policy (BF)

- EU28-wide 1st generation bio-fuel mandate of 7 %

(2020-2030 period)

Agricultural Policy (CAP)

- 2% p.a. reductions in CAP budget payments. Pillar 1 (coupled/decoupled) and pillar 2 (by rural development measure) payment structures assumed unchanged from 2020.

Bio-energy Policy (BF)

EU28-wide 1st generation bio-fuel mandate of 7 % EU28-wide 2nd generation bio-fuel mandate of 1.5%

Bioelectricity output volume in the baseline also drives biomass provision from pellets and residues. Similarly, with growth in the aviation sector of approximately 12% and 9% in the periods 2015-2020 and 2020-2030, respectively (not shown), there are notable percentage output volume increases in the (small) bio-kerosene sector, with an overall growth in volume size by a factor of almost ten over the period 2015-2030. Finally, due to the long standing decline in primary agricultural output, employment decreases in the bio-economy as a whole, a result consistent with Philippidis et al., (2018b). Finally, there is evidence that the assumed trends in fossil fuel prices also drive market decisions on the allocation of biomass for fuel and industrial applications.

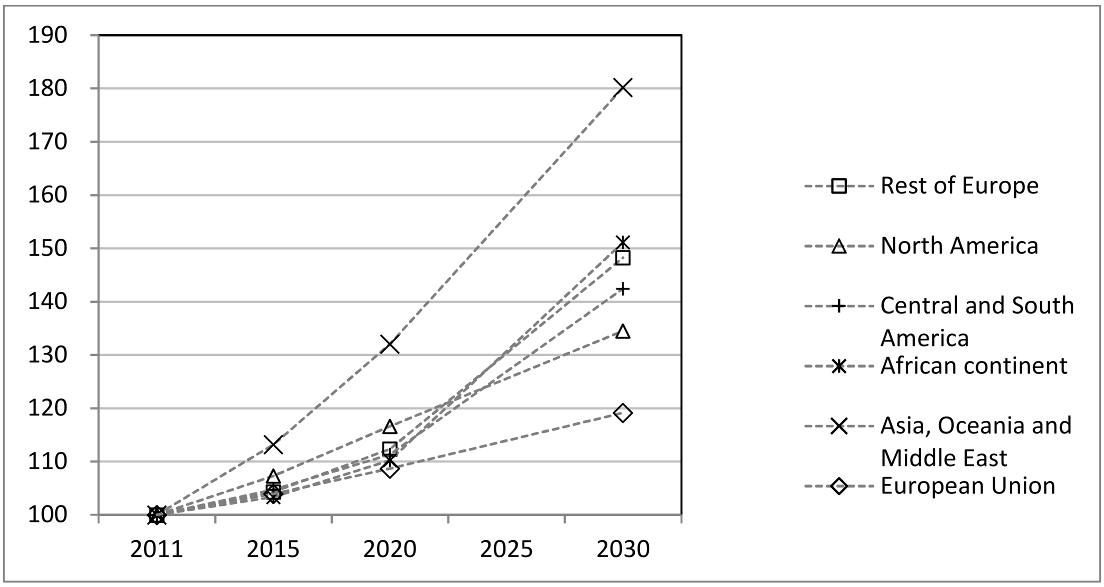
A more detailed analysis of the baseline is available in Philippidis et al. (2018a)

5.2 Economic growth development in the baseline scenario and SDGs 8 and 10

From the assumed changes in real GDP growth and population (see **Error! Reference source not found.**), for the regions under consideration in this study, an index of changes in real per capita income (utility) and normalised nominal income per capita are computed to provide a global insight on component parts of SDG 8 (on decent work and economic growth) and SDG 10 (reduced inequalities).

Examining first SDG8, Figure 2 shows that the highest growth of the per capita utility index is in the "Asia, Oceania and Middle East" region, which combines high annual GDP rates (4% p.a. in 2015-2020, 6.3% p.a. in 2020-2030) and moderate population growth. With a per capita utility index of 151 by 2030, the African continent ranks second as high compound rates of real GDP growth are moderated by high population growth (see **Error! Reference source not found.**). Interestingly, particularly strong GDP growth in the African continent in the 2020-2030 period explains the steepening of the slope of the per capita utility index. A similar slope and 2030 per capita utility index is observed in the "Rest of Europe"[(7)], arising from a plateauing of the expected population. The two regions characterising the American continent attain intermediate levels of per capita utility indices by 2030, whilst the EU has the lowest growth in per capita utility by 2030, which is further disaggregated by Member States (MS) in Figure 3.

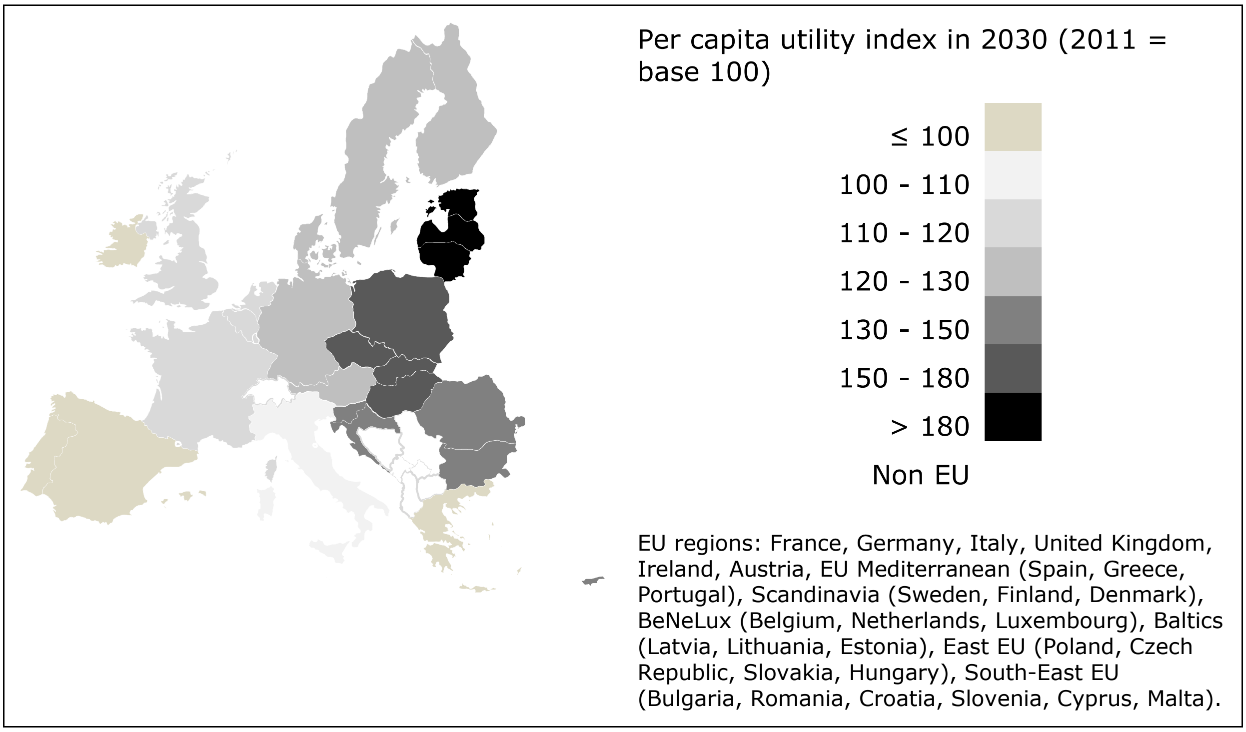
Figure 2. Evolution of per capita utility (2011=100).



[7] The "Rest of Europe" region is composed of the Commonwealth of Independent States (CIS), EFTA members, Turkey, non-EU Balkan states and remaining 'small' states (e.g., Andorra, Faroe Islands, Gibraltar Guernsey, Isle of Man, Jersey).

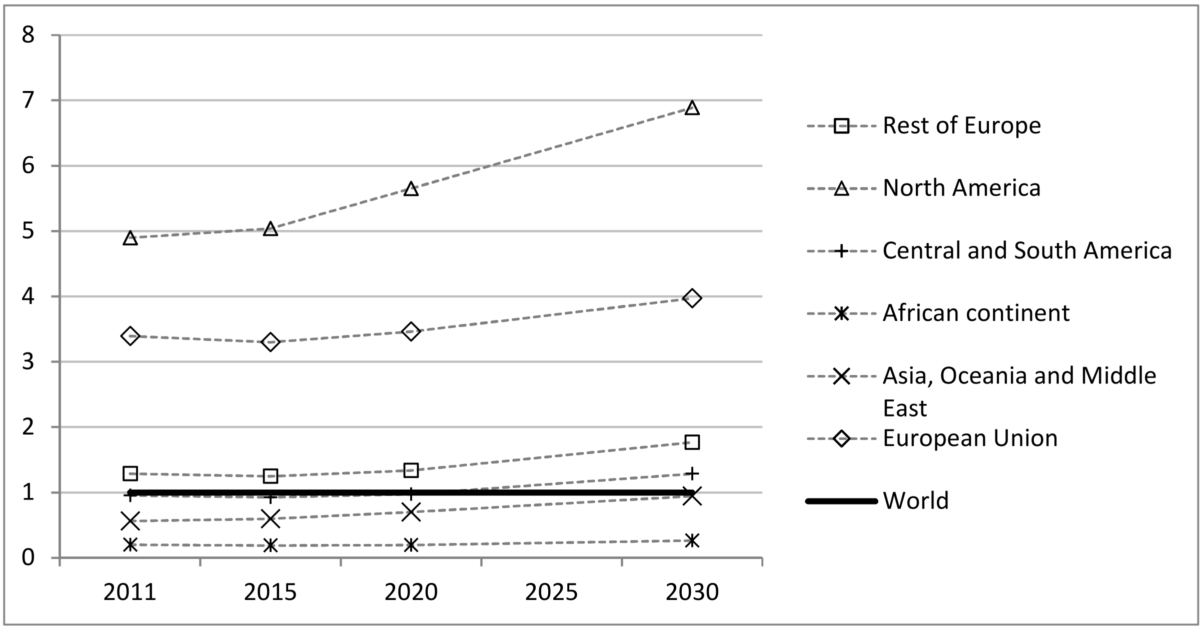
As shown in Figure 3, the trends in the rest of the EU are broadly split between east and west, with the latter recording slower rates of relative growth. The per capita utility index surpasses 145 in 2030 in the south-east (excluding Greece), east and Baltic Member states thanks to GDP growth rates which rank amongst the highest in the EU, coupled with declining population growth. In contrast, the per capita utility index trends to 2030 range between 105 and 125 in western Member States, although in Ireland and the Mediterranean sub-region, per capita utility growth rates are slower in the post-economic crisis period. In summary, the regional economic dynamics of the baseline are contributing positively to SDG 8 (indicator 8.1.1). Below, one examines if the trends observed here are translated into reduced global inequalities (i.e., income convergence).

Figure 3. Per capita utility index within the EU.



In Figure 4 and Figure 5 , we assess the hypothesis of possible income convergence, both across global regions and within the EU, respectively. To perform this analysis, in the former case we deflate all regions' nominal per capita income (in US dollars) corresponding to the time intervals in the study, by a global average. In the latter case, we deflate intra-EU nominal per capita incomes by an EU28 average (all in US dollars). Thus, the closer the ratio is to unity, the closer is the regional per capita income to the average. Looking at the evolution of this ratio over-time (**Error! Reference source not found.**, it appears that the composite 'Asia, Oceania and Middle East' region is rising to the global average over the period of the study. Nominal per capita income is growing in the 'Central and South America' and 'Rest of Europe' regions, such that they both slowly pulls away from the global average. Unfortunately, the nominal per capita income trend recorded in the African continent is not envisaged to be strong enough to close the deficit with the global average. Finally, the gap between the EU and North America nominal per capita income compared with the global average widens, suggesting an increasing wealth disparity (in absolute terms) throughout the world[8]. Indeed, by 2030, the North American per capita income level grows from approximately five times the global average, to almost seven times the global average.

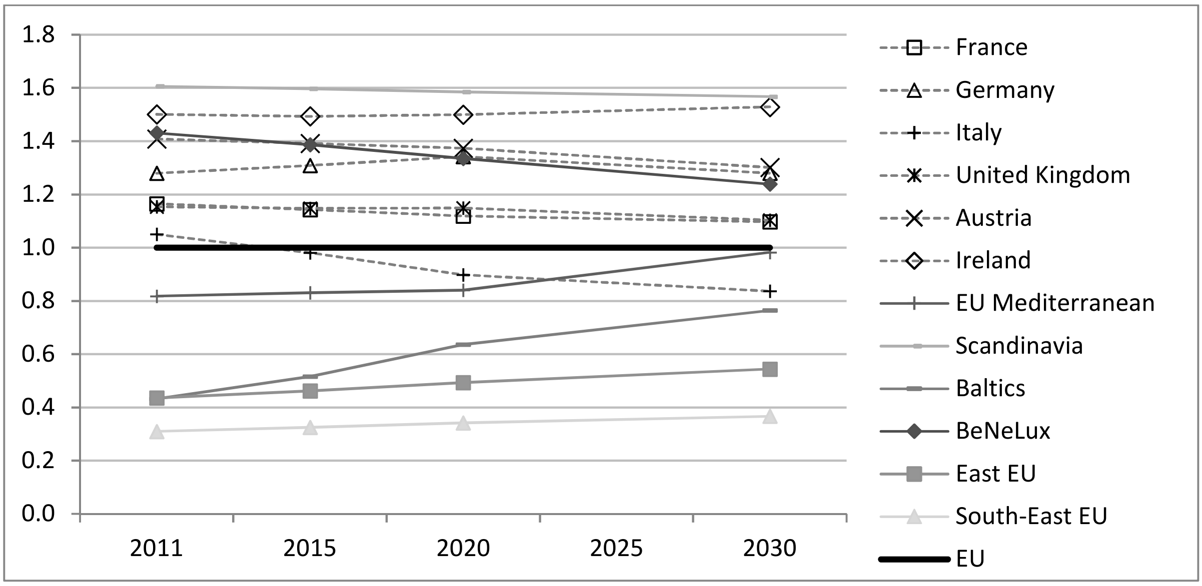
Figure 4. Evolution of the ratio of regional to global nominal per capita income (2011 = 100).



Examining income disparities within the EU MS (Figure 5) in 2015, the ratio of nominal incomes per capita to the EU28 average ranges between 0.3 (south-east EU) to 1.6 (Scandinavia). This range narrows slightly by the end of the period suggesting a slight convergence in the level of intra-EU per capita income. In the Baltic and Mediterranean sub-regions, per capita nominal incomes in 2030 more closely approximate the EU-wide average, reaching 0.8 and 1, respectively. On the other hand, in Austria and the Benelux, there is a gentle fall in per capita nominal incomes toward the EU average.

Figure 5. Evolution of the ratio of regional to global nominal per capita income (2011 = 100).

8 North American and EU citizens earn on average €32,800 per capita income more than in the average of the remaining regions in 2015 vs. €41,800 per capita more in 2030



5.3 The implications for SDG2 of regional levels of food energy consumption in the baseline scenario and SDG2

Ending hunger is a strong aspiration of the SDGs - and of their precursor, the Millennium Development Goals (MDGs). As a result, the MAGNET SIM module also includes indicators related with food security. As an example of food security and nutrition,

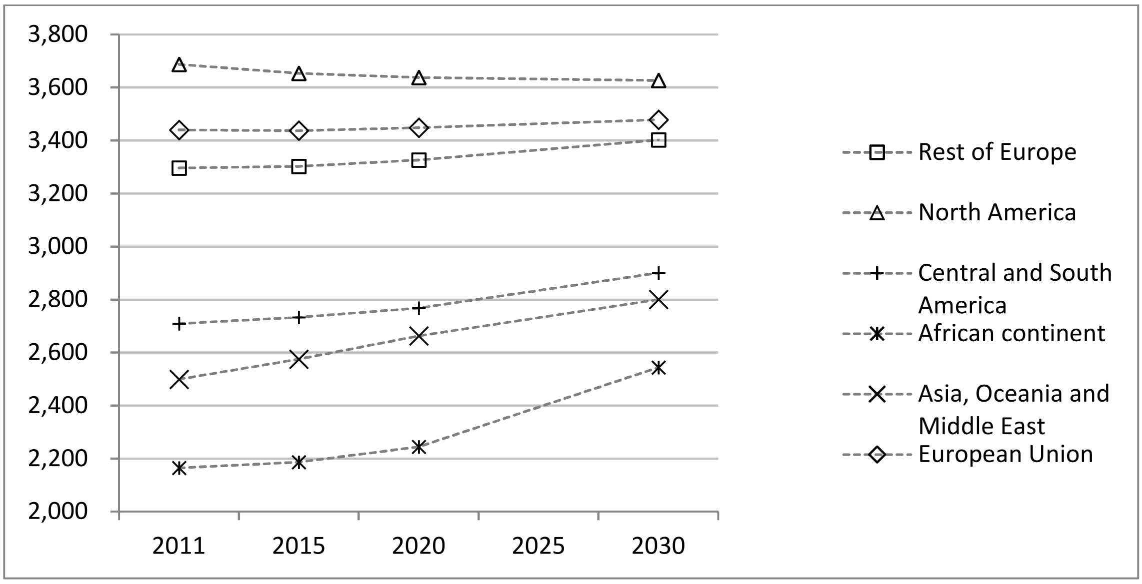
Figure 6 shows the recorded trends in per capita calorie intake[9].

The food transition process described by Popkin (1994) is reflected in the MAGNET model and follows Engel's Law[10]. As such, regions showing a low level of calorie consumption and undergoing particularly rapid growth will (*ceteris paribus*) experience rapid increases in calorie intake (step three of Popkin's food transition). The relation between economic growth and calorie intake will weaken once regions have achieved high levels of income and calorie consumption (step four), then plateau and possibly reverse above a certain threshold (step five).

9 The per capita calorie availability calculated in MAGNET is used as a proxy of calorie consumption or energy consumption and compared to the FAO's estimation of "minimum energy requirements". It does not net out the losses resulting from food waste in the home, or along the supply chain (from the farm gate to the point of sale).

10 Engel observed that with rising real incomes, the share spent on food decreases, even as total food expenditure rises

Figure 6. Evolution of the per capita calorie consumption (2011 = 100).



In

Figure 6, there are two distinct groupings of regions: those regions with an average calorie intake below 3,000 kcal/cap/day throughout the period (i.e. 'Central and South America', the African continent, 'Asia, Oceania and Middle East') and those regions with an average calorie intake above 3,000 kcal/cap/day (i.e., EU28, North America, 'Rest of Europe')(11). The regions in the first group typically exhibit the increase in income and calorie consumption of step three of the food transition. For example, the African continent starts step three with a very low level of calorie consumption in 2015 (2,170 kcal/cap/day). In a context of strong economic growth, calorie consumption in the African continent increases rapidly in the decade 2020-2030 until it reaches 2,540 kcal/cap/day, although the calorie consumption on African continent still remains below the 2015 level of the region 'Asia, Oceania and Middle East'. Step three of the food

[11] Note that, while even the calorie intake in the African continent in 2011 is close to recommended daily intake levels, these averages represent a distribution of calorie intake levels that cover both wealthier and poorer consumers across the entire African continent.

transition is already underway in 2015 in the 'Asia, Oceania and Middle East' and 'Central and South America' regions. As a result, their 2015 level of calorie consumption is higher and their expected increase is less pronounced than in the African continent. Driven by economic growth, average calorie consumption in the 'Asia, Oceania and Middle East' and 'Central and South America' regions grows steadily to 2,800 and 2,900 kcal/cap/day in 2030 respectively.

The second group exhibits three different regional trajectories. The 'Rest of Europe' region starts at the lowest level of calorie consumption (i.e. 3,300 kcal/cap/day in 2015). Between 2020 and 2030, it presents a 'step four' type of evolution: (i.e. increase in calorie consumption coupled with rising income although at levels far above human energy requirements). It finally nearly catches up with the EU level in 2030. Representative of "step five of the food transition", calorie consumption decouples from economic growth, plateauing in the EU28 around 3,450 kcal/cap/day and very slightly decreasing in North America from 3,690 kcal/cap/day in 2015 to 3,630 kcal/cap/day in 2030.

To summarise, the majority of the world population remains at an average level of calorie consumption below 3,000 kcal/cap/day, which is an indicative threshold of minimum energy requirements(12,13). Notwithstanding, regional averages in calorie consumption levels clearly mask intra-regional disparities within the population distribution. Therefore a varying proportion of the population in MAGNET regions are likely to suffer from under-nourishment even though the average regional level is above minimum energy requirements.

5.4 Share of renewable energy and levels of energy intensity as insights into SDG 7

The take-up of renewable energies is another focus of the SDG framework with SDG 7 aiming at the provision of affordable and clean energy. In this regard, two indicators are considered. Firstly, regional comparative advantages in renewable energies, measured by the Balassa index of revealed comparative advantage (RCA). This measure refers to the ratio of a given region's export market share of renewable energies compared with the global export market share in renewable energies. In this way, one gains an idea of the relative comparative advantage of different regions as they undergo structural economic change. Secondly, we have regional energy intensity defined in value terms, as the dollar value of energy requirements per dollar of economic output (i.e., GDP).

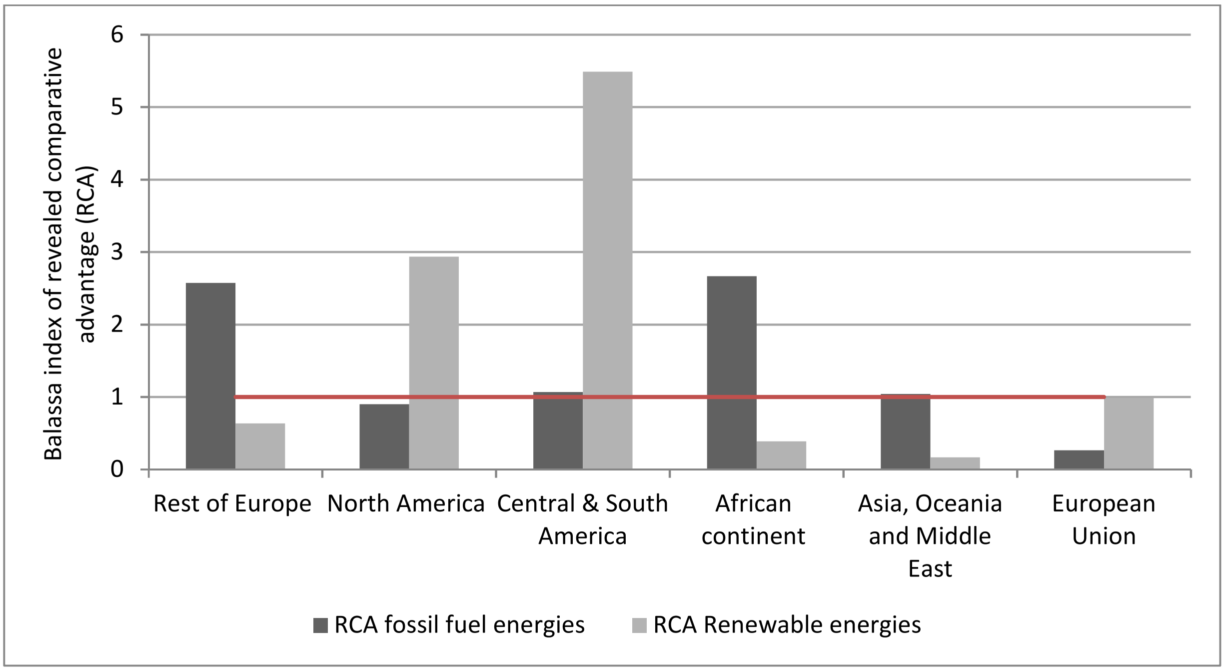
Subject to the technology assumptions in the energy sectors (i.e., elasticities of substitution between capital and energy), the baseline incorporates exogenous assumptions regarding expected technical change and the portfolio of both electricity generation and private energy consumption in the EU, which are important drivers of the measures discussed here(14). The assumed reduction in oil price between 2015 and 2020 hampers the competitiveness of renewable energies at the beginning of the period, although Figure 7 clearly shows that the relative competitiveness of energy in the relatively wealthier (poorer) regions is toward renewables (fossil energies). The exception is 'Central and South America', which has a particularly strong bio-based energy resource.

Figure 7. Trade competitiveness of fossil fuel energy and renewable energy by 2030.

[12] In their last revision (2006-2008), the FAO estimates minimum Dietary Energy Requirements ranging between 1,690 and 2,000 kcal/cap/day among the 178 countries considered (FAO Statistics division 2009).

[13] In Paillard et al. (2014): "According to the FAO (Bruinsma 2003), depending on the inequality of food access to food and the heterogeneity of food rations within the population, and assuming that consumer waste is limited, an average availability of 3,000 kcal/cap/day would make it possible on the scale of a population to maintain the proportion of under-nourished individuals at a relatively low level (of approximately 6% of the global population if inequalities are substantial)"

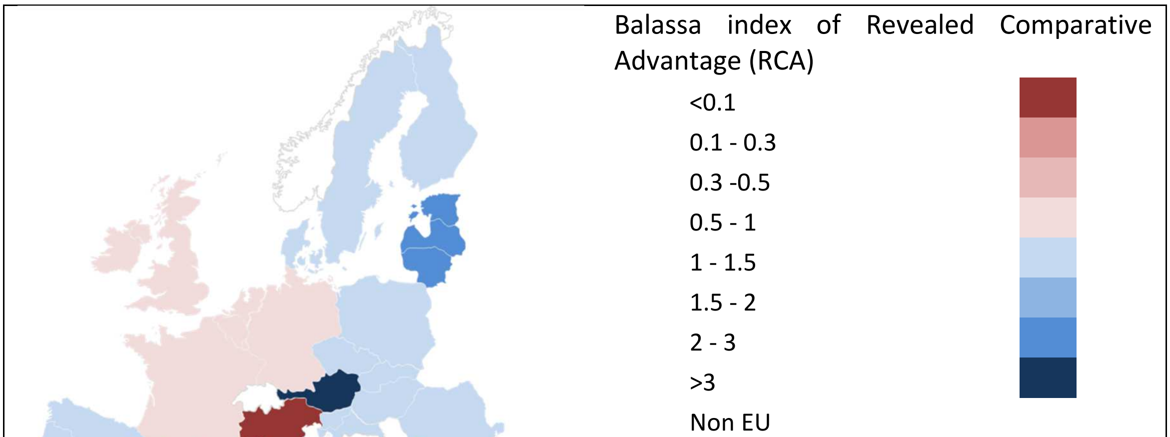
[14] See section 2.4 for a discussion of the assumptions behind the baseline.



Note: If the RCA for region 'r' is greater than 1, then the region exports, as a share of its portfolio, more of tradable i than the global average.

A breakdown of the EU28 aggregate Balassa index for renewables is calculated in Figure 8. The clear pattern that emerges is that those EU regions with a larger bio-resource base, or relatively less developed economies, register higher levels of revealed comparative advantage in renewable energy exports.

Figure 8. Trade competitiveness of renewable energies in EU sub-regions in 2030.

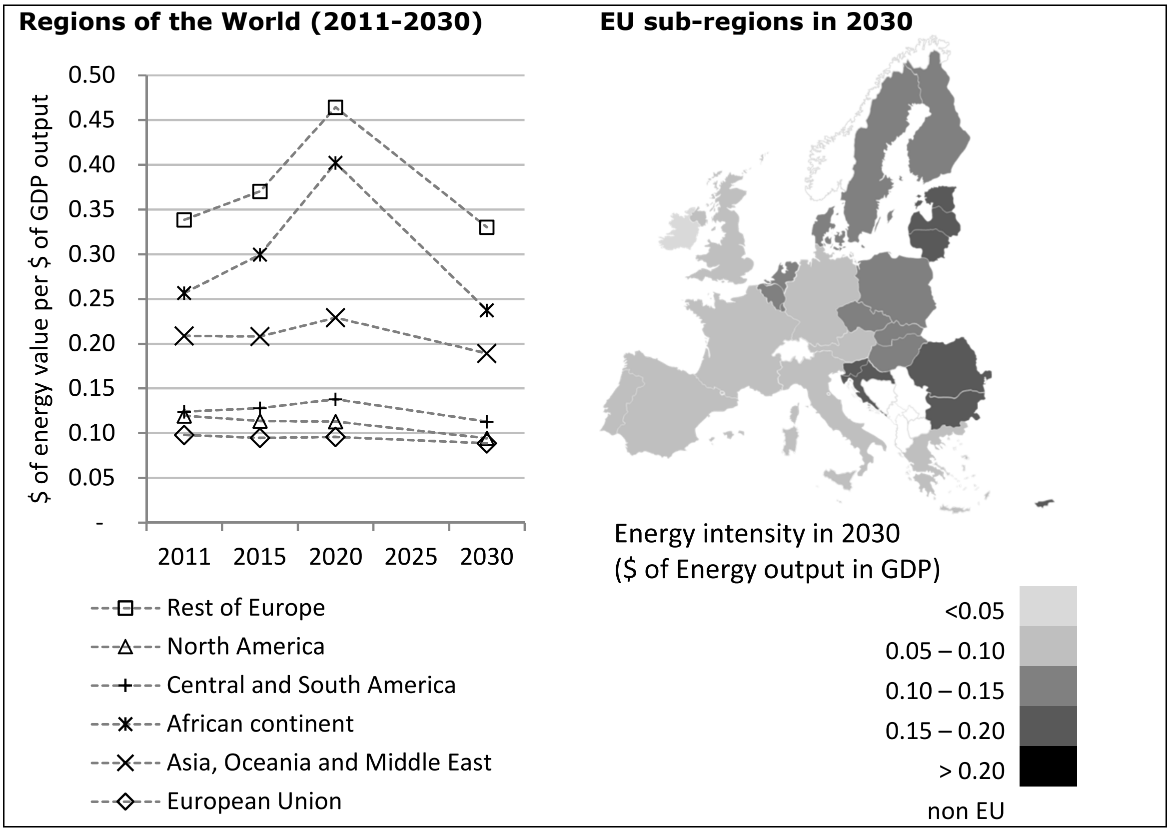


If RCA > 1, then region exhibits revealed comparative advantage

12 EU regions considered: France, Germany, Italy, United Kingdom, Ireland, Austria, EU Mediterranean (Spain, Greece, Portugal), Scandinavia (Sweden, Finland, Denmark), BeNeLux (Belgium, Netherlands, Luxembourg), Baltics (Latvia, Lithuania, Estonia), EU East (Poland, Czech Republic, Slovakia, Hungary, South-East EU (Bulgaria, Romania, Croatia, Slovenia, Cyprus, Malta)

In addition to the development of renewable energies, lowering energy intensity (Figure 9) is another stated aim of SGD 7[(15)]. Indeed, relatively lower levels of per unit energy purchases are already observed for the EU28, North America and 'Central and South America'. On the other hand, the less developed regions of 'Asia, Oceania and Middle East', the African continent and the 'Rest of Europe', exhibit greater value purchases of energy per dollar of GDP. A further observation is a rise in energy intensity from 2011 to 2020, motivated in part by the assumed fall in fossil fuel prices. In the EU, which faces particularly tough greenhouse gas emissions reductions, there is a greater price driven incentive to substitute capital for energy inputs.

Figure 9. Value of energy usage per dollar of GDP output in each region.



Note: 12 EU regions considered: France, Germany, Italy, United Kingdom, Ireland, Austria, EU Mediterranean (Spain, Greece, Portugal), Scandinavia (Sweden, Finland, Denmark), BeNeLux (Belgium, Netherlands, Luxembourg), Baltics (Latvia, Lithuania, Estonia), EU East (Poland, Czech Republic, Slovakia, Hungary, South-East EU (Bulgaria, Romania, Croatia, Slovenia, Cyprus, Malta).

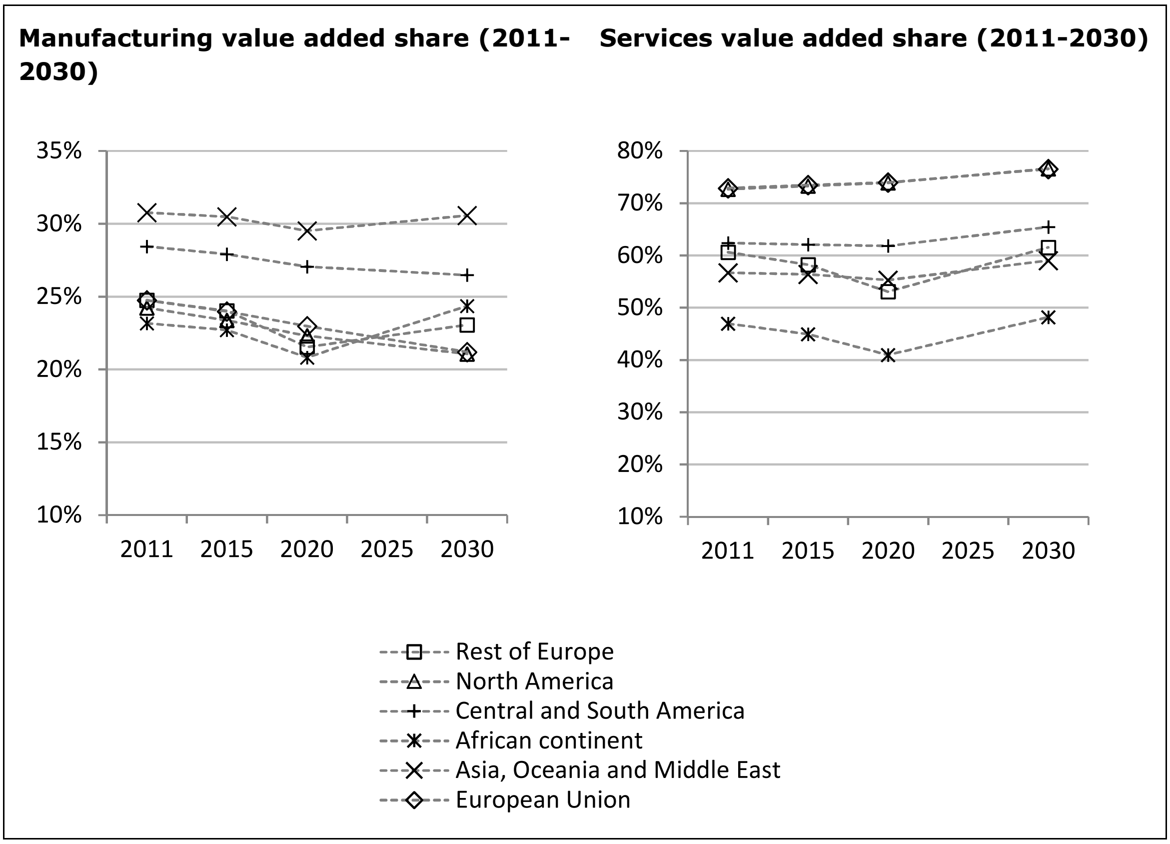
15 In SDG target 7.3, it is stated that by 2030, we must double the global rate of improvement in energy efficiency.

5.5 Industrialisation process in the baseline scenario and SDG 9

The final insight into the baseline scenario's contribution to SDGs discussed here is related to the industrialisation process and its degree of decoupling with environmental impacts (SDG 9). In 2015, the share of manufacturing value added as a proportion of total value added is particularly high in the 'Asia, Oceania and Middle East' region (which includes China) (31%) and 'Central and South' America (28%) (Figure 10). Not surprisingly, the regions of the EU28 and North America reveal a much larger services based economy, with the value added share steadily rising up to 80% by 2030.

The contribution of the manufacturing sector to GDP tends to weaken in all regions between 2015 and 2020 (except in the ROW region). There is evidence of a slight recovery in the decade 2020-2030 except in the EU28 and in North America where manufacturing loses further ground to the service sector (see Figure 10) reflecting an ongoing shift in global comparative advantages. In fact, the manufacturing sector's contribution to GDP is sustained only in the 'Asia, Oceania and Middle East' region and the African continent (1% point more in 2030 than in 2015).

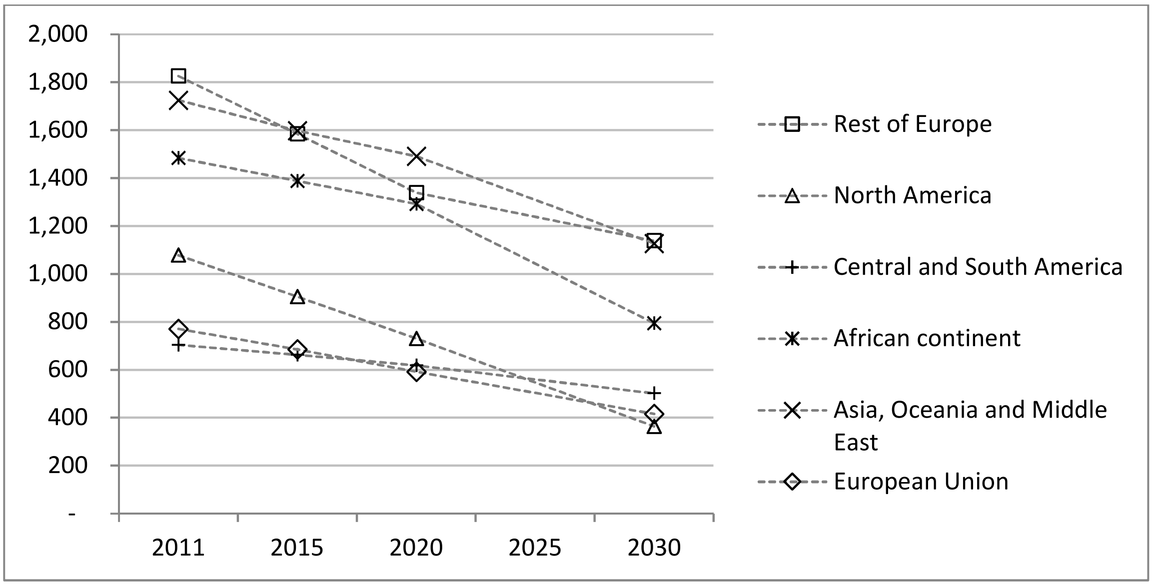
Figure 10. Structural Economic change in the regions.



To complement this picture, estimates of tons of CO_2 equivalent (CO2e) emissions per unit of value added (based on SDG indicator 9.4.1) are computed. With the assumption of falling greenhouse gas emissions in each of the regions in the baseline, it is expected that the resulting price signals and technology changes within the model will lead to a falling intensity of emissions per unit of value added, whilst an increased uptake or lower (or zero) carbon emitting energy sources will be observed.

The manufacturing sector is not an exception (see Figure 11). As a key emitting activity, the 'Rest of Europe' and the 'Asia, Oceania and Middle East' regions as well as the African continent drastically cut their emissions from the manufacturing sector over the period. The emission reduction is also impressive in North America, dropping from 905 tons CO2e/USD of value added in 2015 to 364 tons CO2e/USD in 2030. At the end of the period, the manufacturing sector in North America becomes the best performer in terms of low emissions per value added of manufacturing products.

Figure 11. Tons of CO2 equivalent emissions per unit of value added from manufacturing (2011-2030, Tons per million USD of value added).



6 Conclusions

This report presents a description of an economic modelling tool currently employed by the Joint Research Centre (JRC) to perform impact assessments of the Bioeconomy. More specifically, a state-of-the-art variant of a neoclassical recursive dynamic computable general equilibrium (CGE) model – called MAGNET – is chosen. With its modular structure, the MAGNET model has already been widely used as a tool of analysis in the related fields of land-use, agricultural policy, biofuels and climate change. Recent developments of the database to perform additional sector splits of the bio-based sectors, has further consolidated the positioning of MAGNET as an attractive option for policy coherence impact assessments of different scenarios through the evaluation of synergies or trade-offs. In addition to the state-of-the-art agricultural factor market and policy modelling, MAGNET also includes numerous sector splits covering first and second generation biofuels, biokerosene, bioelectricity and promising biochemical and thermochemical biomass conversion technologies. Moreover, a strong base has been established on the sustainable availability of biomass employing inputs from biophysical models. The launch of a MAGNET Sustainable Development Goal Insights Module (MAGNET SIM) is a co-ordinated response to quantify a series of integrated and universally approved policy metrics using the parlance of the international community.

An analysis of the implications of baseline developments for selected Sustainable Development Goals suggests improvements in SDGs 2, 7, and 8, and to some extent SDG 9. Progress is made towards Goal 8 (Decent Work and Economic Growth) through convergence between richer and poorer regions. Increases in average per capita calorie consumption is consistent with progress towards Goal 2, however, a lack of information on the population distribution around the region means reported here means that one cannot state whether progress has been made towards *Zero Hunger* for all. We observe that progress is made towards Goal 7 (Affordable and Clean Energy), however, it falls short of meeting the ambitious targets set for renewable energy and energy efficiency. Finally, the progress to SDG 9 (Industry, Innovation and Infrastructure) is mixed. On the one hand, there is no clear development trend of the manufacturing sector to meet target 9.2, whilst on the other hand, progress is made in all regions towards target 9.4 when measured in CO_2 equivalent emissions per unit of value added.

As with any modelling endeavour which attempts to capture real-world behaviour, a study of this nature also carries the usual limitations. With neoclassical computable general equilibrium models, the standard structural caveats apply, chief among them being the deterministic (i.e., non-stochastic) behaviour of agents, the assumption of equilibrium market clearing, the stylised representation of investment, and the conditionality imposed on model results by the choice of model closure.

To build on the scientific reputation of MAGNET already garnered through extensive usage in various European foresight projects and peer reviewed publications in high quality research journals, there are further opportunities to enrich the data and modelling framework for assessing both the bioeconomy and for conducting policy coherence analysis.

Thus, in addition to the need for further bio-industrial sector splits to characterise current technologies; the MAGNET database is also lacking a representation of organic and municipal waste streams in (*inter alia*) biogas and bio-heating, which constitutes an important component of the Member States' National Renewable Energy Action Plans driven by the renewable energy targets (Scarlat et al., 2015a, Scarlat et al., 2015b), which have been extended by the European Council up to 2030. A further important omission, alluded to above, is the lack of treatment of forestry land, which has pertinence when examining issues of indirect land use change (ILUC)[(16)] and greenhouse gas emissions, as well as an explicit treatment of water footprints.

From a modelling perspective, a better understanding is required of the uncertainty underlining expected technological advancements in second generation bio-based sectors and their quantification within a CGE framework, especially where longer time frames (i.e., 2050) are concerned. Furthermore, the 'small share' problem which plagues CGE modelling focusing on nascent or promising technologies often leads to an understatement of the potential market impacts of a given policy or technological change shock. Finally, a more thorough characterisation of natural fossil based resources which endogenously reflect sustainability usage (i.e., price changes) subject to expected rates of extraction and depletion, would also represent forward step in improving the veracity of the model results.

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[16] ILUC occurs when agricultural land pressures occur from the displacement of previous activities resulting from changes in biomass. If land use displacement generates more intense land use outside the system, the resulting 'leakage' has environmental repercussions as carbon stocks are released from land clearing.

A number of these research avenues are expected to be addressed incorporated into the model data and equations within the next twelve months, which will further consolidate the usage of MAGNET as a front line choice by policy makers for cutting edge research in this rapidly changing area.

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Annex

Table 2. Study disaggregation of commodities and regions.

Commodity disaggregation (69 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); plant fibres (pfb); crude vegetable oil (cvol).

Livestock and meat (7): cattle and sheep (cattle); wool (wol); pigs and poultry (pigpoul); raw milk (milk); cattle meat (meat); other meat (omeat); dairy (dairy).

Fertiliser (1): fertiliser (fert).

Other food and beverages (4): sugar processing (sugar); rice processing (pcr); vegetable oils and fats (vol); other food and beverages (ofdbv);

Other 'traditional' bio-based (5): fishing (fish); forestry (frs); textiles, wearing apparel and leather products (texapplea); wood products (wood); paper products and publishing (ppp).

Bio-mass supply (11): 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).

Bio-based liquid energy (5): 1st generation biodiesel (biod); 1st generation bioethanol (biog); 2nd generation thermal technology biofuel (ft_fuel); 2nd generation biochemical technology biofuel (eth), bio-kerosene (bkero).

Bio-based industry (4): lignocelluose sugar (lsug); biochemical (fermentation) conversion of sugar biomass to polylactic acid chemicals (pla); biochemical (fermentation) conversion of bioethanol to polyethylene chemicals (pe); thermochemical conversion of biomass to chemicals (b_chem).

Bio-based and non-bio-based 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 (7): chemicals, rubbers and plastics (crp); other manufacturing (manu); aviation (avi); other transport (trans); business services (foodserv); other services (svcs).

Regional disaggregation (17 regions):

EU members (12): France (FRA); Germany (GER); Italy (ITA); United Kingdom (UK); Ireland (IRE); Austria (AUT), Spain, Greece, Portugal (Rest of the Mediterranean); Sweden, Finland, Denmark (Scandinavia), Belgium, Netherlands, Luxembourg (BeNeLux), Latvia, Lithuania, Estonia (Baltics); Poland, Czech Republic, Slovakia, Hungary (East EU); Bulgaria, Romania, Croatia, Slovenia, Cyprus, Malta (South East EU).

Non EU regions (5): Rest of Europe (RestEurope); North America (NorthAmerica); Central and South America (SouandCentAme); African continent (Africa); Asia, Oceania and Middle East (ROW).