Food and Agriculture Organization
of the United Nations

ASSESSING THE CONTRIBUTION OF BIOECONOMY TO COUNTRIES' ECONOMY

A brief review of national frameworks

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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Acronyms

AUD	Australian Dollar
BE	Bioeconomy
BBE	Bio-based economy
BCDP	Bioeconomy Community Development Programme
BCI	Bioeconomy Contribution Index
BMBF	Federal Ministry for Education and Research
BMEL	Federal Ministry of Food and Agriculture
BNX	BioNexus Status
BTP	Bioeconomy Transformation Programme
CGE	Computable General Equilibrium
CNE04	National Economic Census 2004
DCGE	Dynamic Computable General Equilibrium
DOE	Department of Energy of the United States
DOSM	Department of Statistics Malaysia
DST	Department of Science and Technology (South Africa)
EC	European Commission
ETP	Economic Transformation Programme
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GERD	Gross domestic expenditure on Research & Development
GNI	Gross National Income
I-O	Input-Output
IKS	Indigenous Knowledge Systems
ISIC	International Standard Industrial Classification
MINAGRO	Argentine Ministry of Agroindustry
MOSTI	Ministry of Science, Technology and Innovation
NACE	Classification of Economic Activities in the European Community
NAICS	North American Industry Classification System
NOE	non-registered economy
NBP	National Biotechnology Policy
PE	Partial Equilibrium
RM	Malaysian Ringgit
RVO	Netherlands Enterprise Agency
SAM	Social Accounting Matrix
SDG	Sustainable Development Goal

SNA	System of National Accounts
SYMOBIO	Systemic Monitoring and Modeling of the Bioeconomy

Executive summary

This study reports and analyses how different countries are measuring the contribution of bioeconomy (BE) to their overall economy or country objectives. The focus is on Argentina, Australia, Germany, Malaysia, the Netherlands, South Africa and the United States of America. The countries selected from six continents differ in terms of level of economic development and have different bioeconomy strategies. From the sample countries and available literature, general conclusions on constraints and opportunities of bioeconomy for countries with different income level and biomass availability are drawn.

The paper shows that **different sets of sectors and subsectors** are considered 'bioeconomy' by the countries analysed (Table ES.1). The sectors included in the bioeconomy strategy often reflect the **objectives and priorities** identified by the country, and comparative advantages linked; for instance, to endowment in biomass resources, historical economic specialisation, and past investments in research and development (R&D). Some regional efforts to harmonize the measurement of bioeconomy exists. For example, since the launch of the European Commission (EC) strategy for the bioeconomy in 2012, the EC Joint Research Centre (JRC) has been monitoring jobs and turnover in the European Union bioeconomy for all the member states and sectors.

Table ES1. Sectors included into bioeconomy strategy and monitoring in the selected countries, plus the EU

	Argentina	Australia	Germany	Malaysia	Netherlands*	South Africa	USA*	EU
Agriculture	XX	X	XX	XX		X	XX	XX
Automotive and mechanical engineering			XX					
Chemistry (incl. bioplastics)	XX	X	XX	XX	XX	X	XX	XX
Biofuels/ bioenergy	XX	X	XX	XX	XX	X		XX
Biorefining		X	XX	XX		X	XX	
Construction/ Building industry			XX					
Consumer goods such as cosmetics and cleaning products	XX		XX			X		
Feed	XX	X	XX	XX		X		XX
Fisheries	XX	X	XX	XX		X		XX
Food and Beverage industry	XX	X	XX	XX		X		XX
Forestry	XX	X	XX	XX	XX[1]	X	XX	XX

[1] Only forest-based industry.

Health				XX		X		
Knowledge/ Innovation		X	XX	XX	XX	X		X
Mining						X		
Pharmaceuticals industry	XX	X	XX	XX	XX	X		XX
Pulp and paper	XX		XX		XX	X		XX
Textiles	XX		XX		XX	X	XX	XX

Notes: X: sector included in bioeconomy strategy, XX: included in the bioeconomy strategy and monitored or measured.

*The results for the Netherlands monitor bio-based economy (BBE) and the results for the USA refer to bio-based products industries.

Source: Elaborated on the basis of several studies; Wierny, Coremberg, Costa, Trigo, & Regunaga (2015) for Argentina; Alex Cooke, personal communication (2018) for Australia; BMBF & BMEL (2015) for Germany; Zurina Che Dir, personal communication (2018) for Malaysia; RVO (2016) for the Netherlands; Ben Durham, personal communication (2018), and DST (2013) for South Africa; USDA (2016) for the USA and EC JRC (2018) for the EU.

The bioeconomy has already been adopted by a significant number of low and middle income countries as a **new vision of development**, and can be a valid path towards the achievement of the Sustainable Development Goals (SDGs) and the commitments under the Paris Climate Agreement. For instance, in lower income countries with available biomass resources and/or well-developed primary sectors, a sustainable bioeconomy could unlock new opportunities for economic development and industrialization and support economic and social objectives.

If a bioeconomy strategy aims to contribute to sustainable development also in terms of **environmental and social objectives**, these aspects need to be clearly included in the strategy and be measurable. This study shows that a framework to monitor progress in reaching the targets set in the bioeconomy policies and strategies is currently lacking in most countries. The difficulty of measuring progress can be a consequence of the lack of a clear definition of the bioeconomy concept and of concrete and measurable objectives. In fact, most strategies propose quite abstract objectives and qualitative targets.

Most countries measure the bioeconomy contributions in terms of value added and employment, and in most cases, social and environmental criteria are addressed only to a limited extent. The majority of the countries measure bioeconomy progress over time just with economic values and shares of GDP. On top of the lack of international consensus on which products and activities are comprised within the bioeconomy, the **GDP approach** has several limitations due to the inadequacy of the standard industrial classification systems to systematically monitor bio-based production, the lack of systematic data and the often scattered information collected at national level.

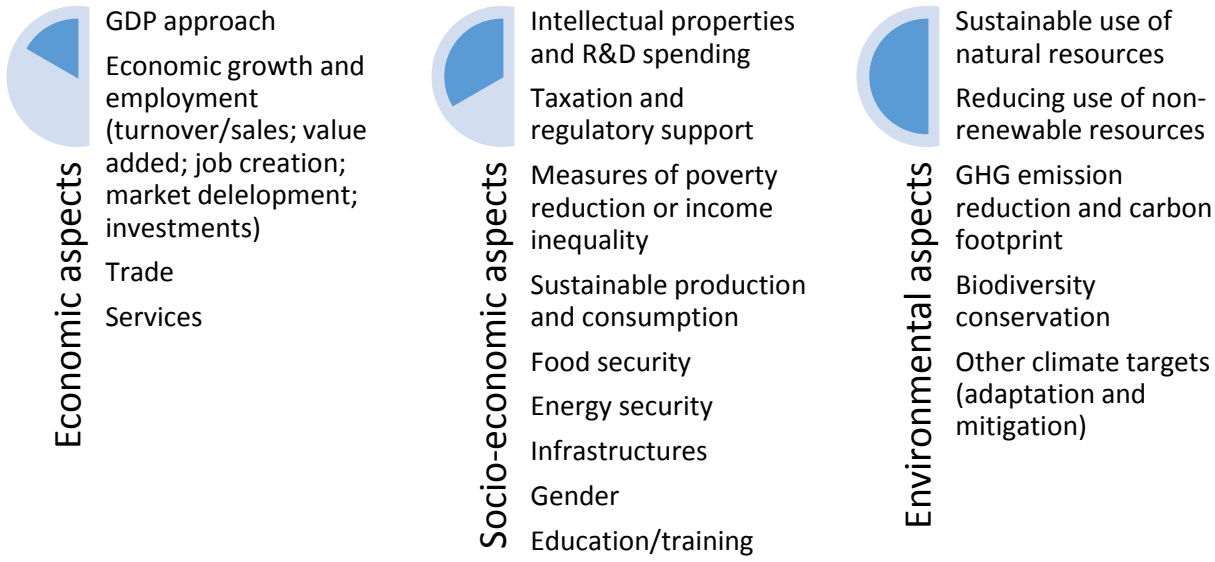
The role of bioeconomy in development strategies should be reflected in the measurement of the achievement of targets. This could allow to monitor, for instance, progress in meeting the SDGs or other environmental and social targets. In fact, important **synergies between countries' commitments towards the measurement of SDGs and bioeconomy** can be leveraged.

Several studies and projects are already developing **comprehensive bioeconomy monitoring systems**, including indicators and sub-indicators which encompass social and environmental

aspects. Some of these studies look at the analysis developed for sustainable biofuels, biomass and bioenergy over the past decade. By leveraging these initiatives, it will be possible to create frameworks to measure and monitor the bioeconomy in a comprehensive manner. Food and Agricultural Organization of the United Nations (FAO) is already coordinating international efforts towards the development of such sustainability guidelines for the bioeconomy.

Figure ES2 summarizes the generic pathway towards sustainable bioeconomy monitoring, starting from the GDP approach to include socio-economic and environmental aspects, in line with the analysed country's objectives and the SDGs. The aspects included are not exhaustive and should be adapted to reflect each country's priorities and strategy.

Figure ES2. Identified pathway towards a sustainable bioeconomy monitoring



1. Introduction

The bioeconomy can be defined as: "the knowledge-based production and utilization of biological resources, biological processes and principles to sustainably provide goods and services across all economic sectors".[2] It involves three elements:

- Utilization of renewable biomass and efficient bioprocesses to achieve a sustainable production;
- Utilization of enabling and converging technologies, including biotechnology;
- Integration across applications such as agriculture, health and industry.

In line with FAO (FAO, 2016), in this study under the name of "bioeconomy strategies", the strategies related to bioeconomy, bio-based economy and bio-industries[3] are inclusively considered, given their rather broader and somewhat similar scope, and their innovative character.

According to their priorities and conditions, different countries include different sectors in their bioeconomy strategies[4]. Countries often try to assess the contribution of bioeconomy to their total economy by considering different variables, which typically reflect their priorities. Country objectives and bioeconomy priorities encompass economic growth, employment, energy security, food security, fossil fuel reduction, climate change adaptation and mitigation, and rural development. There is no agreed methodology to measure the progress in attaining the ambitions and targets set by bioeconomy policies and strategies. Moreover, given the differences between countries' constraints, opportunities and priorities, no uniform way has been developed to date, in order to assess the contribution of bioeconomy to the national economy. The lack of a coherent methodology can create confusion when trying to evaluate the importance of bioeconomy across countries.

This paper reports and analyses how selected countries (Argentina, Australia, Germany, Malaysia, the Netherlands, South Africa and the United States) are currently measuring the contribution of bioeconomy to their overall economy or the country objectives. The countries selected are from six continents, differ in terms of level of economic development and have different bioeconomy strategies. For instance, some countries have limited land availability but developed technologies, while others prioritize small scale farmers and rural development and have greater land availability. From the sample countries, general conclusions on constraints and opportunities of bioeconomy for low, middle and high income countries are drawn.

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[2] An overview of bioeconomy definitions and strategies can be found in (FAO, 2016).

[3] According to (FAO, 2016), *bioeconomy* strategies and policies include regular food and feed chains; *bio-based economy* only takes into consideration the production of non-food goods, i.e. bio-based materials, chemicals and medicine/pharmaceuticals, pulp and paper, wood, textiles, and bioenergy, with the exception of functional foods (nutraceuticals), tailored food products to meet specialized dietary requirements, and nutraceuticals; and *bio-based industries* refers to the industrial production of all possible bio-based goods.

[4] Sectors often included are: agriculture, forestry and fisheries, automotive sector, bio-based chemical/chemistry, biofuels, bioplastics, biorefining, construction/building industry, consumer goods (cosmetics, cleaning products), energy, enzymes, food and beverage industry, health, knowledge/innovation, mechanical engineering, mining, pharmaceuticals industry, pulp and paper and textiles.

2. Economic models and approaches

Typical approaches that can be adopted to measure the bioeconomy contribution to a country's economy include the value added/GDP approach; Input-Output (I-O) and Social Accounting Matrix (SAM) analysis; Computable General Equilibrium (CGE) Model; Partial Equilibrium (PE) Model and other economic models and tools. These approaches are briefly described in Box 1. Some countries, such as Malaysia, developed an index for quantifying economic impacts of bioeconomy (the Bioeconomy Contribution Index) or opted for the creation of a composite index of key indicators, as in the USA case (USDA, 2011).

Box 1. Possible economic models for analysing the contribution of bioeconomy to country's economy

Value added/GDP approach. The value of bioeconomy is determined using the value of the economic sectors/subsectors that contributed to it and fit within the bioeconomy definition. For instance, for Canada sectoral contributors include: the percentage of health sector GDP based on pharmaceutical and medicine expenditures; the percentage of agricultural sector GDP based on added-value crops (i.e. biotech crops); and the bio-based manufacturing GDP, which includes the manufacturing of pharmaceuticals and medicines, organic chemicals, and engineered or fermented foods and beverages (Pellerin & Taylor, 2008). Although this approach seems to allow for country comparisons for international analysis, data is often available at different aggregate levels, by different industry sector breakdowns or simply in divergent forms, which makes direct country comparisons difficult. Moreover, the results depend on the sectors and products that are comprised within bioeconomy according to each country.

Input-Output (I-O). I-O matrices are used to get insights into the inter-linkages of sectors in an economy and to investigate the key sectors in terms of value added, employment, emissions, land and water use, energy use. I-O analysis depends on the crucial assumption that sectoral production is completely demand-driven, implying that there is always excess capacity in all sectors that is capable of meeting increased demand with no price increase. Price are assumed constant. Moreover, I-O models assume constant returns to scale production function with no substitution among the different inputs. Since these assumptions are likely to be unrealistic in the long term, I-O models are more useful for short term descriptive analysis (SAT-BBE Consortium, 2014). Moreover, the lack of substitutions among inputs could be a limitation to analyse the contribution of bioeconomy, since flexibility in inputs adds value.

The social accounting matrix (SAM) framework is an extension of I-O model that separate the accounts into endogenous and exogenous, and assumes that the column coefficients of the exogenous accounts are all constant. Exogenous accounts are those for which expenditures are set independently of income; while changes in the level of expenditure in endogenous accounts directly follow changes in income (SAT-BBE Consortium, 2014). The SAMs are used to identify key sectors of the bioeconomy and to extract the main tendencies in the behaviour of an economy. All sectors of an economy can be classified according to backward and forward linkages, traditionally obtained from a symmetrical I-O table. The *backward linkage* examines the effect of a change in the final demand of a sector on upstream sectors (intermediate input suppliers). The *forward linkage* assesses the effect of a change in the final demand of a sector on the production of a subsequent sector. I-O and SAM analysis are especially useful for evaluating the impact of a change in the demand or production technology and for assessing economic correlations and sectoral effects.

Computable General Equilibrium (CGE) models. The main strength of CGE models is their comprehensiveness in terms of key economic relationships, including market price adjustments and associated changes in terms of trade, market balances and factor markets (SAT-BBE Consortium, 2014). They are particularly useful for analysing the impacts of significant changes in the short-medium term,

or the medium-long term impacts of structural changes. Important limitations to CGE modelling analyses are their high level of aggregation and the limited integration of bottom-up information and data. Moreover, CGE models usually do not provide a temporal trend since they present a new equilibrium after a certain 'shock'.

Partial Equilibrium (PE) models. PE models are habitually used to address sector specific questions (e.g. agriculture and energy) when interrelations with others sectors of the economy are secondary (SAT-BBE Consortium, 2014). Their structure can vary significantly depending on their economic assumptions. The biggest difference comes from the formulation of the welfare function to optimize. The main advantage of PE models is their high level of flexibility in incorporating a large amount of detail, which allows a meticulous representation of sectors and relevant economic dynamics. The absence of links with other sectors and the absence of macro-economic closure are main limitations of PE models, as they can be biased when excluded sectors that have feedbacks or play a big role in an economy.

Some countries do not adopt an economic model but measure the contribution of bioeconomy by means of disaggregated indicators. Although bioeconomy is not univocally defined, among the indicators used to monitor the growth of the bioeconomy and its contribution to the country's economy and development, the most commonly adopted are (SAT-BBE Consortium, 2013):

- Turnover of the bioeconomy (revenue from sales)
- GDP of the total bioeconomy and its sectors, and the contribution of the bioeconomy to total country/region GDP
- Employment in the total bioeconomy and its sectors, and the contribution of the bioeconomy to total employment
- Resource use of the bioeconomy (crops, wood, waste, land, capital, etc.)
- Primary production of biomass in the country (agriculture, forestry, residues, fisheries, waste)
- Import of biomass to the country (agriculture, forestry, residues, waste)
- Global land use for biomass based consumption in the country
- Production of bio-based products (also relevant for the indicator 'Turnover of the bioeconomy)
- Price of biomass and bio-based products (also relevant for the indicator 'Turnover of the bioeconomy)
- Consumption of bioeconomy products
- Trade flows (e.g. including import of biomass as listed above but also imports and exports of bio-based products).

Further indicators focus on the drivers of innovation, such as investments and spending in R&D, or intellectual property. However, it can be difficult to capture the impacts of a new innovation due to a time lag between investments and outcomes. These types of indicators could be used to compare country performances in the development of a bioeconomy (e.g. which countries have a bioeconomy strategy or have dedicated R&D funds).

3. Assessing bioeconomy contribution around the world

This section assesses how different countries (Argentina, Australia, Germany, Malaysia, the Netherlands, South Africa and the United States) are measuring the contribution of bioeconomy to their overall economy or country objectives. Most countries emphasize the bioeconomy contributions in terms of value added and employment, while, in most cases, social and environmental criteria are addressed only to a limited extent.

3.1. Argentina

Bioeconomy definition and strategy

According to the Argentine **Ministry of Agroindustry** (MINAGRO, 2016), bioeconomy consists in the "sustainable production of goods and services through the use or transformation of biological resources". For a country like Argentina, with opportunities for biomass production, experiences in the management of biological productions, sound industrial capacities, services, technologies, information and knowledge, bioeconomy represents an important opportunity to generate economic progress and access world markets, as well as to respond to its climate change commitments within the framework of international agreements (MINAGRO, 2016).

The need to build much less dependent societies on fossil resources is a subject of growing concern in Argentina in recent decades and has now gained renewed validity, because the progress in modern biology offers possibilities to replace, at least in part, the country's dependence on fossil fuels and their derivatives. The bioeconomy is a concept originating from these concerns and opportunities, which today is recognized as a positive alternative for the generation of new behaviours and sources of employment to face the double challenge of climate change and the continued need for economic progress indispensable for poverty reduction (MINAGRO, 2016).

Bioeconomy is a horizontal phenomenon running across GDP components, including not only the agricultural sector – which generates biomass– but also the food sector and other sectors within the manufacturing sector, such as organic chemical products (including manures and biology-based fertilizers), the wood and paper pulp sector, the energy sector (biofuels) and other bio-based sectors, such as those connected with the manufacturing of pharmaceutical products and medicines (Wierny, Coremberg, Costa, Trigo, & Regunaga, 2015).

Bioeconomy represents a strategic option for Argentina. It requires the availability of biomass, scientific and technological capabilities, as well as a public and private institutions capable of promoting the innovations implicit in the new schemes.

Objectives/priorities of the strategy

Bioeconomy is seen as a tool for sustainable development in the country, as it can result in (MINAGRO, 2016):

1. **Regional and territorial development**: The Argentine bioeconomy will reflect the specific paths chosen in each region to optimize the use and addition of value to its natural resources, via business models based on bio-industry and adapted to regional, national or international scales in the framework of public and private investments.
2. Promotion of **added value** from biological resources, more specifically through: (i) increasing the efficiency and productivity of biomass production, (ii) making better use of

biological organisms as 'bio-factories' for the production of molecules of interest / high economic value, (iii) fostering innovative uses of biological resources within industrial processes (food industry, biomaterials and others), and (iv) reducing losses and using waste from industrial processes for secondary uses and/or energy.

3. Development of **local and regional markets**: in some cases, bioeconomy products are new options, in others they are alternatives that replace products or processes already existing in the market and already established competitively (as it is usually the case of biomaterials, although not exclusively).
4. Access to **national and international markets**: the bioeconomy strategy aims to resolve the historical deficits in terms of infrastructure and connectivity, in order to improve the inclusion of each region in the national and global markets and to improve their capacity to root the local populations.
5. **Employment**: bioeconomy can strengthen scientific-technological development and innovation processes, with special emphasis on biotechnology and human resources.
6. **Food Security**: Argentina is one of the main producers of food globally, and can still increase its contribution to the world food supply, both through the incorporation of new lands and through increased productivity.
7. Contribution to **energy security** through the expansion of energy supplied by biomass: the development of Argentina biomass potential can contribute to the solution of the current problems of energy shortage faced by the country, to regional development, to job generation and to foreign exchange savings.
8. **Mitigation and adaptation to climate change**: bioeconomy, by fostering the replacement of fossil products with bio-based resources, is an important mitigation tool. It is also a powerful option to face the challenges of adaptation, through its emphasis on the efficient use of available resources, the protection of ecosystem functionality, circularity and local development and empowerment.
9. **Sustainability**: for a bioeconomy to be environmentally sustainable and productive, policy measures must be taken to promote bioeconomy activities while ensuring the maintenance of ecosystems and biodiversity, the productivity of resources, and the control of pollution.

Methodology and results

A paper from *Bolsa de Cereales*[5] (Wierny, Coremberg, Costa, Trigo, & Regunaga, 2015) designed a general methodology for the criteria, procedures and data bases to be used in the **measurement of bioeconomy and its contribution to GDP**, and develop a pilot application for the Argentine case. The definition of bioeconomy adopted in the paper includes "the production of renewable biological resources and their transformation into food, feed, bio-based products and bioenergy. It also includes agriculture, forestry, fishing, food production and pulp and paper production, as well

[5] Bolsa de Cereales (the Buenos Aires Grain Exchange) is a non-profit civil association that serves as an intermediate service provider. Its members include farmers, grain storage companies, cooperatives, brokers, and buyers (exporters, processing companies) that trade according to the established control and arbitrage mechanisms. More information are available at: http://www.bolsadecereales.com/.

as fractions of textile and chemical industry, and energy and biotechnological industries (health and pharmaceutical industry)" (Wierny, Coremberg, Costa, Trigo, & Regunaga, 2015).

The paper makes an estimation of bioeconomy and its contribution to GDP, respecting the general principles of the System of National Accounts (SNA[6]) for the calculation of GDP and internationally comparable satellite accounts (e.g. for education, capital, productivity and environment). A first step is the estimation of **value added** of bioeconomy and its contribution to GDP. The estimation of value added is also the very first step to obtain the Satellite Bioeconomy Account (SBA), which determines not only the total supply of bio-based products (production value and domestic value added plus imports) but also its final destinations (consumption, investment, exports). An initial approach is top-down: the identification of industries producing bioproducts; industries engaged in the production and sale of intermediate inputs and capital goods to facilitate the production of bioproducts; industries that partially depend on bioeconomy; and support industries in which part of the activities consists in facilitating distribution (commerce, transport, communications and logistics) of bioproducts.

From an empirical perspective, the paper applied coefficients from I-O Matrix or from the Input-Product lists of the Economic Census or expert consultations to production value and value added (year 2012).The main steps of the methodology are summarized below:

1. **Identification and estimation of the gross production value and value added**, according to the producer prices of economic activities produced by **bioproducts**, either as input or core activity.
2. Identification and estimation of the gross production value and value added of industries utilizing bioproducts in the **second stage** of linkage.
3. Identification and estimation of the gross production value and value added of **non-bio industries**, but which still produce bioproducts as a secondary or ancillary activity in a smaller proportion.
4. **Compilation of thorough information** based on the National Economic Census 2004 data (CNE04) and/or registered data.
5. **Extrapolation to a benchmark year** (2012), through reliable price indexes and quantities, through the ARKLEMS database[7].

[6] The internationally agreed standard set of recommendations on how to compile measures of economic activity. See more at https://unstats.un.org/unsd/nationalaccount/sna.asp.

[7] The estimations classified by type of economic activity of the ARKLEMS+LAND (FCE-UBA) band follows the recommendations of SNA08 and the traditional methodology of Argentina National Accounts. For Argentina, the last economic census (CNE04) collects information from 2003. In order to update such data, the estimations provided by official National Accounts cannot be used as they have been distorted or biased since 2007, both in current and constant prices. Consequently, alternative estimations were made through a traditional methodology for the measuring of GDP, which make it possible to have a thorough and reliable update of information, with highest possible breakdown level (Wierny, Coremberg, Costa, Trigo, & Regunaga, 2015).

6. Explicit measuring of the production of **biofuels and biogas**[8], which were not captured in CNE04.
7. Adjustment of the billing levels of each sector for **'non-registered' economy** (NOE)[9].
8. Estimation of 'participation' coefficients of bioeconomy in non-bio activities, as reported by **exogenous information**. Experts working in strategic sectors were consulted to ascertain the bio-production (production from biomass) within segments where there is combined production and the main production is not bio.
9. **Estimation of value added coefficients** according to census information, and adjusted through NOE.

According to the study, Argentine bioeconomy in 2012 represented 15.4% of GDP. Its value added amounted to around USD 72 675 million, with the primary sector accounting to 58% of the total value added of bioeconomy (8.9% of GDP), while the remaining 42% pertains to the manufacturing industry (6.5% of GDP). Moreover, 72% of the industrial value added is generated in production of agricultural origin (MOA), while the manufacturing production of industrial origin (MOI) account for 28% of bio manufacturing industry (Table 1).

Table 1. Participation of sectors in Argentine bioeconomy and GDP (in value added to producer price)

SECTOR	Million USD	Contribution to bioeconomy	Contribution to GDP
Primary	**42 093**	**58%**	**8.9%**
Manufacturing industry	**30 582**	**42%**	**6.5%**
MOA	22 044	30%	4.7%
MOI	8 538	12%	1.8%
TOTAL BIOECONOMY	**72 675**	**100%**	**15.4%**

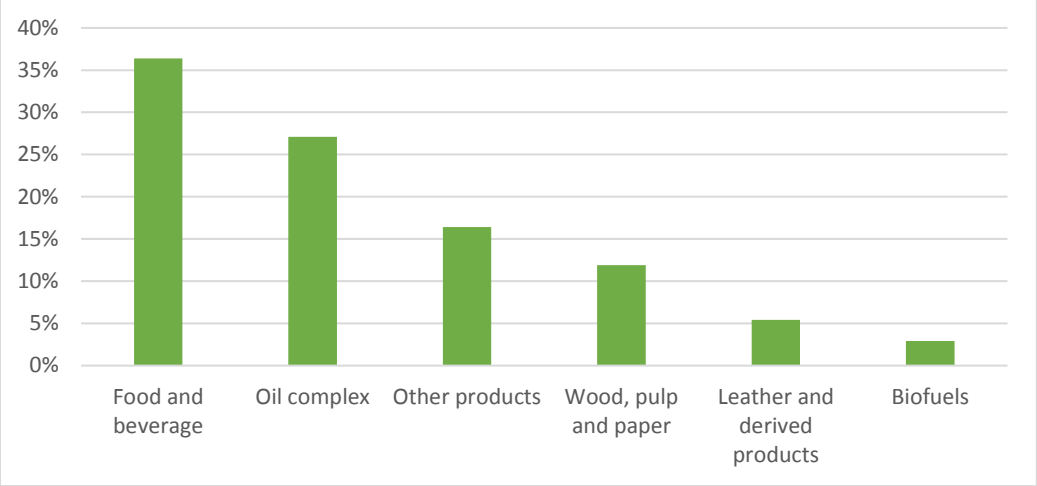
Source: Wierny, Coremberg, Costa, Trigo, & Regunaga (2015).

The main bio-industrial activities are foods and beverages (36%); oil products (27%); other bio-industrial products (16%); wood, pulp and paper (12%); leather and its derived products (5%); and biofuels (3%) (Figure 1). In the biofuel component, soy biodiesel generates 79.5% of the total, sugar cane bioethanol 12% and biogas the remaining 8.5%.

[8] Ethanol estimations derives from the distillation of alcohol of sugar cane (ISIC 15511), and the production of biodiesel is in the ISIC 24290 segment-manufacturing of chemical products not contemplated previously. Specific estimations of the production of biogas that is part of segment 37200, i.e. recycling of waste and non-metallic waste.

[9] National Accounts in Argentina have traditionally included both the economy observed and the non-observed economy in their estimates, while the Economic Census only accounts for the former. Consequently, alternative estimates must give account of both of them.

Figure 1. Participation of the different sectors in the bio-industrial value added (as a percentage of the total)



Source: Wierny, Coremberg, Costa, Trigo, & Regunaga (2015).

Short discussion

The Argentine approach measures the contributions (gross production value and value added) of bio-based products to the national GDP. The true contribution of the bioeconomy can be underestimated due to the **lack of thoroughness, regularity and accuracy in statistics, and lack of reliable data**.

First, bio-based products are usually manufactured jointly with products not derived from biomass, as sub-products or secondary activities, and this creates difficulties in the recording of statistics. In fact, when organizations and industries are not homogeneous within a given level of statistical classification, these are assumed to have a main activity and one or more secondary activities. Inputs of secondary activities are not separated from those of principal activities, auxiliary activities are not analysed or classified according to their own nature, and related products are not presented as autonomous products (Wierny, Coremberg, Costa, Trigo, & Regunaga, 2015).

Furthermore, the complete input-product lists are included in a second stage in the Economic Census, which in Latin America are usually conducted every ten years and only for a sub-sample of all the companies. The existing bias towards big companies in surveys can result in a significant portion of small and medium-sized bio-based companies to be excluded from the sample base of official Industry Surveys.

Another sort of limitation raises when measuring industrial self-generation of bioenergy (e.g. the use of peanut shell and or rice husk in oil plants). In fact, self-generation, unless there is surplus energy traded in the market, does not have a market price and must be generally valued by adding costs, and these are concepts that are difficult to detect and report in a survey or general census covering several activities (Wierny, Coremberg, Costa, Trigo, & Regunaga, 2015).

As well as the production of biorefineries and biogas, other companies and businesses related to bioeconomy emerged after 2003 and needed to be estimated since the CNE04 made for 2003 could

not report such activities. For these reasons, the study by Bolsa de Cereales includes these sectors to the information based on the 2004 Census.

In addition to the criticism to the abovementioned statistical limitations, lack of information often makes it difficult to identify and measure bioeconomy contribution to GDP. In fact, in many cases, the available information is in terms of physical quantities of products, in other cases, only partial information on the inputs is available (Wierny, Coremberg, Costa, Trigo, & Regunaga, 2015).

Finally, the study takes into account just economic variables, without considering the social and environmental aspects of the bioeconomy. For instance, the study does not report on regional and territorial development, employment, food security, energy security, sustainability, or climate change mitigation and adaptation, which are among the objectives of the bioeconomy vision.

3.2. Australia

Bioeconomy definition and strategy

The Australian Government generally refers to the bioeconomy as "the sustainable production and conversion of biomass for a range of food, health, fibre and other industrial products as well as energy" (Department of Industry, 2018). For the Australian **Department of Industry, Innovation and Science**, the bioeconomy encompasses "all industries and sectors producing, managing or otherwise making use of biological resources (including organic waste), such as agriculture, forestry, and fisheries. The modern bioeconomy is based on knowledge and innovation in biosciences, together with other technologies such as engineering, chemistry, computer science and nanotechnologies" (Department of Industry, 2018).

Australia does not have a bioeconomy strategy as of today, but a range of measures that foster bioeconomy as an **enabler across a number of sectors**, such as agriculture; bio-based chemical (including bioplastic packaging); biofuels and bioenergy; biorefining; fisheries; food and beverage industry; forestry and pharmaceuticals industry (Alex Cooke, personal communication, 2018). In terms of intervention focus, most bioeconomy-related Australian policies can be characterized as R&D. In 2013, the Australian government defined fifteen strategic research priorities for the future, which also integrate key topics of the bioeconomy, for example in the areas of bioenergy, ecosystem monitoring and management, optimized food and health (Biookonomierat, 2015).

In Australia, the concept of bioeconomy is often linked to **biotechnology** policy and strategies. For instance, Biotechnology Australia and the Department of Agriculture, Fisheries and Forestry commissioned a report in 2008 entitled "Biotechnology and Australian Agriculture: Toward the Development of a Vision and Strategy for the Application of Biotechnology to Australian Agriculture" (ACIL Tasman, 2008). This report treats bioeconomy as an emerging concept, of which agro-biotechnology is a key part. Additionally, in 2011 the Australian Government released two biorefinery scoping studies investigating the potential of tropical and temperate biomass value chains.

Bioeconomy research is supported by the Australian Government through the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Rural Industries Research and Development Corporations (RIRDC), and Cooperative Research Centres (CRC). For instance, the RIRDC, a national agency, authored the **bioenergy innovation strategy** ("Opportunities for primary industries in the bioenergy sector – national RD&E strategy") and the associated

workplan, based on consultations across Australian government and regional agencies, industry and other stakeholders (Biookonomierat, 2015).

In 2015, the Minister for Industry and Science launched also the "National Marine Science Plan 2015–2025", focused on developing the value added of the "blue economy", while protecting Australia's oceans and marine resources (Biookonomierat, 2015).

Some state and local governments also support bioeconomy. For example, South Australia has a regional bioeconomy strategy "Building a Bioeconomy in South Australia 2011–2015" related to the economic development opportunity arising out of biosciences, and the Queensland State Government has released its Biofutures 10-year Roadmap and Action Plan in June 2016 to grow and promote the industrial biotechnology and bioproducts sector through a AUD $5 million (about USD 3.8 million) Biofutures Industry Development Fund (Department of State Development, 2017).

Objectives/priorities of the strategy

The Australian bioeconomy is expected to increase food security; produce healthier food; and reduce the environmental impact of agriculture and fisheries as well as manufacturing industries. The bioeconomy will also help the world to transition away from fossil fuels for energy and industrial raw materials. In particular, **industrial biotechnology** is seen as a key technology for realising the bioeconomy, as it enables commodities be produced from biomass, rather than non-renewable petrochemical feedstocks (Department of Industry, 2018).

The Department of Agriculture and Water Resources manages various programs and policies related to the bioeconomy, including in rural R&D, farmer support, biosecurity and natural resource management. Overall objectives include **rural development and economic growth, sustainability and food security** (Alex Cooke, personal communication, 2018).

For example, the national Bioenergy RD&E Strategy has four priority areas for innovation: feedstock identification and availability, supply logistics, sustainability and integrated supply chains and industry development, with a special focus on regional applications (RIRDC, 2018).

Methodology and results

Since Australia does not have a specific bioeconomy strategy, no comprehensive approach to measure the contribution of bioeconomy to the overall economy has been developed.

The Australian Government programmes are assessed individually and generally include criteria relating to productivity and profitability wherein the contribution of bioeconomy is not a specific criterion (Alex Cooke, personal communication, 2018). Evaluations of programmes vary in their nature and purpose, and measure a diverse range of impacts including employment, economic, productivity, environmental and social performance. Bioeconomy aspects of a programme are not evaluated separately within the overall programme evaluation.

Bioeconomy is recognised as an enabler of productivity across various sectors. Bioeconomy activities are occurring and are supported in programs in numerous Australian Government portfolios, such as Department of Environment and Energy, Department of Jobs and Small Business, Department of Agriculture and Water Resources and Department of Infrastructure and Regional Development. Responsibility for the programme usually lies with the department with the strongest link, for example, the Department of Environment and Energy has responsibility for renewable energy projects, including projects that divert biomass waste, convert that waste into

energy and then use the energy in its operations. In such projects, productivity is enabled through lower energy costs if compared to fossil fuels and lower waste disposal costs for businesses (Alex Cooke, personal communication, 2018). No explicit indicators of bioeconomy contribution are available in the above mentioned strategies and programmes.

Short discussion

The lack of a specific bioeconomy strategy disciplining the effort towards a structured bioeconomy development make it impossible to measure and monitor systematically the bioeconomy contribution to the Australian economy.

Most bioeconomy-related policies are actually R&D strategies and focus on biotechnology and innovation, and bioeconomy is recognised as an enabler of productivity across various sectors. For these reasons, bioeconomy contributions occur throughout numerous portfolios and are implicitly incorporated into overall measurement criteria, in particular linked to productivity improvement.

3.3. Germany

Bioeconomy definition and strategy

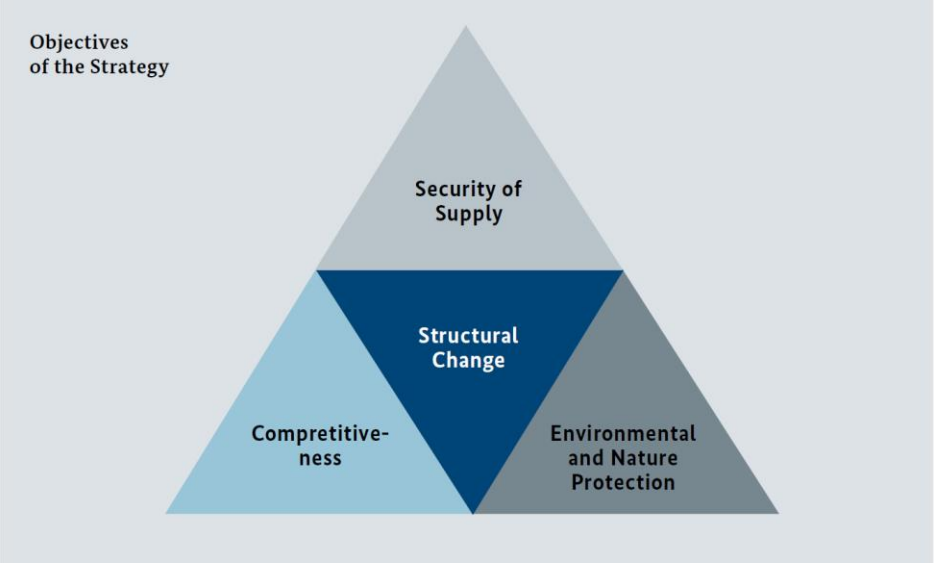
The German national bioeconomy strategy defines bioeconomy as "the knowledge-based production and utilization of renewable resources in order to provide products, processes and services in all economic sectors, within the context of a future-capable economic system" (BMBF & BMEL, 2015). The concept of bioeconomy encompasses all economic sectors and their associated commercial services involved in producing, working or processing, using or trading with renewable resources. Considering scarce fossil-based resources, climate change and growing world population, bioeconomy is seen as an opportunity to achieve economic growth while protecting the nature and the environment.

Germany holds a leading international position in bioeconomy. As one of the first countries to conceptualize bioeconomy, Germany published its **National Research Strategy Bioeconomy 2030** in late 2010 for implementation across policy areas. The key government bodies of the German bioeconomy strategy are the Federal Ministry of Food and Agriculture (BMEL), the Federal Ministry for Education and Research (BMBF) and the Bioeconomy Council, an independent advisory body to the German government.

Objectives/priorities of the strategy

The **National Policy Strategy on Bioeconomy** (BMEL, 2013) sets priorities for advancing towards a knowledge-based bioeconomy and it highlights areas that require action. The structural transition towards a bio-based economy can be successful only if it secures the supply of food, it protects the environment, the climate and biodiversity, and it supports the development-policy objectives in developing countries and emerging economies (Figure 2). In fact, the bioeconomy is closely interlinked internationally, thus decisions and changes in Germany can have consequences in other parts of the world.

Figure 2. Objectives of the German bioeconomy strategy



Source: BMEL (2013).

Objectives/priorities of the German bioeconomy strategy are (BMEL, 2013):

- a **secure supply of high-quality food** to the population in Germany; beyond this, within the scope of what is possible, a contribution towards securing the supply of food globally;
- **strengthening the transition** from an economy mainly based on use of fossil-based raw materials to an economy that is increasingly both efficient in terms of raw materials and based on renewable resources;
- a **supply of renewable resources**, secured over the long term for sustainable and efficient use of resources, to be used as materials and as an energy source, based on reliable framework conditions;
- **sustainable use of renewable resources** while conserving biodiversity and soil fertility;
- protection of the **climate;**
- **strengthening of Germany's innovative power** and its international competitiveness in business and research;
- **securing and creating employment** and added value, particularly in rural areas;
- **sustainable consumption** on the part of consumers, as a part of the bioeconomy value chain.

Methodology and results

Even if some of the individual measures in the German bioeconomy national strategy are associated with quantitative targets (BMEL, 2013), the strategy does not include criteria to measure the contribution of bioeconomy to the overall economy. Nevertheless, the Thünen Institute calculated in a **Progress Report** on the National Policy Strategy Bioeconomy (BMEL,

2016) the share of the bioeconomy in the entire economy for the years 2002, 2006 and 2010 by means of **gross value added and employment** related to bio-based economies. The analysis of bio-based economies include the calculation of:

- **Primary production** (agriculture, forestry, fisheries): determination of employment and gross value added on the basis of land and forestry accounts and fisheries surveys.
- **Manufacturing**: 1) determination of the bio-based share of all related inputs of each industry; and 2) consideration of employment and gross value added of the industry according to the calculated bio-based input share.
- **Trade and Services**: activities that deal exclusively with biological raw materials (e.g. veterinary, specialized fruit trade) were fully allocated to the bioeconomy. The most important industry in the trade is food retail trade. From various studies it was concluded that 80% of the turnover can be assigned to the so-called "food" while 20% of the turnover relates to the "non-food" area. Consequently, 80% of this activity was attributed to the bioeconomy.

The data were mainly based on official statistics such as the national accounts, input-output tables, VAT statistics, cost structure statistics, the materials and goods receipts survey, and where necessary, supplementary market studies. No cluster approach was chosen, but the bio-based fraction was determined for each industry individually (BMEL, 2016).

A comprehensive monitoring approach to measure the contribution of German bioeconomy to the overall economy is currently under development by a joint inter-ministerial undertaking, made of three main projects (Schachtsiek, T. personal communication, 2018. This includes the monitoring of biomass flows, the Systemic Monitoring and Modeling of the Bioeconomy (SYMOBIO[10]) and the identification of economic key performance indicators to monitor the bioeconomy.

1. The Thünen Institut is in charge to develop the basics for a Germany-wide monitoring system of current and future **biomass flows** and their evaluation[11]. This first project lasts until end 2019 and is related to a previous study on the macroeconomic effects of cultivation and use of renewable resources (FNR, 2007).
2. The **Systemic Monitoring and Modelling of the Bioeconomy** (SYMOBIO) project is coordinated by the Center for Environmental Systems Research (CESR) of Kassel University and runs from March 2017 to February 2020[12]. The main goal of the project is to develop the scientific fundamental for a systemic monitoring and modelling of bioeconomy in Germany by:
    a. The development of a framework for systemic monitoring
    b. The development of a system of modelling and evaluation
    c. The analysis of the key drivers for the transformation of the bioeconomy
    d. Modelling trends and their environmental and socio-economic impacts

[10] For more information, see https://symobio.de/en/start_en
[11] For more information, see https://www.thuenen.de/de/institutsuebergreifende-projekte/biooekonomie-monitoring/
[12] For more information, see https://www.uni-kassel.de/einrichtungen/cesr/forschung/projekte/aktuell/symobio.html

e. Indicators and data of certification and life cycle assessment

f. Development of a monitoring system.

3. The identification of economic **key performance indicators** to monitor the progress of bioeconomy is coordinated by the Leibniz Institute for Economic Research at the University of Munich (ATB)[13]. On behalf of the German Ministry of Economic Affairs and Energy, this project develops and analyses indicators that are suitable for describing the bioeconomy and assessing its economic and environmental effects. In addition, it suggests, tests, and validates methodologies and guidelines for data collection, calculation, and analysis of indicators. It thereby contributes to the development of a scientific basis for a long-term monitoring of the bioeconomy, in close collaboration with the other two partnering projects dealing with biomass flows and modelling of the bioeconomy. The transformation towards a bioeconomy, with its potentials and barriers or trade-offs, will become visible and trackable through the monitoring and will support decision-makers in drawing conclusions. The ATB project lasts until March 2019 and it discusses and develops indicators that are specific to the bioeconomy, such as indicators for cascade utilization and economic-ecological impacts. The methods and indicators are tested and validated in a pilot study within the bioplastics industry. The project is coordinated by Ifo Institute for Economic Research[14] and carried out in cooperation with Nova-Institute and the Fraunhofer Institute for Systems and Innovation Research (ISI).

The approach that Germany will use to measure bioeconomy contribution to the overall economy and bioeconomy indicators will be determined by the outcomes of the programmes above.

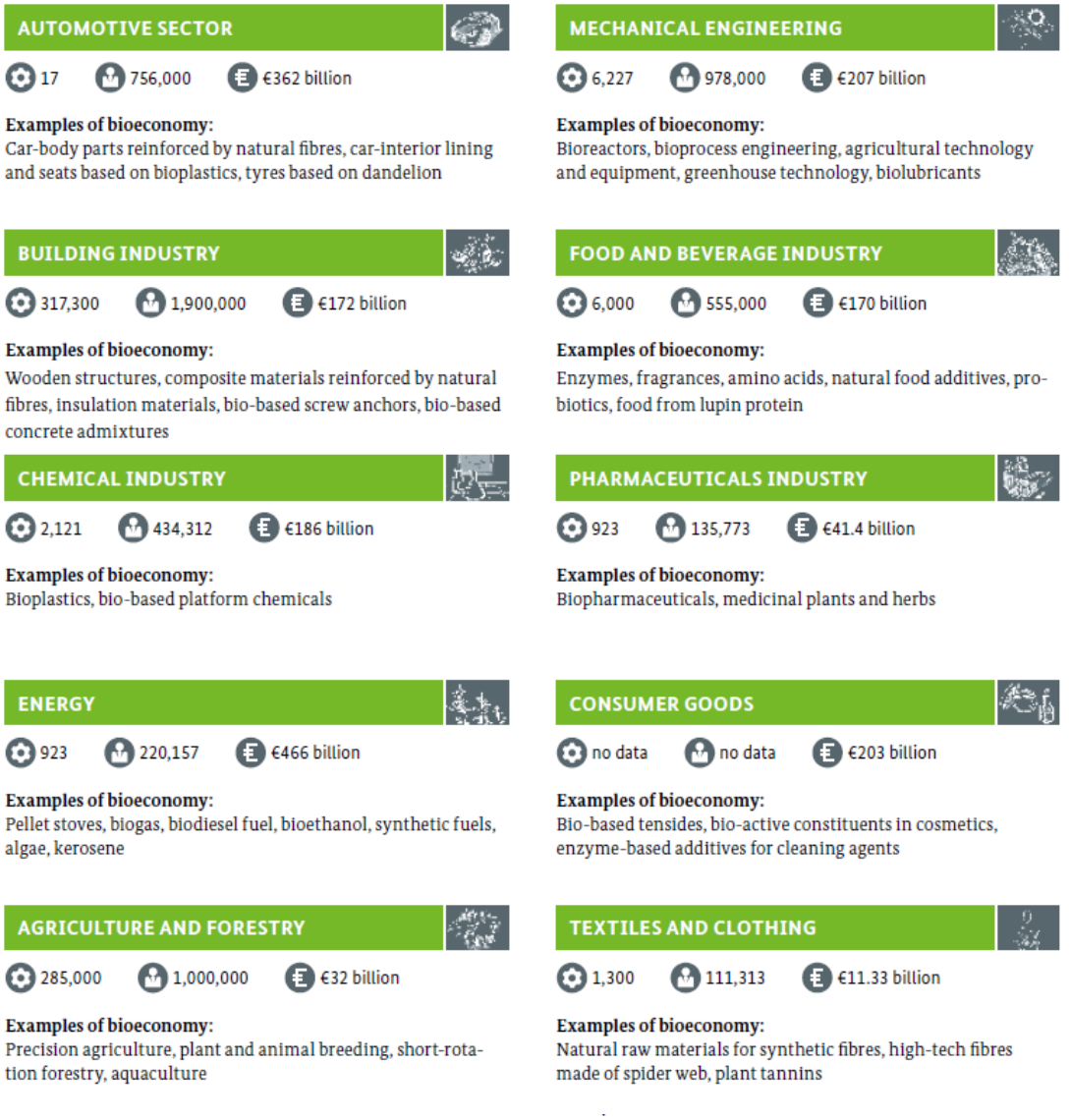
According to a recent report (BMBF & BMEL, 2015), bioeconomy encompasses automotive, construction, chemistry, energy, agriculture and forestry, mechanical engineering; food and beverage industry, pharmaceuticals, consumer goods, and textiles (Figure 3). Bioeconomy contribution is measured in terms of number of companies, employees and sales (in euro) in each sector.[15]

[13] For more information, see https://www.atb-potsdam.de/forschungsprogramme/projekt/portrait/wiebke-jander.html?xq=422

[14] For more information, see https://www.cesifo-group.de/ifoHome.html

[15] These figures do not distinguish between direct and indirect contribution of each sector, and may therefore lead to double-counting if simply summed up.

Figure 3. Facts and figures of bioeconomy in Germany



Source: BMBF & BMEL (2015).

According to the bioeconomy progress report (BMEL, 2016), German bioeconomy contributed 6% of the overall economic value added in 2010. The bioeconomy grew by 22% between 2002 and 2010, while the economy as a whole grew by 16%. If the weight of the bioeconomy is considered on the basis of the employment ratio, the significance of the bioeconomy is doubled compared to the value added view (BMEL, 2016). This indicates that bioeconomy is associated with employment-intensive activities and labour productivity is rather low.

The EC Bioeconomy Knowledge Centre indicates that the turnover in Germany in total bioeconomy sectors in 2015 was EUR 386 billion (1st among EU member states), employment

was around 1.96 million people and location quotient[16] was 0.59 (EC, 2018). If the location quotient is smaller than one, the proportion of people employed in bioeconomy in the country is lower than the proportion of people employed in bioeconomy in the EU member states. Thus, the labour force of Germany is less concentrated in bioeconomy, compared to the average EU countries. This is mainly because agriculture accounts only for a very small proportion of total employment in Germany, and the country has a high agricultural labour productivity (EC, 2016).

Short discussion

In principle most of the areas contributing to bioeconomy in Germany are monitored by traditional statistic accounts (BMBF & BMEL, 2015); however, in most of the cases methodologies for data collection and assessment are not streamlined to assess the impact of the bioeconomy on these items. This leads to **sparse information** on impacts, along with data gaps, uncertainties, inaccuracies, lack of comparability of results and maybe double-counting.

Current estimations in the German bioeconomy progress report has been lacking of a comprehensive, inclusive, systemic and long-term methodology for monitoring, data collection and assessment. Moreover, only market-valued activities were included because only such activities are reflected in statistics. In addition, the statistics upon which the analysis was based suffer from the lack of detection of biological raw materials for technical purposes (BMEL, 2016). The current efforts of the three joint projects mentioned in earlier sections aim at filling these gaps.

3.4. Malaysia

Bioeconomy definition and strategy

Malaysia defines bioeconomy as "the sustainable production of renewable biological resources and their conversion into food, feed, chemicals, energy, and healthcare and wellness products via innovative and efficient technologies". In addition to biotechnology, the bioeconomy encompasses all industries and economic sectors that produce, manage and utilise biological resources. This includes agriculture, forestry, fisheries, food production, healthcare, chemicals and renewable energy.

In 2005, the Malaysian Government introduced the **National Biotechnology Policy** (NBP), a 15-year plan aimed at making biotechnology a key contributor to economic growth (MOSTI and Bioeconomy Corporation, 2015). In 2006, the **BioNexus Status** (BNX) was introduced to recognise and award qualified companies undertaking value-added biotechnology and/or life-sciences activities. In 2012, Malaysia also introduced the **Bioeconomy Transformation Programme** (BTP) as one of the implementation strategies under the Economic Transformation Programme (ETP). BTP is a platform provided by the government for the private sector to channel and maximise commercial opportunities in bio-based industries. Additionally, to further increase competitiveness and the contribution of bioeconomy to economic growth, the **Bioeconomy Community Development Programme** (BCDP) was announced in Malaysia's Budget 2014, with the aim to bolster the upstream portion of the industry value chain through the creation of secure,

[16] Location quotient is the indicator usually used to measure how 'concentrated' a sector is in a Member State compared with the EU. It represents the share of employment in the BE in a Member State divided by the EU employment share in the BE (EC, 2018).

local, high quality source of raw materials for capacity expansion and the downstream ventures (MOSTI and Bioeconomy Corporation, 2016). BCDP focuses on the upstream raw material supply, while BNX and BTP focus on the downstream processing, value adding activities and market access.

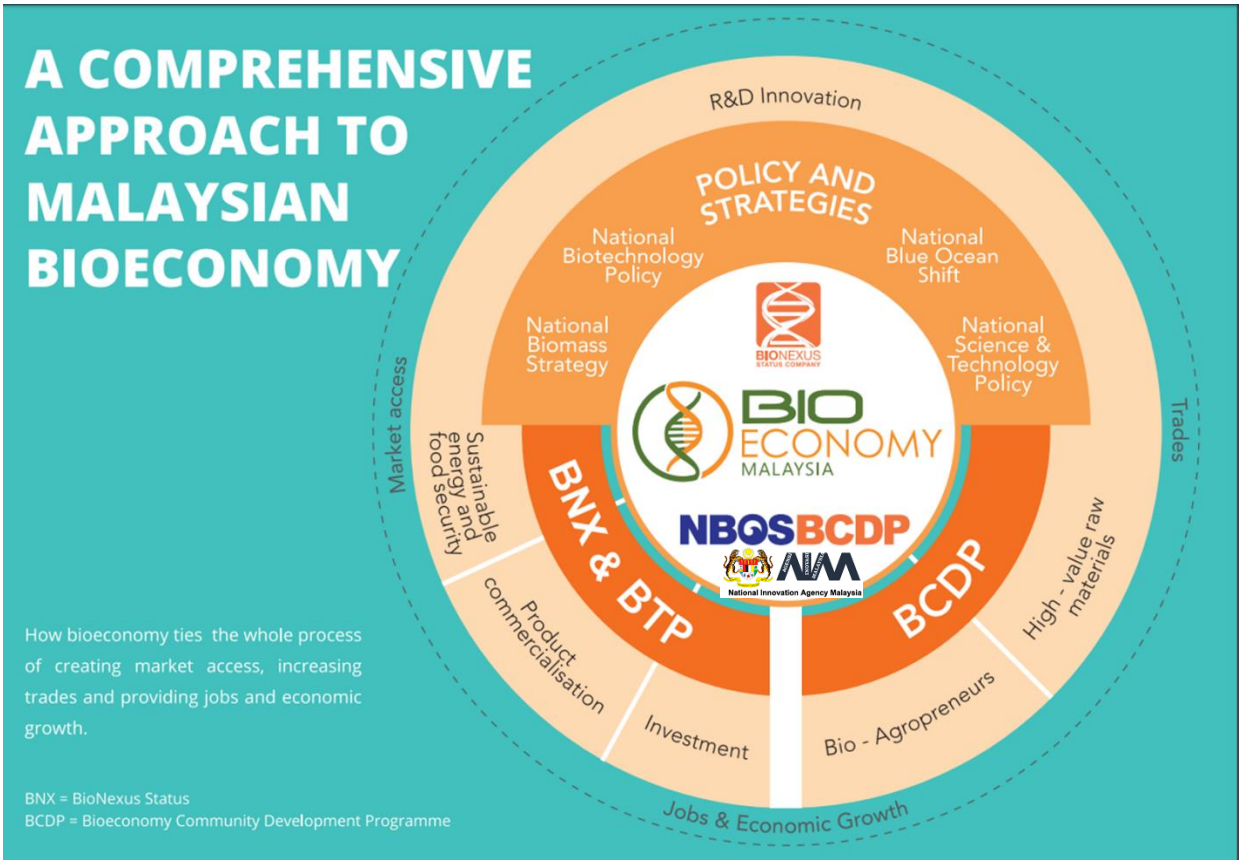
Malaysia envisions the bioeconomy to be a significant contributor to the nation's economy by 2020 and beyond. Bioeconomy is expected to enhance domestic food security, improve health and well-being of people and increase national income by means of greater and more sustainable growth.

The NBP, the BioNexus Status and the BTP have been developed under the purview of the MOSTI with BiotechCorp, most recently called Bioeconomy Corporation (the Malaysian Bioeconomy Development Corporation Sdn. Bhd.) to be the implementation agency overlooking the bioeconomy in Malaysia.

The Bioeconomy Corporation has developed the BTP, BNX and BCDP to have a coherent, supportive bioeconomy policy framework and implementation programmes. In 2017, BTP boasts 77 Trigger Projects, generating additional Gross National Income (GNI) contribution, investments and jobs. These Trigger Projects cover three main sectors: AgBiotech, BioIndustrial and Healthcare Bio (MOSTI and Bioeconomy Corporation, 2016). While for BNX, a total of 283 companies have been awarded with the status (Bioeconomy Corporation, personal communication, 2018).

In addition, agricultural biomass for high value products, in particular oil palm biomass, is also a major pillar of the Malaysian bioeconomy, the culmination of which resulted in the **National Biomass Strategy 2020** ("NBS 2020"), an inclusive strategy developed by Agensi Inovasi Malaysia (AIM) with all biomass stakeholders from industry, government and academia. It is a national blueprint on how Malaysia can leverage its available biomass across a diversified portfolio of higher value downstream uses to create new industries and jobs. Launched in 2011, NBS 2020 covers all types of biomass sources such as palm oil, forestry, rubber, dedicated crops, municipal waste and etc. To drive and further strengthen the execution of NBS 2020, the National Biomass Strategy Delivery Unit (1MBAS) was setup by the Prime Minister of Malaysia in March 2012, and led by AIM. Its core functions are to promote the utilisation of biomass and facilitate Industry explore all commercial biomass opportunities in Malaysia in the entire biomass value chain and across all sectors ranging from bioenergy, advanced biofuels, biochemical up to, eventually, end-products.

Figure 4. A comprehensive approach to Malaysian Bioeconomy



Source: Bioeconomy Corp and MOSTI (2018).

Objectives/priorities of the strategy

As a key contributor to economic growth, the bioeconomy benefits society via breakthroughs in agricultural productivity, innovations in healthcare and the adoption of sustainable industrial processes. BTP and BCDP will help achieving the **six strategic thrusts** of the 11th Malaysia Plan 2016-2020 to allow Malaysia to explore opportunities and address challenges amid the fast-changing global economic environment (MOSTI and Bioeconomy Corporation, 2015):

1. **Enhancing inclusiveness towards an equitable society**: The BCDP can generate additional income by utilising bio-based technology
2. **Improving well-being for all**: The BTP and BCDP aim to raise the living standards of Malaysians through social and environmental benefits
3. **Accelerating human capital development for an advanced nation:** Job opportunities will be created by the BTP and the development of *Bio-Agropreneurs* through the BCDP
4. **Pursuing green growth for sustainability and resilience:** The promotion of green projects under the BTP is closely aligned with green growth
5. **Strengthening infrastructure to support economic expansion**: This will be complemented by the BTP high-impact projects

6. **Re-engineering economic growth for greater prosperity:** aims to accelerate the achievement of the NBP targets, whereby the biotechnology and bio-based sectors would contribute 5% of the nation's GDP by 2020.

Expanding upon the bioeconomy value chain approach, the National Biomass Strategy 2020 aims to **optimise biomass value chain**. The concepts of circular economy is expected to provide positive solutions towards combating climate change while balancing economic growth, rural development and social impact throughout the value chain.

Methodology and results

In order to measure the contribution of bioeconomy to the overall economy, Malaysia has developed a **Bioeconomy Contribution Index (BCI)**, which is a combination of five components/parameters: bioeconomy value added, bio-based exports, bioeconomy investments, bioeconomy employment and productivity performance (Figure 5).

Figure 5. Components of the Malaysia Bioeconomy Contribution Index (BCI)

Source: MOSTI and Bioeconomy Corporation (2016).

The BCI is a comparative tool designed to provide a holistic view, encompassing multiple aspects of the bioeconomy and it is used to identify trends, patterns and synergies within the industry. The index compares the performance of a specific component for a selected year against "adjusted" [17] expected base performance determined by a **Dynamic Computable General Equilibrium** (DCGE) model (MOSTI and Bioeconomy Corporation, 2015).

The share of bioeconomy contribution to national development is estimated from the SAM and assuming that Malaysia is a price taker country (Quasem Al-Amin, 2016). The data regarding the five indicators and their sources are described below (Table 2).

[17] "Adjusted" is defined as the performance expected based on economic circumstances, having applied modifications to simulate real (as opposed to nominal) economic situation. This means accounting for changes in variables such as inflation rates, import-export values, exchange rates, and many others (computed utilising DCGE in the General Algebraic Modeling System software) (Quasem Al-Amin, 2016).

Table 2. BCI indicators description and data sources

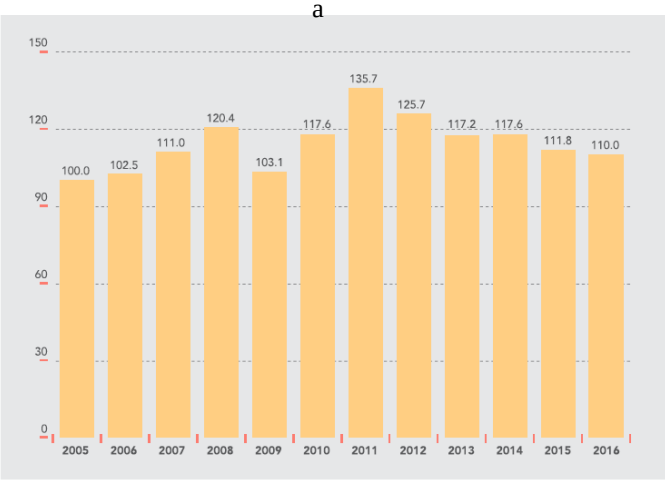
Indicators	Unit	Description	Data source
Value added	Malaysian Ringgit (RM)	Value of bioeconomy-related sector, i.e.: palm oil, paddy, rubber, wood products, food products, biodiesel	GDP value or bio-based-related production by sectors published by Department of Statistics Malaysia (DOSM)
Exports	USD	Value of export of all bio-based products (excluding minerals such as oil and coal)	UN Comtrade
Investment	RM	Domestic and foreign investments into bioeconomy sectors	Estimated proportion of National Gross Fixed Capital Formation by sectors
Employment	Number	Income creation value of jobs created within bioeconomy sectors	Estimated from the Labour Survey by sectors published by DOSM
Productivity	Index (value of output (GDP) per unit of labour)	Innovation and diffusion of factor productivity in the bioeconomy sector	Productivity report for selected sectors published by Malaysian Productivity Corporation (MPC)

Source: Elaboration based on Quasem Al-Amin (2016).

The BCI is constructed using the base year 2005 at 100 points. After growing especially during year 2008 and 2011, bioeconomy showed a contraction in 2015 and 2016 (Figure 6). The outcome of BCI is divided into 5 sub-indices to observe the sub-indicator achievements, patterns and trends from the base year 2005 to 2014 (Quasem Al-Amin, 2016). This allow to see that the moderation in 2015 is due in particular to weaker performance in the exports component.

Figure 6. Trend in a) the Malaysia BCI, b) bioeconomy value added, c) bio-based exports, d) bioeconomy investment, e) bioeconomy employment and f) productivity performance (2005-2016)

a



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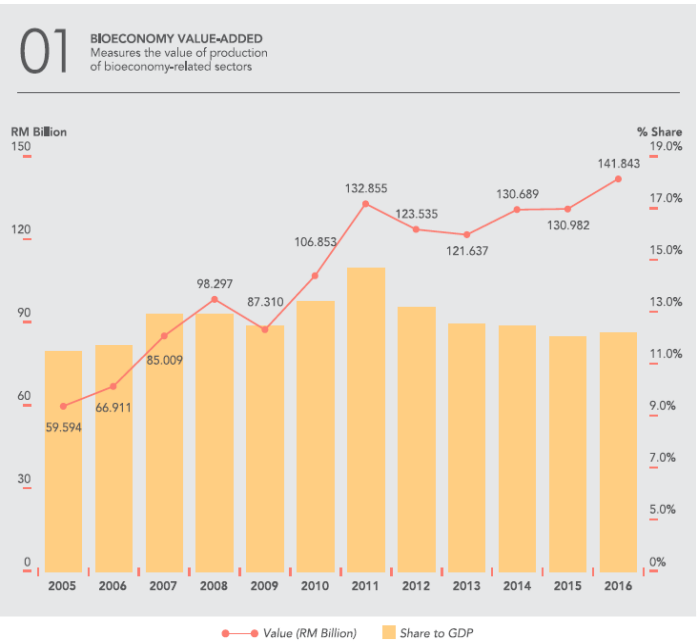

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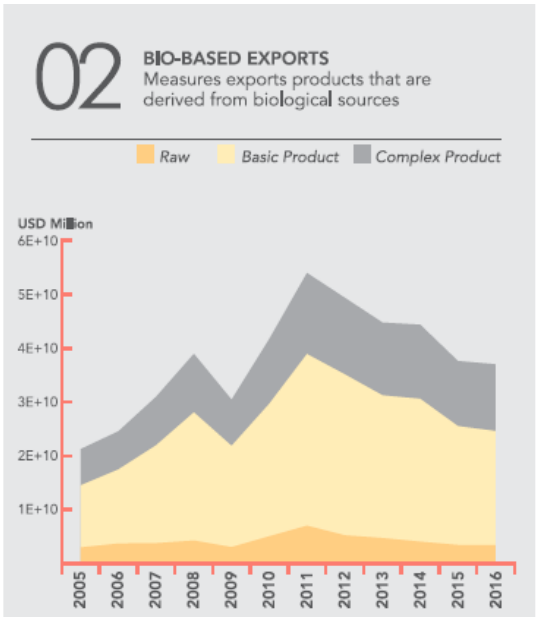

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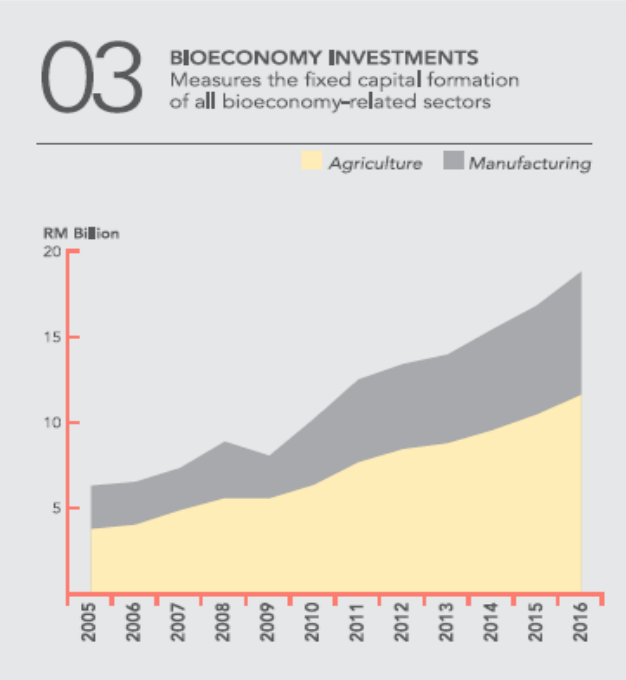

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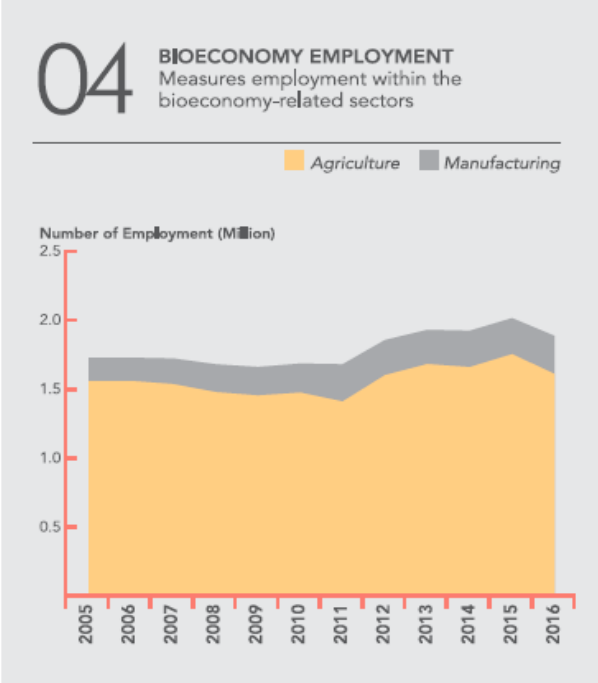

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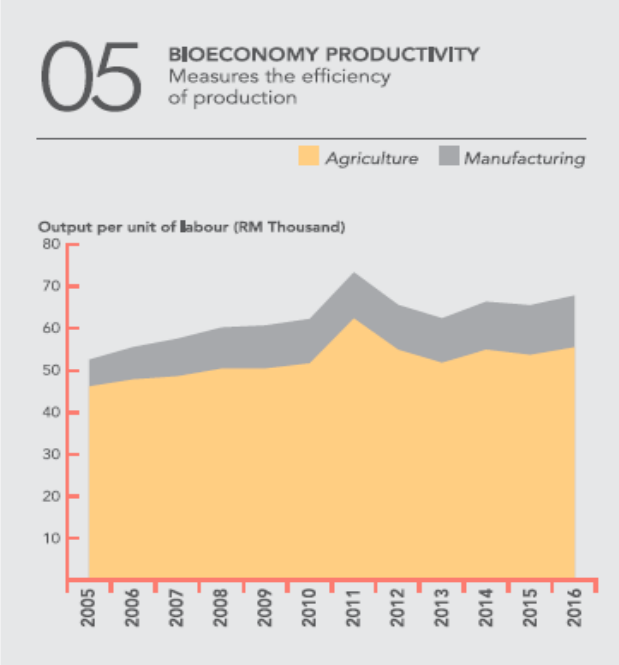


Source: Bioeconomy Corp. (2018).

In addition, the Malaysian Investment Development Authority (MIDA), monitors more broadly investments in the biomass sector covering investments and job creation numbers.

Short discussion

Estimating bioeconomy is a challenge as official statistics are limited to traditional sectors with little distinction made towards bio-based or biotechnology related productions. Therefore, bioeconomy indicators are estimated based on **multiple sources**. As a result, the calculation and estimation of true value of bioeconomy may evolve over time to account for the full potential of bioeconomy such as the inclusion of bio-services (Che Dir, Z., personal communication, 2018).

In addition, the BCI currently measures primarily revenues and **economic flows**, but it could be improved to take into account broader socio-economic or environmental aspects. For instance, the BCI could incorporate measures of poverty reduction or income inequality in the bioeconomy industry, or it could account for CO_2 emissions or level of local biodiversity (Quasem Al-Amin, 2016).

A limitation for data collection and accounting for the bioeconomy comes in terms of **availability of information** in an open platform amongst Ministries and Agencies or in large the Government of Malaysia. As Malaysia is embarking on important digitalization efforts, the availability of big data and complex analytical tools will increase relevance and improve the monitoring of the bioeconomy contribution towards meeting the country's international obligations in terms of GHG emission reduction, carbon footprint and SDGs (Timothy Ong, personal communication, 2018). The effort towards more integrated data platforms will also facilitate the collection of timely data and information, and facilitate data gathering.

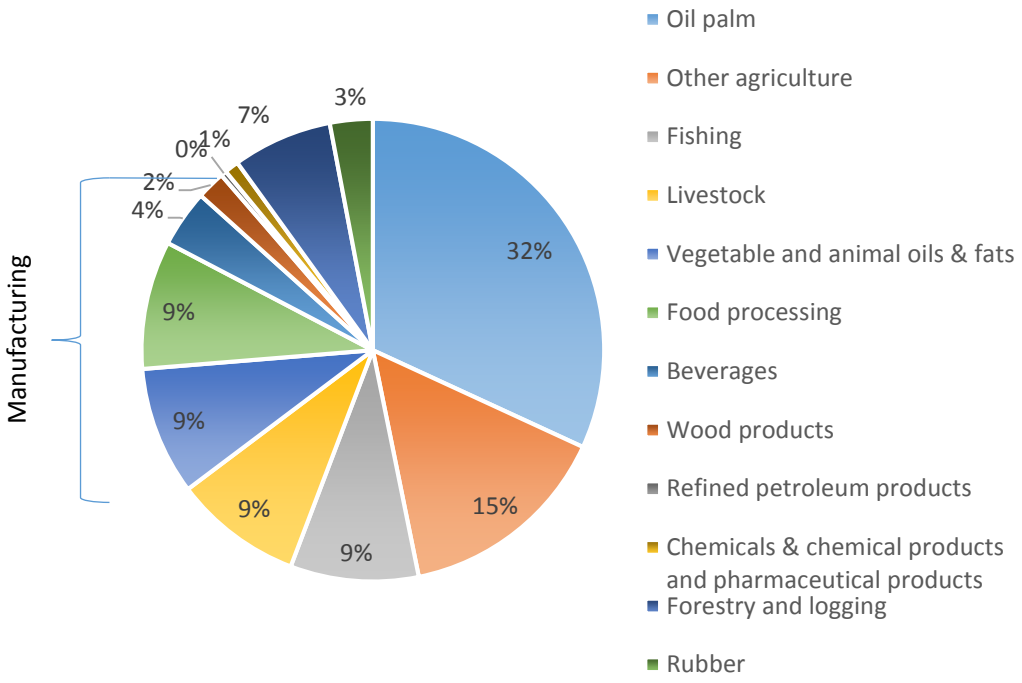
A limitation of the current monitoring of bioeconomy progress in Malaysia is the **partial coverage** of the Bioeconomy Corporation agency. In fact, the Bioeconomy Corporation monitors contribution of biotechnology and bio-based companies that are awarded the Bio-Nexus status (although the scope is currently being expanded). This status is awarded to qualified companies undertaking value-added biotechnology and/or life sciences activities and entitles to fiscal incentives, grants and other guarantees to assist growth. This excludes a number of bio-based projects and companies that may not be covered under the programme but fall under different Ministry setups (Timothy Ong and Zurina Che Dir, personal communication, 2018).

Box 2. Analysing the contribution of Malaysian bioeconomy using the GDP approach

An alternative approach adopted by the Bioeconomy Corporation to measure the Malaysian bioeconomy was by estimating its contribution to GDP. This approach has now been replaced by the BCI. The study (Fadillah, 2015) calculates the **share of GDP of each sector that is related to bioeconomy** from year 2005 until 2014, and then takes the sum of their contribution. The share of each sector is calculated by dividing the GDP of the component by the total GDP of Malaysia for each year. In calculating the total share of the bioeconomy in the GDP, different components are assigned different weights, depending on the extent of bioeconomy in that particular sector. The weights reflect the use of bio-resources either in production or conversion into food, feed, chemicals, energy, and healthcare and wellness products. For instance, refined oil products have a small weight of 0.13% because only the biodiesel subcomponent is considered as bioeconomy related.

In order to understand the trend for bioeconomy, the paper looks into the bioeconomy components. The estimated contribution of bioeconomy to GDP shows that the agriculture sector accounts for about three quarters of the value, while the manufacturing sector accounts for the remaining one fourth (Figure 7). By subsectors, oil palm took the largest share, followed by other agriculture and fishing.

Figure 7. Breakdown of bioeconomy contribution to GDP by subsectors in 2014, by value.



Source: Fadillah (2015).

The study offers only a partial view of the contribution of bioeconomy to the Malaysia economy and, as mentioned above, this GDP approach was later complemented by the use of the BCI. Nevertheless, the study underlines important aspects, such as the fact that the contribution of bioeconomy to Malaysian GDP is closely related to the agriculture sector, and in particular to the palm oil industry. Commodity prices, policies and level of production are important inputs in determining the changes in the share of bioeconomy to GDP.

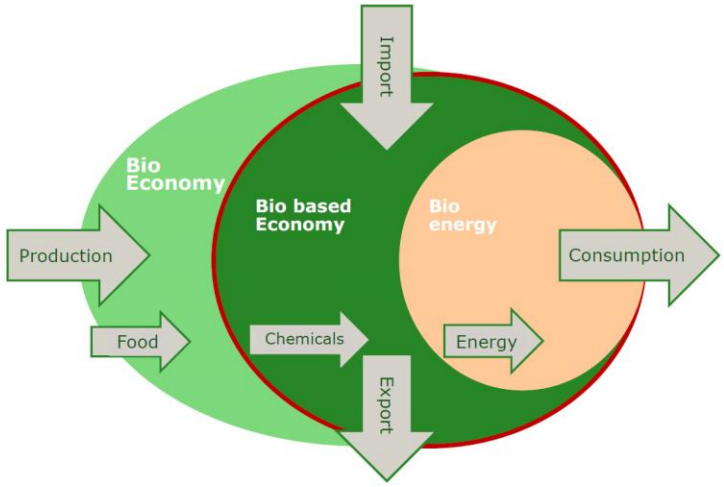
3.5. The Netherlands

Bioeconomy definition and strategy

The Dutch definition of bioeconomy includes every "economic activity based on vegetable or animal raw materials" (RVO, 2013). It refers to the production of biomass for food, fodder, materials, transport fuels and energy, from forestry, agriculture and aquaculture (van Esch, personal communication, 2018). The bioeconomy definition comprises a significant flow of materials that is re-used in the form of soil enhancers. Therefore, the Dutch government focuses more often on bio-based economy (BBE), which is defined as "economic activity based on biomass, with the exception of human food and feed", with the condition that it is based on recently captured carbon (CE Delf, 2017) (Figure 8). The BBE is an economy in which plastics, transport fuels, electricity, heat, and all kinds of everyday products are made from vegetable raw materials (instead of from fossil fuels such as oil, coal or natural gas). All parts of the feedstock should be

used optimally, and cycles can be closed through smart cooperation between companies (NOST, 2013).[18, 19]

Figure 8. The bio-based economy (BBE) embedded in the overall bioeconomy



Source: CE Delf (2017).

Until recently, the Dutch bioeconomy strategy was mainly governed by the Cabinet of Economic Affairs, Agriculture, and Innovation and by regional development agencies (NNFCC, 2015). Currently, the new Ministry of Agriculture, nature and food quality is first responsible for this topic (van Esch, personal communication, 2018).

The main original strategy documents are: *Hoofdlijnennotitie Biobased Economy* (2012), a mid- and long term vision and strategy for the BBE, and *Groene Groei: voor een sterke, duurzame economie* (2013) to address economic growth and environmental improvement.

The main instruments that the Dutch government adopts to promote the bioeconomy are networking, building alliance with stakeholders, stimulate innovation, and support research. The Dutch Government have thus coordinated agreements between stakeholders to align strategies towards a BE, such as the *Manifest* BBE signed in 2011 by businesses and NGOs to support the development of a sustainable BBE, *Green Deals* (co-operation between Government and societal initiatives, to develop sustainable projects, e.g. for community renewable energy projects) and the

[18] Regarding the conversion of a fossil fuel-based economy into a BBE, for the Netherlands (and the EU in general) a main issue is the limited domestic supply of ecologically sustainable biomass. Land use is the most critical problem, especially for the impacts on greenhouse gas (GHG) emissions and biodiversity. To address these challenges in the transition to a sustainable BBE, new technologies, procedures and infrastructure to collect or to produce more biomass without using directly or indirectly valuable natural land; technologies to produce hydrocarbons from types of biomass that have potentially the highest sustainable supply (lignocellulosic biomass) and a system of criteria, certification schemes and enforcement for all types of biomass that aims to reduce the impact of direct and indirect land use on GHG emissions and biodiversity should be developed (PBL, 2012). The last point can be addressed extending the current EU system on transport biofuels to all biomass.

Innovation Contract for the Biobased Economy (a joined agenda of over 100 companies developed by industry and research organisations in 2012) (NNFCC, 2015).

At the level of the EU, the Netherlands has been working together with France and Germany on an EU-wide approach to the BBE. The Dutch government works close with the European Commission and the SCAR (Standing Committee on Agricultural Research) on this theme.

Objectives/priorities of the strategy

The Netherlands has a well-developed agri-food-chemical sector that embeds great potential for a BBE. A BBE strategy has been adopted since the early 2000s. The most important motives behind this adoption were (NOST, 2013):

- striving for more sustainability (reduction of CO_2 emissions, circular economy),
- the awareness of the finite nature of fossil fuels, and
- the economic opportunities offered to Dutch businesses through the use of renewable biological resources and residues.

The Netherlands encourages knowledge development and innovation in particular in **nine top sectors**: agriculture and food, water, chemicals, energy, life sciences and health, horticulture and propagation materials, logistics, high-tech systems and materials and creative industries (NOST, 2013). In particular, the bioeconomy strategy funds research and technology programmes, such as the *MKB innovatieregeling* (MIT) programme, aiming to strengthen the knowledge BBE through R&I, feasibility studies, R&D cooperation projects, innovation and performance contracts, networking and valorisation activities; and the *TKI Biobased program*, which facilitates the cascading use of biomass, funding innovation projects on biorefinery and conversion, and reduction projects on electricity, heat and gas (NNFCC, 2015)[19]. The Netherlands Enterprise Agency (RVO) supports BBE projects, including 40 pioneering projects in biomass through the Programme for Sustainable Biomass (NPSB).

The Netherlands is also one of the few countries to offer R&D tax incentives designed to encourage companies to invest in R&D, such as the WBSO scheme (Salaries Tax and Social Insurance Contributions Act (WBSO 2014)), widely used for innovation grants, and the RDA subsidy (Research and Tax Deduction), which offers tax deduction from profit before taxes.

The objectives of the bioeconomy strategy are the sustainable production of biomass, closing the nutrient loops, food supply, but also the optimal utilisation for food, materials and energy by

[19] The government observes the following principles which guide its policy on the production of biomass (Framework memorandum on the BBE, 2011):
• The production of biomass in agriculture, forestry, fisheries and other sectors must be optimised and sustainable. A stimulus should be provided for the development of alternative ways of producing raw materials without the use of land and biomass, such as artificial photosynthesis. The yield per hectare in agricultural production should be increased and waste during harvest and production should be opposed.
• Cycles should be closed and optimised so that nutrients (phosphates, nitrogen) are retained, organic matter levels are maintained and biomass can be used for composting.
• Stimulus measures should be provided for technological developments in biorefinery, gasification, pyrolysis and torrefaction.
• Sustainability helps avoid the depletion of land, conversion of forest to agricultural land, loss of biodiversity, additional greenhouse gas emissions, negative direct and indirect impact of changes in the use of land and peat extraction.

cascading. The goal is to reduce 50% of the used resources by 2030 (van Esch, personal communication, 2018).

Methodology and results

In 2013, RVO established a **BBE monitor protocol** to quantify the size of the BBE in the Netherlands and to monitor its development over time, with the aim of making trends visible and compare them with developments abroad (RVO, 2013). The protocol defines what the system boundaries are and in which units the size of BBE can be expressed, and it describes how available data are used and how missing data can be obtained. The protocol, built on existing statistical data on production and consumption, prevents double counting and accounts for raw material flows.

In order to monitor BBE, the following items must be accounted for (RVO, 2013):

1**. bio-based raw materials** used by the Dutch industry

2. **bio-based products** used by the Dutch consumers

3. the contribution of the BBE economy to the reduction of Dutch **CO_2 emissions** by fossil fuels

4. renewable **carbon captured** in the Netherlands in (non-food or animal feed) products

5. extent to which the replacement of fossil raw materials occurs through the use of **renewable raw materials**

6. the size of the Dutch contribution to the **EU bio-based economy**

7. contribution of the Dutch bio-based economy to the **Gross National Product (GNP), value added, and employment.**

In the 2013 report, the monitor protocol focused only on determining the use of bio-based raw materials in the economy (point 1): carbohydrate-rich commodities (starch and sugar), oil crops, lignocellulose raw materials, protein crops and other crops (including natural rubber). Point 2, 3 and 5 were answered for some sectors only. The sectors included in the analysis were (RVO, 2013):

- Consumption sectors:
    - Electricity and heat
    - Transport
    - Materials and chemicals
- Production sectors:
    - Timber sector
    - Paper and cardboard industry
    - Chemistry
    - Plastic and rubber processing industry
    - Textile, clothing and leather industry

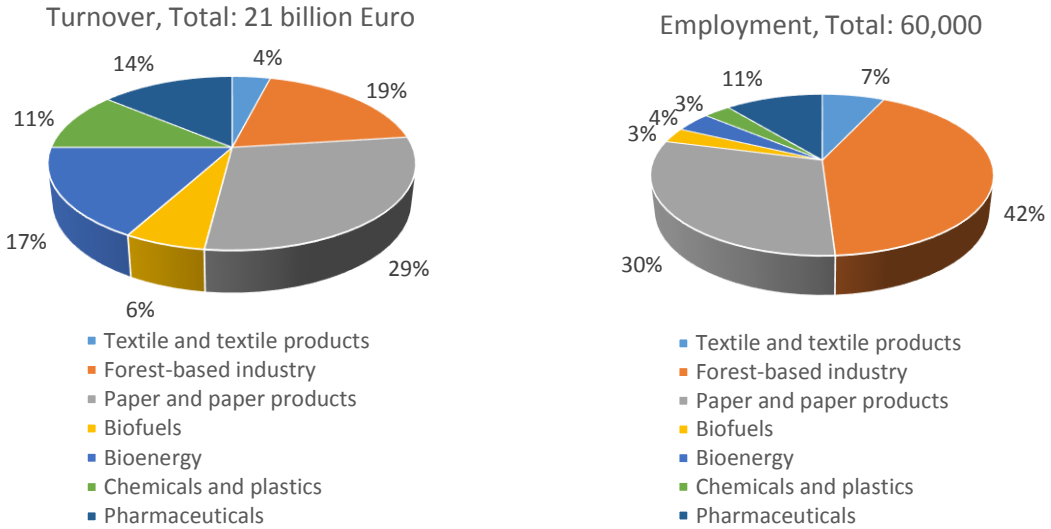
The **Material Flow Monitor** (MFM) was used as basis for BBE monitoring, and not only the Dutch supply but also the import of raw materials was measured. The measurement was carried out at the entrance to the BBE for the energy inputs, timber, paper and chemical sector, where

biomass and agro raw materials are supplied to the BBE. Consumption of bio-based products (energy, transport and materials and chemicals) was measured where products are delivered to consumers and businesses, at home and abroad.

With this protocol, the size of the BBE was estimated to be 13 Mton used biomass. This is an underestimation due to the lack of information regarding the chemistry sector. Energy and heat were the most important pillars of the BBE (5.7 Mton), followed by the wood sector (1.6 Mton) and the paper and pulp industry (2.7 Mton) (RVO, 2013). More recently, also CE Delf (2017) estimated the sustainable biomass and bioenergy used in the Netherlands for bioeconomy and BBE.

Within the EU approach, bioeconomy progress are monitored by the Bioeconomy Knowledge Centre (BKC), a project carried out by the Joint Research Center (JRC). RVO cooperates with this observatory and commissioned the NOVA Institute to apply their methodology to analyse the development of bioeconomy and BBE to the Dutch data, in order to establish the feasibility of this methodology for the Netherlands and to obtain preliminary results about the BBE. Since 2013, every year RVO produces a report on ***Monitoring bio-based economy in Nederland***. The method of the NOVA Institute estimates, using the Eurostat database[20], the extent to which all biomass flows or sectors are bio-based[21] and applies this percentage to variables such as turnover and employment (RVO, 2016). The results of this method estimated the turnover and the employment in the Netherlands of all BBE sectors. In 2013, the turnover was € 21 billion and the employment 60,000 direct jobs (Figure 9).

Figure 9. Turnover and employment in the BBE in the Netherlands (2013)



Note: these figures exclude agriculture, forestry, fisheries, food products, beverages and tobacco products.

Source: Elaboration based on RVO (2016).

[20] Eurostat bases its data on the Material Flow Monitor (MFM) data (RVO, 2016).
[21] According to the NACE codes, the European industry standard classification system for business activities.

Earlier estimates, both commissioned by RVO, were carried out by CE Delft (Smit, Blom, & van Lieshout, 2014) and Biomass Research/FBR Wageningen (2015). The EC Bioeconomy Knowledge Centre shows turnover, employment and location quotient in the total bioeconomy and by bioeconomy sector, up to the year 2015 (EC, 2018). A comparison of the numbers is shown in Table 3. The differences in results between these studies are due to the differences in the methodology and input data. For instance, bioeconomy figures include agriculture, forestry, fisheries and food, beverages and tobacco industry. According to the EC estimates, agriculture and food, beverage and tobacco industries account for more than three quarters of the turnover and employment in the bioeconomy in the Netherlands[22].

Table 3. Economic impacts of bioeconomy and bio-based economy in the Netherlands

		NOVA study (2013)	*CE Delft (2014)*	*Biomass Research*	*EC (2018)*
BIOECONOMY					
Employment	*Nr*	*340,000*			*359,100*
Turnover	*billion €*	*119*			*114*
Location quotient	*Ratio*				*0.54*
BIO-BASED ECONOMY					
Employment	*Nr*	*60,000*	*13,000 (direct)*	*45,000*	*51,190*
Turnover	*billion €*	*21*		*20*	*18*
Value added	*billion €*		*1.6-1.8 (direct)*	*2.6 – 3.0*	*4,5*

Source: Elaboration based on RVO (2016) and EC (2018).

RVO (2016) estimates also the investment in R&D on BBE through tax credits and fiscal exemptions. In 2015, the BBE companies invested €110 million in manpower for R&D via the WBSO and €86 million for bio-based projects via the RDA for R&D investments[23].

Short discussion

The Netherlands still lacks of a clear protocol on which sectors are included in the bioeconomy. As shown above, till now the focus has been on the bio-based economy (van Esch, personal communication, 2018).

[22] For data in the period 2008 to 2015 see https://datam.jrc.ec.europa.eu/datam/mashup/BIOECONOMICS/index.html

[23] Since 2012 the Dutch government finances the top sectors through the TKI, the MIT and other projects and programmes, and supports bio-based related research (RVO, 2016).

From a data collection perspective, the main problems raised by the Material Flow Monitor (MFM) used as basis for BBE monitoring are: **classification of business sectors (SBI), classification of product groups and timely acquisition of data** (RVO, 2013).

In determining the size of the BBE, the following problems emerged (RVO, 2013):

1. There are many different products and intermediates (particularly in the chemical sector), therefore bio-based materials can be difficult to quantify;

2. There is a large volume of imports and (re-)exports of raw materials and intermediates: due to the large re-exports, it is not clear how much bio-based raw material are actually used in the Netherlands, in particular in the chemical sector;

3. Chemicals and materials do not disappear when used (as opposed to fuels), but are passed to the next company in the production chain, thus threatening double counting: this problem can be solved by measuring the materials only at the entrance to the BBE;

4. Raw materials for chemistry often come from the agriculture sector and can therefore also be applied to human and animal nutrition. However, food and feed are not parts of the BBE and should not be counted in BBE[24].

Finally, the inclusion or exclusion of some sectors/subsectors may create differences in the obtained results, as shown in Table 3.

3.6. South Africa

Bioeconomy definition and strategy

According to South Africa, the term bioeconomy refers to "activities that make use of bio-innovations, based on biological sources, materials and processes to generate sustainable economic, social and environmental development*"* (PUB, 2014). It encompasses biotechnological activities and processes that translate into economic outputs, particularly those with industrial application.

The South Africa's Department of Science and Technology (DST) adopted a coordinated approach to develop a bioeconomy strategy, built upon several existing programmes and strategies, such as the 'Farmer to Pharma' concept (one of the Grand Challenges of the Ten-Year Innovation Plan of 2008, aiming to explore the country's biodiversity using both the IKS and biotechnology (DST, 2008a)); the National Biotechnology Strategy of 2001; the Health Innovation Initiatives and the IKS Policy (DST, 2012). The **National Bioeconomy Strategy** was published in 2013 (DST, 2013). Three key economic sectors, namely agriculture, industrial and environmental bio-innovation and health, were prioritised to drive the bioeconomy, with Indigenous Knowledge Systems (IKS) as an important crosscutter contributing to the activities within these three sectors (DST, 2013).

The South African government expects bioeconomy to be a significant contributor to the country's economy by 2030 in terms of the GDP. This is to be achieved through the creation and growth of new industries that generate and develop bio-based services, products and innovations.

[24] By considering the fermentation industry part of the chemical sector, its products would be part of the BBE, even if they have an application in the livestock sector.

Objectives/priorities of the strategy

The objectives of the South Africa's bioeconomy strategy are to make the country more **competitive** internationally (especially in the industrial and agricultural sectors); to create more sustainable **jobs**; to enhance **food security**; and to create a **greener economy** as the country shifts towards a low-carbon economy (DST, 2013).

In particular, the strategic objectives in the three key economic sectors identified are (DST, 2013):

- In the **agriculture** sector, the bioeconomy Strategy aims to 'strengthen agricultural biosciences innovation to ensure food security, enhance nutrition and improve health, as well as to enable job creation through the expansion and intensification of sustainable agricultural production and processing'.
- In the **health** sector, the bioeconomy Strategy can 'support and strengthen the country's local research, development and innovation capabilities to manufacture active pharmaceutical ingredients, vaccines, biopharmaceuticals, African traditional medicines, diagnostics and medical devices to address the disease burden, while ensuring a secure supply of essential therapeutics and prophylactics'.
- In the **industrial and environmental** sector, the bioeconomy Strategy's key objectives are to 'prioritise and support research, development and innovation in biological processes for the production of goods and services, while enhancing water and waste-management practices to support a green economy'.

Methodology and results

The bioeconomy strategy (DST, 2013) contains some indicators to monitor progress in the bioeconomy in comparison with other high and middle-income countries, broadly divided into '**knowledge and skills**' indicators (full-time equivalent researchers, scientific publications, bioeconomy-related publications) and '**financial support**' indicators (gross domestic expenditure on R&D (GERD) as percentage of GDP; funding and governmental support).

The strategy also includes the main **indicators** relevant for a knowledge-based bioeconomy (DST, 2013):

- foreign direct investment (as a percentage of GDP);
- gross fixed capital formation (as a percentage of GDP);
- manufacturing trade balance (as a percentage of total trade);
- trade balance of high-technology manufacturing goods; and
- technology balance of payments.

Finally, the strategy provides **output indicators** that should be used to track and monitor the bioeconomy Strategy (Table 4) (DST, 2013).

Table 4. Output indicators of critical factors to monitor bioeconomy strategy

Critical factors of the strategy		Output indicators
Knowledge base and human resources	• Strengthen basic research excellence. • Promote industry-oriented research programmes. • Facilitate knowledge flow between disciplines. • Develop next-generation technologies. • Develop human capital for the bio-economy.	• Number of publications and citations in high-impact journals per capita. • Size of bio-innovation workforce as percentage of science and technology workforce. • Number of research chairs, centres of excellence, technology platforms and multidisciplinary research and development programmes supported. • Bio-economy research and development as a percentage of GERD.
Knowledge transmission and application	• Technology development infrastructure to facilitate the translation of research and development outputs into products and services. • Strategic development and innovation programmes. • Assimilation and adoption of bio-innovations for new industry applications.	• Number of patents granted. • Number of collaborative product development partnerships. • Availability of technology development and assimilation infrastructure. • Number of technology-transfer transactions. • Availability of incubation facilities of bio-innovation firms.
Market	• Strengthen economic sectors (manufacturing, agriculture, health and environmental) exploiting bio-innovations. • Through enabling legislation, facilitate introduction of new bioproducts.	• Number of regulatory approvals for health products. • Revenues/sales of life science products, processes and services. • Number of field trials with GMO crops.
Industry	• Enable creation of bio-innovation firms. • Strengthen local manufacturing capability of bioproducts. • Attract foreign direct investment in bio-economy sectors. • Alignment of fiscal policy instruments to encourage innovation. • Encourage investment in research and development. • Improve competitiveness of industry. • Exploit regional potentials.	• Number of bio-innovation firms, including dedicated bio-innovation firms by sector. • Venture capital invested in bio-innovation firms. • Technology balance of payment of bio-innovation outputs. • Number of joint ventures and strategic alliances between local bio-innovation firms and international partners. • Multinational corporations in bio-economy sectors locating research and development facilities locally. • Types of biotechnology used by firms.

Source: DST (2013).

However, **systematic metrics to measure and monitor the South Africa's bioeconomy have not yet been implemented**. Ongoing effort will result in detailed implementation plans and value propositions for specific sectors and initiatives that will help refine targets.

The National Advisory Council on Innovation (NACI) is undertaking a study aiming at advising the Minister on **establishing a framework to develop indicators** to measure the growth of the bioeconomy in South Africa (NACI, 2016). The study defines two high level components: metrics for that portion of the economy resulting from the bioeconomy activities/sectors, and metrics for innovation that provide a key input to the development of the bioeconomy (Ben Durham, personal communication, 2018). Indicators likely to be included in the new metrics under development are: export; contribution to GDP; employment; investment leveraging; and innovation. Bioeconomy indicators should also provide status of policy and regulatory support, infrastructure, financial and other incentives to grow the bioeconomy (Ben Durham, personal communication, 2018). The study highlights also the changes that need to be made in order to manage the rapid technological developments that are occurring in the bioeconomy field (NACI, 2017). The study is expected to be published in 2018.

Short discussion

A first limitation of the bioeconomy strategy and the indicators suggested in the strategy is that, being driven by the Department of Science and Technology, it has an **'innovation' bias**. In fact, most indicators in the strategy are related to science, technology and innovation, as they are derived from the measurement of a knowledge-based economy or biotechnology innovation policies, and do not cover all the aspects of a bioeconomy.

South Africa has not yet produced an estimation of the contribution of bioeconomy to its overall economy. Therefore, the ongoing effort to produce metrics for economic sectors and innovation activities is a positive and needed step. On top of measuring the contribution of bioeconomy to economic factors (such as export, GDP, employment, investment and innovation), bioeconomy indicators should ideally also monitor regulatory support; infrastructure; financial and other incentives to foster the bioeconomy, as well as social and environmental issues. In fact, emerging economies often emphasise developmental issues, and the role that bioeconomy plays in their developing strategy can be highlighted in the measurement efforts. This will also allow to monitor, for instance, progress in meeting the SDGs.

Finally, in measuring the contribution of bioeconomy to its overall economy, South Africa may face the challenge of **availability and timeliness of data**. For instance, the last survey on biotech companies was done in 2007 (DST, 2008b). The lack of updated data can be a major constraint to the assessment of bioeconomy.

3.7. United States of America

Bioeconomy definition and strategy

In 2012, the U.S. Administration announced the **National Bioeconomy Blueprint** (The White House, 2012), which outlined steps that agencies would undertake to drive the advancement of the bioeconomy. In the United States, the bioeconomy is defined as "the global industrial transition of sustainably utilizing renewable aquatic and terrestrial biomass resources in energy, intermediate, and final products for economic, environmental, social, and national security benefits*"* (Biomass R&D Board, 2016).

According to the Blueprint, the growth of the bioeconomy in the USA in 2012 was due mainly to the development of three technologies (genetic engineering, DNA sequencing, and automated high-throughput manipulations of biomolecules), but several new technologies were emerging (The White House, 2012). The Bioeconomy Blueprint considered also emerging trends in the areas of health, bio-based energy production, agriculture, bio-manufacturing, and environmental clean-up.

Since 2013, the Biomass R&D Board members[25] have been planning a broad vision to promote the expansion of the bioeconomy (Biomass R&D Board, 2016), based on the projection of one

[25] The Biomass Research and Development (R&D) Board was created through the enactment of the Biomass Research and Development Act of 2000 "to coordinate programs within and among departments and agencies of the federal government for the purpose of promoting the use of bio-based industrial products by (1) maximizing the benefits deriving from federal grants and assistance; and (2) bringing coherence to federal strategic planning." The Board is co-chaired by senior officials from the U.S. Departments of Energy (DOE) and Agriculture (USDA) and currently consists of senior decision makers from the DOE, USDA, U.S. Department of Transportation (DOT), U.S. Department

billion tons of biomass to be sustainably produced and available annually by 2030 (DOE, 2016). The Board and the Biomass R&D Technical Advisory Committee (TAC) aim at a single, coordinated multi-department vision focused on developing and implementing a plan for utilizing the available biomass in order to increase economic activity, decrease reliance on foreign oil, create market-driven demand for bioenergy and bioproducts, create jobs, reduce GHG impacts, and enhance national security (Biomass R&D Board, 2016).

The Agricultural Act of 2014 (the 2014 Farm Bill) reauthorized and expanded the 2002 Farm Bill which established the so-called ***BioPreferred program***, managed by the U.S. Department of Agriculture (USDA), with the goal of increasing the purchase and use of bio-based products. The programme's purpose is to spur economic development, create new jobs and provide new markets for farm commodities, while reducing reliance on oil, increasing the use of renewable agricultural resources, and diminishing adverse environmental and health impacts (USDA, 2018). The two main components of the *BioPreferred program* are mandatory purchasing requirements for federal agencies and their contractors; and a voluntary labelling initiative for bio-based products.

Objectives/priorities of the strategy

The 2012 National Bioeconomy Blueprint designed strategic objectives to help realize the full potential of the bioeconomy in the USA and highlighted early achievements toward those objectives. The **five strategic objectives** for a bioeconomy introduced by the National Bioeconomy Blueprint aimed to generate economic growth and address societal needs (The White House, 2012) by:

1. Supporting **R&D investments** to provide the foundation for the U.S. bioeconomy.
2. Facilitating the transition of **bio-inventions from research lab to market**, including an increased focus on translational and regulatory sciences.
3. Developing and reforming **regulations** to reduce barriers, increase the speed and predictability of regulatory processes, and reduce costs while protecting human and environmental health.
4. Updating **training programmes** and aligning academic institution incentives with student training for national workforce needs: improve science, technology, engineering, and mathematics (STEM) education, and increase the number and diversity of STEM students.
5. Identifying and supporting opportunities for the development of **public-private partnerships and precompetitive collaborations**, where competitors pool resources, knowledge, and expertise to learn from successes and failures.

The **Billion Ton Bioeconomy Vision** complements these objectives with the goal of developing and implementing innovative approaches to remove barriers to expanding the **sustainable use of domestic biomass resources, while maximizing economic, social, and environmental outcomes** (Biomass R&D Board, 2016). This vision leverages existing expertise across the various

of the Interior (DOI), U.S. Department of Defense (DoD), U.S. Environmental Protection Agency (EPA), National Science Foundation (NSF), and the Office of Science and Technology Policy (OSTP) within the Executive Office of the President (Biomass R&D Board, 2016).

agencies of the United States. The objectives of the Billion Ton Bioeconomy Vision can be categorized into five distinct areas, summarized below (Table 5).

Table 5. Proposed objectives of the bioeconomy vision of the United States

Use an integrated systems approach 1	Holistic, integrated supply chains that overcome barriers and reduce financial, environmental, and market risks. Objectives are: • Develop and deploy sustainable biomass systems that improve cost competitiveness and mitigate economic risk, while maintaining or enhancing environmental quality throughout their life cycle. • Utilize financial data and business models to reduce risks in commercialization in order to satisfy needs along the entire supply chain. • Utilize models and data across the federal government to understand and quantify tradeoffs and synergies to optimize the economic, environmental, and social benefits of the bioeconomy to minimize adverse impacts.
Provide the science and the technology 2	Science provides solutions to barriers and innovative technologies help drive the bioeconomy. Objectives are: • Make significant advances in transformational science and technology, throughout the supply chain, that are resource efficient, cost-effective, and environmentally neutral or enhancing. • Efficiently integrate and validate engineering, environmental, and economic data that are associated with biomass production, conversion to bioeconomy products, and use. • Adapt current infrastructure and design and develop new machinery for efficiency. • Integrate biophysical, environmental, and social models in systems development.
Public and private collaboration to overcome barriers and accelerate deployment 3	Expansion of the bioeconomy requires public and private collaboration across the entire sector: federal, state, and local government, tribes, business and industry, academia, producers, landowners, workers, and many others. Objectives are: • Identify and understand roles of the various factions and develop optional mechanisms for information sharing, consensus building, collaboration, and cooperation. • Work with producers (farmers, landowners/managers, waste managers) and communities to encourage/incentivize cellulosic and waste material biomass system adoption while understanding and mitigating risk.
Develop a workforce for the future bioeconomy 4	Millions of additional workers are needed in agricultural, aquatic, and forestal production, biorefineries R&D, transportation, manufacturing, and various allied fields. Objectives are: • Accelerate the emergence of trained professionals in all functions needed to establish a sustainable bioeconomy, including project design and production, transport, market penetration and use, specialized financial management, and regulatory approval. • Develop specific educational programs for professionals and technical students at various levels of higher education. • Provide career pathways information and activities for high school students.
Understand and inform policy 5	Policies seek to improve economic, environmental, and social outcomes, and drive direction and funding of new scientific endeavors and program implementation to accelerate the bioeconomy. Objectives are: • Analyze and understand the impact of national policy on the bioeconomy. • Inform local and state governments, industry, and other stakeholders about policies and their impact. • Integrate economic and environmental policy factors to reduce financial risks to investors, producers, and manufacturers, and to protect environmental quality across the supply chain.

Source: Biomass R&D Board (2016).

Methodology and results

The USDA report, *An Economic Impact Analysis of the U.S. Biobased Product Industry: 2016 Update* (USDA, 2016), examines and quantifies the effect of the bio-based products industry from an economics and jobs perspective at the state level. It was preceded by a report analyzing the effect at national level (USDA, 2015) and by a report (Golden & Handfield, 2014) which provided a snapshot of available information on the bioeconomy in the country and a platform upon which to build future efforts to measure the bioeconomy.

The 2014 report, commissioned by the USDA *BioPreferred Program*, underlined a lack of understanding and quantification of the economic benefits of the bioeconomy and in particular the non-fuel bioeconomy in the United States. The 2016 report was thus intended as a platform for understanding and tracking the progress of the bioeconomy in the country. The report provided detailed information on the contributions of the **bio-based products industry**[26] in the United States, in particular (USDA, 2016):

- The quantity of **bio-based products sold**;
- The **value of bio-based products**;
- The quantity of **jobs** contributed by bio-based products industry;
- The quantity of **oil displaced** by bio-based products;
- Other **environmental benefits**, such as the reduction in the use of fossil fuels and in the associated GHG emissions.

The report adopted a three-pronged approach to gather information: **interviews** of representatives of government, industry, and trade associations involved in the bio-based products; **data collection** from government agencies and published literature on the bio-based products industry; and economic modelling. This last method was conducted using IMPLAN modeling software, which adopts **input-output analysis** to quantify the economic impacts of an industry in a given region (in terms of dollars added to the economy and the number of jobs produced), by using national industry data and county-level economic data (USDA, 2016). The outputs are measured by the industry's gross sales to other sectors and to final demand. The value added of a sector describes the new wealth generated within it and its contribution to GDP.

IMPLAN generates four types of indicators to assess the economic contribution of an industry (in terms of employment and value added)[27] (USDA, 2016):

[26] USDA defines bio-based products industry: "Any industry engaged in the processing and manufacturing goods from biological products, renewable resources, domestic or agricultural or forestry material". The seven major sectors chosen to represent the bio-based products industry's contribution to the US economy are: agriculture and forestry; biorefining; bio-based chemicals; enzymes; bioplastic bottles and packaging; forest products and textiles. The USDA's definition of bio-based products excludes the energy, livestock, food, feed, and pharmaceutical industries (USDA, 2016).

[27] A particular multiplier, considering portions of value added to be both endogenous and exogenous to a study region, was used to determine the overall monetary contribution (value added) or jobs (employment) supported by an industry sector (USDA, 2016). This Type Social Accounting Matrix (SAM) multiplier is calculated dividing the total effects by the direct effect.

- *Direct effects:* effects of all sales (measured in USD or jobs) generated by a sector;
- *Indirect effects*: effects of all sales by the supply chain for the selected industry;
- *Induced effects:* the influence of the employees in the selected industry spending wages in other sectors to buy goods and services.
- *Total effect:* the sum of the direct, indirect and induced effects.

The USDA 2016 report models the bioeconomy at the national level using IMPLAN's 2013 and 2014 national databases, on the basis of the supply/demand pooling method. A particular multiplier (the Type Social Accounting Matrix (SAM) multiplier), considering portions of value added to be both endogenous and exogenous to the target region, was used to determine the overall monetary contribution (value added) or jobs (employment) supported by the bioeconomy (USDA, 2016). This Type SAM multiplier is calculated dividing the total effects by the direct effect for all bio-based industrial groups.

The **economic impacts** calculated show that the bio-based industry in 2014 contributed to a total of about USD 400 billion value added to the U.S. economy; supported a total of 4.2 million jobs through direct, indirect and induced contributions; and generated 1.76 jobs in other sectors of the economy for every bio-based job. Additionally, the indirect jobs in satellite activities are estimated to be around 1.53 million jobs, while induced jobs (produced from the purchase of goods and services generated by the direct and indirect jobs directly supported the bio-based product industry) resulted in 2.7 million spillover jobs. The report also estimates that the bio-based industry generated USD 127 billion in direct sales and USD 266 billion in spillover sales (USDA, 2016).

The report also estimates the **environmental impact** of bio-based product industries, in terms of reduction in the use of fossil fuels and in the associated GHG emissions. It estimates that bio-based products displaces about 6.8 million barrels of oil a year and have the potential to reduce GHG emissions by 10 million metric tons of CO_2eq/year (USDA, 2016).

Box 3. Bio-based economy indicators

The 2005 Energy Policy Act mandated the Secretary of Agriculture of the United States to submit to the Congress an analysis of economic indicators of the bio-based economy. To fulfil this requirement, the USDA produced in 2011 a report on ***Biobased Product Economic Indicators*** (USDA, 2011) showing the process taken and the results of an analysis of indicators done in collaboration with Iowa State University. The report contained data gathered in 2008 and reflected the information available in 2011 on bio-based economy indicators.

The various indicators were grouped in the broad categories of inputs, investments and outputs. Inputs were defined as the basic resources for the production recipe of a business, and may include physical goods or nonindustrial inputs such as labour. Investments include for instance tax and trade policies, direct and indirect public spending, public and private R&D, education initiatives and private investments. Outputs include above others: commodity flows, prices, value added, patents, environmental and social outcomes.

The key economic indicators were selected by industry and government stakeholders for being particularly relevant to public policy and business decision making. The discussion for each indicator addresses several issues, including (1) its relevance to the condition of the bioeconomy; (2) how the

indicator was measured or might be measured; (3) identification of available data sources; and (4) illustration of one or more of the suggested measures, if data were available.

Four input indicators, four investment indicators, and eight output indicators were selected as key indicators:

1. Prices of energy inputs for bio-based production
2. Amount of cropland in energy-dedicated crops
3. Quantity of grain and oilseed inputs used in bio-based production
4. Quantity of chemical and other inputs used in bio-based production
5. Tax and trade policies
6. Government spending on bioeconomy R&D
7. Private capital investment in plant and equipment
8. Company-funded research and development
9. Carbon offsets from bio-based production
10. Industrial absorption and/or consumer acceptance of bio-based products
11. Production levels (sales) of chemical-based (and fiber-based) products
12. Emissions from bio-based production
13. Biofuels price levels
14. Direct value added (GDP) from bio-based production
15. Production levels (gallons) of biofuels
16. Quantity (tons/gallons) of by-products from biofuel production.

Additional analysis was conducted to explore how indicators could be combined to assess growth, profitability and uncertainty in the bioeconomy. The report suggested two types of **composite indicators** to aggregate multiple aspects of the industry: the bioeconomy diffusion index and the bioeconomy composite indicator. The former measured the short-term condition of bioeconomy, as adopted by a representative number of companies. The diffusion index was based on an assessment of the change in companies in the principal sectors of the bioeconomy (fuels, chemicals, end-use products, and power). However, the index was not calculated since a bioeconomy GDP was not available, therefore the different sectors could not be weighted before aggregation.

Similarly, a Composite Indicator of the bioeconomy aimed to take into account changes in the biofuel, biochemical, bio-based end-use product, and bio-power sectors, to measure the overall condition of the bioeconomy. However, due to the lack of sufficient data, the report developed only an illustrative composite index for the biofuels sector.

Overall, the report showed that many of the key indicators could not be calculated because appropriate data are not collected, data are confidential, suppressed to protect the identity of the firm, or not readily measurable. Therefore the publication did not serve as a basis for measuring or monitoring the progress of the bioeconomy in the United States. The USDA economic impact analyses of the U.S. bio-based products industry done in 2015 and 2016 (USDA, 2015 and 2016) did not make any reference to these indicators.

However, the 2011 USDA report includes recommendations that could support the development of a variety of indicators, improve the accuracy of indicators, and assist in the development of timely

indicators. For instance, the report recommends the formalization of bio-based industry measurement standards between government agencies and the private sector in order to obtain more consistent estimates, and the development of a bio-based industry and commodity usage survey. In addition, a revision of the North American Industry Classification System (NAICS) is deemed necessary to more effectively gather bio-based industry data.

Source: USDA (2011).

In 2018, the USDA also released a report on **Indicators of the U.S. Bio-based Economy** (Golden J. S., et al., 2018) to further understand and analyse trends in the bio-based economy, by comparing 2011 and 2016 report data on agriculture, bioenergy, renewable chemicals and bio-based products, and policy. The report develops the following indicators and analysed their trends in the period 2011-2016:

- ***Agriculture indicators:*** (1) *land use*, (2) *production*, (3) *consumption*, and (4) *economics* (prices and economic value). It takes into account all the various organic inputs into biofuels, renewable chemicals, and bio-based products: starches, lipids and cellulosic feedstocks.
- ***Bioenergy indicators*** for ethanol, biodiesel, wood pellets, waste-to-energy and biogas:
    1. *physical*: number of States with bioenergy plants; total number of existing bioenergy plants; and number of plants under construction from years 2010 to 2016;
    2. *production*: amount of ethanol/biodiesel/biogas produced; amount of ethanol/biodiesel imported, exported, and total ethanol/biodiesel consumed within the transportation and non-transportation sector; consumption in British thermal units (BTU) of wood used for energy from 1970 to 2010; amount of wood pellets produced in the United States and worldwide; amount of energy produced from waste and breakdown on how much energy is used within the commercial and utilities sector; information on the methane potential produced from landfills, wastewater, animal manure, and organic waste; amount of kWh energy generated by biogas from year 2010 to 2016, and the methane emissions reductions of each year;
    3. *economics*: price per gallon of ethanol/biodiesel from 2010 to 2016, direct and indirect jobs created from the bioenergy industries; ethanol/biodiesel/waste-to-energy industries' influence on GDP; revenue generated from the waste-to-energy sector; household average income influence from the bioenergy industry; tax revenue generated from the ethanol industry; and a theoretical economic analysis of the potential market value of the biogas industry and an estimate on job creation from constructing new biogas systems.
- ***Renewable chemicals and bio-based products:*** number of bio-based product companies; number of categories for mandatory Federal Purchasing (FP) and voluntary labelling categories; number of certified products in the USDA BioPreferred Program.

  Economics and Investment indicators are: number of direct, indirect or induced, and total jobs contributed to the United States economy through the bio-based products industry; biotech revenues; venture capital investments and academic research and development expenditures on bioscience.

In particular, the analysis focuses on:

a) *Bioplastics*: United States bioplastic manufacturing data on imports, exports, and industry value added; global and United States bioplastic production; revenues from the United States bioplastic manufacturing; plastic bottle manufacturing gross output in the United States;

b) *Renewable Chemicals*: value added by United States renewable chemical products; revenues from the United States chemical industry; global chemicals market value with bio-derived chemicals market value;

c) *Forest Products, Apparel, and Textiles*: wood and paper products, textile, apparel, leather, and allied products' value added to the United States economy (based on North American Industry Classification System (NAICS) classification).

- ***Policy***: summarizes main *federal legislation, state tax incentive and rebate programs, international agreements,* and *business to business* initiatives related to alternative fuels and bio-based products that has impacted the bio-based economy in the period 2011-2016.

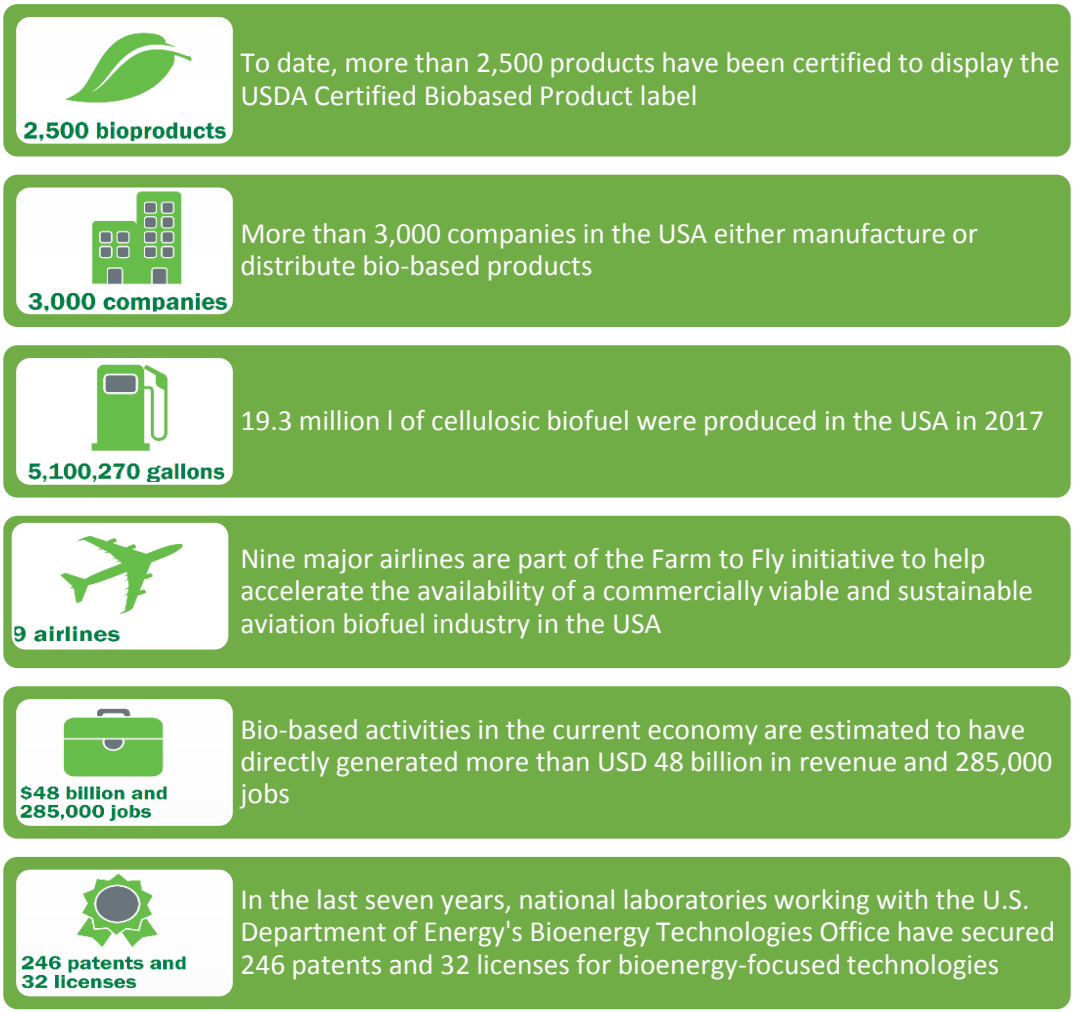
According to the USDA 2018 report, the renewable chemicals and bio-based product sectors contributed 4.2 million jobs to the U.S. economy in 2014, with a value-added contribution of USD 393 billion. Under the USDA BioPreferred Program, the number of renewable chemicals and bio-based products that are USDA-certified has increased from 1 800 in 2014 to 2 900 in 2016. The report also found that ethanol production in the United States generates 270 000 jobs (Golden J. S., et al., 2018).

In 2017, also the Department of Energy (DOE) provided some figures about the size of the bioeconomy (Figure 10), in terms of:

- number of **products** that have been certified to display the USDA *Certified Biobased Product* label;
- **companies** that either manufacture or distribute bio-based products;
- gallons of cellulosic **biofuel** produced[28];
- **airlines** that are part of the *Farm to Fly* initiative to accelerate the availability and viability of a sustainable aviation biofuel industry;
- **revenues and jobs** generated by bio-based activities;
- **patents and licences** secured by laboratories working with the DOE's Bioenergy Technologies Office (in the last seven years).

[28] 1 gallon = 3.78541 liters

Figure 10. The bioeconomy in the United States by the numbers according to the DOE



Source: Elaboration based on DOE (2017).

According to the DOE figures, bio-based activities in 2014 have directly generated more than USD 48 billion in revenue and 285 thousand jobs. These estimates are significantly lower than those reported by the USDA 2016 report. The difference is due to the different sectors included in the estimation of the economic impacts of the bioeconomy. The DOE estimates are taken from a paper considering **direct employment and revenues from biomass resources fed into a number of end-uses and products** including heat and power generation, bio-based chemicals and products (including wood pellets), and biofuels and coproducts (Rogers, et al., 2016). Most of these sectors were instead excluded from the USDA 2016 report, which considered as bioeconomy industries: agriculture and forestry; biorefining; bio-based chemicals; enzymes; bioplastic bottles and packaging; forest products and textiles.

Short discussion

Despite being intended as a platform for understanding and tracking the progress of the bioeconomy in the United States, the USDA 2016 report does not provide a complete picture of the bioeconomy, as it focused on seven major sectors chosen to represent the bio-based products industry's contribution to the U.S. economy (agriculture and forestry; biorefining; bio-based chemicals; enzymes; bioplastic bottles and packaging; forest products and textiles). This estimation excludes for instance the energy, livestock, food, feed, and pharmaceutical industries. As mentioned above, for instance, the DOE and other authors adopt another approach to measure the bioeconomy, built up the Billion Ton Bioeconomy Vision. This approach considers the end-use of biomass resources (heat and power generation, bio-based chemicals, wood pellets, biofuels and coproducts) to assess the size and benefits of a Billion Ton Bioeconomy. The USDA 2018 report represents the first initiative to combine multiple indicators of the bio-based economy from multiple sources into a single unified dashboard, across a wide range of products and sectors. This can complement the efforts of the Biomass R&D Board to coordinate programs within and among departments and agencies of the federal government towards a single, harmonized bioeconomy vision should ideally produce a **single comprehensive approach** able to monitor and measure all the sectors included in the bioeconomy vision of the Unites States in a coherent way.

The first limitation is that the USDA 2018 report does not provide a homogenous and complete picture of the contribution of bioeconomy to the U.S. economy, but rather some scattered figures and trends on a wide range of variables. On the other hand, the USDA 2016 report suffers from a limited **availability of data** quantifying the bio-based products industry in the Unites States (USDA, 2016). In particular, the lack of specific industrial sector (NAICS) codes to track the percentages of bio-based sectors within the larger economic sectors (such as bio-based chemicals within the chemical industry) is a mayor issue. The USDA 2016 report consistently utilized percentages at the lower end of the ranges modelled in order to provide conservative estimates of the bio-based products sectors, but this can create an underestimation of the bioeconomy contributions.

Finally, a bioeconomy vision based on **the expansion of biomass can face challenges** such as the reliable availability of raw materials due to the increased climate and severe weather impacts, water availability, and stability of the markets (Golden & Handfield, 2014). For these reasons, in additional to the simple GHG accounting performed in the USDA report, additional socio-economic and environmental indicators could be included in the monitoring of the bioeconomy expansion, to guarantee the sustainable use of resources.

4. Discussion and concluding remarks

4.1. Bioeconomy definitions and strategies

The paper shows that different sectors and subsectors are considered 'bioeconomy' among the countries analysed and this reflects different priorities and strategies.

A first important point is the variance in the **definition** of bioeconomy. For instance, the Netherlands has a focus on *bio-based economy*, excluding the agriculture and food sectors. The United States aims to analyse the bioeconomy, but the USDA shows results referring to *bio-based products industries*, which exclude the energy, food, feed, livestock and pharmaceutical industries.

According to Argentina, the bioeconomy includes agriculture, forestry, fishing, food production and pulp and paper production, as well as parts of textile, chemical, energy and biotechnological industries (medical and pharmaceutical industry). Australia does not have a specific bioeconomy strategy. The Australian Department of Industry, Innovation and Science includes under bioeconomy all industries and sectors producing, managing or making use of biological resources (including agriculture, forestry, fisheries, energy and organic waste), and based on knowledge and innovation in biosciences and advanced technologies. In Germany, bioeconomy includes agriculture, forestry, fishing, manufacturing and trading of bio-based products. Similarly, the Malaysian bioeconomy includes agriculture, forestry, fisheries, food, feed, healthcare wellness products, chemicals and renewable energy. South Africa's bioeconomy strategy focuses on agriculture, industrial and environmental bio-innovation and health, but still has not developed metrics to monitor it.

Due to the lack of a clear and homogenous definition of which sectors are included into bioeconomy strategies, it is impossible to compare the contribution of bioeconomy between countries in a consistent way. For instance, in the case of the Netherlands, the economic impact results of bioeconomy by various studies were different, due to differences in the methodology and in input data.

Some regional efforts to harmonize the measurement of the bioeconomy economic significance exist. For instance, since the launch of the European Commission (EC) strategy for the bioeconomy in 2012, the EC Joint Research Centre (JRC) is monitoring jobs and turnover in the European Union bioeconomy for all the member states and sectors. The sectors included in the analysis are: agriculture; food (including feed), beverage and tobacco industry; wood products and furniture; bio-based textiles; manufacture of paper and paper products; forestry; bio-based chemicals, pharmaceuticals and plastics; fisheries and aquaculture; biofuels and bio-based electricity (EC JRC, 2018).

Table 6 summarizes the various **sectors** included in the bioeconomy definition by the six countries analysed and the EU according to the JRC work.

Table 6. Sectors included into bioeconomy strategy and monitoring in the selected countries, plus the EU

	Argentina	Australia	Germany	Malaysia	Netherlands*	South Africa	USA*	EU
Agriculture	XX	X	XX	XX		X	XX	XX
Automotive and mechanical engineering			XX					
Chemistry (incl. bioplastics)	XX	X	XX	XX	XX	X	XX	XX
Biofuels/bioenergy	XX	X	XX	XX	XX	X		XX
Biorefining		X	XX	XX		X	XX	
Construction/Building industry			XX					
Consumer goods such as cosmetics and cleaning products	XX		XX			X		
Feed	XX		XX	XX		X		XX
Fisheries	XX	X	XX	XX		X		XX
Food and Beverage industry	XX	X	XX	XX		X		XX
Forestry	XX	X	XX	XX	XX[29]	X	XX	XX
Health				XX		X		
Knowledge/Innovation		X	XX	XX	XX	X		X
Mining						X		
Pharmaceuticals industry	XX	X	XX	XX	XX	X		XX
Pulp and paper	XX		XX		XX	X		XX
Textiles	XX		XX		XX	X	XX	XX

Notes: X: sector included in bioeconomy strategy, XX: included in the bioeconomy strategy and monitored or measured. *The results for the Netherlands monitor bio-based economy and the results for the USA refer to bio-based products industries.

Source: Elaborated on the basis of several studies; Wierny, Coremberg, Costa, Trigo, & Regunaga (2015) for Argentina; Alex Cooke, personal communication (2018) for Australia; BMBF & BMEL (2015) for Germany; Zurina Che Dir, personal communication (2018) for Malaysia; RVO (2016) for the Netherlands; Ben Durham, personal communication (2018), and DST (2013) for South Africa; USDA (2016) for the USA and EC JRC (2018) for the EU.

[29] Only forest-based industry.

When countries do not have an encompassing bioeconomy strategy, they tend to adopt a fragmented approach by considering the different uses of biomass and each sector separately. This approach to governing the bioeconomy lead to different policies for different uses of biomass, different incentives for investment and different regulations for the areas from which feedstocks are sourced (Johnson, 2016). In these countries, the efforts should aim at integrated approaches across different levels, sectors, landscapes and end-uses, in order to avoid boom and bust policies as it happened for first-generation biofuels in the EU and elsewhere.

4.2. Objectives/priorities of bioeconomy strategies in low, middle and high income countries

The sectors included in the bioeconomy strategy often reflect the priorities identified by the country and comparative advantages linked for instance to endowment in biomass resources, historical economic specialisation, labour productivity and past investments in R&D. For these reasons, the bioeconomy usually plays different roles in low or middle income countries versus high-income countries[30] as well as in countries with different biomass availability.

The bioeconomy has already been adopted by a significant number of low and middle income countries as a **new vision of development**, and can be a valid path towards the achievement of the SDGs and the commitments under the Paris Climate Agreement. For instance, efficient and sustainable natural resource management is directly tied to at least 12 of the 17 SDGs, and could cut GHG emissions by 60 per cent by 2050 (Ekins & Hughes, 2017). In addition, for lower income countries, better management of natural resources is often a key component of poverty eradication, climate change mitigation and resilient economic growth (Chatham House, 2017).

In low and middle income **countries with available biomass resources and/or well-developed primary sectors**, a sustainable bioeconomy could unlock new opportunities for economic development and industrialization, and support economic and social objectives, such as reducing unemployment and expanding access to energy. For instance, in Latin American countries, the increase in the value added to agricultural production can create employment and improve the competitiveness of export-oriented sectors. The agriculture sector has the potential to generate productivity gains, which could result in significant improvements in the country's inclusion in international trade (Wierny, Coremberg, Costa, Trigo, & Regunaga, 2015). Improvement in agriculture productivity can also play an important role in building resilience while increasing yields for farmers (EIP-Agri, 2015). Countries with low labour productivity level in the bioeconomy sectors but abundant primary production and a sound manufacturing base could add value through bio-based methods of production (Ronzon, Piotrowski, Barek, & Carus, 2017).

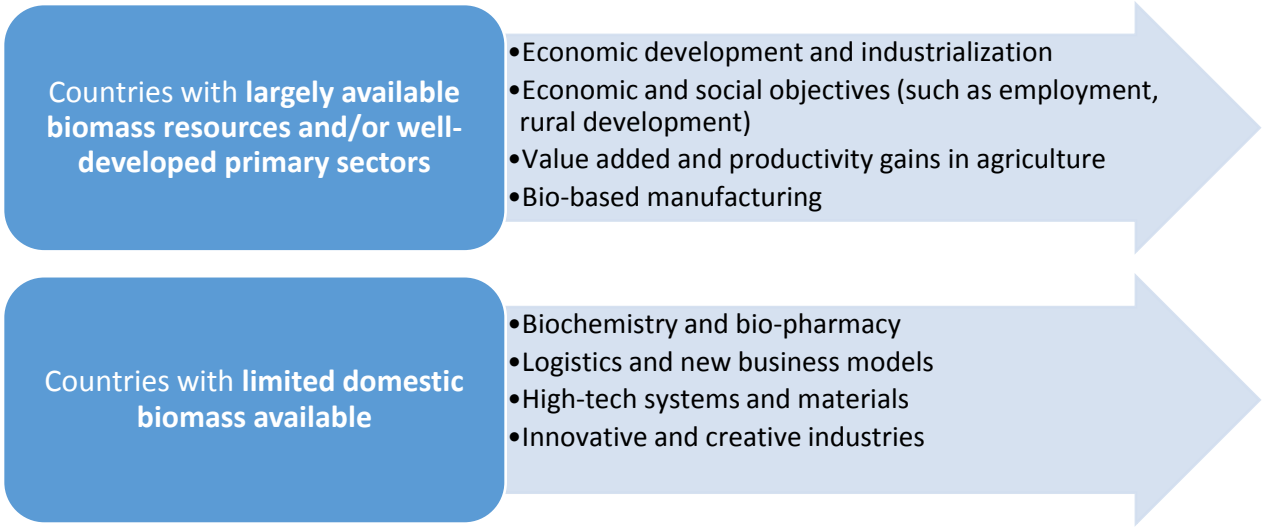
The agriculture sector is also a key component of the bioeconomy strategy for both Malaysia and South Africa. In Malaysia, the performance of the palm oil sector seems to somewhat determine the overall direction of Malaysian bioeconomy development (Fadillah, 2015). In South Africa, enabling job creation through the expansion and intensification of sustainable agriculture production and processing is part of the three objectives of the bioeconomy strategy.

On the contrary, some high-income countries such as the Netherlands have excluded the agriculture sector from their strategy to move away from a fossil fuel-based economy. The main reasons for this is the **limited domestic biomass available**, which concerns several other EU

[30] Specific future analysis for low income countries will be needed, as this paper reviewed only middle and high income countries which aim at measuring the contribution to their bioeconomy objectives.

countries as well. Estimates suggest that, for the EU, the sustainable biomass supply will be enough to meet about 10% to 20% of the final energy and feedstock consumption in 2030 (PBL, 2012). In considering sustainable biomass production, land use is the most critical problem, therefore countries with limited land availability face relevant constraints. In countries with limited biomass availability, such as some Western European countries, the bioeconomy strategies focus more on biochemistry and bio-pharmacy benefiting from long-standing experience and R&D investments (EC JRC, 2018). Also in Australia most bioeconomy-related policies are R&D strategies and focus on biotechnology and innovation, and bioeconomy is considered as an enabler of productivity across several sectors. In countries focusing on high-value-added bioeconomy sectors, bioeconomy can generate higher turnover compared to the employment generated, whereas the less value added sectors of the bioeconomy (mainly primary biomass production in agriculture, forestry and fisheries) typically generate more employment.[31]

Figure 11. Typical examples of bioeconomy priorities for countries with high and limited biomass availability



Technical innovation and new business models associated with the bioeconomy should potentially aim at decoupling economic growth from resource use also in countries with available resources (Chatham House, 2017). A sustainable bioeconomy cannot foster depletion of resources, degradation of the environment, loss of biodiversity and social injustice.

For instance, the Nordic bioeconomy strategy is based on five principles for sustainable bioeconomy, involving economic, social and environmental aspects (Nordic Council of Ministers, unpublished):

[31] Similar aspects are addressed by the Sustainable Trade & Innovation Transfer in the Bioeconomy (STRIVE) project by the University of Bonn, which aims at improving the knowledge base for the design of sustainable bioeconomy policies and investments with a focus on international regulatory frameworks.

1. Sustainable resource management: responsible use of shared resources;
2. Health, food and dietary habits: safe, sufficient and nutritious food for all;
3. Resilient and diverse ecosystems: a liveable planet;
4. Inclusive economic and social prosperity: sustainable fair societies;
5. Sustainable consumption: changing mind-set and consumer behaviour.

If a bioeconomy strategy aims to contribute to **sustainable development and environmental and social objectives**, these should be clearly included in the strategy and be measurable (by means of quantitative, qualitative or as aggregate indicators). Environmental and sustainability component in the bioeconomy approaches should be closely connected with supply and production of bio-resources, as well as consumption patterns. In fact, the core of transformation strategies is not limited to the technological aspects, but includes behaviour change and institutional innovations for enabling settings and long-term incentives, at the level both of companies and of international policy (Von Braun, 2014).[32]

This study shows that a means to monitor progress in reaching the targets set in the bioeconomy policies and strategies is currently lacking in most countries. The **difficulty of measuring progress can be a consequence of the lack of a clear definition of the bioeconomy concept and of concrete and measurable objectives**. In fact, most strategies show quite abstract objectives and qualitative targets.

Most countries monitor bioeconomy progress just with economic values and shares of GDP, while the aspects of sustainability and resource availability are addressed only to a limited extent in many cases (Staffas, Gustavsson, & McCormick, 2013). Some efforts exist to develop measurable **social and environmental indicators** to monitor the bioeconomy. For instance, Italy has developed a set of sustainability indicators[33] with measurable impacts on food security, natural resources sustainability, dependence on non-renewable resources, climate change, in addition to economic growth (Table 7).

[32] In the EU, the Bio-based Industries Joint Undertaking (BBI JU) (a Public-Private Partnership between the EU and the Bio-based Industries Consortium driven by the Vision and Strategic Innovation and Research Agenda (SIRA)) had been developed by the industry to contribute to a more resource efficient and sustainable low-carbon economy and to increasing economic growth and employment, in particular in rural areas, by developing sustainable and competitive bio-based industries in Europe, based on advanced biorefineries that source their biomass sustainably.

[33] Indicators on sustainability dimension are based on the results of Sat-BBE consortium, "Systems Analysis Tools Framework for the EU Bio-Based Economy Strategy", Overview of the systems Analysis Framework for the EU Bioeconomy, 9 November 2013 and Tools for evaluating and monitoring the EU bioeconomy: Indicators, 31 December 2013.

Table 7. Sustainability indicators in the Italian bioeconomy strategy

OBJECTIVES	SUSTAINABLE PRINCIPLE	INDICATORS
Ensuring food security	Social	Change in food price volatility; Change in macronutrient intake/availability; Change in malnutrition or risk of hunger
Managing natural resources sustainably	Environmental/Social	Change in freshwater availability; Level of water pollution; Change in land use intensity; Rate of biodiversity loss; Secondary material price changes; Organic waste diverted from landfills
Reducing dependence on non-renewable resources	Economic/Environmental	Final energy consumption; Energy intensity of the economy; Share of renewable energy in gross final energy consumption
Coping with climate change	Environmental/Social	Change in greenhouse emissions; Level of emission of air pollutants
Enhancing economic growth	Economic/Social	Change in employment rate; Job creation in skilled/unskilled labour

Source: BIT Bioeconomy in Italy[34].

In order to measure the **environmental impact** of the bioeconomy, the EC JRC has developed and integrated modelling framework (IMF) to implements the consequential life cycle assessment (C-LCA[35]) and allow policy impact assessment once it is fully implemented (Ronzon, et al., 2017)[36]. However, data gaps still need to be filled and concepts and methodology, including the IMF for the environmental impact assessment, need to be further developed and implemented.

An ongoing project, *MontBioEco* (from the Natural Resources Institute Finland (Luke), the Standing Committee on Agricultural Research (SCAR) Bioeconomy Strategic Working group (BSW), and CASA Ministry of Agriculture and Forestry Finland (MMM)) is developing a **synthesis on bioeconomy monitoring systems in the EU Member States**, including indicators and sub-indicators. The analysis has currently developed 22 indicators and 146 sub-indicators, around five main objectives: creating jobs and maintaining competitiveness; reducing dependence

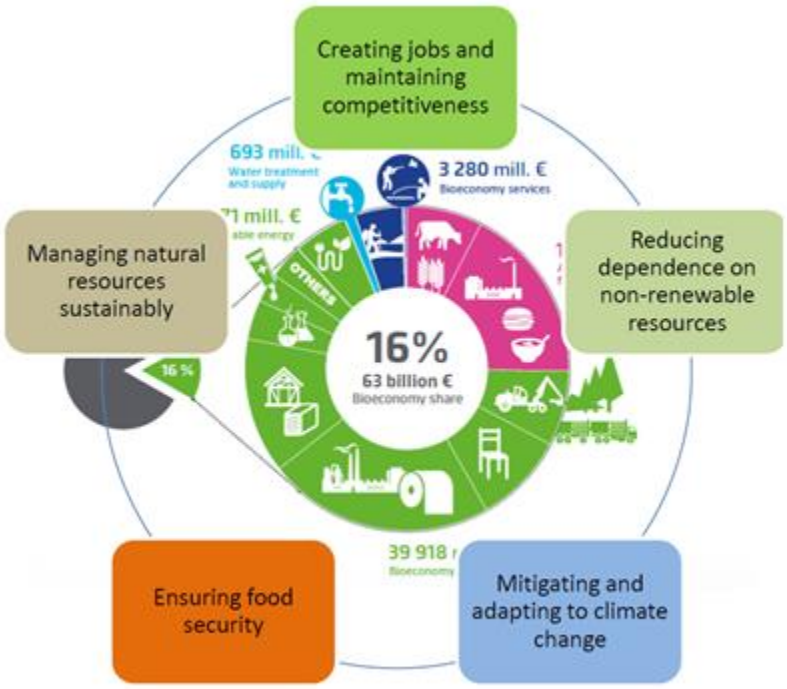
[34] Available at http://www.agenziacoesione.gov.it/opencms/export/sites/dps/it/documentazione/NEWS_2016/BIT/BIT_EN.pdf

[35] There are three approaches to LCA: firstly, the attributional LCA (A-LCA) assesses environmental impacts associated with all stages of a product's life from cradle to grave; secondly, the advanced A-LCA methodology looks beyond the immediate system boundaries by comparing multiple systems and by taking into account further GHG and environmental indicators; and thirdly, the consequential LCA (C-LCA) identifies the consequences that a decision in the foreground system has for other processes and systems of the economy, both in the analysed background system and on other systems outside the boundaries (Ronzon, et al., 2017).

[36] Other environmental assessment and environmental management techniques include carbon footprinting, eco-audit, environmental and social impact assessment, and strategic environmental assessment (Proposal for a SEI Initiative on Governing Bioeconomy Pathways).

on non-renewable resources; mitigating and adapting to climate change; ensuring food security and managing natural resources sustainably (Luke, 2017) (Figure 12).

Figure 12. Bioeconomy strategy objectives used in MontBioeco



Source: Luke (2017).

This assessment is developing measurable indicators and sub-indicators that go beyond economic monitoring. This approach is a positive step in the path towards monitoring the sustainability of bioeconomy in addition to its contribution to the economy.

In countries with an existing bioenergy or biofuels strategy, efforts towards monitoring the sustainability of bioeconomy can be linked with the previous efforts on biofuels, biomass and bioenergy. Moreover, several standard, certification and labelling initiatives already set some indications both on the 'quality' of the bio-products and on their sustainability. For instance, the USDA has developed a *Certified Biobased Product* label which certifies the carbon content of a number of bio-products. Many existing bio-product certifications and standards give indications for monitoring environmental and social sustainability.

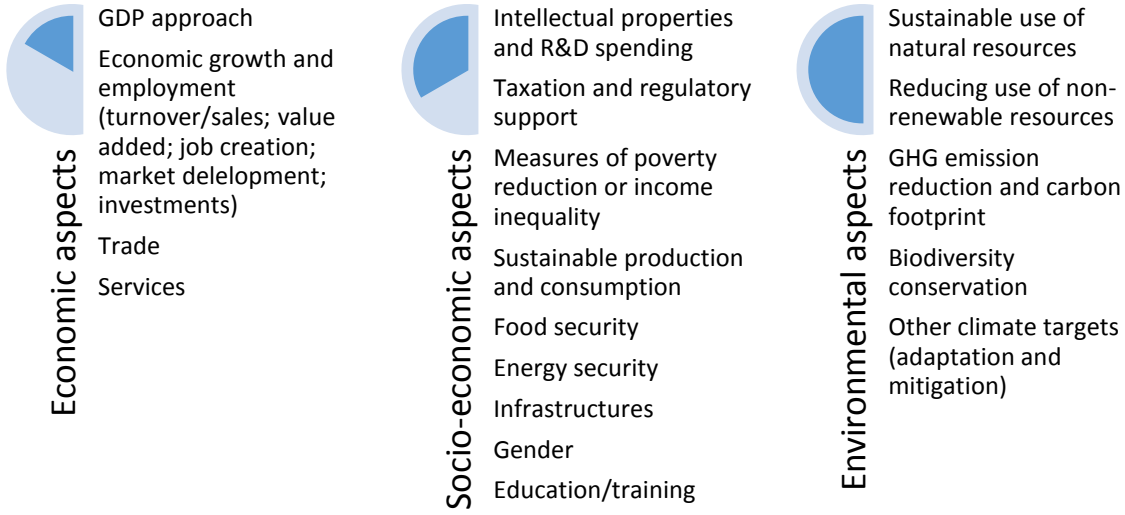
A further step in monitoring bioeconomy should ideally include the measurement of **taxation** and services. For instance, the Dutch RVO (2016) estimates also the investment in bioeconomy R&D through tax credits and fiscal exemptions (RVO, 2016). Other national studies are analysing existing policy to assess how public finance, regulations and capacity building can enable growth of the bioeconomy (see for instance (Fielding & Thazin Aung, 2018) for Thailand). Most countries currently measure only the share to the GDP of bio-based *products*. Some bioeconomy related

services could also be included in the measurement of the bioeconomy. For instance, Finland includes in its bioeconomy strategy nature tourism, hunting and fishing as bioeconomy services (Biotalous, 2014).

Bioeconomy is also an opportunity for young people and next generations, and it is often linked to improved science, technology, engineering, and mathematics (STEM) **education and training** programmes to meet the workforce needs. However, these aspects rarely come as a key priority in the bioeconomy strategies. One relevant exception is the Finnish bioeconomy strategy, for which developing the bioeconomy competence base by upgrading education, training and research is a key objective (Biotalous, 2014).

Figure 13 summarizes the identified pathways towards a sustainable bioeconomy monitoring, starting from the GDP approach to include socio-economic and environmental aspects, in line with the analysed country's objectives and the SDGs. The aspects included are not exhaustive and should be adapted to reflect country's priorities and strategy.

Figure 13. Identified pathway towards a sustainable bioeconomy monitoring



4.3. Methodological limitations in data availability and statistical approaches

Most of the countries currently measure only the contribution of bioeconomy to their GDP and employment. Even this economic approach has some limitations, above all because there is no standard methodology allowing the international comparison of bioeconomy contribution to GDP. Additionally, as mentioned above, products and activities comprised within the bioeconomy vary according to countries' priorities and comparative advantages.

The most commonly used **classifiers of economic activity**, trade and products at international-level (ISIC: International Standard Industrial Classification, NAICS: North American Industry Classification System, NACE: Classification of Economic Activities in the European Community;

NET: Nomenclature for External Trade and CPC: Classifier per Category) are not compatible with the complexity of the bioeconomy. Even the System of National Accounts (SNA 08) from the United Nations, which provides recommendations for measuring the national production, wellbeing and other economic issues internationally comparable, does not incorporate measurement for bioeconomy (Wierny, Coremberg, Costa, Trigo, & Regunaga, 2015). Classifiers based on the traditional industrial activities are not conceived to classify the bio-based industry. ISIC, NACE and NAICS group production units according to the similarity of their productive processes, technology, inputs and equipment; therefore they are not appropriate for the heterogeneous nature and variety of bio-based products. Their classifying criteria make no distinction into bio or not bio inputs (Wierny, Coremberg, Costa, Trigo, & Regunaga, 2015). This can lead to under or overestimation of the size of the bioeconomy.

The high number of bio-based products and their heterogeneity and the amount of data that needs to be collected make it very difficult to provide a fully quantitative picture of the status and evolution of the bioeconomy (Nattrass, Biggs, Bauen, Parisi, & Gómez-Barbero, 2016). Often, data on the bioeconomy are retrieved from **surveys on the bio-based industry** (Ronzon, et al., 2017; Wierny, Coremberg, Costa, Trigo, & Regunaga, 2015; USDA, 2011). These surveys represent an important first step for a systematic approach to quantifying the bioeconomy, but are not able to provide a complete picture of the bioeconomy, also for the difficulty for the companies to assemble the data requested, and the incomplete response rate (Ronzon, et al., 2017). These limitations are even more relevant in low and middle income countries, where statistical systems are not well-developed and the surveys may not be updated and may include limited and biased samples (as shown for instance by the Argentine and South Africa analyses). Digitalization efforts as the ones undertaken in Malaysia can play an important role in the measuring and monitoring of bioeconomy.

4.4. Concluding remarks

This study underlines the lack of a homogenous definition of bioeconomy across the countries analysed, which does not allow any straightforward comparison about the relevance of bioeconomy in the different economies. In one case (Australia), the country does not have a specific bioeconomy strategy, but it has a range of measures that foster bioeconomy as an enabler across a number of sectors.

The sectors comprised in the bioeconomy country's strategy mostly reflect priorities identified by the country and comparative advantages linked for instance to availability of natural resources, traditional industries, labour productivity and past investments in R&D. For instance, the agri-food sector is identified as a priority for Argentina, Malaysia and South Africa; while the Netherlands and the Unites States focuses more on non-food sectors.

Most countries measure bioeconomy progress just with economic values and shares of GDP. On top of the lack of international consensus on which products and activities are comprised within the bioeconomy, the GDP approach has several limitations due to the inadequacy of the standard

industrial classification systems to methodically monitor bio-based production; the lack of systematic data and the often scattered information collected at national level[37].

Some ongoing efforts aim to harmonize the definition and measurement of bioeconomy, at least across macro-regions, as the EU. These efforts will allow to have structured and comparable measurement and monitoring of the trends in bioeconomy, at least for some sets of countries (as the EC already does for few economic indicators (EC, 2018)).

Bioeconomy strategies often consider also 'soft' aspects, such as institutional set up, policies, governance, regulations, incentives and financial instruments, which create an enabling environment for the bioeconomy, as well as social and environmental issues (FAO, 2016). Low and middle income countries often emphasise the role bioeconomy plays in their development strategy, which is an important aspect to reflect in their measurement efforts. This could allow to monitor, for instance, progress in meeting the SDGs or environmental targets. In fact, **important synergies between countries' commitments towards the measurement of SDGs and bioeconomy can be leveraged**.

In order to facilitate the measurement and monitoring of bioeconomy at national level, the governments could enhance and coordinate communication between different domestic agencies and entities and establish protocols for sharing data; formalize bio-based industry measurement standards; develop a comprehensive survey for bio-based industry and commodity usage; and review and revise industry classification systems (USDA, 2011). These efforts should go hand-in-hand with the development of relevant and comprehensive guidelines on how to measure the sustainability of the bioeconomy, possibly agreed at international level. These set of indicators should consider also social and environmental issues (FAO, 2016). FAO is already coordinating international efforts towards the development of international Bioeconomy Sustainability Guidelines. These could be used by the countries to measure sustainability aspects of their bioeconomy strategy and monitor the achievement of targets and priorities.

[37] In addition, the GDP is being increasingly criticized as an inappropriate indicator to measure sustainable development since it includes activities considered detrimental to humans and the environment, and does not take into consideration social aspects that define human well-being, nor the biological processes. Moreover, the GDP does not include transfer payments, such as subsidies for fossil fuels.

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