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Indicators for a circular economy

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building science into EU policy

EASAC

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EASAC's activities include substantive studies of the scientific aspects of policy issues, reviews and advice about specific policy documents, workshops aimed at identifying current scientific thinking about major policy issues or at briefing policy-makers, and short, timely statements on topical subjects.

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Foreword

EASAC, which celebrated its 15th anniversary in 2016, brought together the collective resources of Europe's academies of science to primarily address policy-relevant scientific issues, and since 2001 we have worked on a very wide range of issues within the broad categories of environment, energy and biosciences. Since our creation, however, it has becoming increasingly obvious that key science-based issues with major policy ramifications may also include important aspects that are best addressed from the perspective of the social sciences, particularly economics. It has long been a topic for discussion in our Council to what extent we should extend our activities to recognise this and include the social sciences in relevant projects.

With the intensive debate that took place during 2013 to 2014 within the European Commission and Parliament on the circular economy, an issue emerged that is very much an inseparable combination of science, technology and social sciences which cannot easily be compartmentalised into one or the other. With a strong wish in the Council to contribute to this debate, we took EASAC's first decision to actively engage social scientists in a major project. Member Academies were invited to nominate experts for the Circular Economy Working Group across all fields of natural and social sciences, and we were pleasantly surprised to find that our membership responded very positively and provided a rich resource of experts in social as well as the natural sciences.

The result of that original project was a statement we released in November 2015 addressing some of the issues related to the circular economy from the perspective of the natural and social sciences. Given the limited time available to that initial project, we were unable to address some of the issues which arose in sufficient detail and the working group suggested possible additional projects which EASAC could undertake to contribute to the Commission's declared follow-up actions in its 2015 circular economy statement.

One of the critical questions in the circular economy is how we should measure its performance, since its objectives are substantially different from those in the traditional linear economy. The Commission had recognised this in its 2015 statement and undertook to produce a set of reliable indicators during 2017; thus EASAC decided to conduct a more detailed analysis to contribute to the Commission's considerations on this issue. Members of the original working group on the circular economy with a particular interest in this subject worked together with our programme director to compile the detailed analyses in this report. We hope that our analysis of this issue will be useful to all the stakeholders involved in this process.

Jos WM van der Meer
EASAC President

Summary

EASAC's earlier comments on the circular economy from the perspectives of the natural and social sciences observed that new indicators are likely to be required for the circular economy and this has been confirmed by the European Commission decision to establish a set of reliable indicators. EASAC thus decided to conduct an analysis of indicators that may be appropriate for monitoring progress towards a circular economy. Indicators are critical for economic assessment at all scales—from the micro- (businesses) level to the macro- (regional and national) to global levels. As a result, selecting indicators has significant implications and care needs to be taken to ensure that the indicators are appropriate for the policy objectives.

This report considers basic drivers for shifting from a linear to a circular economy and the demand for related indicators. Major priorities in the circular economy are the decoupling of resource use and environmental impact from economic activities; measurement of resource efficiency and waste reduction, and tracking material flows is thus a key component. However, such basic concepts do not capture the environmental impact of resources extraction and use, or the objective of more efficiently using goods, including repairing and reusing. The report reviews in detail the indicators recently proposed in different fields and assesses their relevance for the circular economy. The indicator sets considered include those from the United Nations Environment Programme (UNEP), United Nations Development Programme (UNDP), Global Reporting Initiative, World Bank, Yale and Columbia Universities, Eurostat, Ellen MacArthur Foundation, European Union (EU) Resource Efficiency Scoreboard and European Innovation Partnership. Economy wide material flow analysis is given particular attention. In addition, the report notes that owing to the linkages between the circular economy, human well-being and sustainable development, the indicators for monitoring progress towards a more circular economy can be included in the wider debate on developing alternatives to gross domestic product (GDP), where the Commission's circular economy indicators, 'Beyond GDP', sustainable development indicators and environmental pressure index actions are involved. Case studies are presented on indicators in the Chinese and Japanese circular economy initiatives.

EASAC finds that many indicators are available which are relevant for the circular economy. These are grouped in the present report into sustainable development, environment, material flow analysis, societal behaviour, organisational behaviour and economic performance. A general guidance is provided on the criteria for selecting indicators. These relate to the links with sustainability, the relation with driving policy, their effectiveness in communicating to the public, the compatibility with more circular means of production, the compatibility between Member States at different stages and degrees of industrial development, and possible boundaries in indicators selection. EASAC hopes this analysis will provide the Commission with useful hints for developing an indicator set appropriate for monitoring the circular economy. In particular, EASAC makes the following specific points.

- Resource productivity is already widely measured but captures only whether output is growing more than resource use and emissions. Other measures are required to provide information on environmental pressures in absolute terms.

- Recycling and reuse targets exist under five existing Directives, which provide an obvious potential source of indicators. A composite indicator expressing the degree to which EU Member States were reaching the directives' targets could be considered.

- Material flow indicators should take into account the complexities of recycling and the potential trade-offs between outputs of different recycled metals from mixed waste streams.

- To support policy objectives, indicators by industrial sector on critical raw materials may be desirable, in consultation with industry.

- Indicators should provide insights and raise public awareness on the global effects of EU production and consumption.

- Indicators on materials should receive equal importance as those on energy.

- In view of the emphasis in the circular economy package on economic outcomes (global competitiveness, sustainable economic growth and new jobs), data on cost reduction and economic benefits of circular activities are desirable. These could include indicators of social change, infrastructure, human resources and changes in business models, and the scale of economic activities related to the circular economy (employment, circular economy-related business).

- The Commission needs to monitor the performance of markets in the recycling business and address regulatory barriers, such as those related to transforming waste into secondary raw materials. An indicator which showed the extent to which waste was being transformed to 'end-of-waste' secondary raw materials would allow this important basic activity to be illuminated.

- Indicators for industry should aim as far as possible to minimise costs of implementation by exploiting information which is already collected for other purposes (including sustainability reporting).

- In areas of recycling which are complex (particularly those of rarer metals), the value of economic output from the recycling process may be an indicator that best reflects whether the physical realities of the recycling process have been optimised.

- Since some potential indicators may show positive development when their values are decreasing and others a regression, composite indicators may useful for communicating trends in a circular economy. An illustrative example is given in the report.

- Particular challenges exist in developing an indicator for water, but in view of the need for proper water accounting and maximising potential for reuse, EASAC concludes that water should be included in the indicator sets for the circular economy.

1 Introduction

EASAC's earlier comments on the circular economy (EASAC, 2015) reviewed some of the underlying scientific and economic issues relevant to the debate on the circular economy, including the economic debate on the potential benefits and risks of transition from a linear to circular economy, the fundamental systemic failure of prices, competitiveness and other aspects. We observed *inter alia* that economic indicators based on traditional national accounts such as GDP do not measure the efficiency with which resources are used, nor do they monitor some contributions to well-being. Consequently EASAC undertook to consider indicators that should be taken into account for monitoring progress towards a circular economy. This report briefly introduces the role of indicators in guiding economic monitoring and policy, the debate which was already underway on shifting their exclusive focus on economic growth to a more equilibrated measure of progress that is sustainable for both humanity and nature, and then considers issues which arise from an increased priority to a circular economy. This report is intended to contribute to the commitment by the European Commission (EC) document on 'Closing the loop - An EU action plan for the Circular Economy' (EC, 2015) which states that '*To assess progress towards a more circular economy and the effectiveness of action at EU and national level, it is important to have a set of reliable indicators.*' Our starting point in this report is that a policy decision to develop indicators has already been made and we do not thus revisit the underlying economic issues covered in our earlier report.

This EASAC project has been guided by the Project Group listed in Annex 1.

2 The role of economic indicators

Indicators[1] are critical for economic assessment at all scales, from the micro- (business) level to macro- (regional and national) and global levels. Many are collected according to international standards and provide the basis on which critical decisions are taken in both public and private sectors. It is not the role of this report to summarise let alone review the wide range of economic indicators currently in use. However, it is important to recognise the critical role of some in the linear economy if we are to consider new indicators (to be added to or replace those currently used) appropriate for measuring progress towards a more circular economy. The extent to which indicators are integrated into statistical agencies, private financial systems, the decision-making mechanisms in private companies, as well as incorporated into the economic decision-making process of governments can be very resistant to change, and introduction of new indicators may be expected to face resistance from statistical institutes, policy makers, researchers, private companies, non-governmental organisations and other stakeholders which have come to rely on existing indicators.

An illustration of such institutional inertia can be shown in the decades of discussion on the role of gross domestic product (GDP) for measuring economic performance. As pointed out in the debate on the adequacy of this indicator (Heal and Kriström, 2005; van den Bergh and Antal, 2014), even though GDP was originally introduced as a statistical means of recording certain types of economic activity, it has evolved over time as a reference measure for economic growth used by media, politicians and the general public. One of its main drawbacks is that its calculation does not capture people's well-being, a weakness recognised at the very outset (Kuznets, 1934). For instance, if economic progress generates pollution negatively impacting on human health, the resulting health care expenditure rise will positively contribute to GDP and will be equated to economic progress rather than to a decrease in peoples' well-being. Similarly, natural capital stock contraction induced by intensive consumption of natural resources will negatively impact future generations' well-being, but is not accounted for since GDP calculations do not apply any depreciation to natural capital.

How to correct or adjust GDP to use it as a measure of social welfare has been extensively discussed and analysed by economists over several decades. In November 2007 a conference on 'Beyond GDP' was organised by the European Union (EU) and other international institutions, recognising the limits GDP has in measuring well-being and quality of life. Without taking into account the state of the environment, social cohesion and happiness rate, GDP cannot support policy makers dealing with social and environmental themes.

[1] The term 'metric' is also used to refer to parameters used for measurement, comparison or tracking performance. Indicators may well be metrics but tend to be used to quantify a parameter with specific policy or performance significance. The link with such an objective is thus inherent in a metric used as an indicator.

The results of this conference led to a Commission Communication (EC, 2009) and the still ongoing initiative 'Beyond GDP- measuring progress in a changing world'. Despite the extensive critiques and the alternatives proposed, GDP remains the dominant headline indicator for national and global economic growth, broadly used in economic forecasting and for cross-country comparisons. Aspects of the debate on the topic are summarised in Annex 2.

Before considering potential indicators for measuring progress towards a circular economy, it is necessary to briefly highlight the main differences between the 'linear' and 'circular' economy.

3 Indicators in a linear and circular economy

The concept of the circular economy (CE) has been analysed by the Commission, the European Resource Efficiency Platform (EREP), the Ellen MacArthur Foundation (EMF) and others (EASAC, 2015). The current economic model is based on a linear process going from raw materials extraction for production purposes, to waste disposal of manufactured goods no longer used by consumers (take-make-consume-dispose). The Commission's vision (EC, 2015) is instead supporting a '*transition to a more circular economy, where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised, and is an essential contribution to the EU's efforts to develop a sustainable, low carbon, resource efficient and competitive economy.*' Key aspects (EMF, 2012; Club of Rome, 2015) are the overall reduction of resources consumed and the overall increase of resources reused or recovered.

As pointed out in EASAC (2015), society's main purpose in the circular economy is to reduce the adverse interactions between the economy, the environment and its natural resources to safeguard the well-being of future generations, so contributing to sustainability. Among the factors supporting a shift from a linear to circular economy are the following.

- Existing production and consumption patterns' long-term sustainability. During the 20th century, the extraction of construction materials grew by a factor of 34, ores and minerals by a factor of 27, fossil fuels by a factor of 12, and substantial reductions in the resource requirements of economies will be necessary to support sustainably the growing world population (UNEP, 2011, 2016). Business as usual is predicted to lead to scarcities of non-renewable materials such as metals and require a radical change in the ways we use nature's resources to produce goods and services and generate well-being (Angrick *et al.*, 2014). As emphasised by UNEP (2011, 2016) 'decoupling' by using less resources per unit of economic output (resource decoupling) and reducing the environmental impact of any resources that are used (impact decoupling) are essential components of sustainable development (Figure 3.1).

- The above considerations are especially important for regions such as the EU which possess only scarce non-renewable resources and therefore depend on imports (Figure 3.2).

- Climate change. Production and consumption patterns need to be sustainable in the long term also with respect to greenhouse gas emissions, which have to be globally reduced to zero by 2050 to respect the 2 °C global warming threshold (UNFCCC, 2015). Current global consumption patterns appear to be 50% over sustainable levels (Global Footprint Network, 2015).[2] Since in developed countries, 55–65% of greenhouse gas emissions are related to the extraction, transport and processing of raw materials (OECD, 2012), circularity, through a reduction in the energy needed to extract, transport and process these materials, reduces greenhouse gas emissions.

- The environmental damage associated with resource extraction can be substantial[3]. Since the basic objective of the circular economy is to reduce consumption of natural resources, the associated environmental impact of resource extraction and waste disposal will also be reduced. The Commission also points out that environmental impacts have associated business risks through regulations aimed at restricting or pricing key resources (e.g. carbon pricing, water pricing, payments for ecosystem services, landfill taxes) which may also be reduced in a circular economy.

- An additional focus of the Commission's latest action plan is the role of the circular economy in green growth, innovation and job opportunities which are not dependent on an unsustainable linear growth model. Such trends may also contribute to industrial competitiveness (see EASAC, 2015).

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[2] Attempts to quantify more specific targets for the shift needed to achieve a sustainable consumption level are underway within the OECD.

[3] Mining is an inherently invasive process that can cause damage to a landscape in an area much larger than the mining site itself. The effects of this damage can continue years after a mine has shut down, and operational damage can also be substantial. For example, the damage from the large amounts of water and tailings containing toxic metals especially when released through dams bursting (e.g. the 2015 BHP-Vale dam burst in Brazil has already involved compensation payments of $5.6 billion and is subject to a further $44 billion civil damages claim (https://www.ft.com/content/f771c230-1182-11e6-bb40-c30e3bfcf63b)). There are also examples connected with coal extraction like in the Ruhr (Germany) and Sulcic Iglesiente (Sardinia, Italy).

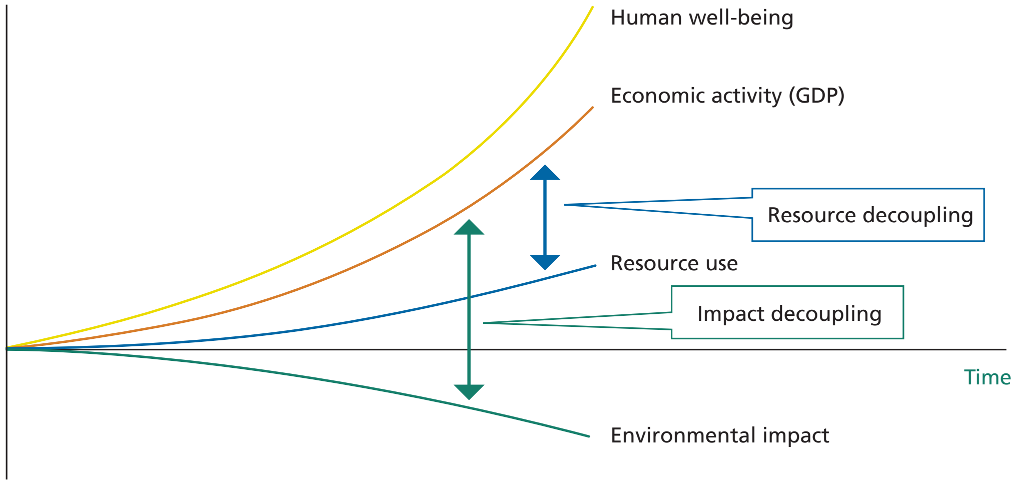

Figure 3.1 Decoupling resource and impact decoupling (UNEP, 2011).

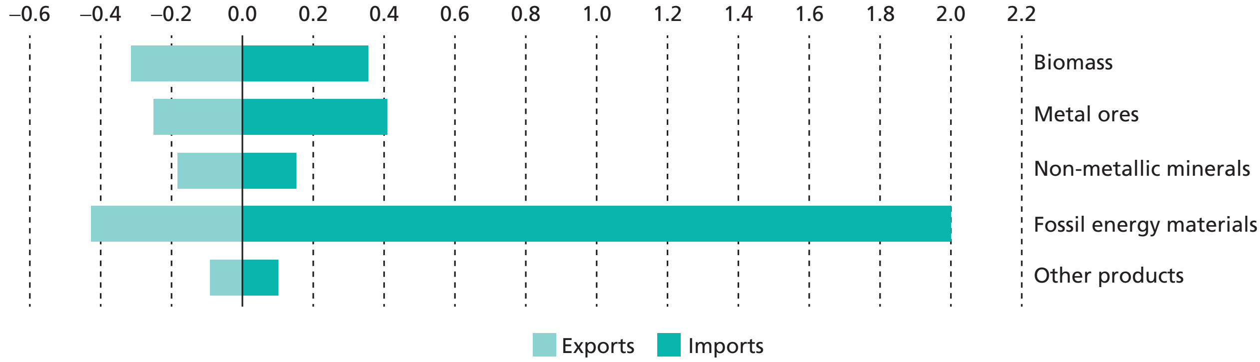

Figure 3.2 EU-28 physical imports and exports by main material category, 2014 (tonnes per capita) (Eurostat, 2015a).

In short, the linear economy (which sees nature as providing resources for use in the economic system to add anthropic value and then accepting the resulting wastes), shifts to a nonlinear (circular) economy where new technological information is used to diminish and diversify resources taken from the environment, and where the anthropic value added in products also takes into account the negative impacts on nature from resource use and waste generated. The outcome being that in the circular economy, material fluxes, stocks and waste are diminished and have a less destructive impact on the environment.

Since resource efficiency and waste reduction are central in a circular economy, indicators on material flows are particularly relevant. The interpretation of material flows nevertheless varies according to the type of material considered (1 tonne of rock from a quarry is very different from 1 tonne of cadmium; 1 tonne of biodegradable waste has a different environmental impact than 1 tonne of electronic waste). Indeed, material flows reported in the recent Raw Materials Scoreboard (EIPRM, 2016) show the extent to which such flows are dominated by construction materials. The use of indicators may also need to be different depending on whether they apply to a business (individual firms), sector (e.g. construction, mining) or whole economy (Bringezu *et al.*, 1997). Flows can also be separated into individual substances (e.g. lead, cadmium), materials (e.g. paper) and products (e.g. cars, computers), further complicating the consideration of indicators.

When considering material flows, considerations from market and environmental perspectives may not coincide. Matthews *et al.* (2000) offered a conceptual design for the main material flows (Figure 3.3), which can be applied also for selecting indicators. A national economy can be depicted as an open system in which inputs come from domestic extraction and imports, and outputs are absorbed by internal and external consumption (export). Products not consumed and at the end of their life are released into the domestic environment (waste). Additional (hidden) flows account for those materials lacking economic value but extracted together with other materials and then discarded (e.g. overburden or tailings materials/waste rock from mining activities), as stressed

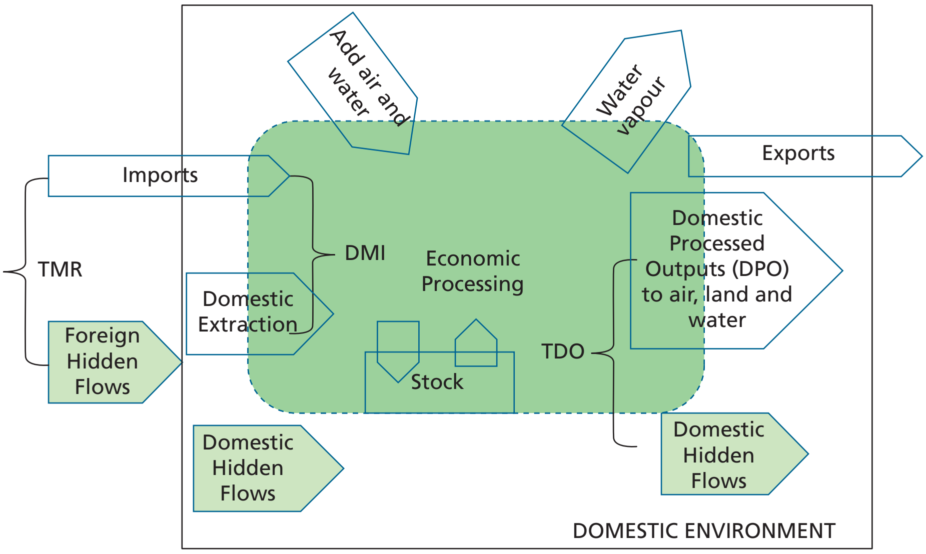

Figure 3.3 Material flows conceptual design (based on Matthews et al., 2000). DMI, direct material input; TMR, total material requirement; DPO, domestic processed output; TDO, total domestic output.

by the concept of 'ecological rucksack' (Schmidt-Bleek, 1994; von Weitzsäcker *et al*., 1998)[4].

Quantifying through material flow analysis has already provided data relevant to monitoring the circularity of an economy, and provides a useful baseline to allow comparison between different countries and to provide a metric to inform decisions on national targets of circularity. Reflecting the considerations above however, subsets of material flow data may also provide useful indicators-for instance, comparison of imports and exports of virgin raw materials and their scrap (for instance aluminium, steel); flows of specific substances or elements; levels of reuse and recycle; methods of disposal of waste; recycling indicators for separate waste types and elements; and industry/sector-specific indicators, for example construction/demolition waste recycling. However, concentrating on waste overlooks another key objective of a circular economy that goods should be used longer and more efficiently – through repair, reuse, sharing, etc. Non-material measures are also relevant to the circular economy- particularly those associated with social change (e.g. sustainable consumption, growth of sharing, extent of reuse/repair) or changes in business models (e.g. making durable and repairable equipment, remanufacturing). We return to this in Chapter 5.

[4] The 'ecological rucksack' refers to the total amount of natural resources removed minus the quantity of the target material extracted. The amounts of overburden, processing residues, etc. that are associated with extracting raw materials can be extremely large: for instance for each kilogram of platinum extracted, there is a 'hidden' flow (or ecological rucksack) of 350,000 kilograms. Equivalent figures for other materials are steel (21 kg), aluminium (85 kg), recycled aluminium (3.5 kg) and gold (540,000 kg).

4 Indicators currently in use relevant to a circular economy

There are many indicators related to environment and resources which have already been proposed by several organisations. A thorough review of all these is beyond the scope of this report, but we point to some specific sets which may be relevant to the circular economy as summarised in Table 4.1, with more detail provided in this section. In sections 5.1 and 5.2 we consider some case studies of indicators in use in China and Japan.

As listed in Table 4.1, the **United Nations Environment Programme** (UNEP, 2013) has a set of key environmental indicators that can serve as a basis for elaborating sustainable development goals and indicators for tracking progress towards environmental sustainability. These correspond to the major global environmental issues: climate change, ozone depletion, chemicals and waste, natural resource use (air, land, water, biodiversity) and environmental governance. Recently, UNEP (2016) has advocated a new indicator for material consumption which is the amount of materials that are required for final demand (consumption and capital investment) in a country or region (expressed as tonnes per capita). The **United Nations Development Programme** (UNDP, 2016) is developing 17 Sustainable Development Goals, which include goals related to resource use (climate action, responsible consumption and production).

A comprehensive set of indicators relevant to corporate sustainability reporting has been assembled by the **Global Reporting Initiative** (GRI, 2016) covering the three pillars of sustainability (economic, environmental, societal). These include indicators related to use of materials, energy, water as well as wastes and recycling, and indicate data that should be available in companies and other organisations reporting the sustainability of their activities.

Another set of indicators has been developed in a joint project between **Yale and Columbia Universities and the World Economic Forum**. This started with an Environmental Sustainability Index (ESI) based on a compilation of 21 indicators[5] derived from 76 underlying data sets (Yale University, 2005). Since 2005, this has been adapted to produce an Environmental Performance Index (EPI) which ranks how well countries perform in protection of human health from environmental harm and protection of ecosystems (Hsu *et al*., 2014).

Table 4.1 Indicator sets considered in this report

Indicator set	Advocated by	Characteristic/ data source	Number of indicators
Sustainable Development Indicators	UNEP	Major global environmental issues	10
Sustainable Development Goals	UNDP	End poverty, fight inequality and injustice, and tackle climate change	17
Corporate sustainability	Global reporting initiative (GRI)	Sustainability-relevant indicators for organisations	>100
Environmental sustainability index (ESI); environmental performance indicator (EPI)	Yale and Columbia universities	Environmental indicators	21 (ESI) 20 (EPI)
Little Green Data Book	World Bank	Environment and sustainability	50
Green Growth Indicators	OECD	Environment, resources, economic and policy responses	25–30
Economy-wide material flow accounts EW-MFA	Eurostat Wuppertal Institute	Focused on material flows	6
Circular economy indicators	Ellen MacArthur foundation (EMF)	Indicators currently available	7
Resource efficiency	EU Resource Efficiency scoreboard (EURES)	Eurostat, EEA and others	32
Raw materials	European Innovation Partnership (EIP)	Raw Materials Scoreboard European Union Raw Materials Knowledge Base (EURMKB)	24 4

5 The 21 indicators were in the areas of air quality, biodiversity, land, water quality, water quantity, reducing air pollution, reducing ecosystem stress, reducing population pressures, reducing waste and consumption pressures, reducing water stress, natural resource management, environmental health, basic human sustenance, reducing environmental-related natural disaster vulnerability, environmental governance, eco-efficiency, private sector responsiveness, science and technology, participation in international collaboration efforts, greenhouse gas emissions, reducing transboundary environmental pressures.

The **World Bank** has also assembled 50 indicators which can be used to measure progress on the sustainable development goals (SDGs) as well as highlight important trends in the environment; these are in Table 4.2.

The **OECD** is also developing green growth indicators, comprising 25–30 indicators under four main headings. In summary, these are (OECD, 2014) as follows:

1. Environmental and resource productivity

- Carbon and energy productivity (carbon dioxide productivity (2); energy productivity (3))
- Resource productivity (material productivity: indicators of demand-based material productivity; production-based domestic material productivity; waste generation intensity and recovery ratios; nutrient flows and balances)
- Water productivity
- Multifactor productivity reflecting environmental services

2. Natural asset base

- Natural resource stocks (index of natural resources)
- Renewable stocks (freshwater resources, forest resources, fish resources)
- Non-renewable stocks; mineral resources
- Biodiversity and ecosystems (land resources, soil resources and wildlife resources)

3. Environmental dimension of quality of life

- Environmental health risks (2),
- Environmental services and amenities (2)

4. Economic opportunities and policy responses

- Technology and innovation (3)
- Environmental goods and services
- International financial flows
- Prices and transfers (environmentally related taxation, energy pricing, water pricing and cost recovery)
- Regulations and management approaches
- Training and skills development.

These indicators are being used as the basis for national green growth indicators in some countries (e.g. in Switzerland; Federal Office for the Environment, 2016).

While the above examples include some indicators relevant to a CE, more specific information (already used in several countries) is obtained in **economy-wide material flow accounts** (EW-MFA[6]). These are already widely used to obtain trends in resource efficiency (see, for example, Figure 4.1), but more detailed statistics are available on the material inputs into national economies, the changes in material stock within the economic system, and material outputs to other economies or to the environment. These have been collected under guidance developed by Eurostat,

Table 4.2 World Bank 50 indicators (World Bank, 2016)

Category	Indicators
Economic	GNI per capita, adjusted net national income per capita, urban population
Agriculture	Agricultural land as percent of land area, agricultural irrigated land, agricultural productivity, cereal yield
Forests and biodiversity	Forest area, deforestation, terrestrial protected areas, threatened species, mammals, threatened species-birds, threatened species-fish, threatened species-higher plants
Oceans	Total fisheries production, marine protected areas, coral reef area, mangroves area
Energy and emissions	Energy use per capita, energy from biomass products and waste, electric power consumption per capita, electricity generated using fossil fuel, electricity generated by hydropower, carbon dioxide emissions per capita
Water and sanitation	Internal freshwater resources, total freshwater withdrawal, agricultural percentage of total freshwater withdrawal, access to improved water source (rural and urban populations), access to improved sanitation (rural and urban)
Environmental and health	PM2.5 pollution annual exposure, PM2.5 exposure percentage exceeding WHO guidelines, acute respiratory infection, diarrhoea, under five mortality rate
National accounting aggregates	Gross savings, consumption of fixed capital, education expenditure, energy depletion, mineral depletion, net forest depletion, carbon dioxide damage, air pollution damage, adjusted net savings

6 Bringezu (2001) defined MFA as 'the analysis of the throughput of process chains, comprising the extraction or harvest, chemical transformation, manufacturing, consumption, recycling and disposal of materials'. MFA provides a diagnostic tool to monitor material flows in physical units, typically in tons throughout the entire supply chain. MFA is also increasingly used as a diagnostic tool to understand the material use related impacts from company scale to those of entire economies.

Figure 4.1 Resource productivity compared with GDP and DMC, EU-28, 2002–2014.[7]

the Wuppertal Institute and national statistical offices in Europe. A more detailed MFA analysis for Germany is being developed in the SIMRESS project (http://simress.de/). Most European statistical offices compile the statistics from existing sources under a regulation on the compilation of annual statistics on material flows (EC, 2011)[8].

The material flows in the economy and the indicators available are shown in Figure 4.2, which includes the main indicators of:

- **Domestic extraction (DE).** Material extracted within the territories of the EU.
- **Direct Material Input (DMI)** comprises all materials with economic value which are directly used in production and consumption activities. DMI equals the sum of domestic extraction and direct imports.
- **Raw Material Input (RMI)** adds the Raw Material Equivalents (RME) of imports to DMI.
- **Total Material Requirement (TMR)** comprises all types of input flows.
- **Domestic Material Consumption (DMC)** measures the total quantity of materials used within an economic system, excluding indirect flows.
- **Raw Material Consumption (RMC)** deducts from RMI the export of materials plus the RME of exports.
- **Total Material Consumption (TMC)** adds to RMC the unused extraction related to RMEs of both imports and exports.

Other indicators derived from material flow analysis include:

- **Physical Trade Balance (PTB)** shows to what extent domestic material consumption is based on domestic resource extraction or on imports from abroad.
- **Domestic processed output (DPO)** measures the total weight of materials which are released back to the environment after having been used in the domestic economy. These flows occur at the processing, manufacturing, use, and final disposal stages of the production-consumption chain. Recycled material flows in the economy are not included.
- **Total Domestic Output (TDO)** represents the environmental burden of materials use, i.e. the total quantity of material outputs to the environment caused by economic activity. TDO equals DPO plus unused domestic extraction.
- **Net Additions to Stock (NAS)** reflect the physical growth of the economy, i.e. the net expansion of the stock of materials in buildings, infrastructures and durable goods.

The above material flow model forms the primary source of indicators under consideration in

[7] http://ec.europa.eu/eurostat/statistics-explained/

[8] Data mining is an area of data analytics that is becoming more widespread in business use and practice and may be useful to extract valuable information from databanks/databases for the development of new CE indicators.

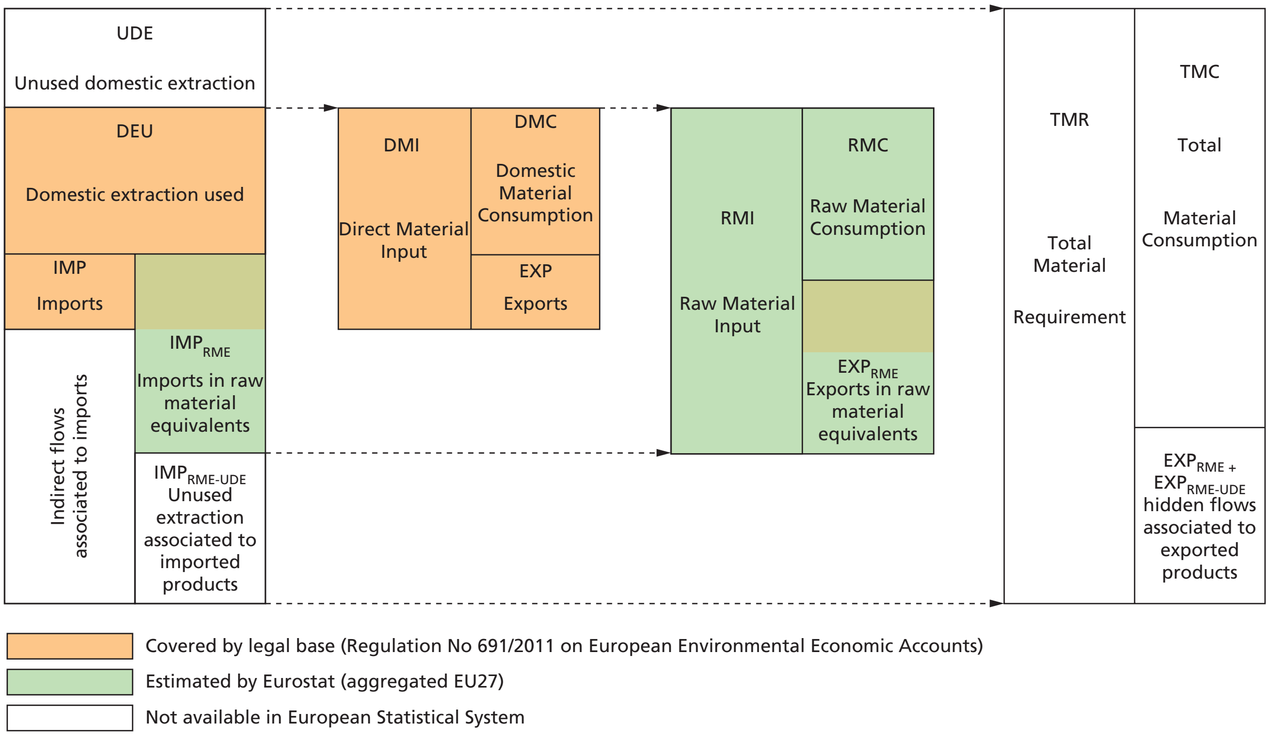

Figure 4.2 Input and consumption indicators, which are most frequently applied in MFA (source: www.materialsflow.net).

Germany (Umweltbundesamt, 2012, 2015). However, as can be seen from Figure 4.2, substantial parts of these flows are not available from collected statistics and the EU needs a better harmonised reporting structure to monitor the movement of materials. Such data that are available from Eurostat can, however, provide some insights into trends (see, for example, Figure 4.3 used in a review of sustainability at the metropolitan level by METREX Futures Group (2014)).

Another example of the use of material flow accounting can be found in the EU Packaging Waste Directive for the commercial/industrial sectors, where the various packaging flows need to be assessed to demonstrate compliance with their associated percentage recycling obligations (EC, 1994).

In recent debate on the CE, the **Ellen MacArthur Foundation** (EMF, 2015) advocate an initial approach to circular economy indicators based on existing metrics of:

- **Resource productivity** (amount of GDP produced per tonne of DMI)**.** The advantage is that data are available and transparent; the disadvantages are that it is highly influenced by the industrial structure in a given country, and that weight does not relate directly to environmental impact.
- **Circular activities**. This refers to the level of remanufacturing, sharing and other relevant activities. However, since such data are not readily available, recycling rate and eco-innovation indexes can serve as proxy indicators.
- **Waste generation**. Two potential metrics are waste generated per GDP output (excluding major mineral waste) and municipal waste generated per capita.
- **Energy and greenhouse gas emissions** can be represented by metrics of renewable energy use and greenhouse gas emissions per GDP output.

The **EU Resource Efficiency scoreboard** (EURES, 2014) and **Raw Material Consumption** (RMC) indicators show progress towards increased resource productivity in individual Member States and the European Union[9]. EURES uses the most recent statistics from Eurostat, the European Environment Agency (EEA) and other EU/international sources. It uses a three-tiered approach (Figure 4.4):

[9] EURES supports the 'resource-efficient Europe' flagship initiative as part of the Europe 2020 Strategy towards smart, sustainable and inclusive growth. It aims to support the shift towards a resource-efficient, low-carbon economy with high levels of employment, productivity and social cohesion (EURES, 2014).

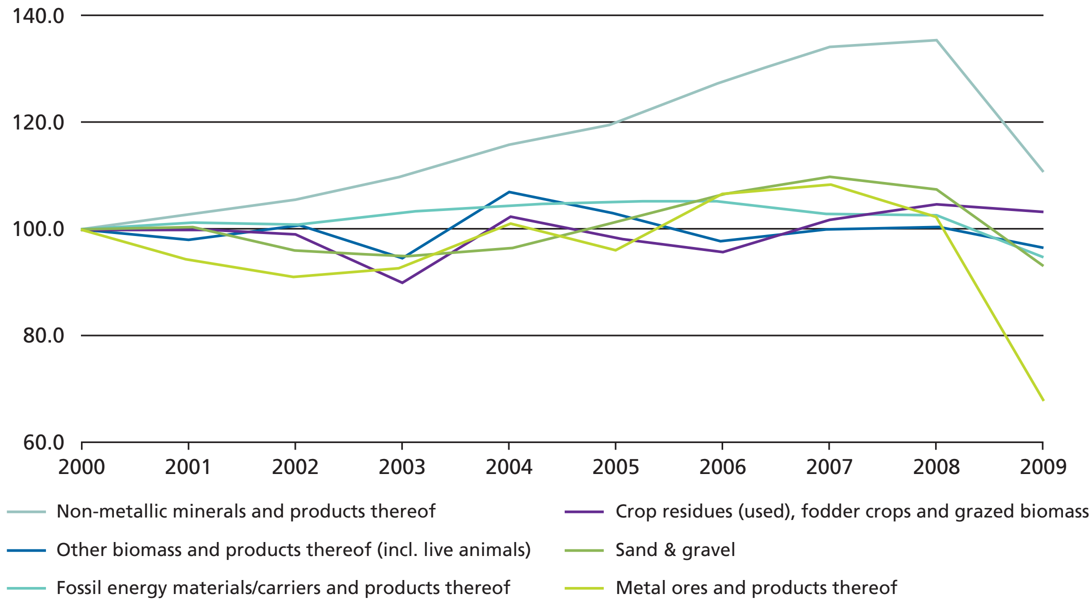

Figure 4.3 Domestic material consumption (DMC) by main material categories, EU-27, 2000–2009 (index 2000 = 100) (Source: Eurostat).

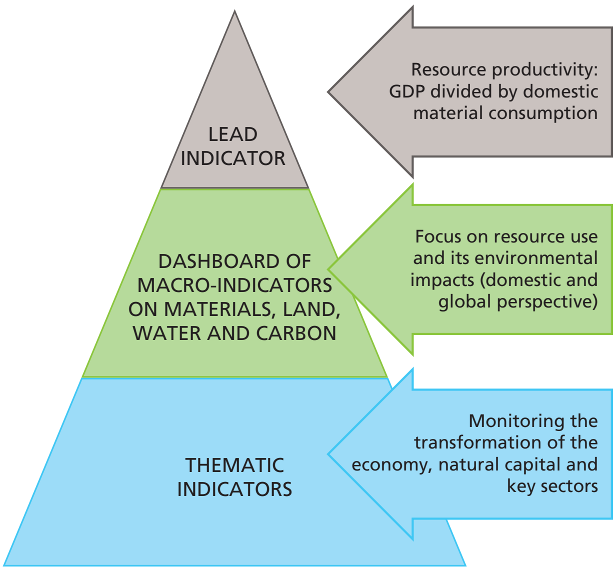

Figure 4.4 EU resource efficiency scoreboard indicators (EURES, 2014).

1. Overall lead indicator for 'resource productivity'.

2. Second-tier 'dashboard' of complementary macro indicators for materials, land, water and carbon.

3. Third tier of theme-specific indicators to measure progress towards key thematic objectives, and the actions and milestones set out in the EU Roadmap to a resource efficient Europe.

Specific indicators proposed are in Table 4.3.

EURES is one response to the recommendations of EREP (2013) to apply indicators that accurately show progress towards a resource-efficient economy. These should include indicators that cover resource use in the production chain, both in Europe and globally, providing insights and raising public awareness on the global effects of EU production and consumption. Such indicators should help put in place measures to ensure reduction of the environmental impacts of production and consumption, taking into account differences in economic structure. EREP also recommended that resource efficiency indicators should be considered in measuring social and environmental progress beyond GDP. It was also recognised that there may be a distinction between the efficient and sustainable use of non-renewable and renewable materials.

The European Innovation Partnership (EIP) is also developing a Raw Materials' Monitoring and Evaluation Scheme to monitor progress on its strategic implementation plan on raw materials (EIP, 2014), aimed at ensuring the sustainable supply of non-energy, non-agricultural raw materials (minerals, metals, etc.) to the European economy. Its Strategic Implementation Plan includes activities from improving technology (both for primary and secondary raw material production and for substitution of rarer raw materials), non-technology initiatives (including minerals policy, improving Europe's waste management framework, and knowledge and best practice along value chains). Included in this is the need to track progress by developing appropriate indicators through a Raw Materials Scoreboard based on statistical indicators relevant to the EIP's general objectives, the EU raw materials sector's competitiveness and any systemic change that could be brought about by the EIP. The Scoreboard was recently published (EIPRM, 2016) with 24 indicators in the following areas:

Table 4.3 Resource efficiency indicators in EURES

Indicator classification	Sub-theme	Indicator
Lead indicator	Resources	Resource productivity
Dashboard indicators	Land	Built-up areas
		Productivity of artificial land
	Water	Water exploitation index
		Water productivity
	Carbon	greenhouse gas emissions per capita
		Energy productivity
		Energy dependence
		Share of renewable energy
Thematic indicator 1:	Waste into a resource	Generation of waste
Transforming the economy		Landfill rate of waste
		Recycling rate of municipal waste
		Recycling rate of e-waste
	Supporting research and innovation	Eco-innovation index
	Getting the prices right	Environmental tax revenues
		Energy taxes
Thematic indicator 2:	Biodiversity	Common farmland bird species
Nature and Ecosystems		Areas under organic farming
		Landscape fragmentation
	Safeguarding clean air	Urban exposure to particulate matter (PM10 and PM25)
	Land and soils	Soil erosion
		Gross nutrient balance in agricultural land-nitrogen and phosphorus
Thematic indicator 3:	Addressing food	Daily calorific intake per capita
Key areas	Improving buildings	Household energy consumption by fuel
	Ensuring efficient mobility	Average carbon dioxide emissions per kilometre from new cars
		Pollutant emissions from transport (NO_x, PM10, volatile organic compounds)
		Modal split of passenger transport
		Modal split of freight transport

- raw materials in the global context;
- circular economy and recycling;
- competitiveness and innovation;
- social and environmental sustainability;
- framework conditions for mining.

These include four indicators that are particularly relevant to the circular economy (material flows, trade in secondary raw materials, recycling's contribution to meeting material demand, and waste electric and electronic equipment (WEEE) management).

The EIP project also provides access to a set of databases which are part of the building blocks of the **European Union Raw Materials Knowledge Base (EURMKB)**[10]. Current data are limited to the four stages on (1) the location of primary raw materials within EU Member States, (2) data on mining waste, (3) dedicated facilities permitted to accept waste for permanent burial (Directive 99/31/EC) and (4) annual arising of waste which are deposited in landfill.

In addition to the various indicators specifically advocated by the groups above, obvious candidates for indicators are the **targets in various directives related to waste and recycling**. We note five relevant directives, each with numerical targets which could be used for indicator purposes (see Table 4.4).

10 http://ec.europa.eu/growth/sectors/raw-materials/specific-interest/knowledge-base/index_en.htm

Table 4.4 EU Directives with recovery/reuse targets

Directive 2000/53 on end-of-life vehicles	Target date	Target (%)
Target of recovery and reuse	1 January 2015	95
Target of reuse and recycling	1 January 2015	85
Directive 2004/12 on packaging and packaging waste		
Minimum recovery rate, including incineration with energy recovery, by weight of packaging waste	31 December 2008	60
Minimum recycling rate by weight (glass, paper and board)	31 December 2008	60
Minimum recycling rate by weight (metals)	31 December 2008	50
Minimum recycling rate by weight (material that is recycled back into plastics)	31 December 2008	22.5
Minimum recycling rate by weight (wood)	31 December 2008	15
Directive 2006/66 on batteries and accumulators and waste batteries and accumulators		
Target of collection	26 September 2016	45
Target of reuse and recycling	1 January 2015	85
Recycling rate as medium weight of batteries and accumulators in lead/acid maximising the recycling of lead	26 September 2010	65
Recycling rate as medium weight of batteries and accumulators in nickel-cadmium maximising the recycling of cadmium	26 September 2010	75
Recycling rate as medium rate of other waste of batteries and accumulators	26 September 2010	50
Directive 2008/98 on waste		
Preparing for reuse and the recycling of waste materials (such as at least paper, metal, plastic and glass) from households and from other similar waste streams	2020	50
Preparing for reuse, recycling and other material recovery, including backfilling operations using waste to substitute other materials, of non-hazardous construction and demolition waste	2020	70
Directive 2012/19 on waste electric and electronic equipment (WEEE)		
Minimum collection	1 January 2016 1 January 2019	45 65
Minimum recovery of large household appliances and automatic dispensers	14 August 2018	85
Minimum recycling of large household appliances and automatic dispensers		70
Minimum recovery of IT and telecommunications equipment or consumer equipment and photovoltaic panels		80
Minimum recycling of IT and telecommunications equipment or consumer equipment and photovoltaic panels		70
Minimum recovery of small household appliances, lighting equipment, electrical and electronic tools (with the exception of large-scale stationary industrial tools), toys, leisure and sports equipment, medical devices (with the exception of all implanted and infected products), monitoring and control instruments		75
Minimum recycling of small household appliances (as above)		55
Minimum recycling of gas discharge lamps	From 15 August 2018	80
Minimum recovery of temperature exchange equipment or large equipment		85
Minimum target for preparation for reuse or recycling of temperature exchange equipment or large equipment		80
Minimum recovery of screens, monitors, and equipment containing screens; area >100 cm^2		80
Minimum target for preparation for reuse or recycling of screens (as above)		70
Minimum recovery of small equipment or small IT and telecommunication equipment		75
Minimum target for preparation for reuse or recycling of small equipment or small IT and telecommunication equipment		55%
Minimum recycling of lamps		80%

5 Case studies

5.1 China's use of circular economy indicators

China adopted the concept of the CE as a national regulatory policy priority over the last decade leading to the Circular Economy Promotion Law of 2008 (Pinter, 2006; Geng *et al*., 2012, 2013). This promotes the CE principle at three levels: individual firm level, the eco-industrial park level and the macro- or eco-city/eco-province level. At the firm level, CE mainly involves eco-design and cleaner production strategies and actions. At meso-level (inter-firm level), eco-industrial parks and networks with positive impacts on both the regional economy and the natural environment are promoted, while at macro/national level both sustainable production and consumption activities are promoted with the aim of creating a recycling-oriented society.

For an initial set of indicators, China turned to the European system described above for indicators in the following four categories:

- **Input category**: (1) Direct Material Input (DMI), corresponding to the materials used as direct input into the production process; (2) Total Material Input (TMI), including both DMI and unused domestic extraction, and (3) Total Material Requirement (TMR), including indirect material flows in addition to TMI.

- **Consumption category**: Domestic Material Consumption (DMC), including the total material requirements for domestic consumption and Total Material Consumption (TMC), measuring the total amount of materials directly used in the economic system.

- **Balance category**: Net Additions to Stock (NAS) and Physical Trade Balance (PTB) are the main balance indicators. NAS can be used to measure growth in the physical stocks of the economy, while PTB represents the net inflow or outflow of physical materials.

- **Output category**: Domestic Processed Output (DPO) measures all out flows of used materials.

It was, however, noted that the above indicators derived from material flow analysis have limitations. Firstly, the necessary data may not be readily available; secondly, simple measurement by weight does not reflect effects on the environment and health which depend also on the characteristics of the material and the environments in which they are extracted or disposed (converting statistics in weight to environmental impact may thus be difficult and vary with circumstances). Thirdly, available indicators are recognised as failing to measure *reduction or prevention* of resource use or waste which is a critical part of the '3R' principle[11].

Following these considerations, a set of indicators has been derived in the four categories shown in Table 5.1. In addition, other indicators are applied to carbon emissions and ecological characteristics, as adopted by the Ministry of Environmental Protection.

5.2 Japan's recycle-oriented society and use of indicators

Japan introduced a basic legal framework for encouraging a circular economy 25 years ago, with the Law for Promotion of Effective Utilisation of

Table 5.1 Macro level circular economy indicators (Geng et al., 2012)

Category	Indicators used
1. Resource output rate	Output of main mineral resource, output of energy.
2. Resource consumption rate	Energy consumption per unit of GDP, energy consumption per added industrial value, energy consumption per unit of product in key industrial sectors, water withdrawal per unit of GDP, water withdrawal per added industrial value, water consumption per unit product in key industrial sectors, coefficient of irrigation water utilisation.
3. Integrated resource utilisation rate	Recycling rate of industrial solid waste, industrial water reuse ratio, recycling rate of reclaimed municipal waste water, safe treatment rate of domestic solid wastes, recycling rate of iron scrap, recycling rate of nonferrous metal, recycling rate of waste paper, recycling rate of plastic, recycling rate of rubber.
4. Waste disposal and pollutant emissions	Total amount of industrial solid waste for final disposal, total amount of industrial wastewater discharge, total amount of sulphur dioxide emissions, total amount of COD discharge.

11 3R is used in several countries' basic resource policy, generally referring to 'Reduce', 'Reuse', 'Recycle'.

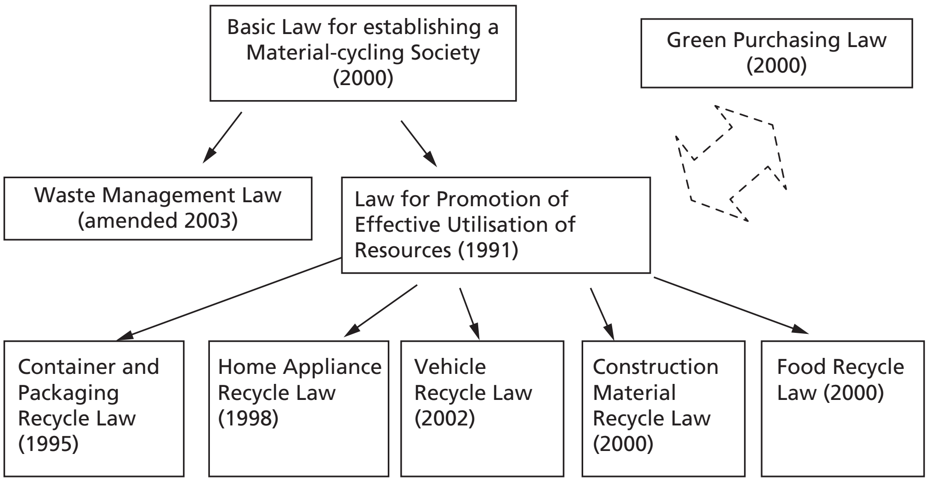

Figure 5.1 Japan's actions towards a 'sound material-cycle society'.

Table 5.2 Amounts recycled and recycling costs 2000–2014 (JCPRA, 2016)

Product	Volume of recycling in 2014 (tons)	Change since 2000 (%)	Recycling unit costs in 2014 (¥/kg)	Change since 2000 (%)
Glass bottles, no colour	146,563	–20.7	4.4	+4.7
Glass bottles, brown	123,216	+32.5	6.1	–22.8
Glass bottles, other	91,619	–6.1	8.7	+4.4
PET bottles	294,756	+150.2	1.5	–98.36
Paper	33,145	–26.8	14.0	–76.8
Plastics	743,835	+491.1	57.0	–37.4

Resources (1991). This was followed by a Basic Law for Establishing a Material-cycling Society (2000) and sector-specific legislation in subsequent years applied to recycling of cars, packaging, home appliances, construction waste and food wastes (see Figure 5.1). Comprehensive and consumer-friendly return systems which include prepayment for return and recycling at the point of purchase, and collaboration between manufacturers in recycling have delivered very high recycle rates for electrical appliances and overall 98% of its metals are recycled (MOEJ, 2010).

Indicators used in the Japanese context include measures of the efficiency with which resources are recovered, and are taken as indicators of whether the institutional implementation of recycling is cost effective. For instance, Table 5.2 shows trends in recycling rates and the costs of recycling the main waste streams[12].

Basic material flow analysis for the Japanese economy is published by the Ministry of the Environment and summarised in the Sankey diagram shown in Figure 5.2. This expresses the main flows by weight within Japan and between Japan and the rest of the world in a form that is easy for non-specialists to understand.

Japan also established three core indicators of resource productivity, material recycle rate and the weight of waste for final disposal, and set targets in each category. For instance, the 2015 targets were 420,000 yen of GDP per tonne of resources used (resource productivity); 14–15% for recycle rate; and 23 million tons for waste disposal. Looking at the achievements by 2010, resource productivity amounted to 374,000 yen per ton, cyclical use rate improved to 15.3%, and final disposal amount declined to 19 million tons. Targets have since been revised for 2020 to 460,000 yen GDP per tonne, 17% and 17 million tons respectively.

Japan also measures indicators of societal effort towards a circular economy, including the size of the market for rental and leasing of goods, results of surveys of consumer awareness and actions related to circularity, while other general indicators include per capita generation of municipal waste for consumers

[12] Recycling is organised by the Japanese Container and Package Recycling Association (JCPRA) which coordinates between government, municipalities and companies involved in collection and recycling processes. Consumers follow sorting and collection rules of each municipality, which contracts with recycling companies through competitive tendering. Recycling businesses receive a subsidy from the JCPRA which is funded from recycling fees levied on companies using containers and packaging. Recycling businesses only receive payment after confirming receipt of recycled products, ensuring recycling is completed and waste not diverted to lower-cost alternatives.

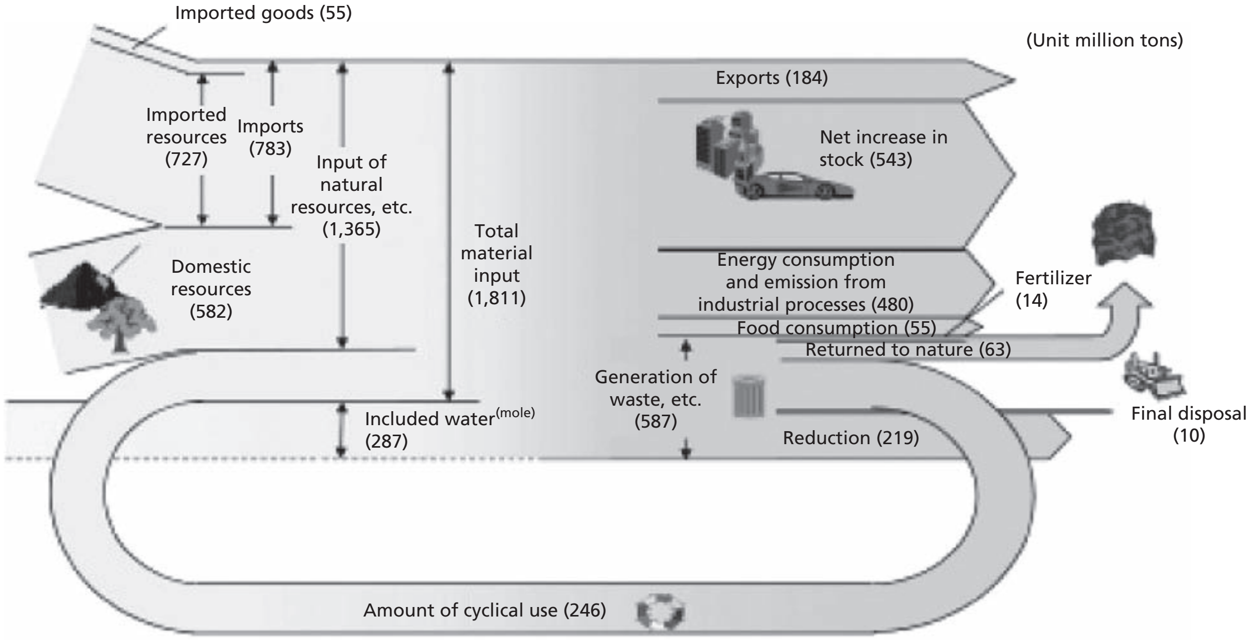

Figure 5.2 Material flows in Japan (2010) (MOEJ, 2013).

which amounted to 976 grams as of financial year 2010 (down 18% from 2000 relative to a target set for 2015 of a 20% reduction). Business waste amounted to 12.97 million tons (down 28% by financial year 2000) in 2010, meeting the target of a 20% reduction by 2000. The economic contribution of recycling is also monitored and the market size was estimated for 2010 at approximately 39 trillion yen (about 8% of GDP) with approximately 990,000 people employed (MOEJ, 2013).

6 Indicators for a European circular economy

Although far from exhaustive, the above overview shows the extent to which indicators with an environmental and resource perspective already exist. They can be grouped into the broad categories in Table 6.1, together with their relevance for the circular economy.

EASAC is conducting this study against the backdrop of the Commission's commitment to develop a set of reliable indicators for monitoring progress towards a circular economy (EC, 2015). The Commission notes that '*relevant data already collected by Eurostat can form a basis for this monitoring. In addition, the Resource Efficiency Scoreboard and the Raw Materials Scoreboard contain relevant indicators and analysis which will be particularly useful for tracking progress.* The Commission also committed to '*propose a simple and effective monitoring framework… include a set of key, meaningful indicators that capture the main elements of the circular economy. These will be published in connection with the Commission's reporting on the Sustainable Development Goals and will include new indicators on food waste and indicators based on existing Eurostat and other official data in areas such as security of supply for key raw materials, repair and reuse, waste generation, waste management, trade in secondary raw materials in the EU and with non-EU countries, and the use of recycled materials in products.*' Conscious of the need to minimise administrative and economic burdens, the emphasis is expected to be on indicators already available or easy to derive from existing reliable and comparable data, relevant for monitoring the circular economy policy.

The question already under consideration is what basic criteria should be applied in selecting indicators? Here EASAC wishes to emphasise some basic principles.

Links with sustainability. The Commission places the circular economy indicators in the context of sustainable development goals, specifying that '*This action plan will be instrumental in reaching the Sustainable Development Goals (SDGs) by 2030*'. Indeed as pointed out in our earlier statement, the circular economy is a means to enhancing sustainable well-being, rather than an end in itself (EASAC, 2015) and thus closely connected with SDGs. Principles for selecting sustainable development

Table 6.1 Broad classifications of current indicators potentially relevant to the circular economy

Indicator type	Examples	Availability of data	Relevance to the CE
Sustainable development	Social economic development, sustainable consumption and production, social inclusion, demographic changes, public health, climate change and energy, sustainable transport, natural resources, global partnership, good governance (Table A2)	Voluntary based reporting via EU Directorate-General for Energy (focused), European Sustainable Development Network (ESDN); corporate sustainability indicators (e.g. carbon disclosure)	Natural resources, sustainable consumption and production
Environmental	Agriculture, air pollution, biodiversity, climate change, energy, fisheries, land and soils, transport, waste, water	Regulatory based reporting via EEA cores indicators and country-specific statistics	Waste generated, packaging waste generation and recycling
Material flow	Domestic extraction, direct material consumption, domestic material input, physical trade balance, net additions to stock, domestic processed output, total material requirement, total domestic output	Eurostat, SERI	All
Societal behaviour	Sharing, municipal waste recycle, waste generated per capita (total and segregated), environmental/resource taxation	National and voluntary organisation statistics	All
Organisational behaviour	Material flow accounting in organisations, remanufacturing, use of recycled raw materials, eco-innovation, per capita statistics (e.g. reduction in waste generation per capita)	Private sector voluntary reporting via EU Forum for Manufacturing; ZVEI (German Electrical Industrial Association); VDMA (German Engineering Federation); etc.	All
Economy performance	Resource productivity, recycling industry, green jobs, waste generation/GDP, 'transformation of the economy'	Eurostat EU Resource Efficiency Scoreboard	All

indicators have already been proposed (Bellagio Principles; IISD, 1997). These, *inter alia*, recognise the relevance of the selection process, which should as much as possible reflect *the specific policy targets and objectives* and respect the accounting conventions underlying the System of National Accounts (SNA) and the more recently-developed System of Integrated Environmental and Economic Accounts (SEEA).

While currently direct links between the CE Action Plan and SDGs are limited, the Commission is right to see potential for synergy between CE indicators and SDGs as a factor to be considered in the selection of indicators. Moreover (Chapter 2 and Annex 2), owing to the linkages between the circular economy, human well-being and sustainable development, the indicators for monitoring progress towards a more circular economy can be included in the wider debate on developing alternatives to GDP, where the Commission's CE indicators, 'Beyond GDP', Sustainable Development Indicators and Environmental Pressure Index actions are involved.

Links with policy. The Bellagio Principles suggest that indicators should be linked to specific policy objectives and have the effect of supporting and driving those objectives. Setting regulatory targets based on new indicators has significant implications and care thus needs to be taken to ensure that the indicators are appropriate to the policy objectives, since they may have unintended consequences. For instance, EU legislation such as the end of life vehicle directive and the WEEE directive were developed in the 1990s with a major motivation to avoid hazardous emissions and recover mass materials such as steel and plastics. However, the recovery of critical materials has now assumed a much higher priority. Such metals (platinum, palladium, rare earths, etc.) are present in only very small quantities which are insignificant compared with the figures in mass-based recycling targets (e.g. 80% of the weight of the car needs to be recycled). By not recognising the importance of critical materials present at low levels, achieving such broad recycling targets can lead to losses of technology-critical metals (Hagelüken, 2014). In particular, as we point out in our report on critical materials (EASAC, 2016), there is a substantial leakage of critical materials from the EU through WEEE. EASAC thus shares the view of the Raw Materials Scoreboard (EIPRM, 2016) that WEEE management should be included in circular economy indicators, with indicators compatible with a product-centric approach to collection and recycling (EASAC, 2016).

Public communication and impact. The effectiveness with which indicators communicate with the key stakeholders in society (particularly companies, municipalities and individuals) is also important. One aspect is their use in public communication to raise awareness of performance and potential for circularity. This is particularly important since public attitude and behaviour may determine the extent to which policies are effective. As we pointed out earlier, some pictorial methods such as the use of Sankey diagrams can be particularly effective (chapter 5.2). Another pictorial approach could be the distribution of different types of recycling facilities within the country. Such a map of recycling infrastructure would not only inform citizens about the state of their own society but also identify gaps which could offer opportunities for businesses (for example where there is a lack of recycling facilities for key materials). Our parallel report on critical materials (EASAC, 2016) emphasises the importance of a critical materials infrastructure which could also serve as an indicator of a country's performance on key aspects of the circular economy. Furthermore, since cost considerations feature prominently in the public debate, data such as that published in Japan on cost reduction and economic benefits of circular activities could also be valuable in conveying positive economic outcomes (employment, CE-related business activity, etc.) As EURES also suggests (Chapter 4), indicators should also provide insights and raise public awareness on the global effects of EU production and consumption.

Industry compatibility. As emphasised in EEA (2015), CE indicators should harness existing environment/sustainability-related compliance data, or those included in sustainability reporting, so as not to add to the demands placed on businesses. Indicators must also facilitate and not impede transition to a circular economy, and encourage innovative solutions to eliminate or significantly reduce waste impacts[13]. It is also necessary to recognise that advances in technology could reduce the relevance of some historical indicators. For instance, information and industrial technologies allow the creation of circular economy business approaches which were previously not possible- such advances allow more efficient collaboration and knowledge sharing, better tracking of materials, improved forward and reverse logistics set-ups, as well as increased use of renewable energy[14]. Such systems allow transformation of the previous linear model to take account of and prioritise efficiency for material throughput in production.

Indicators for industry thus have a double challenge: first they must objectively measure progress towards the overall objectives of a CE but secondly in a way that does not impede businesses from taking the

[13] This also relates to the need to ensure definitions of 'waste materials' versus secondary raw material /off-cuts, etc. do not impede use of recycled materials.

[14] Such '4th generation' industry combines big data, intelligent machines, sensors, artificial intelligence to reshape the entire process from design to final delivery to customer. As one example, a Siemens '4th generation factory' produces seven times as much product in the same area as 25 years ago with associated reductions in water, energy and materials waste. Defects have also been reduced by 98% over the same period.

most efficient path. Indicators designed for traditional industrial production models (e.g. on the basis of waste per product or waste per unit of raw material) should ensure that they are flexible enough to record and encourage circular economy-related innovation, and able to adjust for such innovations as they occur.

EASAC shares the Commission's vision of 'design for circularity' aimed at keeping materials in a closed loop, but notes that there may be complex trade-offs between different approaches used in circularity. For instance, refurbishing and remanufacturing needs to consider the total energy and materials consumed over the lifetime of a product. In most cases, it should reduce energy and materials consumption if a product is remade from re-usable parts at the end of its life. However, innovation cycles (supported by the EU Horizon 2020 work programme 'Industry 2020 in the Circular Economy') are getting shorter so newer technology that is more efficient from an energy point of view may sometimes be the better choice over refurbishing or remanufacturing. This highlights a need for strategic design planning for product manufacture in a CE, for instance making it easier for replacement technology to be installed into older models at the design stage.

As noted in our report on critical materials (EASAC, 2016) however, trends driven by consumer convenience and demand, together with design optimisation for mass production (EIPRM, 2016), continue to introduce additional burdens to repair and recycling rather than facilitating the process. For instance, the continued trend towards miniaturisation of computers and other electronic equipment depending on gluing rather than detachable fixtures only adds to the difficulty of reusing or recovering materials or parts. Many of the procedures required to separate (e.g. a screen from the body of a mobile phone) are proprietary information which is unavailable to smaller independent repair shops, so that repair can only be offered by the manufacturer at prices close to those of a new product, discouraging repair. The Commission should engage major manufacturers in a dialogue on ways of reducing or eliminating these inherent conflicts with a circular economy; for instance, by encouraging 'design for resource efficiency' to become standard practice, and by encouraging manufacturers to share key information on disassembly with repair businesses to reduce costs. Such factors connect with the issue of extended producer responsibility (EPR), which the Commission has also undertaken to review and develop minimum operating requirements for EPR schemes. Design to reduce environmental impacts and the generation of waste is one contributor to waste prevention, which the Commission also recognises as an activity which requires uniform measurement and common indicators.

A further important issue in encouraging recycling and reuse is the conditions which are applied to defining secondary raw materials as having ceased to be waste. Currently regulations have been issued for only three types (scrap metals, glass cullet and copper scrap), and the Commission appears to recognise this should be improved. An indicator which showed the extent to which waste was being transformed to 'end-of-waste' secondary raw materials would allow this important basic activity of the circular economy to be illuminated.

Comparability. A further practical consideration is to recognise the different starting points between EU countries. EEA (2011) conducted a survey including 25 countries of the EU27, and showed that there is no clear definition or common understanding of key resource efficiency terminology, with some countries' responses indicating that they have difficulty interpreting basic concepts such as 'resource efficiency'. The survey found that countries interpret resource efficiency quite broadly, and only five countries define 'resources' in their strategies. Introducing new requirements for indicators thus has to recognise these different starting points and allow for some normalisation of parameter values. For instance, the Competitiveness Report 2014 (EC, 2014a) shows that energy intensity varies by a factor of five across Member States. Drawing any conclusions from such comparative data would need to recognise that a country`s energy consumption is affected by its average temperature, transport-related energy consumption by population density; such factors need to be considered to allow objective comparison between performance in Member States.

Special case of water. In the Chinese case study above (section 5.1), water use and reuse was included in the circular economy indicator set. In the EU, it was estimated that the total volume of reused treated wastewater in 2006 amounted to 964 Mm^3 a year, accounting for just 2.4% of the treated urban wastewater effluents (Hochstrat *et al.*, 2006), with Spain and Italy among the highest reuse levels (36% and 24% respectively). There is thus significant potential for increasing the levels of water reuse in the EU, with climate change pressures likely to increase the need to both mitigate wastewater disposal impacts and reduce susceptibility to shortages especially in droughts (Falloon and Betts, 2010). The Commission's 2012 Water Blueprint (EC, 2012), looks at policy options to optimise water reuse in the EU, and has stimulated work by Directorate-General for Environment and the EEA to fully implement water resource assets accounting. The EEA is evaluating appropriate methodologies (EEA, 2013), although it points out that '*building hydrologically consistent water accounting to usefully address the balance between resource and uses is a very complex task*'. Indicators currently in use include the Falkenmark water stress indicators, and the Water Poverty Index which integrates water scarcity issues and socio-economic aspects (Sullivan, 2002). In addition, one watershed sustainability index has been devised to take into account hydrologic, environmental, livelihood and policy issues and provide an integrated assessment of watershed management in a given basin for a specific period of time (Chavez and Alipaz, 2007). Including water in material flow analyses distorts the material flow figures owing to the large quantities used (both in human and ecosystem uses), and thus MFA accounts generally include flows *into* water (e.g. emissions of pollutants to water) rather than the weight of water itself. Water use is usually captured in separate water resource accounts, as part of a country's overall environmental accounts. EASAC recognises the importance of proper water accounting and maximising potential for reuse, and considers that an appropriate indicator for water should be included in the indicator sets for the circular economy. In this context, we note that water use is one of the 24 indicators advocated in the Raw Materials Scoreboard.

Finally, the issue of **boundaries** is relevant to the selection of indicators. As demonstrated in Chapter 3 (Figure 3.3), much of the environmental burden of resource consumption within the EU is borne by raw material supplier countries outside the EU. These hidden flows are not included in the basic material flow statistics and raise the question of whether this should be taken into consideration when measuring the EU's performance through material flow analysis. Furthermore, where the most cost-effective approach to recycling may be outside the country of origin, indicators need to take this into account.

The above provides several different perspectives for consideration as the Commission implements its commitment on indicators. Specific points which EASAC emphasises[15] are as follows:

- Likely sources of indicators include the material flow accounts and/or those in the European Resource Efficiency Scoreboard indicators (Chapter 4). Indeed, at the macro-level, resource productivity has already assumed the role of a headline indicator, as shown in the Japanese and Chinese case studies. This is also seen as indispensable to meeting climate change targets cost-effectively and essential to meeting Sustainable Development Goals, 12 of which directly depend on the sustainable economy-wide management of a whole range of natural resources (Ekins and Hughes, 2016). Resource productivity improvement is, however, only an indication that output is growing more than resource use and emissions, and separate measures are required to provide information on environmental pressures in absolute terms.

- Obvious candidates for indicators are the targets in various directives related to waste and recycling (Table 4.4) but rather than adopting separate indicators for each category in each directive, a composite indicator expressing the degree to which EU Member States were reaching the directives' targets could be considered.

- Basic material flow indicators give equal weight to all materials without factoring in different material values. In complex recycling systems that involve a trade-off between outputs of different materials from mixed waste streams, it may be counter-productive to use simple performance standards, such as mass or percentage of a single material. In metals recycling, this approach may lead to waste of high-value metals (UNEP, 2013a; Hagelüken, 2014).

- A primary criterion for selection as an indicator is a direct link with policy. Indicators should be managed in such a way as to support policy objectives and help to drive change towards those policy objectives. It may be desirable to have more industry sector or critical element-specific indicators, in consultation with industry.

- Indicators related to materials should not be seen in isolation from other key indicators, particularly energy. A basic philosophy should be to consider energy and materials efficiency as equally important in the economy. The current tendency to measure efficiency by energy alone should be supplemented by materials efficiency, not only at the macro-level but also at individual product level. For instance, the reduction in environmental footprint of innovative products such as a LED over its life-cycle should balance the improvement in energy efficiency with material efficiency and consider the extent to which critical materials are recovered.

- A fundamental rationale for the circular economy is that it not only addresses the underlying environmental and resource issues but also '*boosts global competitiveness, fosters sustainable economic growth and generates new jobs*'. Circularity implies reversing the strategies of some manufacturing sectors of 'built-in obsolescence' and 'fast fashion' intended to safeguard future demand, and compensating for this by developing new activities related to the circular economy and 'green' growth. This should inform the choice of indicators; for instance, data such as those published in Japan on cost reduction and

[15] And which are in line with the concept of R.A.C.E.R., i.e. that indicators should be relevant, acceptable, credible, easy and robust.

economic benefits of circular activities is desirable in conveying positive economic outcomes (employment, CE-related business activity, etc.). This is recognised in the Commission's initial proposals which note that indicators could include behavioural indicators (for instance the growth of repair or shared use), as well as indicators monitoring the growth of employment in reuse, repair, recycling and other related activities. Other possible indicators include infrastructure (e.g. accessibility to recycling and reuse centres), human resources (e.g. level of repairing skills), or changes in business models (e.g. making durable and repairable equipment, remanufacturing).

- Potential impact with industry should be a critical consideration. From an industry point of view, indicators need to be based on information which industry already collects for other purposes. One option advocated by some in the recycling industry is that economics rather than simple legislation-imposed rates should drive recycling (UNEP, 2013a), as legislation cannot capture fully the complexity of a recycling system. Economics-based and environmentally benign key performance indicators (KPI) could be considered. In such cases, rather than industry having to achieve a mandated performance target, policy and industry need to create the conditions and incentives that facilitate high performance and use of Best Available Techniques (BAT). Hagelüken (2014) suggests that the summed value of recycled outputs from a process allows for whether the valuable materials were successfully recycled and provides an indication whether policy and industry have successfully created the conditions and incentive structures that facilitate high performance.

- The Commission needs to monitor the performance of markets in the recycling business and address regulatory barriers such as those related to transforming waste into secondary raw materials. An indicator which showed the extent to which waste was being transformed to 'end-of-waste' secondary raw materials would allow this important basic activity to be illuminated.

- A final criterion for circular economic models is that the indicators used should reflect the cyclic and more complex non-linear behaviour of the economy, where some indicators may show positive progress when their values are decreasing and others a regression. Thus a decrease of the quantity of resources taken from the environment, waste generated or greenhouse gas emissions would be a positive trend, whereas a decrease in recycle rate or extent of reuse would be a negative trend. One option would be to combine current linear indicators in a formula that would convey circularity trends clearly. Such composite indicators of the progress being made by industry would enable transparency and indicate bottle-necks for improvements so that market innovation can take hold to help develop a 'Smart Reindustrialised Europe', through the CE model. Statisticians already use combined/aggregated linear economy indicators based on division of pairs of simple indicators (energy per capita, energy/GNP, carbon dioxide emissions per capita, etc.). However, for a circular economic model, indicators should better reflect the inter-correlation between the various dynamic fluxes of positive and negative

Box 1 An illustration of a potential composite indicator

One possible combination would be as follows:

- energy productivity (GDP/total primary energy supply) where larger values are associated with progress;
- GDP per capita (GDP/population): the present indicator for progress;
- the rate of resource recycling (recycle rate as a percentage): improved recycling would increase this indicator
- divide by the amount of carbon dioxide emissions, so reducing emissions would increase the indicator.

According to the formula

$$\frac{\text{GDP} \times \text{GDP} \times \text{recycle rate}}{\text{TPES} \times \text{population} \times CO_2 \text{ emission}}$$

Using data from IEA (2013) (except for the recycling rate), results in the following.

Country	Population	GDP (trillion US$)	TPES (toe per capita)*	CO_2 emissions (Mt CO_2)	Recycle rate (%)	Composite indicator value†
USA	314.3 M	14.232	6.8	5,074	37	2.2
Germany	81.9 M	2.851	3.8	755	45	19.01

*TPES, total primary energy supply; toe, tonnes of oil equivalent. †The composite indicator value is given as 10^8 US dollars per capita per tonne of oil equivalent of carbon dioxide.

trends. Demonstrating trends may be achieved by using a formula that would include positive evolution indicators (e.g. GDP) at the nominator (a positive trend if they increase) and negative evolution indicators at the denominator (a positive trend if they decrease). This way the complex indicator would increase if evolving trends are positive (e.g. high GDP, low waste) and decrease in the opposite case. An example is given in Box 1, where this composite indicator shows very clearly the extent to which the German economy is more efficient in energy and materials use relative to the USA. While EASAC is not suggesting any specific composite indicator, it does recommend that the Commission explore, together with stakeholders, the concept further to aim at a credible and easy to understand indicator of circularity.

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Glossary

BAT	Best available techniques
CE	Circular economy
COD	Chemical oxygen demand
CSI	Core Set of indicators
DE	Domestic extraction
DMI	Direct material input
DPO	Domestic processed output
EASAC	European Academies' Science Advisory Council
EEA	European Environment Agency
EC	European Commission
EIONET	European Environment Information and Observation Network
EIP	European Innovation Partnership
EMF	Ellen MacArthur Foundation
EPI	Environmental Performance Indicator
EPR	Extended producer responsibility
EREP	European Resource Efficiency Platform
ESDN	European Sustainable Development Network
ESI	Environmental sustainability index
EURES	EU Resource Efficiency Scoreboard
EURMKB	European Union Raw Materials Knowledge Base
EW-MFA	Economy-wide material flow analysis
DMC	Direct material consumption
DMI	Domestic material input
GDP	Gross domestic product
GNI	Gross national income
GRI	Global reporting initiative
GPI	Genuine progress indicator
HDI	Human development index
ISEW	Index of sustainable economic welfare
JCPRA	Japanese Container and Package Recycling Association
KPI	Key performance indicator
LCA	Life cycle assessment
MOEJ	Ministry of the Environment Japan
NAS	Net additions to stock
OECD	Organisation for Economic Cooperation and Development
PM	Particulate matter
PTB	Physical trade balance
RMC	Raw material consumption
RME	Raw material equivalents
RP	Resource productivity
SCP	Sustainable consumption and production
SDG	Sustainable development goal
SDI	Sustainable development indicators
SEEA	System of integrated environmental and economic accounts
SNA	System of national accounts
SERI	Sustainable Europe Research Institute
TDO	Total domestic output
TEEB	The Economics of Ecosystems and Biodiversity
TMI	Total material input
TMR	Total material requirement
TMC	Total material consumption
toe	Tonnes of oil equivalent
TPES	Total primary energy supply
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
VDMA	German Engineering Federation
VOC	Volatile organic compounds
WEEE	Waste Electric and Electronic Equipment
ZVEI	German Electrical Industrial Association

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Annex 2 Debate over indicators: GDP versus possible replacement indicators

The inherent strengths and weaknesses of GDP have been debated almost since it was adopted as the international standard for measuring economic progress in the aftermath of the Second World War, attracting the attention of many distinguished economists (Samuelson, Nordhaus, Dasgupta, Hamilton, Löfgren, Mäler to name just a few[16]). Even before its adoption, its author (Kuznets, 1934) had pointed out it was not for measuring social well-being: on the basis of market transactions, it provides a monetary measure of the value of all final goods and services produced in a given period of time. It does not take into account social costs, environmental impacts and income inequality, as recognised by many environmental economists and politicians[17]. Despite this, GDP remains the headline indicator against which economies' performance tends to be assessed.

As observed by Constanza *et al*. (2014), in 1944 there was a clear societal relevance for its use. After the Second World War, economic growth was strongly related to income and employment. However, rapid demographic and economic growth has multiplied pressures on society and the environment. Many attempts have thus been made to design an indicator more accurately capturing social and environmental trends. As pointed out by the Commission on Economic Performance and Social Progress (Stiglitz *et al*., 2009), there are two relevant aspects to this debate. Firstly, well-being[18] assessment involves non-economic aspects of peoples' life (quality of personal life, and the natural environment in which they live). Secondly, it involves inter-generational sustainability (whether levels of well-being can be sustained over time), which depends on whether stocks of capital that matter for our lives (natural, physical, human, social) are passed on to future generations.

A basic characteristic of GDP is that it does not take into account negative externalities associated with some

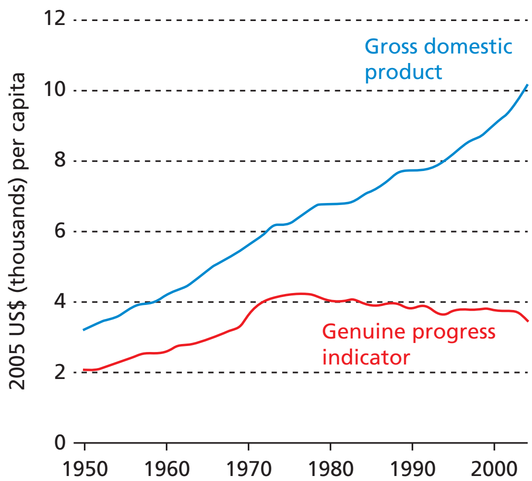

Figure A1 Separation of trends in GDP and GPI (after Kubiszewski et al., 2013).

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16 There are too many to mention in this short annex, but Nordhaus and Tobin (1972), Dasgupta (2001), Weitzman and Löfgren (1997) and Zolotas (1981) were some of the earliest detailed analyses. Eisner (1988) provides a comprehensive review.
17 For instance Robert Kennedy is quoted as saying in 1968 that GDP measures 'Everything except that which makes life worthwhile'.
18 This Commission identified eight components of well-being. These were (1) material living standards (income, consumption and wealth); (2) health; (3) education; (4) personal activities including work; (5) political voice and governance; (6) social connections and relationships; (7) environment (present and future conditions); (8) insecurity, of an economic as well as a physical nature.

Table A1 ***Alternatives (or additions) to GDP indicators in use or development***

Alternative indicator	Abbreviation	Reference	Aspects/issues covered
Better Life Index	BLI	OECD http://www.oecdbetterlifeindex.org/about/better-life-initiative/	Housing, income, jobs, community, education, environment, civic engagement, health, life satisfaction, safety, work–life balance
Ecological Footprint		WWF / Global Footprint Network http://www.footprintnetwork.org/en/index.php/GFN/page/footprint_basics_overview/	The impact of human activities measured in terms of the area of biologically productive land and water required to produce the goods consumed and to assimilate the wastes generated
Environmental Pressure Index	EPI	SERI http://alt.seri.at/en/projects/completed-projects/environmental-pressure-index/	A composite indicator that describes the pressure for the environment on the EU territory. Includes indicators of quality of life, integrated strategies, energy and climate, resource use, economy, global responsibility, consumption and production, communication
European Environment Agency Core Set of Indicators	EEA CSI	EEA (2005) http://www.eea.europa.eu/publications/technical_report_2005_1	Air pollution and ozone depletion, climate change, waste, water, biodiversity and terrestrial environment in four sectors (agriculture, energy, transport and fisheries)
Genuine Progress Indicator	GPI	rprogress.org/sustainability_indicators/genuine_progress_indicator.htm	Incorporates environmental and social factors which are not measured by GDP. Includes indicators of resource depletion, pollution, and long-term environmental damage. Social indicators include costs of crime, family breakdown. GPI calculated according to: GPI = A + B - C – D + I (A is income weighted private consumption; B is value of non-market services generating welfare; C is private defensive cost of natural deterioration; D is cost of deterioration of nature and natural resources; I is increase in capital stock and balance of international trade)
Gross National Happiness Index	GNHI	http://www.grossnationalhappiness.com/	Housing, income, jobs, community, education, environment, civic engagement, health, life satisfaction, safety, work-life balance
Happy Planet Index	HPI	http://www.happyplanetindex.org/about/	The product of life expectancy and life satisfaction divided by ecological impact
Human Development Index	HDI	UNDP http://hdr.undp.org/en/content/human-development-index-hdi	Life expectancy, education, per capita gross national income
Index of Sustainable Economic Welfare	ISEW	Daly and Cobb (1989)	Precursor to GPI and similar indicators
Sustainable Development Indicators	SDI	EU Commission http://ec.europa.eu/eurostat/statistics-explained/index.php/Sustainable_development_indicators_introduced	Social economic development, sustainable consumption and production, social inclusion, demographic change, public health, climate change and energy, sustainable transport, natural resources, global partnership, good governance
World Values Survey	WVS	www.worldvaluessurvey.org	Support for democracy, tolerance of foreigners and ethnic minorities, support for gender equality, the role of religion and changing levels of religiosity, the impact of globalisation, attitudes towards the environment, work, family, politics, national identity, culture, diversity, insecurity, and subjective well-being

Box A1 Indicators under consideration in the Beyond GDP project

Enlarged GDP

Enlarged GDP indicators start from GDP (or other figures from the System of National Accounts) but adjust for some of its shortcomings to deliver a more comprehensive overview of a country's wealth or well-being

Social indicators

Social indicators give insights into a broad range of social issues, concerns and trends such as life expectancy, poverty rates, unemployment rates, disposable income, and education levels, etc. Many social indices combine several areas to better illustrate the overall social progress of nations

Environmental indicators

Environmental indicators cast light over the state and development of the environment and related issues such as human health. These indicators can give information about very specific and local matters, such as water pollution or solid waste generation. They can also be used to gauge more general environmental matters at the global level such as climate change and the human ecological footprint

Well-being

Well-being indicators are used to broadly illustrate people's general satisfaction with life, or give a more nuanced picture of quality of life in relation to their jobs, family life, health conditions, and standards of living. Subjective measures are based on self-reporting by individuals, which makes it possible to capture direct measures of high complexity such as life-satisfaction. Objective measures look at indicatory variables, such as leisure time, marital status, and disposable income

Table A2 Headline indicators of the sustainable development indicator (SDI) set in EU countries (Eurostat, 2015b)

SDI theme	Headline indicator
Socio-economic development	Real GDP per capita
Sustainable consumption and production	Resource productivity
Social inclusion	People at risk of poverty or social exclusion
Demographic changes	Employment rate of older workers
Public health	Life expectancy and healthy life years
Climate change and energy	Greenhouse gas emissions, and primary energy consumption
Sustainable transport	Energy consumption of transport relative to GDP
Natural resources	Common bird index
Global partnership	Official development assistance
Good governance	None

activities. Thus catastrophes such as the Fukushima disaster in Japan, the Deepwater Horizon spill in the Gulf of Mexico and hurricane Sandy all contributed positively to GDP. Moreover, it equally treats activities to which society associates a positive (e.g. building a hospital or school) and negative value (e.g. criminal activities). Some activities (e.g. volunteering) and personal conditions (e.g. being healthy) with a positive social recognition are not taken into account. Some social issues are even blamed on the use of GDP (Constanza *et al*., 2014), such as social problems associated with increasingly unequal income and wealth distribution, the depletion of natural resources, and critical environmental issues yet to be solved (including climate change). The emphasis on GDP in developed countries is also seen as preventing developing countries from adopting more-sustainable development models.

Many alternative measures of progress have been devised. Some of them (the Index of Sustainable Economic Welfare, ISEW, and the Genuine Progress Indicator, GPI) adjust GDP to incorporate social and environmental factors, for example the benefits from volunteer work, the costs of divorce, crime and environmental pollution. The GPI also weights income marginal increase by income group (a 1 unit income increase has a bigger weight for low income people than for high income people). GDP and GPI per capita of 17 considered countries show a divergent trend since the 1970s (Figure A1).

Other approaches to measuring people's well-being are based on surveys. The World Values Survey (WVS) is based on a survey involving 70 countries and includes questions about personal satisfaction. Composite indicators have also been proposed. For instance, the Gross National Happiness index, used in Bhutan to measure people's happiness in nine domains, and the Happy Planet Index, which combines life satisfaction and life expectancy with a measure of ecological impact (NEF, 2006). The OECD has also developed a 'Better Life Index', resulting from indicators covering a range of variables and weighted in a flexible way. These and other examples of alternative (or supplementary) indicators in use around the world today are listed in Table A1.

The state of progress towards a replacement for GDP has been reviewed by Heal and Kriström (2005) and van den Bergh and Antal (2014). The latter examined ISEW and GPI as two primary candidates and considered three other groups of indicators[19], but concluded that comparing these with GDP reveals that none has yet succeeded in systematically repairing the shortcomings of GDP, and that an ideal indicator of social welfare has yet to be developed.

The European Commission supports an initiative 'GDP and beyond- Measuring progress in a changing world' (EC, 2009) which summarises potential adjustments or replacements for GDP (see Box A1). This is in parallel with the United Nations Development Programme (UNDP) having developed a Human Development Index (HDI) to benchmark countries on the basis of the combined measurement of GDP, health and education.

Related to the Beyond GDP initiative, the European Environment Agency (EEA) has established a core set of indicators (CSI) to measure environmental effects and these have been approved by EEA member countries and are regularly updated (EEA, 2005). Together with the European Environment Information and Observation Network (Eionet), these provide a manageable and stable basis for indicator reporting by the EEA, and for the EU's contributions to other European and global indicator initiatives, e.g. structural indicators and sustainable development indicators. The core set covers six environmental themes (air pollution and ozone depletion, climate change, waste, water, biodiversity and terrestrial environment) in four sectors (agriculture, energy, transport and fisheries).

Work has also progressed at Eurostat towards extending national accounts to key aspects of sustainable development using the set of sustainable development indicators in Table A2 (Eurostat, 2015b).

The Commission has also launched a pilot version of an index on environmental pressure which reflects pollution and other harm to the environment within the EU (SERI, 2015). A fall in the value of the index will show that progress on environmental protection is being made and includes the following:

- climate change and energy use;
- nature and biodiversity;
- air pollution and health impacts;
- water use and pollution;
- waste generation and use of resources.

This index will initially be published annually for EU and Member States with the longer-term aim being to publish it in parallel with GDP. The Commission will also continue to work on indicators that capture the environmental impact outside the EU (e.g. indicators to monitor the Thematic Strategy on Sustainable Use of Natural Resources[20]).

Specific reviews of potential indicators have also been conducted under the auspices of sustainable consumption and production (SCP) which requires data which may be relevant to the circular economy. For instance the EEA analysis of environmental pressures from European consumption and production (EEA, 2013) drew on physical flow accounts on air emissions (including greenhouse gases) and on material consumption, as well as data on environmental protection expenditure and taxes. It also proposes that physical environmental accounts could be set up for energy consumption, waste generation and treatment, and monetary accounts for environment-related subsidies. It is also hoped that initiatives such as TEEB (The Economics of Ecosystems and Biodiversity) will allow physical environmental accounts to be correlated with monetary figures, on the basis of valuation of the damage caused and prevented, changes in the stock of natural resources and in ecosystem goods and services.

[19] One starts from GDP but focuses entirely on environmental externalities and natural resource depletion to give a 'sustainable' or 'green' GDP indicator. Other approaches include 'Genuine savings/investments' and composite indicators.
[20] Thematic Strategy on the sustainable use of natural resources. Brussels, 21.12.2005 COM(2005) 670.

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