commentary

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Circular economy: a commentary from the perspectives of the natural and social sciences

Summary

In May 2015, the European Academies' Science Advisory Council (EASAC) started a review of issues related to the 'circular economy'. The circular economy involves many aspects of science, technology and social science but this commentary is intended to contribute to the debate between stakeholders on the principles and objectives of the European Commission's policy. This has been compiled by a Working Group of scientists and economists nominated by member academies of EASAC.

This commentary provides background on natural and social science aspects relevant to policy devlopment on the circular economy; it may be used to inform debate on the principles and broad approach to the circular economy. It reviews the benefits foreseen for a circular economy and potential risks for the transition phase. In a world of increasing population and per capita consumption where existing levels of consumption of resources are already well above sustainable levels, improving the efficiency with which humanity uses resources is a priority. However, barriers that stand in the way of a transition to a circular economy are substantial and increased by some current trends in corporate and consumer behaviour. EASAC accepts the rationale for, and potential qualitative benefits of, the circular economy. However, there are uncertainties over models used in quantifying the benefits, and questions remain over transition to a circular economy. Further research options to reduce these uncertainties are identified.

Underlying the barriers to shifting from a linear to a circular economy is the failure of current pricing systems to fully integrate all costs (including social and environmental costs), which means that pricing systems are failing to transmit the necessary information to inform individual decisions. A research priority is thus to increase the pace at which these external costs can be introduced. Until this failure is remedied, rules and regulatory instruments may be unavoidable, but need to be carefully designed, taking into account fields of behavioural economics, and providing sufficient flexibility to allow companies to respond in the most efficient ways and to respond to rapid changes in technology and associated effects on product life cycles.

The potential impact of a circular economy on international competitiveness is also considered. There is potential for improved competitiveness and new markets, but there are also potential disadvantages from an economic theory perspective where policies for a circular economy are applied only within the European Union. It is thus important to ensure that these policies are also fully embraced in international trade negotiations, and the United Nations policy process involving Sustainable Development Goals.

This commentary also briefly considers other issues including evaluating scarcity, eco-design and potential indicators for a circular economy, which will be examined in later stages of this project.

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1 Background and scope of this commentary

1.1 *From recycling, resource efficiency to a 'circular economy'*

The circular economy concept can be traced back many decades. In making the case for a circular rather than linear flow of material resources in the economy, Boulding (1966) drew an analogy from manned space exploration by advocating a shift from the 'cowboy economy' (endless frontiers/resources and the ability to move on and abandon problems) to the 'spaceship economy' where limited resources had to be reused and recycled as a precondition to sustainable life-support systems. The concept has since been developed at a theoretical level and as part of environmental economics by many authors (for example Smith (1972), Mäler (1974) and Dasgupta and Heal (1979)).

Measures to promote some of the central features of the circular economy have also started to be implemented. In the 1990s, concerns over environmental impact of waste, security of supply, and limits on the land available for disposal led to an increased emphasis on recycling in several countries. Japan introduced a range of measures over 15 years ago to mandate recycling of certain categories of goods and launched a 'Plan for establishing a sound material-cycle society' in 2003[1]. Other countries have introduced similar measures and the European Union (EU) has introduced measures to encourage recycling of certain categories such as electronic waste[2]. Recycling of other major categories remains the responsibility of governments of EU Member States and varies considerably (for example the recycling rate for municipal waste ranges from 3% to 46% (EEA, 2013)).

Following the interest in 'green growth' after the financial shock of 2008 (OECD, 2010), resource productivity/efficiency (doing more with less) attracted increased attention and the European Commission (EC) developed a vision of a 'Resource Efficient Europe' (EC, 2011a), as an important part of the 'Europe 2020 Strategy'. An analysis in 2011 laid out a 'Roadmap to a Resource Efficient Europe', which concluded that greater efficiency in the use of resources was critical not just for environmental reasons but also for competitiveness, employment and resource security (EC, 2011b). In addition, a High Level Group was established which led to the European Resource Efficiency Platform (EREP); this issued a manifesto for a resource-efficient Europe and policy recommendations (EREP, 2013).

Such measures are now generally seen as part of a move towards a 'circular economy' to replace the current 'linear economy', which is based on extracting resources from the Earth, using them in production, selling products to consumers, and treating discarded products as waste (the EC calls this 'take–make–consume–dispose' but it is also referred to as 'cradle to grave'). In contrast, a circular economy seeks to maximise the value obtained from natural resources, is restorative or regenerative by design, and aims to eliminate waste through design of materials, products, systems and business models (EMF, 2011).

The EC developed detailed proposals for a circular economy[3] in 2014 (EC, 2014), on the basis of supporting studies which suggested that improving resource efficiency along value chains could reduce overall material inputs by 17–24% by 2030, and save up to €630 billion per year for European industry. The EC (2014) cited business-driven studies based on product-level modelling which saw significant material cost saving opportunities for EU industry from circular economy approaches, and a potential to boost EU gross domestic product (GDP) by up to 3.3% by creating new markets, products and added value for business. Waste prevention, eco-design, reuse and similar measures could bring net savings of €600 billion (8% of annual turnover) for business, while at the same time the increased efficiency would also lead to a reduction in greenhouse gas emissions of 2–4%. A greater emphasis on the circular economy was also envisioned as allowing European firms to benefit from rapid growth in markets for eco-industries. By decoupling economic growth from resource use and impacts, the circular economy was seen as offering the prospect of sustainable growth in human welfare.

1.2 *Benefits foreseen for a circular economy and EC policy*

The case for a circular economy has been led by several recent studies, which are summarised in Annex 1. In brief, such studies identify the following benefits, which could derive from a circular economy:

- improved competitiveness by creating savings and reducing raw materials and energy dependency;

[1] http://www.env.go.jp/en/recycle/smcs/2nd-f_plan-result2.pdf.
[2] An example for functioning e-waste recycling schemes is Switzerland (see www.swicorecycling.ch/en, www.sens.ch/en).
[3] The EC's vision can be seen in its statement that '*circular economy systems keep the added value in products for as long as possible and eliminate waste. They keep resources within the economy when a product has reached the end of its life, so that they can be productively used again and again and hence create further value. Transition to a more circular economy requires changes throughout value chains, from product design to new business and market models, from new ways of turning waste into a resource to new modes of consumer behaviour. This implies full systemic change, and innovation, not only in technologies but also in organisation, society, finance methods and policies*' (EC, 2014).

- improved security of supply and control of rising costs;
- contributing to EU climate change policy by reducing greenhouse gas emissions;
- employment opportunities;
- reducing environmental impact of resource extraction and waste disposal;
- opportunities for new businesses going from earning revenue by selling goods to offering services.

The EC has noted, however, that existing infrastructure, business models and technology, together with a lack of incentives through existing market prices (for example which do not enforce the polluters-pays principle), as well as established behaviour, keep economies 'locked-in' to the linear model. Companies may lack the information, confidence and capacity to move to circular economy solutions. This is compounded by a lack of sustainability education in design, engineering, economics and other relevant subjects, and in business schools. Further problems include a lack of training in practical skills to repair products to keep them longer in circulation. The financial system may also fail to invest in efficiency improvements or innovative business models, which may be perceived as more risky and complex. Conventional consumer habits can also hinder new products and development of services. Such barriers tend to persist in a context where prices do not reflect the real costs of resource use to society, and where policy fails to provide strong and consistent signals for a transition to a circular economy. This led to the EC developing new proposals to encourage the circular economy during 2014 (EC, 2014) but this was withdrawn by the new Commission in January 2015.

At the time of writing (September 2015), the Commission is consulting on a new policy to be prepared by the end of 2015. This has led to substantial debate among stakeholders including the European Parliament (EP), which has urged the Commission to implement measures to break the link between growth and the use of natural resources[4]. EASAC also considered how the expertise of Europe's academies of science could contribute to this debate, and EASAC Council decided in May 2015 that a study should be conducted on relevant aspects of the circular economy, setting up the Working Group listed in Annex 2. This study will progress during 2016, but in view of the current consultation on a new policy, it was decided to prepare an initial commentary on some scientific (both natural and social sciences) aspects to contribute to the current debate. This commentary has thus been prepared by the Working Group and endorsed by EASAC member academies.

2 EASAC commentary

2.1 *The concept of the 'circular economy'*

As already mentioned, the circular economy concept is not new, and has featured in United Nations summits on sustainable development since 1992, as a key means of reducing demand for natural resources and contributing to more sustainable patterns of production and consumption[5]. Current arguments in support of the circular economy point to continued growth in population and per capita consumption and thus increasing demands both for renewable and for non-renewable resources, which have led to an environmental footprint for humanity that is unsustainable (Hoekstra and Wiedmann, 2014). According to UNEP (2012) analyses, consumption already exceeds several critical global, regional and local thresholds; a conclusion also reached by analyses of the 'planetary boundaries' which should not be exceeded to ensure a sustainable future for humanity (Rockström et al., 2009; Steffen et al., 2015). Such imbalances provide strong arguments for increasing the efficiency with which the economy uses natural resources. These environmentally based arguments are also supported by concerns over future shortages (Sverdrup and Ragnarsdottir, 2014) in raw materials.

Such underlying trends are widely accepted, but not all accept that this implies that the most effective solution is to adopt a 'circular economy'. Some point out that the availability of non-renewable resources has often been underestimated, that technology and prices can increase the quantity of economically available resources, that substitutes to scarce resources may be developed on the market, and that some of the targets or regulations commonly associated with a circular economy may be inefficient and adversely affect competitiveness. Finding an optimum position between these differing perspectives may be dependent on the resource in question, technologies available for recovery and

[4] At the 9 July plenary, the EP reaffirmed the need to use natural resources more efficiently and called for a 30% increase in resource productivity by 2030, binding waste-reduction targets, revamped eco-design laws and measures to uncouple growth from resource use.

[5] While most policy debate focuses on national or international measures, successful change sometimes requires bottom up processes, where local societies motivated by self-interest voluntarily develop solutions, which then give incentives for national or even international policies. Examples of collective behaviour scaling-up throughout Europe can be seen in the managenergy.net energy efficiency and renewable energy uptake case studies (see, for example, http://www.managenergy.net/), and of new living models (for example ecovillages and transition towns; http://sites.ecovillage.org). One challenge will be to link or integrate these local initiatives to those at national and global level.

recycling, prices and other factors, which are beyond the scope of this initial commentary.

The Working Group notes, however, that the circular economy is now discussed annually at conferences such as the World Resource Forum, the European Resource Forum, and the German Resource Forum; moreover, the 2015–2030 Sustainable Development Goals (SDG) of the United Nations (UN, 2015) also refer to the importance of developing new and more resource-efficient economic models. This adds to the significance of the Commission's current actions to develop a new policy package for a circular economy.

Before considering specific issues, the Working Group makes some general points relevant to developing policy towards a circular economy.

- Society's main purpose in the circular economy debate is to reduce the adverse interactions between the economy, the environment and its natural resources in order to safeguard the well-being of future generations. The circular economy is best seen therefore as one possible tool for achieving this primary goal of enhancing sustainable well-being, rather than as an end in itself.
- Recovery and recycling of materials that have been dispersed through pollution, waste and end-of-life product disposal require energy and resources, which increase in a nonlinear manner as the percentage of recycled material rises (owing to the second law of thermodynamics: entropy causing dispersion). Recovery can never be 100% (Faber et al., 1987). The level of recycling that is appropriate may differ between materials.
- The circular economy is a concept not just for exhaustible resources such as metals, but also for renewable resources and includes recognition of the importance of preserving, restoring and enhancing the environment and natural resources (natural capital)[6]. Even so, the circular economy is insufficient to address specific issues such as climate change, ocean acidification, loss of natural ecosystems, soil degradation, species extinction, water supply and shortages, so should not detract from the many separate and targeted national and international policies on those issues.
- While the focus of this commentary is on the EU, policy cannot be developed in isolation of the international situation including the extent to which measures are consistent with existing trade rules (World Trade Organization) and new trade agreements currently under negotiation (for example Transatlantic Trade and Investment Partnership (TTIP), Trans-Pacific Partnership (TPP)). The circular economy concept should thus be given proper attention within these areas. In addition, treatment of the circular economy in the United Nations SDG framework needs to be part of the EU's circular economy strategy.

2.2 *Quantitative estimates*

Several quantitative studies have been put forward by groups advocating a shift to a circular economy (Annex 1). However, the extent to which the potential benefits of a circular economy can be quantified remains uncertain. The models used so far have inevitably included several simplifications, some of which may affect the validity of the outcomes; for instance the assumption that economic agents make accurate forecasts of the pace of change, and the degree to which they include reactions to policy changes[7]. Such simplifications may exaggerate benefits. Furthermore, some estimates appear to be based on data from a 'representative product' or 'representative firm', which are scaled up to an aggregate level (economy/country, EU or global level). Such mechanistic aggregation is not generally used in economic analyses. Nevertheless the estimates do indicate potential favourable outcomes on trade balance, employment, reductions in greenhouse gas emissions, company and national resource efficiencies, improved security of supply, which the Working Group finds credible, assuming the availability of the required capacity (skills, technical possibilities) related to reuse/recycling activities.

Better estimates of what could be economically feasible in decentralised markets may require different models. For example, estimating a socially optimal amount of municipal waste to be recycled would require analysis of physical costs of recycling, the social costs of waste management options and consumers' environmental preferences (Huhtala, 1997). One option would be to use a systems analysis approach such as that already underway in the SimRess project (http://www.simress.de). A further approach would be to use computer general equilibrium (CGE) models since input–output analyses have difficulties in identifying both price and income effects. The Working Group thus considers further

[6] Indeed, natural capital and ecosystem resources often lack ownership, making policy instruments an important tool for increasing the efficiency with which the economy uses natural resources (for example water, soil, minerals and vegetation).

[7] For instance, models may assume other parameters remain unchanged when certain factors (such as recycling rate) change. In reality, there are dynamic interactions so that changing one parameter will influence others—as one example, switching to low-energy lighting releases more money due to lower bills, which may increase consumption and cancel out some of the energy savings: a rebound effect. Such nonlinearity is not adequately treated in linear models.

research, to better characterise quantitative models for various aspects of circularity, a priority.

Such research also needs to incorporate insights from behavioural economics to inform the dynamic interactions of policy changes. Moreover, models so far have not dealt adequately with the transition phase, and it remains unclear how some of the long-established (and thus resistant to change) linear-economy structures can be reshaped towards a circular structure. Further aspects include potential effects on distribution of income, international trade and competitiveness—especially if Europe transforms its economy, but the rest of the world does not. A capital theory perspective (see, for example, Stephan, 1995) may be required to get better understanding of the costs and benefits of transforming economies into circular ones, and how different ways of financing the phase of transition affect the welfare of present and future generations.

Significant increases in employment are foreseen in the studies described in Annex 1. However, such employment opportunities may require further analysis. In particular, forecasts that a circular economy could help specific social groups (for example the unemployed or socially excluded youth) ignore the reality that the market can respond in many ways to a demand for more working hours. A circular economy would mean fundamental structural changes in industries, and the associated restructuring would require different kinds of skills in labour markets. For example, in repairing cell phones instead of buying new phones, additional staff (repair technicians) may be required but demand for others (for example salespeople, factory workers) may be reduced. Moreover, under the current system where repair costs exceed replacement costs, initial pressures to shift towards repair and reuse without reform in circularity on design and production would risk driving down wages, as would more labour-intensive production in relation to the use of capital and natural resources. Providing the human resources needed for a circular economy may require substantial shifts in education and training at all levels; university and business school curricula need to provide people who can design, manage and lead in a more circular economy; vocational training will need to be adapted to the emerging requirements for green jobs, and investments made in skills monitoring and forecasting (Vona et al., 2015).

2.3 *Evaluating scarcity and assigning priorities*

While many of the advantages of a circular economy emerge from the structural changes towards greater efficiency and reduced environmental impact, security of supply remains an issue for a continent where internal resources are limited and import dependency is high. Furthermore, as already mentioned, the energy and resource effectiveness of recycling may differ between materials recycled. Deciding priorities in policy towards recycling may thus need to consider relative scarcities of specific elements as one of the relevant factors. Here, recent research has evaluated how resources for specific elements will last under business-as-usual, using systems-based dynamic models (Sverdrup et al., 2013; Sverdrup and Ragnarsdottir, 2014). This would seem to indicate that scarcities are imminent for several elements as shown in Table 1.

Table 1 Elements with burn-off times* estimated at below 50 years in business-as-usual scenarios and life extensions at 50% and 70% recycling rates (Sverdrup et al., 2013)

Element	Business-as-usual burn-off time (years from 2011)	50% recycle	70% recycle
Nickel	42	42	209
Copper	31	31	157
Zinc	20	37	61
Manganese	29	46	229
Indium	19	38	190
Lithium	25	49	245
Tin	20	30	150
Molybdenum	48	72	358
Lead	23	23	90
Niobium	45	72	360
Helium	9	17	87
Arsenic	31	62	309
Antimony	25	35	175
Gold	48	48	71
Silver	14	14	43
Rhodium	44	44	132

* Burn-off time is defined as the estimated extractable resources divided by the present net extraction rate.

However, similar conclusions were reached in earlier assessments (for example the Club of Rome's 'Limits to Growth' of over 40 years ago), and reflect that scarcity is affected by factors other than just physical quantities present in the geosphere. It may, for instance, be a reflection of how much effort companies and countries put into verifying reserves and how this effort depends on prices and rates of extraction. It may also be the case that it is only profitable to invest in proving resources to cover a few decades, in which case such estimates may not be a reflection of scarcity *sensu strictu*. Nevertheless, some of the currently estimated scarce elements are associated with low recycle rates and may be priority targets for enhanced recycling technology development (Sverdrup and Ragnarsdottir, 2014)[8]. The Joint Research centre (JRC, 2013) has also looked at which metals are critical to technologies required for a low-carbon economy[9].

Potential scarcity in supply is clearly one factor in setting priorities for high recycling rates. Other factors may involve the energy reduction involved in recycling rather than production from ore: for example, aluminium needs 20 times more energy when processed from ore than from aluminium scrap (Sverdrup and Ragnarsdottir, 2014). The extent to which scarce elements can be substituted is another factor, while recycling rates are clearly also influenced by market prices (for example gold's global recycle rate is 96% compared with copper's 42% (Sverdrup and Ragnarsdottir, 2014)). Scarcity of exhaustible natural resources and optimal policies for specific elements is extensively covered in economics (for example Hamilton and Hardwick, 2014), and the implications of these and recent estimates such as those in Table 1 will be further considered in the next stages of this EASAC project.

2.4 *Barriers: why does the linear economy stay linear?*

Promoting a circular economy requires an understanding of why the linear economy continues to be the dominant paradigm. The EC has pointed to several reasons why economies remain 'locked in' to a linear model (section 1). At a company level, some reasons it remains profitable for companies to pursue the linear economy model (even if overall impacts on society are negative) include the following:

- True costs of the company's operations (negative environmental and social impacts of operations or financial costs associated with compliance-environmental and social externalities) are not captured or made transparent.
- Ignoring the potential impact of cumulative effects of production and consumption (such as resource depletion, pollution, and climate change) on the firm itself.
- Market priorities for *short*-term profits and dividends to shareholders make it difficult to take the *long*-term perspective required for investments into resource efficiency and other aspects of circularity.

A key underlying factor is **prices**. The failure to incorporate all costs leads to prices that are too low and do not fulfil their theoretically essential roles of providing information on scarcity, coordinating between supply and demand, or providing full monetary compensation for *all* the goods and services that are used when consuming and producing. The evolution of linear economies has been, *inter alia*, driven by these market failures and the fact that prices typically do not tell the 'ecological truth'. Measures to promote the circular economy model may thus be seen as being at odds with that long-established paradigm. Moreover, efforts needed to establish a circular economy model through price policies (such as taxes and subsidies, or by more truthful pricing) are seen, not as an essential adjustment to an inherently flawed and unsustainable economic model, but as a burden to society.

An inherent political weakness is that debate on the costs of a circular economy versus a linear economy seldom includes complete disclosure of the linear economy's inbuilt assumptions. If the *true* cost of the circular economy model (embedding all externalities into prices) were compared with the *true* cost of the linear economy model (which currently excludes most externalities), then a proper comparison of the costs for pursuing a circular economy over a linear economy could be made. This would be transparent for both producers and consumers and would assist in understanding value chains, and the value to society and the environment from changing to a circular economy model. It is thus a fundamental condition for decision-making to 'get the prices right' through internalising environmental and social costs, and through full-cost assessment in terms of the life cycles of products. With correct pricing, the linear economy should automatically evolve towards a circular economy model, which would be an iterative and interacting system; this is in contrast to the linear economy, which lacks feedback and is thus more rigid and risky.

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8 For example the Commission is looking into the options for recovery of phosphorus in view of the limited and finite nature of supplies (EC, 2015).

9 For example, dysprosium for hybrid and electric vehicles and wind turbines. Other key materials included lithium, neodymium, praseodymium, cobalt, tellurium, indium, tin, gallium, platinum, terbium and europium.

A circular economy aims to maximise the added value of products and services in the economic value chain, both to minimise residual waste and to ensure that resources can stay longer within the economy. A central tenet is thus that the life of products will be extended through repairs or updating instead of throwing away and replacing with a new model. However, in the current linear economy it can be more expensive to recondition or refurbish a product than to purchase a new product. Moreover, the market for return for reconditioning (rather than disposal) is still poorly developed. One of the main stumbling blocks for achieving circularity is the lack of product take-back schemes and industrial infrastructure to reuse by-products. Moreover the potential value recoverable by materials recycling can be very low[10]. Solutions include reforming national and international recycling systems to enable more streamlined collection and reprocessing of materials. Opportunities can then arise for higher value re-manufacturing. To overcome these weaknesses, value networks need to be established and built on intelligent reverse logistics and facilitative product/material asset management to help support business models that capture resource value from the production phase, through markets for secondary materials, to the consumption phase.

Other barriers include the following:

- Lack of indicators and targets at EU/national level, and lack of a coherent policy framework and supportive regulation. Such uncertainty on the scale and direction of future regulations may be a particular barrier for entrepreneurs. And clear 'game rules' for markets are a priority in any transformation towards a circular economy.
- Existence of skills gaps in the workforce and lack of circular economy programmes at all levels of education;
- Lack of investment and long pay-back periods;
- Collection and local recycling facilities in rural areas, where inefficient systems can carry high energy and resource penalties; this may therefore require very different approaches to those used in urban areas.

Moreover, patterns in consumer attitudes and behaviour are also the source of barriers:

- Many industries are based on increasingly fast turn-around driven by fashion rather than obsolescence (typified by fast fashion in clothes and electronic devices). Trends to a more cyclical structure focused on longevity, may thus face resistance—not just from consumers used to this rapid change, but also from the large number of powerful stakeholders associated with globalised production, trade, media and advertising, which are committed to the linear model;
- Market signals may be inadequate or unstable and not provide the necessary incentives to consumers to shift behaviour;
- Lack of information/awareness (on alternative options and economic benefits).

2.5 *Competitiveness considerations*

Studies in support of a circular economy (Annex 1) see potential for improved competitiveness:

- Since there are wide differences in resource efficiency between EU Member States, addressing this internal resource productivity gap could stimulate technological innovation, boost employment in the fast developing 'green technology' sector and benefit consumers through more sustainable products.
- Global competition for resource security is increasing while the concentration of resources (particularity critical raw materials) outside the EU makes industry dependent on imports and vulnerable to high prices, market volatility and political situations in supplier countries. The lower demand for new resources in a circular economy thus reduces these business risks, at least to some extent.

A further theoretical advantage is the potential for increased competitiveness of companies, which are required to comply with trend-setting environmental regulations. This 'Porter hypothesis' argues that initial costs of more environmentally friendly production methods would provide an advantage through better competitiveness in export markets. Recent reviews (Ambec et al., 2013) suggest that the evidence for the 'weak' version of the Porter hypothesis (that stricter environmental regulation leads to more innovation) is fairly clear and well established. Empirical evidence on the 'strong' version of the Porter hypothesis (that stricter regulation enhances business performance) remains mixed, but with more recent studies providing clearer support. If there are advantages for companies to be in the forefront when the production system is transformed

[10] The commodity value of a used PC (which costs €1,100 new) is only €8.60 (UNEP, 2013). This low return is also under pressure because of the additional costs of collection and processing. However, if recovery is simplified by better product design that incorporates the end-of-life stage, higher-value materials can be recovered, contributing to economic viability.

into a circular economy, this suggests it may also be an advantage for a country to use measures to stimulate change in this way.

However, overall impacts on competitiveness will also depend on several key aspects. These include the degree of internationalisation of circular-economy-related measures; interactions between trade and domestic policies; and they will depend on the necessary regulations for developing a circular economy substituting/replacing (rather than adding to) existing regulations and associated costs of compliance.

In particular, there is the question of how circular economy measures that take place just within the EU would interact with two basic principles that have led to the current globalised market with many (and increasing numbers) of multilateral agreements on trade. The principle of specialisation being a driver of productivity growth goes back to Adam Smith, and local market restrictions could hamper this. For instance, if circularity restricts the ability to work with the 'best-in-the-world' and limits to local suppliers, nominal wages could be lowered and prices raised.

A second principle – that of comparative advantage – underpins the global moves to free trade, and could interact with circular economy measures. Sorting of materials to be recycled or reused, particularly plastics and textiles, can be very labour intensive and is therefore best done in low-wage countries (as long as transport costs do not outweigh this advantage). On the other hand, recycling of appliances and electronics is subject to substantial economies of scale, and is best concentrated in a few, large centres. Moreover, the demand for recycled materials relative to virgin material may vary with the material, and may be greater for some materials in developing countries than in developed countries. Consequently, recycling within a Member State and even recycling within the EU may be more expensive than recycling were it to be conducted globally, and for certain items the costs may be prohibitive. If only one locality (at national or regional scale) introduces special measures, this may thus raise the costs of circularity considerably. Ignoring such implications in pursuing circularity within the EU could lead to a reduction in international trade, and even autarky if circularity were to be strictly applied to all custom unions, hampering the ability to exploit comparative advantage with potential implications for economic growth in both rich and poor countries.

These considerations suggest that the circular economy should not be considered a *locally* circular economy and that the aim should be global circularity. In parallel with EU-wide measures, the concept should therefore be encouraged internationally (including through the United Nations Sustainable Development Goals fora) and in international trade negotiations, as already mentioned (section 2.1).

2.6 *New indicators*

Economic indicators based on traditional national accounts such as GDP do not provide a means of measuring the efficiency with which resources are used, and new indicators that are more consistent with sustainable development are under discussion[11]. An increasingly important task for statistical agencies and companies will thus be to measure and follow material flows, not only in money terms when materials change ownership, but also in weights, possibly also in time and space.

Indicators relevant to the circular economy could use domestic material consumption as a measure of the total amount of materials directly used by an economy. When the economy grows at the same time as domestic material consumption is decreasing, 'absolute decoupling' of resource use from economic growth is observed. A widely used indicator in the Organisation for Economic Co-operation and Development (OECD) and G8 context[12] is 'resource productivity', which is measured by the ratio of GDP to domestic material consumption. Economy-wide material flow analysis provides an aggregate overview of annual material inputs and outputs of an economy. In contrast to GDP, which measures production and consumption market activities in monetary terms, the material flow analysis measures these activities in physical terms (tonnes).

EMF (2015b) summarises indicators that can be used now to measure an economy's current performance and to inform policy (Table 2). However, setting regulatory targets based on new indicators has significant implications and care needs to be taken to ensure that the indicators are appropriate to the policy objectives. Moreover, some of the indicators in Table 2 use physical measures (tonnes of material) mixed with monetary measures (GDP). Such simplistic measures (for example waste per GDP output) fail to consider the different environmental impacts of different wastes, which should be considered if environmental policy is to be informed.

[11] For example, the human development index (http://hdr.undp.org/en/content/human-development-index-hdi); the United Nations Open Working Group for the United Nations 2015–2030 Sustainable Developing Goals (Happiness: Towards a New Development Paradigm. Report of the Kingdom of Bhutan. NDP Steering Committee). Also 'New development indicators beyond GDP' (Fiorimonti, 2013; Costanza et al. 2014; Ragnarsdottir et al., 2014), and the European 'Beyond GDP' initiative (http://ec.europa.eu/environment/beyond_gdp/index_en.html), which is related to the EU regulation on European environmental economic accounts, COM (2010)132 final http://unstats.un.org/unsd/envaccounting/ceea/meetings/ninth_meeting/UNCEEA-9-Bk5.pdf.
[12] See, for example, http://www.oecd.org/env/waste/47944428.pdf

Table 2 Indicators of circularity in an economy (EMF, 2015b)

Scope	Indicator
Resource productivity	GDP per kilogram domestic material consumption
Circular activities	Recycling rate
	Eco-innovation index (index from green investment, employment, patents, etc.)
Waste generation	Amount of waste per GDP output
	Amount of municipal waste per capita
Energy and greenhouse gas emissions	Share of renewable energy
	Greenhouse gas emissions per GDP output

EASAC intends to consider this aspect in more detail in the next phase of its work on the circular economy.

2.7 General policy considerations

A basic tenet of the circular economy is that the resource-flow systems that underpin design models need to be re-engineered. There is no point designing a product for disassembly if take-back mechanisms are lacking to recover component parts effectively. This requires new policies and market levers to incentivise the designing out of waste, but greater transparency across supply chains is also required so that end-of-life products and materials can be effectively tracked and recaptured. Such changes require innovation and investment in technologies, organisation, education, society, finance methods and government policies. Changes are needed throughout the value chains—from extraction processes, material and product design and production processes to new business and market models, and from new ways of turning waste into a resource to new modes of consumer behaviour. The Internet of Things and the acceleration in artificial intelligence capabilities is constantly transforming industry processes and manufacturing through digitisation, electrification and automation. A circular economy thus needs to be flexible enough to be able to move and adapt with the quickening pace of new developments in this technological arena.

Initial EC proposals included quantitative targets for recycling rates (percentages) or resource use/energy efficiency; these also feature in recommendations from the EP[13]. These have the advantage of contributing directly to the objectives of a circular economy, and of being measurable. However, setting targets that are not justified by analyses on benefits and costs (including social costs associated with externalities such as environmental damages) may lead to inefficient use of resources, at odds with the ultimate target of a circular economy. Ideally, economic policy instruments should be used to price externalities; when the market prices of inputs (nature's services, human services) signal the true social and natural costs, companies themselves can choose optimal technologies (including product design, recycling or abatement of pollution) to minimise the costly environmental burden. If the key concern is the depletion of natural resources and environmental damages, then the correct pricing of (non-renewable) natural resources and the use of environmental/ecosystem services (for example, environment as a waste sink) necessitate fiscal policies that incentivise 'good' and penalise 'bad' behaviours (see Sterner and Coria (2012) for an analysis of various instruments). If there are positive externalities related to recycling (Huhtala, 1999a), subsidies could be used.

This policy model based on correct pricing should be the long-term driver of moves towards a circular economy, but different valuation methods have different strengths and weaknesses, data gaps remain and it is not currently possible to implement such objective economic measures to drive a shift from linear to circular economic structures. Starting the shift in transforming the linear to a more circular and ultimately sustainable economy will thus require the setting of incentives through price changes and regulations. Where internal targets and standards incur transition costs not borne outside the EU, the question also arises of how to protect domestic industries from international competitors unaffected by such policies. It may thus be necessary to evaluate policy instruments such as World Trade Organization-compliant border adjustment measures. Furthermore, if standards (for example recycled content of material input) should be used to promote recycling, it is important to harmonise standards in economically meaningful ways to take into account heterogeneity in abundance/scarcity of resources by region, etc. (Huhtala and Samakovlis, 2002). Research should also continue internationally into a system of resource pricing to account for their environmental damage and depletion rates (following on from the previous NEEDS work (New Energy Externalities Development for Sustainability; www.needs-project.org) on monetary evaluation of externalities).

[13] The Environment Committee called for binding waste-reduction targets, revamped eco-design legislation and measures to break the link between growth and use of natural resources. Specifically included were waste-reduction targets for municipal, commercial and industrial waste; application of the 'pay as you throw' principle; targets for recycling and preparation for reuse to be raised to at least 70% of municipal solid waste and 80% of packaging waste by 2030; incineration to be strictly limited by 2020 to non-recyclable and non-biodegradable waste; and a reduction of all landfill waste.

A key concept is eco-design, as recommended by the EP, which advocates a review of eco-design legislation by the end of 2016, broadening its scope and covering all product groups. Eco-design aims for longer-lived products and to develop those products in such a way that the product can be disassembled at the end of life and parts can be individually reused, as well as considering the environmental impact of materials used. Promoting eco-design requires adequate coverage of eco-design principles and practice in design and engineering education. New approaches may be required to support a transition to a circular economy; for example some new fields of eco-design may include (Irwin, 2015) 'design for service' (moderate change for existing paradigms and systems), 'design for social innovation' (significant change for emerging paradigms and systems) and 'transition design' (radical change for future paradigms and systems).

Other policy challenges relate to making society (public and private sectors) more aware of the direct and indirect effects of all waste streams (the externalities or embedded costs), the scarcity of materials and the moral imperatives to address inter-generational equity in decision-making both at the home/domestic level and at the work/business level, to better understand the underlying drivers for a circular economy. The required shifts to a circular economy will also involve more innovative leasing and rental contracts, different attitudes to possession, the introduction of lending and sharing schemes as well as collective insurance schemes that offer cover for repaired goods and products containing used parts.

In the wider context of education or lifelong learning, policies that encourage up-skilling, training and skills sharing will be required as the nature of the circular economy is dynamic and changing with new ideas. As mentioned previously, industry training networks need to deliver the required skills sets and business courses needed for a resource-efficient and low-carbon economy.

2.8 *Policy instruments*

A range of policy instruments are available which can be applied to increase resource efficiency (see Annex 3).[14] These can be categorised as follows:

- Regulatory instruments including laws and directives.
- Economic instruments, including environmental taxes, fees and user-charges, certificate trading, refunded emission payments, environmental financing, green public procurement, deposit and refund schemes and subsidies.
- Research and educational instruments, including funding or incentives for research and development, and education and training.
- Cooperation instruments, for example technology transfer and voluntary agreements.
- Informational instruments, including eco-labelling, sustainability reporting, supply chain reporting, environmental profit and losses labelling, natural capital reporting, information centres, consumer advice services, environmental quality targets and environmental monitoring.

In this initial commentary, the Working Group has not conducted an assessment of the advantages and disadvantages of specific detailed policy options but has three general comments, as follows.

Firstly, on the question of subsidies as a policy instrument, there is a substantial literature in environmental economics showing that subsidies are often inferior to tax and other instruments. There are cases when subsidies may be effective instruments but the reasons should be clearly stated.

Secondly, the importance of the role of the waste management regime in driving (or potentially hindering) transition to a circular economy is recognised both in EC and in EP considerations, but EASAC notes that a critical issue is how to set the regulations and criteria for determining when recycled waste ceases to be treated as waste and becomes a resource, raw material or product. Currently only three EU regulations have established such criteria (for some scrap metal, glass cullet and copper scrap), yet technology and the industry are allowing a much wider range of materials to be recycled.[15] A priority will be to ensure that future regulations do not impede the full deployment of available technologies and development of new businesses.

Thirdly, valuable case studies already exist within the EU and its industries[16].

EASAC will address these and other issues in later, more detailed reports on the circular economy.

[14] See Sterner and Coria (2012) for a full introduction to this subject. An Irish example is available from the COMHAR Sustainable Development Council: Making the Case for Resource Efficiency in Ireland and Options for Taking it Forward by Eoin.McLoughlin@environ.ie, Policy Paper, December 2011.

[15] Important sectors of the recycle industry already include paper, glass, plastic, rubber and end-of-life tyres, non-ferrous material and aluminum packages, ferrous material and steel packages, wood, textiles, electric and electronic equipment, batteries and accumulators, used mineral oils, animal and vegetable oils, organic fraction from municipal solid waste, sewage sludge, inert wastes from construction and demolition, end-of-life vehicles.

[16] One example is industrial parks that operate as systems oriented to resource efficiency. For example in Kalundborg, Denmark, the basic industry is an oil refinery, but associated with that are many industries that use surplus heat or resources: greenhouses, a district heating system, sulphuric acid production, pharmaceutical industry, power plant, fertiliser production, gypsum plasterboard production, fish farming and ashes used in cement. Similar philosophies have been applied in the Kawasaki (Japan) eco-town.

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Annex 1 Recent studies supporting a circular economy

The European Environment Bureau (EEB, 2014) developed different scenarios for future waste and resources targets for textile reuse, municipal solid waste recycling and for food waste, under 'modest', 'medium' and 'ambitious' scenarios. Employment opportunities ranged from 634,769 (modest) to 747,829 (ambitious) by 2025; carbon dioxide reductions from about 260 million tonnes to about 330 million tonnes, as well as reductions in water, fertiliser and pesticide use. Monetary estimates of the value of the carbon dioxide reductions ranged from €2.5 billion to €12 billion.

The **Ellen MacArthur Foundation** (EMF, 2013a; 2013b; 2014) estimated the overall economic impacts in the EU towards 2025 as annual net material cost savings of $380 billion (transition scenario) and $630 billion (advanced scenario), involving a 19–23% reduction in input costs. Studies focusing on product-level analysis include

- food and beverage: potential of $1.5 billion per year income stream from waste;
- packaging offers potential profit of $200 per tonne of plastic collected for recycling;
- mobile phones cost halved if phones were easily disassembled and recycled.

The EMF's most recent analysis looked at how the circular economy could affect food, mobility and the built environment, which together account for 60% of EU household costs (EMF, 2015a). It concludes that a circular economy would increase European competitiveness and deliver better social outcomes than a linear economy; for example:

- overall benefits of €1.8 trillion by 2030 (double those expected from current development paths);
- average disposable income for EU households would increase by €3000 and GDP by 11% by 2030 (compared with €2700 and 4% respectively in current development paths);
- cost of time lost to congestion would decrease by 16% by 2030; carbon dioxide emissions would halve by 2030; primary material consumption could drop 32% by 2030 and 53% by 2050.

A policy toolkit for policy making has also been published (EMF, 2015b).

In a study of the **Swedish economy,** the Club of Rome (2015) projected that by 2030

- increasing energy efficiency by 25% would reduce CO_2 emissions by 28%, create approximately 20,000 jobs (+0.5%) during a retro-fitting period and improve the trade balance by 0.2% of GDP;
- increasing the percentage of renewable energy in the energy mix to 75% would halve CO_2 emissions, create about 5000 jobs (+0.1%) and improve the trade balance by approximately 1% of GDP;
- organising manufacturing towards a circular economy (25% increase in material efficiency, half of virgin materials replaced by secondary materials, doubling the lifetime of long-lived consumer products) would cut carbon dioxide emissions by about 10%, create 50,000 jobs (an increase of 1–2%) and increase the trade surplus (more than 2% of GDP).

Concerning **business, EREP** (2013), based on experience of successful initiatives, saw 19 significant opportunities:

- In the production phase. Sustainable sourcing standards, voluntary schemes led by industry and retailers, and industrial symbiosis to provide markets for by-products.
- In the distribution phase. Improving information on the resources contained in products and how they can be repaired or recycled, referred to in the recommendations of the Platform as a 'product passport'. And
- In the consumption phase. Collaborative consumption models based on lending, swapping, bartering and renting products; and product service systems to get more value out of underutilised assets or resources (for example cars, tools, lodging).

EREP also emphasised the importance of design of production processes, products and services. Products can be redesigned to be used longer, be repaired, upgraded, remanufactured, or eventually recycled, instead of being thrown away. Production processes can be based more on the reusability of products and raw materials, and the restorative capacity of natural resources, while innovative business models can create a new relationship between companies and consumers. Specific business strategies included the following:

- reducing material quantity required to deliver a particular service (light-weighting);
- lengthening products' useful life (durability);

- reducing the use of energy and materials in production and use phases (efficiency);
- reducing the use of materials that are hazardous or difficult to recycle in products and production processes (substitution);
- creating markets for secondary raw materials (recyclates) through standards, public procurement, etc.;
- designing products that are easier to maintain, repair, upgrade, remanufacture or recycle (eco-design);
- developing the necessary customer services (maintenance/repair services, etc.);
- incentivising/supporting waste reduction and high-quality separation by consumers;
- incentivising collection/separation systems minimising costs of recycling and reuse;
- facilitating clustering to prevent by-products from becoming wastes (industrial symbiosis);
- encouraging wider and better consumer choice through renting, lending or sharing services as an alternative to owning products, while safeguarding consumer interests (in terms of costs, protection, information, contract terms, insurance aspects, etc.).

In addition, there is substantial work on enhancing resource efficiency under the concept of 'Factor X' (Angrick et al., 2013).

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Annex 3 Menu of policy interventions (Wuppertal Institute, 2006; Sterner and Coria, 2012; EMF, 2015b)

Type of policy instrument	Description	Examples of specific policy interventions
Education, information and awareness	Education and training, eco-labelling, sustainability reporting, providing information on resource efficiency in economies and companies. Environmental quality targets and monitoring.	Encourage integration of circular economy/ systems thinking into school and university curricula. Public awareness campaigns using various media and approaches.
Collaboration	Collaboration between industries on common issues in resource use and efficiency. Government–industry collaboration in defining the legal framework, setting targets, etc.	Public and private partnerships at national, regional and city levels. Voluntary industry collaboration platforms. Industrial symbiosis.
Business support	Financial support from government to encourage resource-efficient products, processes.	Provision of subsidies, capital, financial guarantees. Technical support, advice, training and demonstration of best practice.
Public procurement and infrastructure	Public purchasing criteria include environmetal and resource efficiency conditions.	Green purchasing laws. Public investment in infrastructure (recycling facilities, etc.).
Regulatory frameworks	Norms and standards that can be voluntary (guidance) or legally obligated.	Government strategy and targets on indicators. Product regulations, including design, extended warranties and product passports. Waste regulations: collection and treatment standards, extended producer responsibility and take-back systems. Accounting, reporting and financial regulations affecting the duty of managers and investors related to natural capital and resources.
Fiscal frameworks and economic intsruments	Adjusting taxes to reflect environmental externalities. Incentives to consumers or businesses to become more resource-efficient.	Value-added tax (VAT) or excise duty reductions for circular products and services. Tax shift from labour to resources.
Research and development	Incentives to private and publicly funded research and collaboration.	Projects on material efficiency and resource conservation. New technologies for collection, disassembly, recovery, etc.

EASAC

EASAC – the European Academies' Science Advisory Council – is formed by the national science academies of the EU Member States to enable them to collaborate with each other in giving advice to European policy-makers. It thus provides a means for the collective voice of European science to be heard. EASAC was founded in 2001 at the Royal Swedish Academy of Sciences.

Its mission reflects the view of academies that science is central to many aspects of modern life and that an appreciation of the scientific dimension is a pre-requisite to wise policy-making. This view already underpins the work of many academies at national level. With the growing importance of the European Union as an arena for policy, academies recognise that the scope of their advisory functions needs to extend beyond the national to cover also the European level. Here it is often the case that a trans-European grouping can be more effective than a body from a single country. The academies of Europe have therefore formed EASAC so that they can speak with a common voice with the goal of building science into policy at EU level.

Through EASAC, the academies work together to provide independent, expert, evidence-based advice about the scientific aspects of public policy to those who make or influence policy within the European institutions. Drawing on the memberships and networks of the academies, EASAC accesses the best of European science in carrying out its work. Its views are vigorously independent of commercial or political bias, and it is open and transparent in its processes. EASAC aims to deliver advice that is comprehensible, relevant and timely.

EASAC covers all scientific and technical disciplines, and its experts are drawn from all the countries of the European Union. It is funded by the member academies and by contracts with interested bodies. The expert members of EASAC's working groups give their time free of charge. EASAC has no commercial or business sponsors.

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.

The EASAC Council has 29 individual members – highly experienced scientists nominated one each by the national science academies of EU Member States, by the Academia Europaea and by ALLEA. The national science academies of Norway and Switzerland are also represented. The Council is supported by a professional Secretariat based at the Leopoldina, the German National Academy of Sciences, in Halle (Saale) and by a Brussels Office at the Royal Academies for Science and the Arts of Belgium. The Council agrees the initiation of projects, appoints members of working groups, reviews drafts and approves reports for publication.

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