Quantifying the benefits of circular economy actions on the decarbonisation of EU economy

Final report

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List of Abbreviations

CE	Circular Economy
CO_2 eq.	Carbon dioxide equivalent
CGE	Computable General Equilibrium
EE	Energy efficiency
EEA	European Environment Agency
EEE	Electrical and Electronic Equipment
EPR	Extended Producer Responsibility
GHG	Greenhouse Gas
Gton	Giga tonnes
I/O	Input Output
LCA	Lifecycle Assessment
Mtons	Million tonnes
P2P	Peer-to-Peer
RES	Renewable energy sources
RMC	Raw Material Consumption
RP	Resource Productivity
WEEE	Waste Electrical and Electronic Equipment

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Executive Summary

The importance of circular economy for decarbonisation

Today's economy functions predominantly in a linear fashion, meaning that raw materials enter the economy to serve as inputs for production, then products are used and subsequently disposed of. Only a small share of the materials and products that end up in waste are recycled and fed back into the economy. This linear configuration has several negative effects. Growth in demand for raw materials causes an increase in resource scarcity as well as increasing environmental pressures due to raw material production (e.g. mining). Furthermore, the linear economy model generates substantial levels of GHG emissions, due to energy-intensive material production processes, but also at the end-of-life phase of products.

The EU has made it a policy priority to shift from the current linear economy to a circular economy (CE), that is restorative and regenerative by nature. This transition will not only improve the EU's resource efficiency and reduce dependence on raw material imports but will also contribute to reducing greenhouse gas (GHG) emissions as circular economy actions try to minimise and optimise energy materials and flows. However, up to now the EU's circular economy policies and climate mitigation policies are barely linked. As requested by EEA, **this report investigated the impact that the transition to a circular economy could have on GHG emissions, explored the methodologies that are available to calculate these impacts and explored setting up a framework to allow for a quantification of the potential benefits of circular economy actions in reaching EU climate targets.**

This study reviewed the existing body of work on the GHG impacts of circular economy actions, to bring together all the available GHG impact estimates and identify relevant methodologies. The review focused on the non-energy[1] elements of circular action and **showed that such actions can make modest, yet valuable impacts on GHG abatement throughout sectors and throughout the different lifecycle stages of products in Europe.** As an illustration, some studies estimated the GHG potential of the sum of the circular actions covered to be around 80-150 Mtons of CO_2 eq. per year by 2030 in Europe, which equals to around 2 to 4% of the GHG baseline emissions by 2030 in the EU Reference Scenario. By 2050, the GHG abatement potential is estimated to rise to around 300-550 Mtons of CO_2 eq. per year in Europe, amounting to around 10-18% of the GHG baseline emissions by 2050 in the EU Reference Scenario. However, it should be noted that these estimates do not cover all the circular actions and results between studies cannot be compared due to different methods and assumptions. In fact, there has been no study performed to our knowledge giving a comprehensive overview of all circular actions and their decarbonisation potential.

The literature points to the following sectors as having the highest GHG abatement potential:

- Materials (notably plastics, but also metals and cement)
- Food (loss reduction, improved packaging, nutrient recycling)
- Construction (material substitution, modular design, smart crushers, space-sharing, improved end of life)
- Waste management sector
- Automotive (car sharing, durability, improved end of life).

[1] As opposed to energy elements of circular action, such as renewable energy and energy efficiency, which have a considerable impact on GHG emission reduction.

The review also showed that the **versatility in circular actions**, which differ in importance depending on the product or sector concerned, **makes it difficult to analyse the impacts of circular economy actions on GHG emissions in a systematic manner**. To lay the foundations for the options for a European Methodological Framework, five existing studies were selected as case studies for further examination of their methodologies, applicability to different circular economy actions and specific strengths and weaknesses. These cases were selected based on the quality of the description of the methods and assumptions used. Furthermore, attention was paid in the selection process to make sure that a variety of different methods and circular economy actions were covered in the set of selected case studies, which were as follows:

- A study by WRAP on the impacts of resource efficient business models on the economy and the environment[2]
- Eunomia's Impact assessment of the Waste Framework Directive, Landfill Directive and Packaging and Packaging Waste Directive[3]
- A study by Material Economics called 'The circular economy - A powerful force for climate mitigation'[4]
- TNO's study on the impacts of circular actions set out in the Dutch national programme on circular economy and transition agendas on GHG abatement[5]
- A study on the environmental impacts of the collaborative economy, conducted by Trinomics et al[6].

From the analysis, two fundamental approaches were identified for developing a European methodological framework for estimating the GHG benefits of the CE. The first would be to develop the best possible methodology, based upon learnings from the case studies about the advantages and disadvantages of the different methods used in those studies. The second approach would be to perform a meta-analysis of existing studies, seeking to synthesise their individual results into a single estimation of GHG benefits.

A new methodology

Reviewing the case studies helped identify a set of characteristics that would feature in an *ideal* methodology for estimating the GHG benefits of the circular economy, including that it be comprehensive, detailed, robust, easily aggregated, synergistic and built on a limited set of existing data. However, it was also recognised that some of these characteristics conflict. This was one of the topics discussed in an expert workshop convened towards the end of the project, in which the authors of four of the five case studies led discussions about the suitability of their approaches for the EEA's requirements.

[2] WRAP (2016) Extrapolating resource efficient business models across Europe. http://www.rebus.eu.com/wp-content/uploads/2017/07/Extrapolating-resource-efficient-business-models-across-Europe.pdf

[3] Eunomia, CRI, Oeko and Argus (2014). Impact Assessment on Options Reviewing Targets in the Waste Framework Directive, Landfill Directive and Packaging and Packaging Waste Directive. http://ec.europa.eu/environment/waste/pdf/target_review/Targets%20Review%20final%20report.pdf

[4] http://materialeconomics.com/material-economics-the-circular-economy.pdf?cms_fileid=340952bea9e68d9013461c92fbc23cae

[5] TNO (2018). Effecten van het Rijksbrede Programma Circulaire Economie en de Transitieagenda's op de emissie van broeikasgassen. https://www.tno.nl/media/8551/tno-circular-economy-for-ienm.pdf

[6] Trinomics, VITO, Cambridge Econometrics and VVA (2017). The environmental potential of the collaborative economy. https://publications.europa.eu/en/publication-detail/-/publication/8e18cbf3-2283-11e8-ac73-01aa75ed71a1/language-en

Based on the workshop and subsequent analysis, it has been possible to draw a number of conclusions that help establish a framework to allow for a quantification of the potential benefits of circular economy actions.

- **Coverage**
  There are so many different facets to the circular economy that it is practically unrealistic to estimate the impacts of all possible actions in the methodology.

- **Priority Sectors**
  The above conclusion implies the analysis must be prioritised to the most significant GHG benefits. It is recommended that the evaluation be performed on a sectoral basis rather than on an individual circular action, focussing on the sectors already named above. Circular actions cutting across sectors are possible to capture through the use of macro-economic models containing cross-sectoral linkages.

- **Available Data**
  Whilst some valuable datasets have been identified, such as the wealth of information available from Eurostat and national GHG inventories, further efforts would be valuable to collect further data and improve existing datasets. The main data gaps related to circular economy is that circular economy actions often cut across default sector categories used by existing datasets and hence these datasets cannot be used directly in the analysis of GHG impacts of circular actions. Another gap relates to the innovative activities that fall under circular economy, for which no data has been collected so far in a systematic way.

- **Methodology**
  No clear winner was identified from the available methodologies to deliver the EEA's requirements. It was felt that a hybrid solution, combining detailed analysis (such as LCA) with macro-economic modelling, offered the most promise, but further work is needed to facilitate the exchange of data between the techniques.

Further analysis suggests that, faced with these lingering difficulties, the EEA might be well advised to seek further information, on subjects such as how to link detailed and macro-economic datasets in hybrid models, how to split macro-economic data into smaller subsectors, and how to improve some of the key datasets. When it comes to the methodological framework itself, it is suggested that a bottom-up model might be the more appropriate technique. One option could be for the EEA to pursue the development of the methodology with an initial focus on just one of the identified key sectors.

The meta-analysis approach

The alternative way to arrive at an estimation of the GHG benefits of the CE in Europe is to perform a meta-analysis of the existing studies, in order to identify the most relevant studies and their data, and then bring that information together in a coherent and consistent analysis of the overall impacts.

This initially appears to be a somewhat more manageable task than developing the optimised methodology described above. The analysis identified 43 literature sources, 23 of which quantified the

GHG impacts of the CE actions examined. This is apparently a broad body of information from which to draw appropriate data.

In reality, however, critical inconsistencies were discovered in the datasets that significantly challenge the possibility of combining their results. Studies with different methods (LCA versus macro-economic) perform their analysis across very different system boundaries, invalidating any data combination. Some issues of study scope, such as being national rather than pan-EU, are problematic but potentially surmountable with careful and appropriate upscaling. However, if one study includes (for example) rebound effects but another does not, their results cannot practicably be compared. Another type of scope conflict arises where studies “overlap”, for example when one looks particular sectors (such the Material Economics case study no. 3) and the other at a particular life cycle stage (such as the Eunomia case study no. 2, focussing on waste management).

Further issues were identified with studies having different purposes (research question), reporting results at different levels, using different baseline, having different ambitions for the implementation of the CE and reporting results in different formats. Finally, a meta-analysis approach can only be done once, unless all of its underlying data sources are subsequently updated, or can be effectively updated by proxy.

These varied difficulties lead to the conclusion that the literature sources currently available offer limited opportunity to perform a meta-analysis of the GHG benefits of the CE. However, a framework is presented as to how such an analysis could be performed in the future, if new data become available and what elements to consider when interpreting the results.

1 Introduction

1.1 Background

Both, the low-carbon and circular economy policy agendas are anchored in the 2050 vision of the 7th Environment Action Programme (EAP), recognizing that environmental deterioration is rooted in unsustainable use of natural resources and (fossil) energy. The low-carbon economy agenda of the European Union (EU) aims at ensuring the successful implementation of the Paris Agreement with its overarching objective of limiting the increase in the average global temperature well below 2°C above pre-industrial levels. The European Council has endorsed the objective of reducing Europe's GHG emissions by between 80% and 95% by 2050, compared with 1990 levels. In order for the EU to be able to take cost-effective steps towards this long-term goal and to make an ambitious contribution to the Paris Agreement, EU leaders adopted the 2030 climate and energy framework that sets three key targets for the year 2030, which are now parts of the EU's Energy Union strategy. According to this framework, by 2030, the domestic GHG emissions have to be reduced by at least 40%, compared with 1990 levels, the share for renewable energy has to be at least 27% of total energy consumption, and the energy efficiency has to be improved by at least 30%, compared with projections of future energy consumption in 2030 (as taken from the 2007 Energy Baseline Scenario from the European Commission).

The circular economy concept envisages a more efficient use of materials and products, through recycling, reuse, repair, refurbishment and remanufacturing. The ambition is that a cyclical and regenerative economy will reduce the dependency on extraction and import of raw materials, as well as lower waste generation, energy use and emissions to the environment. At European level, the circular economy agenda is focused on material use and waste generation, with special attention to plastics, food waste, critical raw materials, construction and demolition, biomass and bio-based products. The Circular Economy Package includes revised legislative proposals on waste, key elements of which are the 2030 targets that cover the recycling of municipal and packaging waste and reduction of landfilling.

Synergies exist between the decarbonisation and the circular economy policy agendas. Circular material use is strongly linked with the climate and energy system through energy flows (e.g. increased share of renewables), material inputs (avoidance of GHG emissions related to extraction, production and waste generation) and natural capital (reliance on bio-based materials and bio energy). Hence, the circular economy holds a potential to support a decarbonisation of the European economy by 2050. However, little quantified evidence is currently available about the extent to which circular economy can contribute to future climate change mitigation. Therefore, this study focussed on the identification and evaluation of existing methods in which circular economy actions resulted in greenhouse gas emission reductions and in identifying options for setting up a framework to allow for a quantification of the potential benefits of circular economy actions in reaching EU climate targets.

1.2 The transition to a decarbonised and circular economy

The energy system and the economy are intimately linked, since energy is fundamental to the production and consumption processes that form the basis of our economy. Since the industrial revolution, when fossil fuels started to be massively used for energy production purposes, their use has been increasing. As a result, greenhouse gas (GHG) emissions have skyrocketed, increasing the global atmospheric CO_2 concentration to unprecedented levels. The ongoing climate change is largely attributed to this GHG concentration and poses a severe threat not only to humans, but also to other life on earth. Direct challenges for our society include, among others, sea-level rise, increased intensity and occurrence of extreme weather events, changes in the spread of infectious diseases, and changes in precipitation patterns, all of which have far-reaching consequences at multiple domains.

The use of fossil energy sources also enabled us to ramp up production dramatically, which resulted in large increases in the demand for natural resources, e.g. metals, nutrients and biomass. The rate at which raw materials are being extracted from finite natural resources has reached a level that poses a significant threat to the environment, economy, and society. In addition, the current mode of production and consumption is considered highly wasteful in terms of resource use, which except for exacerbating the aforementioned problem, it also generates high GHG emissions. For example, ambitious targets for recycling municipal and packaging waste could reduce GHG emissions by around 44-62 Mtons CO_2-eq. in 2030.[7] Other resource efficiency measures apart from waste management, such as in the food, mobility, hospitality and built environment systems, can have similar results regarding GHG emissions mitigation.

As around 80% of Europe's GHG emissions originate from the energy use and production [8], climate change mitigation efforts have mostly focused on increasing energy efficiency and switching to low-carbon energy sources. However, circular economy actions such as optimising resource use, optimisation of product utilisation and increased looping of materials can also (indirectly) lead to energy savings and thus lower the European emissions. Nevertheless, this potential of the circular economy to contribute to climate change mitigation is still poorly understood and hardly integrated into national climate mitigation strategies. Therefore, there is a need for a comprehensive analytical framework for the quantification of the GHG impacts of circular economy activities, which generates results that are compatible with existing national GHG reporting requirements.

1.3 Study objectives and scope

1.3.1 Study objectives

The objective of this study was twofold:

1) It aimed to improve the EEA's understanding on the relation between circular economy actions and associated GHG emission impacts and the methods available to calculate these impacts.
2) It aimed to lay the foundations for a European methodological framework for assessing the GHG impacts of circular economy activities in a comprehensive and scientifically sound manner, while making sure that such a framework can be implemented in practice. This proved to be more difficult than expected during the course of the study as the review showed that quantification of GHG impacts of circular actions is complex and relies on tailored methodologies (often modelling techniques), the results of which are difficult to standardise and compare.

Within the objectives explained above, this study had several sub-objectives. The study:

- Identified, selected and assessed existing cases where the GHG impacts of circular economy actions were analysed;

[7] Eunomia (2014) Impact Assessment on Options Reviewing Targets in the Waste Framework Directive, Landfill Directive and Packaging and Packaging Waste Directive " Final Report Report for the European Commission DG Environment; EEA (2016) Circular economy in Europe – Developing the knowledge base, EEA Report No 2/2016, European Environment Agency

[8] 78% of the GHG emissions were energy-related in 2016, EEA GHG data viewer.

- For these cases, the quantified GHG impacts were reported, accompanied by an assessment of the methodologies used to arrive at these quantifications;
- Tensions and trade-offs between potential GHG emission reduction due to circular economy actions and other environmental impacts were identified, but no significant trade-offs were found in the literature; and
- No trade-offs between circular economy and climate change mitigation policies and their implementation measures were identified from the literature.

1.3.2 Scope

This study reviewed and evaluated studies that have assessed GHG impacts of circular economy actions as well as the methodologies to do so. The circular economy affects both production and consumption and all lifecycle stages of products and therefore this study assessed the impacts of actions across lifecycle stages, including but not limited to: product design, production, consumption and waste management. For this assignment we clarified a working definition of the circular economy and a classification of in-scope circular economy actions, as explained in detail in chapter 3. The focus of this study was on potential benefits of circular economy actions relating to GHG emissions, but potential negative impacts were not found. Next to the GHG impacts of the circular economy, other non-climate related environmental impacts and trade-offs were discussed where information was available.

With regard to the geographical scope of the study, we analysed cases from all over the world, where possible with a focus on cases from EEA member countries. In a world where many production chains are global, circular actions somewhere in the lifecycle can have large repercussions for where the impacts occur. One could imagine a product where one material in the product is replaced by another, but the original material was produced outside Europe and the replacement within Europe. This could mean that the GHG emissions generated within Europe increase, whereas the net emissions are reduced when taking a lifecycle point of view. Such an action is a positive development from a global climate change mitigation point of view but complicates the achievement of the GHG abatement targets within Europe. Furthermore, some circular economy actions having direct GHG emission impacts in Europe show already in the EU GHG inventories, however, other circular actions are not properly captured in these inventories, in particularly those cutting across sectors. In this study we pointed out if a certain methodology took a lifecycle perspective, incorporating the GHG impacts occurring in all lifecycle stages no matter whether these occur within Europe or elsewhere in the global supply chain.

1.4 Structure of the report

This report is structured as follows:

- Section 1 begins with an introduction, which embeds the policy environment and explains the broader circular economy context, the study objectives and its scope.
- Section 2 presents the methodology we followed to achieve the objectives and our task-specific approach.
- Section 3 is concerned with the definition of the circular economy concept, expanding ideas of what circular economy is and which circular economy actions were considered relevant to our study.
- Section 4 describes the literature that focuses on the circular economy actions that have a positive effect on GHG emissions. It also presents the selection of five cases that exhibit the

highest potential to best quantify the GHG emission reductions resulting from the circular economy.

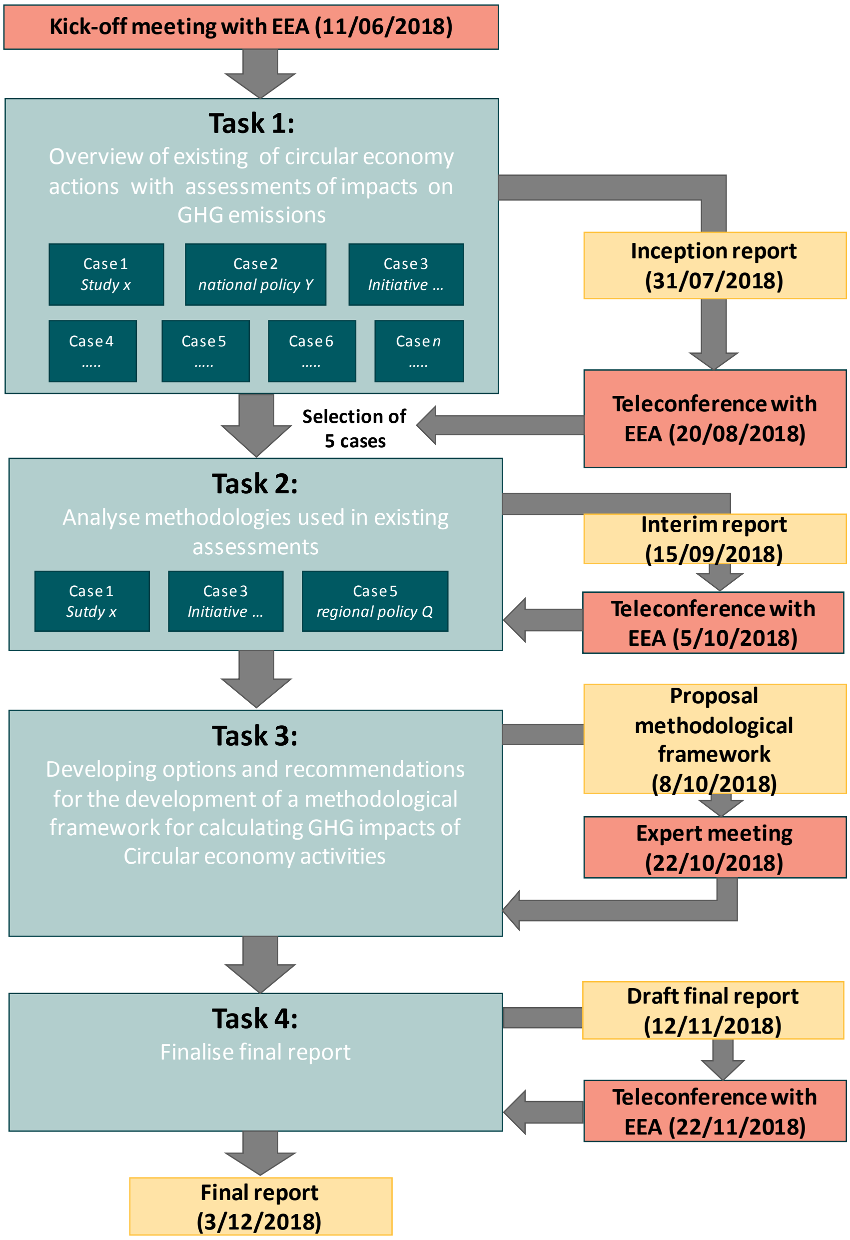
- Section 5 gives an overview of the options for a European methodology framework and discusses the different challenges and ways forward.
- Section 6 concludes.

2 Methodology

2.1 Overall approach

To meet the main objectives of this study as well as the specific sub-objectives as stated in Section 1, the overall approach followed in this study was divided into four tasks. Task 1 aimed to give an overview of the results of literature review on the assessment of the impacts of circular economy actions on GHG emissions. From the inventory of studies compiled in Task 1, five cases were selected for further analysis in Task 2 in terms of their methodological approach. The analysis of the five cases and an expert workshop allowed for the development of options and recommendations for a European methodological framework for calculating GHG impacts of circular economy activities in Task 3. Task 4 was a reporting task. Figure 2-1 gives an overview of the steps taken in this study, the outputs generated in the different stages and the moments of contact with the client.

Figure 2-1 Overview of the overall approach, the study's outputs and meetings



2.2 Methodology Task-by-Task

2.2.1 Task 1

Task 1 was divided in four distinct sub-tasks that in turn consisted of several steps. The first sub-task was to organize an online kick-off meeting with the EEA to agree upon the scope of our study and to align our methodology to meet the objectives of this project with the EEA's expectations.

The second sub-task involved a review and selection of a circular economy working definition, which is presented in Section 3 of this report. To do so, we first reviewed widely used definitions of circular economy, since there is a multitude of definitions used in the literature. Then we applied the EEA definition and adapted it to the scope of this assignment. Ultimately, we discussed and compared the most common classifications of circular economy actions in order to determine which actions should be examined in the literature review.

An overview of studies that include the assessment of the impacts of circular economy actions on GHG emissions is presented in Section 4 and in Annex A. The development of the approach to this literature review as well as the establishment of the criteria according to which we selected the relevant literature was the first step of this sub-task. The inclusion criteria developed were based on the working definition of circular economy, which determined the scope of our study. In order to conduct a structured and concise literature review, we first constructed an Excel template (see Annex A) that guided the manner in which the literature review was conducted by indicating which information is needed to adequately assess the reviewed studies. From the literature review, we derived a list of circular economy cases with an impact on GHG emissions (see Annex A), which was subsequently analyzed in terms of the scope of the study and the types of methodologies, as well as the types of circular economy actions, the stakeholder implementing it, the scale-level, and key challenges. Moreover, our literature review gathered quantitative and qualitative information on the GHG emissions and other environmental, economic, and social impacts of circular economy actions.

The last sub-task involved the selection of five cases for an in-depth review in Task 2, presented in Section 4. The initial step in the selection of the five cases was the methodological and topic-based characterization of the reviewed studies in order to ensure that a variety of methods and circular economy actions will be covered in Task 2. The approach developed for the selection of these cases included the establishment of inclusion and exclusion criteria, which allowed to filter out less suitable studies and keep only those that can have a significant potential to help in the development of options to create an analytical framework to calculate avoided emissions resulting from circular economy actions in Task 3.

2.2.2 Task 2

This task aimed at giving an overview of the methods available for quantifying the impact of circular economy actions on GHG emissions through an in-depth analysis of five cases selected in the previous task. To achieve this overall objective, we analysed which type of methodology has been used and to which type of circular activity the methodology has been applied as well as the scale-level at which the action is or will be taken. The analysis further proceeded to the examination of the scope of the methodology and how the circular economy action is translated in the calculation method, considering also the types of data used to reflect this action.

After the qualitative description of the methodologies, we evaluated each case in terms of their strengths and weaknesses and reflected on potential improvements or alternatives that could enhance the methodological approach. Within the evaluation of each method, we also included some considerations surrounding the policy implications of the methodological choices made. Finally, we considered the replicability and applicability of the methodologies used in the five case studies to other products and to the EU economy as a whole. Selected case studies can be found in Annex B.

2.2.3 Task 3

The objective of this task was to recommend options on how the EEA could develop a framework with one or more methods for estimating the GHG emission changes associated with circular economy actions when applied across the EU. The focus of this task was on the practicality of the methods, meaning that the methods should be easily upscaled, and should not rely on data that are not easily available. Moreover, we focused on only the best methods from the five presented in Task 2 and analysed how to implement them and what their requirements in terms of data, resources, modelling, etc. were.

Having that in mind, the development of recommendations and options for the development of a European methodological framework was done in four steps. The first was to analyse the advantages and disadvantages of the methodologies analysed in Task 2. Subsequently, step 2 analysed the implications of GHG monitoring and reporting requirements for these methodologies as well as the data needs for generating the results in the right format and sufficient level of detail. Step 3 analysed to which extent the investigated methodologies can be upscaled to arrive at EU-wide GHG emission impacts. Based on the results from these three steps, step 4 concludes which methodologies or combinations thereof would be most fit for the calculation of GHG emission impacts of circular economy actions at the EU-level. Furthermore, it was analysed to what extent the investigated methods can be used across different types of circular economy activities. Finally, step 5 identified areas where methodological gaps exist or required data is lacking, so that it is clear in which areas further research is required and what the limitations are in terms of data availability.

Integral part of this task was support provided for the organisation of a workshop in which the options and recommendations for a methodological framework were presented to experts in the field in order for them to provide their feedback. The workshop took place in Copenhagen on 22 October 2018. The feedback from the expert workshop was integrated in our final recommendations. The list of participants can be found in Annex C.

2.2.4 Task 4

The aim of this task was to summarise the main findings under this study in a final report, which will serve as a starting point for an EEA report on the benefits of circularity on the decarbonisation of the European economy.

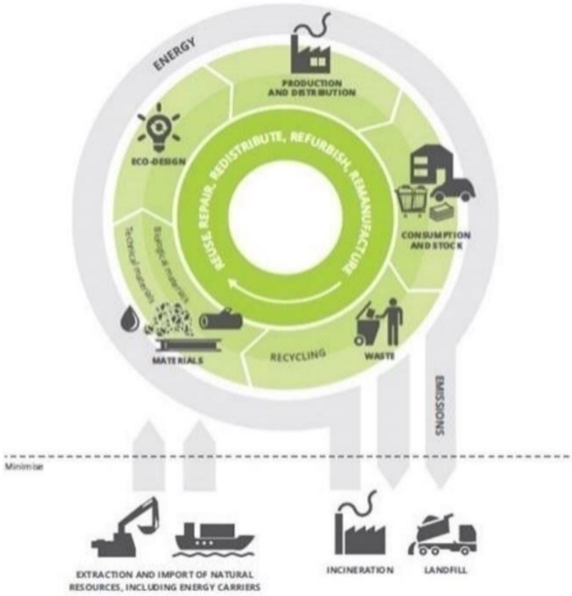
3 What is the Circular Economy?

3.1 Widely used circular economy definitions

The circular economy is a concept that has been widely discussed in literature and there are multiple definitions for what the circular economy is. One of the most commonly used definitions is the definition formulated by the Ellen MacArthur Foundation. They characterise the circular economy as an economy that is '*restorative or regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles*'. This new economic model seeks to ultimately decouple global economic development from finite resource consumption[9]. Similarly, the European Commission defines the circular economy as an economy '*where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste is minimised*'[10].

According to the EEA[11], the circular economy aims at minimizing waste generation and material inputs through eco-design, recycling and reusing of products, as represented in Figure 3-1 from the same report.

Figure 3-1: EEA Schematic of the Circular Economy



From the aforementioned definitions it becomes apparent that the concept of the circular economy is a holistic notion that implies that the *entire economy* is transformed to become restorative and regenerative by design. This means that the circular economy affects all aspects of resource use, from product design, resource extraction and product manufacturing, to its distribution, use and disposal. Too often the circular economy is equated to improving waste management and increasing recycling rates, however, the notion of the circular economy goes far beyond this, as will be detailed further in section 3.3.

[9] Ellen MacArthur Foundation, Sun, and McKinsey Center for Business and Environment (2015). Growth Within: A Circular Economy Vision for a Competitive Europe, Ellen Mac Arthur Foundation, Sun, and McKinsey Center for Business and Environment

[10] European Commission (2015). Closing the loop – An EU action plan for the Circular Economy, COM(2015)614 final, Brussels

[11] EEA (2016). Circular economy in Europe – Developing the knowledge base, EEA Report No 2/2016, European Environment Agency.

The circular economy does not only affect the use of material resources, but also the use of energy resources. Our economy is highly dependent on the energy system, consuming electricity and fuels during materials and products' manufacture and use phases. Therefore, the shift to a regenerative economy also entails the shift to an energy system based on renewable energy sources (RES)[12]. Additionally, as energy is a valuable resource, improvement of energy efficiency (EE) can also be seen as a resource efficiency measure and thus as a circular economy action. This is important because both these actions (moving to RES and improving EE) are proven to be valuable means to reduce climate change impacts, by reducing the combustion of fossil fuels. As such, there is an overlap between climate change mitigation and circular economy actions. However, circular economy actions can also have GHG benefits apart from the common GHG mitigation measures focusing on energy efficiency and renewables. As an example, reducing the amount of raw materials needed to manufacture a product, indirectly also reduces the emissions from production by reducing demand for raw materials.

3.2 Working definition of circular economy in this study

As explained in the previous section, the transition to a circular economy also encompasses the shift to a highly-efficient, low-carbon energy system. Due to the fact that the methodologies for assessing the GHG impacts of typical climate change mitigation actions (related to EE and shifting towards RES) are already well established, this project aims to assess GHG impacts associated with circular economy activities that are *not yet covered* in current climate mitigation policies and associated impact studies. The methods for assessing non-energy related emission mitigation actions use similar concepts as those used in energy-related actions, but the effects are often much more complex as many circular actions have an effect across different parts of a value chain and sectors. Looking at non-energy related circular economy activities reduces the risk of double counting the GHG emission impacts from circular economy activities and other (energy-focused) climate change mitigation policies. However, since some CE actions are linked to energy accounts, the GHG inventories do capture to a small extent CE actions. For these reasons, we proposed to exclude from the scope of this study actions that solely aim to replace fossil fuels with renewable energy sources and policies aimed solely at the improvement of energy efficiency as such. In practice, there might sometimes be a fine line between circular actions and actions aiming at energy efficiency. As a rule of thumb, actions that generate circular resource use or resource use efficiency improvements next to energy efficiency improvements were regarded as within the scope of this study. In this context, resources refer to raw materials and natural capital, thus including biomass (bioenergy and biomaterials), but not fossil energy carriers, unless they are used for non-energy purposes. For more details on what actions are in and out of scope, please see the next section.

3.3 Classification of circular economy actions

The circular economy comprises a large range of actions throughout the lifecycle of products starting at product design and ending with the product's end-of-life stage. In a circular economy, product design should ensure aspects such as minimisation of the use of (scarce) resources in the product itself, durability of the product, minimisation of resource/energy use during the use phase and the ease of disassembling at the product's end-of-life stage. For the production of new products, the use of

[12] Ellen MacArthur Foundation, Sun, and McKinsey Center for Business and Environment (2015). Growth Within: A Circular Economy Vision for a Competitive Europe, Ellen Mac Arthur Foundation, Sun, and McKinsey Center for Business and Environment; EEA (2016) Circular economy in Europe – Developing the knowledge base, EEA Report No 2/2016, European Environment Agency

secondary materials is preferred and where this is not possible it is important that resource extraction is optimised so that losses and negative environmental impacts are minimised. Downstream manufacturing and distribution processes need to be optimised to minimise material losses and energy consumption.

As emphasised in a recent EEA report, our growing welfare has led to an ongoing increase in consumption, which results in increased pressure on the environment, as reflected in pollution of air, water and soils, emission of greenhouse gases and degradation of natural capital and biodiversity[13]. A large part of the circular economy potential resides in the consumption phase. Substantial potential exists in changing consumer behaviour and the way in which the use of products and assets is organised. The first step here is to prevent people from buying new products (the refuse strategy) e.g. by stimulating reuse (e.g. through second hand markets) and by addressing the ever-present desire to own the most fashionable and trendy products. Secondly, for a lot of products the utilisation rate is very low. On average, cars are parked for 98% of the time, office spaces are utilised for only 40% of the office hours and power drills are disposed when run for only 1% of their technical lifetime[14]. In all these cases, utilisation rates can be increased significantly, e.g. through sharing and renting activities. Lastly, it is important that the lifespan of products is extended, which can be enabled by the design of more durable products, the promotion and facilitation of product repair or refurbishment and increased reuse. Also, Eco-design of products can reduce the energy consumption of products during the use phase. However, design activities aimed at reducing energy use are not within the scope of the current study.

The treatment of products at the end-of-life stage can shift to much more circular practices as well. Here, it is important that components and materials are kept at the highest value possible. If possible, components of disposed products can be remanufactured to produce new products or components that can be reused in the production of new products. If these options are not feasible, the materials need to be recovered from the products so that they can be recycled and used for the production of new products. Here it is essential that high-quality materials are obtained, so that downcycling of the materials is prevented.

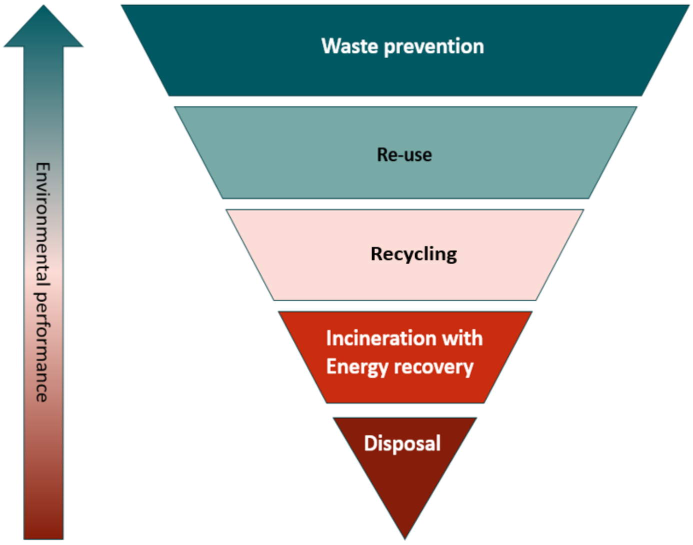
Different classification systems – the 9 R's versus the RESOLVE framework

Circular economy actions can be classified in several different ways and in this section we discuss and compare the most common classifications. Several methods have approached the classification from a waste perspective following the waste hierarchy approach (see figure 3-2). In this approach waste prevention is the priority, followed by recycling, waste incineration with energy recovery and lastly waste incineration without energy recovery and landfilling.

[13] EEA (2013) Environmental pressures from European consumption and production – A study in integrated environmental and economic analysis, Technical report No 2/2013, European Environment Agency

[14] Material Economics (2018) The Circular Economy – A powerful force for climate mitigation, Material Economics Sverige AB, Stockholm; Ministerie van Infrastructuur and Milieu (2015) Milieu-impact en -kansen van de deeleconomie.

Figure 3-2 Schematic of the waste hierarchy. Source: own illustration based on the waste hierarchy



This hierarchy is sometimes expanded to the framework of the **9 Rs**[15], which adds a couple of strategies that apply to the use phase of products. The 9 Rs are the following:

- Refuse (preventing the need to buy a product)
- Reduce
- Reuse
- Repair,
- Refurbish,
- Remanufacture,
- Re-purpose,
- Recycle,
- Recover (energy recovery during waste incineration and recovery of nutrients after anaerobic digestion).

These actions can all be seen as circular actions in order of importance (refuse is most circular, recover the least, not mentioning landfilling) and it is therefore a useful addition to the waste hierarchy framework as it can help to realise the circular potential in the design, use and production phases. Within this system, the EEA puts emphasis on some of the 9 Rs in the top of the hierarchy (the inner loops of the circular economy), namely reuse, repair, redistribute, refurbish and remanufacture[16].

The Ellen MacArthur Foundation has taken the 9 Rs approach even further to reflect the circular economy in its broadest possible sense and defined the **RESOLVE framework**, consisting of six different actions to achieve a circular economy. This framework encompasses each of the 9 Rs and goes beyond it by making more concrete suggestions on how **R**educe actions can be reached, for example by ***Virtualising*** consumption (so that no physical products are needed). Also, in addition to the 5 Rs emphasised by the EEA, it mentions sharing as an important action as part of the inner loops of the circular economy. The six RESOLVE actions include:

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[15] Cramer J. (2015). Moving towards a circular economy in the Netherlands: challenges and directions. Available at: https://wp.hum.uu.nl/wp-content/uploads/sites/32/2015/04/Paper-HongKong-JC-april-2014.pdf [Accessed 26 Jul. 2018]

[16] EEA (2016) Circular economy in Europe – Developing the knowledge base, EEA Report No 2/2016, European Environment Agency

1. ***R**egenerate* - to shift to the use of more renewable (biological) resources.
2. ***S**haring* - maximising the use of products during the use phase, by sharing assets, but also by prolonging the use phase through good proper product operation and maintenance.
3. ***O**ptimise* - optimising resource use throughout the lifecycle, which includes minimising resource use during production, but also designing a product in such a way that the use of resources (e.g. energy) during use is minimised.
4. ***L**oop* - cycling back materials and products back into earlier lifecycle stages, including many of the 9 Rs.
5. ***V**irtualise* - replacing physical goods by digital services and products (e.g. replacing CDs by music streaming services).
6. ***E**xchange* - concerns the shifting to different materials with better performance, lower scarcity or a lower environmental impact, but also replacing old-fashioned manufacturing processes by innovative techniques.

Inclusion and exclusion of circular actions for this study

In this study, we investigated all circular economy actions aiming to achieve the optimal and cyclical use of resources, which do not solely aim at the replacement of fossil fuels by renewable energy carriers or the improvement of energy efficiency *per se*. Table 3-1 gives an overview of circular economy actions that we considered as part of our working definition of circular economy and how they can be classified. We proposed to have a classification of circular economy actions based on their product lifecycle stage, i.e. into which lifecycle stage they fit in. We acknowledge that no classification system is perfect, that some actions might fit into one or more lifecycle stages, and that this table is not an exhaustive list of circular actions. We have tried as much as possible to couple the circular actions to the product lifecycle phase to which they apply. Some actions require products to go back from the consumption/use phase to the distribution or production phase to enter another use cycle. Such actions are labelled in Table 3-1 as 'reverse logistics' actions and include: reuse (including second hand sales), refurbishment and remanufacturing.

It should be noted that to make sure the actual circular economy actions are implemented, policy action is needed. Some studies list circular economy policies such as eco-innovation, extended producer responsibility, extended warranties, etc. as circular economy actions. In the context of this report we see these policy instruments as a means to promote circular economy actions. Furthermore, the impacts of the actual circular economy actions can be quantified more easily then the effect of policies.

Table 3-1 Overview of in-scope circular economy actions by lifecycle stage

Lifecycle phase	Circular economy action
Design	Exchanging materials to prolong products' lifetime or reduce environmental impact (this includes replacing technical nutrients by biological ones, or using non-toxic materials and materials with high recycled material content)
	Design products to be more durable
	Modular design, design for disassembly and reassembly and enable remanufacturing and refurbishment
	Design to enable (easy) repair
	Design to minimise resource (e.g. energy) in use phase

Lifecycle phase	Circular economy action
	Design to minimise waste and enable recycling (material recovery)
	Design for user friendliness (in particular in connection with changing business models, see consumption phase)
Production	Resource use optimisation
	Automation, 3D printing, etc.
	Use of bio-materials and recycled materials
Distribution	Prevent losses (e.g. food losses during transport and storage, excess stocks of retailers, etc.)
Consumption/use phase	Sharing/ renting/ leasing business models
	Reduce consumption and prevent/ minimise waste (e.g. food waste)
	Virtualisation
Reverse logistics	Reuse (including second-hand sales)
	Remanufacturing
	Refurbish
End-of-life stage	Recycling
	Waste-to-energy (including anaerobic digestion and incineration with energy recovery *)

* Waste-to-energy should be seen as a last resort as it does not preserve the materials present in the waste and it prevents materials from re-entering the economy for the manufacturing of new products. In a fully circular economy, materials need to be recycled as much as possible.

Note: Some of the circular economy activities cover more than one lifecycle phase. The list of actions is not exclusive for one particular lifecycle phase as well as not exhaustive.

Actions that are explicitly not covered in this study were actions specifically aimed at replacing fossil fuels with renewables, e.g. replacing a gas-fired boiler with solar water heating system or actions aiming at energy efficiency as such, e.g. route optimisation, or the replacement of an engine in a factory with a more energy efficient one. Many of the actions listed in Table 3-1 might lead indirectly to improvements in energy efficiency or reduction of GHG emissions. Such energy savings were included in the scope of this study.

4 Circular Economy Actions with Positive Effects on Greenhouse Gas Emissions

4.1 Approach to the literature review

Objectives of the literature review

The objective of this literature review was twofold. Firstly, it aimed to give an overview of the studies that assess the impacts of circular economy actions on GHG emissions, including their quantitative estimations as well as on other environmental, economic, and social impacts. Secondly, it intended to provide an outline of the methodologies used to assess these impacts, which guided our work in Task 2.

The first step to achieve these goals was to define the scope of our assignment (Section 3), in order to determine which of the circular economy actions found during the literature search should be included in the literature review list. Having this in mind, the minimum requirements for a study to be considered relevant to our assignment were:

- The study had to examine circular economy activities that fall into our scope, and
- The impacts of these activities on the GHG emissions had to be clearly assessed.

To scan the identified studies in an efficient and organized manner in the interest of meeting the abovementioned goals of this assignment and before starting the actual search of literature, we constructed an Excel template (see Annex A), which indicated the kind of information that should be extracted from each of the reviewed sources. Consequently, each of these studies was decomposed in smaller, easily manageable pieces of information, which filled in the relevant categories of the Excel database. This step was significantly important as it permitted the systematic review of the studies according to predetermined categories of key information, enabled the comparison of different studies, and allowed an effective internal coordination of the project team members.

Literature search and identification of relevant sources

Since the circular economy concept is a relatively novel idea, the relevant literature is not yet extensive, let alone the limited literature on the impacts of circular economy actions on GHG emissions. Therefore, in order to sufficiently cover this field of study, we adopted a relatively broad approach to the identification of relevant sources. As a result, studies on resource efficiency and improvements of waste management practices were also considered in our research. However, we were cautious not to include studies that are out of the scope of our analysis. Lastly, studies that assess global emission changes resulting from circular economy activities in a global or non-European region were included in our analysis. However, their results were interpreted with great care, without extrapolating their findings to the European context.

In order to identify relevant studies and reports to populate the literature list, we performed a literature search. The search criteria were composed of two types of terms. The first group of terms included keywords relevant to circular economy and its activities, such as ‘circular economy’, ‘resource use’, ‘resource efficiency’, ‘materials management’, etc. and the second group included keywords related to GHG emissions, such as ‘Greenhouse Gas emissions’, ‘decarbonisation’, ‘emissions mitigation’, ‘climate change’, ‘environmental impact’, etc. These terms were searched both individually and in various combinations with each other. The types of sources mainly considered here were:

- **Academic literature:** Scientific Journals (e.g. Sustainability, Journal of Cleaner Production, Journal of Industrial Ecology), ResearchGate,
- **Regulatory/policy reports:** European institutions and associated bodies (e.g. JRC, EEA), International organizations (e.g. UNEP, OECD, Nordic Council of Ministers),
- **Reports from industry, think tanks and NGO's:** Organizations active in the circular economy field (e.g. Ellen MacArthur Foundation, WRAP, Circle Economy).

Once the online search was completed, we followed the snowballing approach according to which the reference lists of the reviewed studies were scrutinized to identify and extract additional relevant literature. To make sure that no relevant study is omitted, we relied on the collective knowledge of the members of the project team and our respective in-house experts, who are aware of relevant publications, projects, initiatives, and other contributions either specifically on the circular economy or closely linked activities. In addition, we have analysed several sources that were provided to us by the EEA. Although some of these sources contained quantitative assessments of the GHG impacts of circular actions, most of them primarily provided useful contextual information on the circular economy and on policies implemented to promote it.

Considering that the purpose of this study was the development of options and recommendations for the EEA on how to quantify the impact of circular economy actions on GHG emissions at the EU level, we excluded studies that analysed circular actions at the most granular level. We deemed product-specific Life Cycle Assessments (LCA) to be too detailed for the purpose of this study, as this would give us an almost endless list of studies on how the lifecycle resource use of specific products or product groups can be improved. Generalization and up-scaling of the results of such studies would likely be extraordinarily complex or even impossible. Therefore, such studies, including many product specific studies from the JRC, were excluded from our review and instead we focused on higher-level analyses. However, this does not mean that we exclude all LCAs. LCAs that cover actions or product groups that are broad enough to enable upscaling as well as studies combining LCAs with other methods were taken into account in our literature review.

It should be noted that there is a gap in the level of detail between the product-level LCAs that are commonly used for carbon footprinting, and the macro-economic methods that take a very aggregated sector approach. The former are too detailed and an analysis of all products available in a consistent way at this granularity level would require a vast amount of resources, whereas the latter often lacks a sufficient level of detail to accurately reflect the dynamics of particular circular actions.

Assessment of literature sources

After the finalization of the literature list, the sources were systematically reviewed and the details on the scope, methodology and main findings of the study were filled in in the excel database. The main findings from the literature review included an overview of the analysed sources using descriptive statistics, a summary of the quantitative estimates of the GHG emission reductions resulting from circular economy actions investigated in the reviewed studies, and other environmental, economic, and social spillover effects from such actions. Next to that, the analysis provided a preliminary assessment of the scope and methodologies used in the reviewed studies. This assessment enabled us to propose a selection of cases to be analysed further under Task 2 of this study.

4.2 Analysis of Circular Economy cases with an impact on Greenhouse Gas (GHG) emissions

4.2.1 Overview of literature sources analysed

In the literature review we have analysed a total of 43 sources, of which 24 assessed the GHG impacts of circular economy actions and 23 of those also quantified these impacts (left pie chart Figure 4-1). The studies quantified the GHG impacts through a variety of methods, with a bias towards methodologies operating at the macro-level. However, this is inherent to the question we want to answer, namely to what extent circular economy actions can contribute to GHG emission reduction at the national and EU level.

Topic-based characterisation of the analysed cases

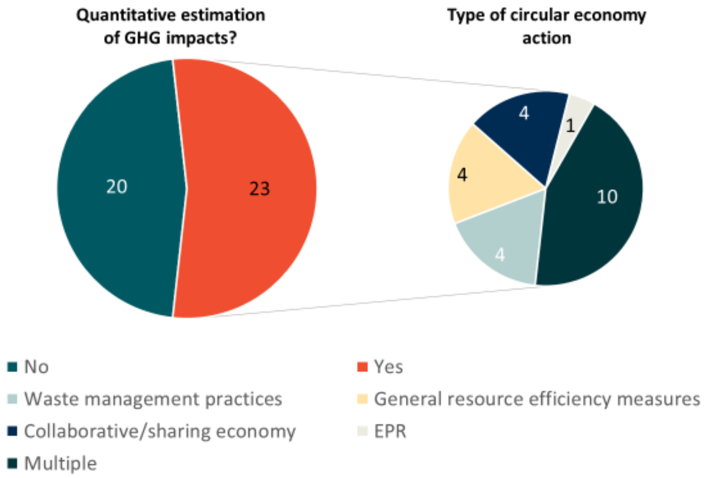
Most of the 23 studies assessed the GHG emissions reductions resulting from different types of circular economy activities had a relatively broad approach to the circular economy, spanning to all the various lifecycle stages. Historically, the circular economy evolved from the waste hierarchy and as such it is not surprising that a number of studies (4) assessed the GHG impacts from a waste management perspective. Other studies (4) looked in a broader sense at resource efficiency improvements. Such resource efficiency improvements could theoretically be brought about by a variety of circular actions in different lifecycle stages. However, most of these resource efficiency focused studies do not specify in depth what kind of actions underlie such improvements.

In the recent years the collaborative economy has grown strongly and many of the activities in the collaborative economy can be seen as one of the inner loops (‘sharing’) of the circular economy. There are four studies that looked at the effect of the collaborative/sharing economy on GHG emissions.

Moreover, numerous studies (10) examined multiple types of circular economy activities at once and the vast majority of these studies looked at how these activities will affect different sectors of the economy as well as their respective GHG emissions. There are various activities included in this category, such as actions to increase repair and reuse of materials and products, policies to reduce the demand of resources, decrease food and other types of waste.

Lastly, one of the reviewed studies examined the impact of implementing an Extended Producer Responsibility (EPR) scheme on GHG emissions in France on household packaging.

Figure 4-1 - Overview of literature sources and the type of circular economy actions.



4.2.2 *Findings from literature review*

Greenhouse gas impacts of non-energy related circular economy actions in Europe are modest, yet significant

The climate change mitigation debate and policies mostly revolve around actions aiming at the decarbonisation of the energy system. This focus is logical as around 80% of the GHG emissions produced in the EU to date are energy-related GHG emissions[17]. However, it is important to note that the manufacture of materials and products is responsible for a significant part of our total energy consumption. Therefore, actions aimed at optimising these manufacturing processes to minimise energy and material demand can have large impacts on the total energy demand and thus also on GHG emissions[18]. However, it is also important to consider that such reductions in material demand actually translate into reduced GHG emissions in Europe rather than having the excess materials exported abroad, with no reduction in GHG emissions in Europe. Apart from that, the production of several types of materials, especially steel, cement and ammonia, generates a substantial amount of process-related emissions.

The circular economy is not only a possible supplement to measures aimed at decarbonising the energy sector but also an essential strategy that is needed to achieve the climate objectives to which the international community committed itself in the Paris Agreement. Due to the global population growth and fast economic growth that is expected in many parts of the world until the end of this century, the demand for many raw materials are expected to increase strongly under baseline developments (Table 4-1). As a result of this tremendous increase in demand for raw materials, the commitments made in the Paris Agreement cannot be achieved if only the GHG emissions from the energy supply are fully abated[19]. Most of the climate scenarios suggest that until 2100 a carbon budget of only 300 Gton CO_2-eq. can be allocated to the production of materials. However, even when baseline improvements in efficiency and recycling are assumed, the forecasted increase in material demand will require a carbon budget of 649 Gton CO_2-eq. even if the decarbonisation of the energy system is completed in 2050.[20]

[17] Eurostat (2017) EU Energy in figures – Statistical pocketbook 2017.
[18] Material Economics (2018) The Circular Economy – A powerful force for climate mitigation.
[19] *Ibid.*
[20] *Ibid.*

Table 4-1 - Expected demand trends (compared to 2015 demand) for four common raw materials

Steel	Plastics	Aluminium	Cement
+130%	+320%	+240%	+70%

Source: Material Economics (2018) The Circular Economy – A powerful force for climate mitigation.

Before discussing the GHG impacts of particular circular economy actions and sectors in more detail, Table 4-2 gives an overview of the estimates that have been done for the EU economy as a whole and/ or for CE actions that span across different lifecycle stages and sectors. A very wide range of estimates exists for the GHG impact of circular economy actions. **However, none of the studies are comprehensive, i.e. assessing the total GHG impacts of all CE actions that could potentially be implemented in Europe.**

There are studies that cover a wide range of CE actions, for example the study by Material Economics, covering four heavy industry materials and two important supply chains, where circular actions span across different economic sectors and industries. There are also studies focusing on specific economic sectors or Member States. It should be noted that the fact that a specific study looks at a 'sector' does not necessarily mean cross-sectoral impacts of circular economy activities in that sector are not taken into account. Rather the opposite, studies that use a macro-economic model, such as a CGE or I/O which incorporate cross-sectoral linkages in the model, often provide 'sectoral' results taking into account the cross-sectoral character of circular economy if modelled so. The main issue is that sectors in such macro-economic models are usually highly aggregated, meaning they look at for example motor vehicles sector (or even 'transport sector' as a whole) which includes the automotive industry as well as passenger cars transport, etc. It should also be noted that most of the studies did not develop their methodology matching sector classification according to the UNFCCC GHG reporting (as did for example the TNO's model EXIOMOD). Hence, creating a direct link to the EU GHG inventories becomes difficult.

The results of these different studies cannot be aggregated into a total GHG impact as they use different (modelling) methodologies, including different ambition levels of circularity. Hence, a high level GHG abatement impact in a specific sector might be due to the assumptions taken in this study. As an illustration of the level of magnitude in the studies that assessed the GHG impact of CE actions in multiple sectors, most estimates of annual GHG emissions reduction potential in the EU by 2030 are in the order of 80-150 Mtons CO_2-eq.[21] (a reduction of 2.1-4% compared to GHG baseline emissions by 2030 in the EU Reference Scenario[22]), with some outliers estimating that even larger emission reductions are possible. For 2050, the estimated GHG benefits are estimated to be larger, namely in the order of 300-550 Mton CO_2-eq. per year[23], which is equivalent to approximately 7.5-13.7 % of the EU's overall GHG emissions today[24] and 10-18% compared to 2050 emission levels based on the EU Reference scenario[25]. But this does not cover all CE actions, as explained. The aforementioned figures should be interpreted as indications for the order of magnitude of the GHG impacts of circular activities, rather than complete estimates of the total emission reduction potential of the shift to a circular economy.

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[21] For example, WRAP (2016); Club of Rome (2011); Cambridge Econometrics (2018)
[22] These percentages were calculated based on baseline emission levels in the EU Reference scenario 2050 for 2030, namely 3731.6 Mtons CO_2-eq.
[23] For example, Material Economics (2018); Deloitte (2016)
[24] Based on 3991 Mton Co2-eq. total emissions in 2016, from: EEA (2018)Greenhouse gas emissions by source sector (source: EEA) [env_air_gge].
[25] These percentages were calculated based on baseline emission levels in the EU Reference scenario 2050 for 2050, namely 3008.8 Mtons CO_2-eq..

Table 4-2 Overview of GHG impacts of circular actions across multiple sectors.

Circular action	Sector	GHG impact (Mton CO_2-eq.) p.a.	Geographic scope	Note	Source
25% increase in resource efficiency, substitution of 50% of raw materials with secondary materials and doubling the lifetime of durable products	All	In 2030: -4% for Finland, -5% for Sweden and France, -3% for the Netherlands, and -10% for Spain; -4% across the EU (own assumption), this would be equivalent to 120 Mtons CO_2-eq. reduction[26].	Finland, Sweden, France, Netherlands, Spain, EU.	It was suggested to achieve this shift via waste and natural resource use taxation. This would force producers and consumers to invest into circular economy-viable products.	Club of Rome (2011)
Combination of CE actions, e.g. modular design, use of lighter materials (more wood), reduced use of steel, recycling of unreacted cement, new cement production methods etc. and increased utilisation of buildings through sharing activities.	Construction & real estate	In 2050 a total GHG reduction of 80 Mtons compared to the baseline[27] can be achieved.	EU	This is a sum of measures in the built environment	Material Economics (2018)
Material efficiency in buildings, by reducing material use (e.g. through lightweighting) and waste generation (by 5%) during construction, increasing reuse of building components and by optimising building use through increased space sharing.	Buildings	Abatement 55 Mtons of CO_2-eq p.a. by 2050 compared to the baseline[28].	EU		Material Economics (2018)
Combination of intensive car sharing (two-thirds of the car travel volume done using a shared car fleet) with electrification and automation of cars and design that optimises car lifetime and reduces average weight and size of, as well as the need for maintenance.	Passenger cars	A reduction of 43 Mtons by 2050, (70% reduction of emissions from materials required for car production) compared to a baseline with predominantly private car ownership	EU	This is a sum of measures in the mobility sector	Material Economics (2018)
Increase vehicle lifetime; vehicle size adjustments (some passenger cars could be smaller).	Passenger cars	Abatement 30 Mtons of CO_2-eq p.a. by 2050 (part of the aforementioned 43 Mton)	EU		Material Economics (2018)
The combined effect of optimised use and increased recycling of steel, aluminium, plastics and cement; and the implementation of circular economy actions in the passenger car sector and in the built environment.	Steel, aluminium, plastics, cement (passenger cars manufacturing and construction and real estate	296 Mtons CO_2-eq. reduction by 2050 p.a. This impact is the combined impact of CE actions for steel, aluminium, plastics and cement production as well as CE actions in the passenger car sector and the value chain of the buildings sector. GHG abatement is against a baseline with full decarbonisation of the energy sector and for the rest baseline trends (e.g. in recycling).	EU	Synthesis of the findings from the different materials (steel, aluminium, plastics and cement) and the two value chains (passenger cars and buildings), accounting for synergies and double-counting.	Material Economics (2018)

[26] Based on a 4% emission reduction for the EU overall (conservative assumption) and the total GHG emissions of 3008.8 Mtons CO_2-eq., taken from the EU Reference scenario 2016. The report does not mention against which type of baseline the scenarios are modelled.
[27] As a baseline for the 2050 scenario, the baseline growth in building area (m2) was taken into account as well as baseline demolition and renovation rates. No circular actions in the baseline.
[28] *Ibid.*

Circular action	Sector	GHG impact (Mton CO_2-eq.) p.a.	Geographic scope	Note	Source
High-quality secondary production; Avoiding copper contamination; Increased collection of post-consumer scrap; reduced fabrication scrap	Steel industry	Abatement 41 Mtons of CO_2-eq p.a. by 2050, compared to a baseline with stable recycling rates and steel losses and sustained reliance on blast oxygen furnaces, albeit with adoption of best available technologies	EU	Available scrap could cover 85% of EU's steel requirements by 2050	Material Economics (2018)
Product design measures to facilitate recycling; specialised recycling operations; technology development for sorting, automation, and chemical recycling.	Plastics industry	Abatement 117 Mtons of CO_2-eq p.a. by 2050, compared to baseline emissions[29]	EU	More than half of plastics needs could be supplied via recycling by 2050.	Material Economics (2018)
Reduced collection losses; Increased alloy separation (to keep quality of secondary material); reduce scrap during production.	Aluminium industry	Abatement 29 Mtons of CO_2-eq p.a. by 2050 compared to the baseline[30]	EU	Circular scenario is not a 100% circular benchmark, but a more ambitious/realistic representation of what is achievable (unspecified how much that is).	Material Economics (2018)
Increase development of smart-crushers to increase recovery of concrete in construction; develop markets for reuse of structural segments.	Cement industry & construction sector	Abatement 25 Mtons of CO_2-eq p.a. by 2050 compared to the baseline[31]	EU	A shared car system can reduce material requirements for passenger cars by 75%	Material Economics (2018)
light-weight materials for products; local markets for building component reuse; prolonged lifetimes; leasing model to increase utilisation.	Other (product groups within transportation and machinery)	Abatement 13 Mtons of CO_2-eq p.a. by 2050 compared to the baseline[32]	EU		Material Economics (2018)
Increased car sharing use (share of total passenger-kilometres by car-sharing = 20% by 2030 and 30% 2050); Electric vehicle use (share of total passenger-kilometres by electric vehicle = 14% by 2030 and 60% 2050); Fully autonomous vehicles (share of total passenger-kilometres by autonomous vehicle = 25% by 2030 and almost all by 2050); and Remanufacturing and recycling of cars (10-15% by 2030, 40% by 2050).	Automotive	(-55% emission reduction by 2030, -96% by 2050), compared to baseline year 2012, which is a business as usual scenario.	EU		Ellen MacArthur (2015[A])
Emphasising importance of local food supply chains and reduced food waste; closing nutrient loops; valorisation of resource consumption and losses in natural capital; and shifting the tax system against finite resources (lower taxes on secondary materials and increased on primary).	Food and Agriculture	(-20% emission reduction by 2030, -61% by 2050), compared to baseline year 2012, which is a business as usual scenario.	EU		Ellen MacArthur (2015[A])

[29] Scenario with current recycling rates, and thus a significant level of plastics incineration and full decarbonisation of the energy system.
[30] Baseline is defined as the marginal improvement of recycling rates and full decarbonisation of the energy supply.
[31] Baseline is defined as the current practice in cement production, no significant increases in recovery of unreacted cement, no development of markets for structural building elements.
[32] These emission reductions are compared to a baseline based on current material use practices.

Circular action	Sector	GHG impact (Mton CO_2-eq.) p.a.	Geographic scope	Note	Source
Food Waste Reduction by 50% per capita (via consumer, retail, and supply-chain waste/loss reduction, or the valorisation of unavoidable food waste), packaging solutions (reducing packaging and improving the preservation of food), and nutrient recycling (Nitrogen, Phosphate, ad Potassium in particular)	Food and Agriculture	52-60 (Mton CO_2-eq.) calculated from estimated emissions from food waste in the EU[33] - and addition 3-4 (Mton CO_2-eq.) from recycling nutrients from organic waste[34].	EU	Based on embedded emissions of 471 $MtCO_2$-eq in the European Food Sector, in 2007. Deloitte estimated that 157 $MtCO_2$-eq could therefore be attributed to food waste. The figures therefore apply to the halving of per capita food waste and applying circular economy measures to this figure.	Deloitte (2016)
Recycling the materials for the construction of buildings. (an increase from 22% in 2007, to 70%)	Construction	-17% reduction in emissions, compared to baseline emissions[35].	EU		Deloitte (2016)
Increased reuse of materials (steel and aluminium can be reused up to 50%, a conservative assumption of 30% has been used for other materials). AND Recycling the materials for the construction of buildings. (an increase from 22% in 2007, to 70%)	Construction	-34% reduction in emissions, compared to baseline emissions[36].	EU		Deloitte (2016)
The recycled content of cars increases up to 100% for metals, up to 70% for plastics and 80% for glass. The recycling of rubber for the production of new tyres has been neglected. Actions to increase recycling include achieved by eco-design of vehicles in order to facilitate the reuse and recycling of parts; implementation of a system to systematically dismantle the reusable parts of a vehicle; ensuring the traceability of parts and materials to enable their reuse in closed loops; finding economic outlets for materials retrieved from used cars; R&D investments, training of stakeholders, alternatives in transport modes, etc.	Automotive	-45% reduction in emissions compared to baseline emissions[37]	EU	Estimation of the percentage reduction is based on their graph Fig 11, which does not specify the decrease in scenario 1 precisely, but it is somewhere between 40-50%.	Deloitte (2016)

[33] Based on estimated 2007 emissions from food waste in Europe and applying an assumption of 50% reduction of food waste per capita and applying circular economy measures.
[34] Based on current fertilizer consumption levels and assuming that all fertilizers are used for food production.
[35] The baseline seems to be based on current emissions, but the report does not specify this clearly.
[36] *Ibid*
[37] *Ibid.*

Circular action	Sector	GHG impact (Mton CO_2-eq.) p.a.	Geographic scope	Note	Source
The development of the reuse and repair market: spare parts are reused, and the lifetime of vehicles increases by 50%. Among the total material put on the market for car production and repair, it's assumed that 10% could be reused components. This rate is higher for tires (hypothesis of 30%) as 20% of all tires put on the market today would already be reconditioned tires.	Automotive	-65% reduction in emissions compared to baseline emissions[38].	EU	Estimation of the percentage reduction is based on their graph Fig 11, which does not specify the decrease in scenario 2 precisely, but it is somewhere between 60-70%. Emission reductions are based on baseline recycling rates from 2007: for steel (50%), aluminium (37%), rubber and plastic (11%), Copper (45%), Glass (45%).	Deloitte (2016)
Significantly increase recycle content for steel, aluminium, rubber and plastic, copper, and glass, having EEE designs that are almost 100% made of secondary materials. Reuse rate is not tampered with and would remain at the baseline rate of 2%.	Electrical and Electronic Equipment (EEE)	-43% reduction in emissions compared to baseline emissions.[39]	EU	Estimation of the reduction percentage is based on their graph Fig 14, which does not specify the decrease in scenario 1 precisely, but it is somewhere between 40-45%. Emission reductions are based on current recycling rates: for steel (50%), aluminium (37%), rubber and plastic (11%), Copper (45%), Glass (45%).	Deloitte (2016)
Same as above but including minimal efforts to achieve a reuse rate of EEE to 30% by 2030.	Electrical and Electronic Equipment (EEE)	-51% reduction in emissions compared to baseline emissions[40]	EU	Based also on current recycling rates of materials: Steel (50%), aluminium (37%), rubber and plastic (11%), Copper (45%), Glass (45%). And current reuse rate of 2% for total EEE flow. Estimation of the emission reduction percentage based on their graph Fig 14, which does not specify the decrease in scenario 2 precisely, but it is somewhere between 50-53%.	Deloitte (2016)
Increased circularity in the food sector (reduction of food waste), construction (a number of measures), electronics (a number of measures, in particular Waste Electrical and Electronic Equipment (WEEE) targets), waste and mobility sector (increased P2P sharing)	(extended)food sector, construction, electronics and electronic appliances, passenger cars	60 Mtons CO_2-eq. in 2030, 83 Mtons CO_2-eq. by 2035 compared to baseline emissions[41]			Cambridge Econometrics (2018)

[38] The baseline seems to be based on current emissions, but the report does not specify this clearly.
[39] *Ibid.*
[40] *Ibid.*
[41] The baseline is defined as continuation of historical trends and existing legislation (adopted by Member States until December 2014), i.e. some circular actions and legislation included (what is reflected in data up to 2014).

Circular action	Sector	GHG impact (Mton CO_2-eq.) p.a.	Geographic scope	Note	Source
	and waste sector				
Increase in resource productivity (RP), or GDP per unit of Raw Material Consumption (RMC)), by 3% pa - or 50% improvement in 2030 (with a 2014 baseline)	All	25% reduction compared to baseline[42] in this ambitious scenario. All the other scenarios proposed only resulted in a <0.5% increase in GHG emissions.	EU	Identified as a Single EU28 target. This is funded by 1/3 publicly funded investments (i.e. capital stock), 1/3 privately funded business measures (recycling systems), and 1/3 market-based instruments (tax measures)	Cambridge Econometrics (2014)
A broad set of actions in the food, construction, machinery, plastic packaging and hospitals sectors	Food & beverage, construction & real estate, machinery, plastic packaging, and hospitals	Conservative scenario: A -0.8 Mtons of CO_2 or 2.5% reduction in Denmark's CO_2 footprint; Ambitious scenario: -2.3 Mton of CO_2 or 6.9% reduction by 2035 relative to a business as usual scenario. The carbon emission reductions do not occur only in Europe, but throughout the lifecycle (globally)	Denmark	CO_2 footprint = "Change in Global CO2 emissions vs. Denmark baseline 2035 emissions; other GHG emissions are not included. " From previous table: EU - 88 Mtons (conservative) to 242 Mtons (ambitious) by 2035 previously noted (couldn't find how this was quantified)	Ellen MacArthur (2015[B])
Shifts to healthier diets with less red meat	Food	Between 20 and 50 Mtons CO_2 per year[43]	EU	This report is not focused on circular activities; hence it was not part of the literature review.	PBL (2011)
Increasing the recycling rate of municipal waste to two-thirds of the volume	Waste	180 Mtons CO_2 eq. (calculated based on current waste volume – years 2013/2014 (which acts as the baseline figure)	EU		CE Delft (2016)
A combination of restricting landfilling and increasing waste collection and recycling rates	Municipal Waste	20-62 Mtons CO_2-eq. in the EU by 2030 compared to the 'full-implementation' scenario, i.e. implementation of the current waste targets. The magnitude of GHG savings depends on the ambition level chosen, i.e. the level of targets chosen in the scenarios.	EU	The study provides GHG impacts for all their scenarios. Table 4-4 mentions more concrete details on the GHG impacts.	Eunomia (2014)
Closed and open loop recycling	Wholesale of waste & scrap Waste & recycling	For all five circular actions, a saving of 82-154Mton by 2030 is forecast compared to the baseline trend with current levels of CE actions, with the range depending on the level of adoption of the measures.	EU	In the report, the GHG impacts are split by member state rather than by circular action. We have approached the authors to enquire whether they could	WRAP (2016)

[42] This baseline is based on historical trends in resource consumption between 2001 and 2011, projections for economic growth and demographic developments as well as drivers of demand for specific resources identified in literature.
[43] The report only reports on cumulative GHG emission reductions between 2010 and 2030 which would be between 400 and 1000 Mtons. When it is is assumed that the emission reduction is equally split over the years, which likely is an oversimplification, annual GHG savings of 20-50 Mtons are obtained. Baseline emissions are based on a reference scenario that foresees a continuation of the current trend of igrowing consumption of animal protein (including red meat) globally, with strong increases outside Europe, which also affect EU production. Furthermore, some yield inmprovements are included, especially outside Europe.

Circular action	Sector	GHG impact (Mton CO_2-eq.) p.a.	Geographic scope	Note	Source
Repair - where products need repair or reconditioning before going back into use.	Repair of machinery & equipment Repair of electronics & household goods		EU	share the data cut by circular action instead.	WRAP (2016)
Reuse - examples included are electrical & electronic goods and textiles.	In-store retail of second-hand goods		EU		WRAP (2016)
Servitisation – business models that make more effective use of assets including leasing and "products as services" thereby deferring consumption of new assets.	Renting & leasing activities		EU		WRAP (2016)
Remanufacturing - rebuilding a product to its original spec using reused, repaired and new parts.	All manufacturing		EU		WRAP (2016)

Circular economy actions in steel production and associated GHG emission impacts

In the steel sector there are several actions that can be taken to reduce emissions. Although there are several technologies under development to reduce the GHG emissions from the production of primary steel, e.g. the use of charcoal instead of coal in blast furnaces or biogas or hydrogen in direct iron reduction[44], the largest potential for reducing the emissions from steel production lies in replacing a large share of primary steel production with secondary steel production. Already today, the GHG emissions from the production of secondary steel in electric-arc furnaces are 80% lower than those arising from primary steel production, even when electricity is used that originates primarily from fossil-based sources. With a decarbonised electricity supply, GHG emissions can be reduced from the current 2.3 tons of CO_2/ton steel for primary steel production to only 0.1 tons of CO_2/ton steel for secondary steel. It should be noted that emission reductions from the decarbonisation of electricity supply are outside the scope of this study.

In Europe there is a large opportunity for switching largely to secondary steel production. The steel stock is saturating, and steel demand will only serve to replace existing stock and therefore it is expected that by 2050 85% of the European steel demand can be covered by secondary steel production. However, there are several barriers to reach such a high level of secondary steel production, most notably the fact that today the quality of secondary steel is often lower than that of primary steel[45].

Circular actions leading to reductions in steel demand can reduce the GHG emissions from steel production even further. Over 70% of the steel demand is either used for construction purposes or for transport applications, primarily passenger cars. This means that actions focused at reducing steel demand for these applications can have a substantial effect on emissions. It is estimated that buildings contain on average twice as much steel as is needed for construction quality and safety standards, so called overspecification. Reducing overspecification can reduce steel demand on average by 50%, which could lead to 31 Mtons in GHG emission savings annually. Similarly, optimisation of passenger car use, through increased sharing and improved car design amongst other actions, could reduce steel demand significantly.

Together, the combination of the circular actions in steel *production in the EU* is estimated to reduce the total emissions from steel production in the EU from 104 Mton CO_2-eq. in 2050 (if no circular action taken) to 57 Mtons, that means an abatement of 47 Mtons CO_2-eq. per annum by 2050[46]. These emission reduction potentials do not include emission savings that can result from reduced steel use, due to demand-side material savings, e.g. in car industry and the construction sector. The latter are counted in the sections on construction and mobility. In addition, these emission reduction potentials also do not include the GHG emission savings from decarbonisation of energy supply.

Circular economy actions in aluminium production and associated GHG emission impacts

In the aluminium sector there are also significant opportunities for implementing more circular actions. In contrast to steel production, primary aluminium is done with electricity. This means that decarbonisation of the power supply can largely reduce the GHG emissions from aluminium production. This measure lies outside the scope of this study as it is already covered by climate change mitigation

[44] McKinsey (2018) Decarbonisation of industry: the next frontier.
[45] Material Economics (2018) The Circular Economy – A powerful force for climate mitigation.
[46] Ibid.

policies. Recycling aluminium lowers the emissions even further, as the production of secondary aluminium only requires 5% of the energy that is required for primary aluminium production[47]. Currently, secondary aluminium production accounts for approximately one third of the EU aluminium demand.

Several solutions are at hand to increase the use of secondary aluminium. First of all, collection rates can be improved further, as to date still 23% of the aluminium present in end-of-life products are not collected for recycling[48]. Next to this, collection of aluminium has to be done in such a way that different alloys are kept separated, so that no unwanted impurities end up in the secondary aluminium alloys. In car industry, automated dismantling processes can separate the different kinds of aluminium components before the car is shredded. Additionally, more closed recycling loops can be created for particular types of alloys, as is currently done for aluminium beverage cans. Another aspect that currently limits the use of secondary aluminium is the fact that buyers often require specific types of alloys, while other secondary aluminium alloys would meet the same quality requirements. A solution to this would be to let buyers ask for specific product requirements and let the aluminium producers decide which alloys could be fit for purpose.

The overall GHG emission reduction from increasing circularity in the aluminium industry, i.e. reduce collection losses, increase alloy separation in scrap recycling to avoid downgrading and reduce scrap forming during production in the EU is estimated to amount to an annual abatement of 29 Mtons CO_2-eq. by 2050 compared to baseline trends.[49]

Circular economy actions in plastics production and associated GHG emission impacts

Although at a global level plastic demand is still expected to increase by more than a factor four, the demand in Europe is stabilising, or growing only at a slow pace. At the EU level, plastics generate 132 Mtons of CO_2 emissions per year, of which the majority share originates in the production phase[50]. This is because incineration of plastics at the end-of-life phase is often done in incineration plants that produce electricity. As this electricity serves demand that would otherwise have been supplied by electricity produced to a large extent from coal and gas, the incineration of plastics currently hardly leads to additional CO_2 emissions. However, in an electricity sector where renewables dominate it will be a different story as electricity generation from plastics incineration will lead to much higher emissions per kWh than the average electricity supply. As a consequence, continuation of plastics incineration with energy recovery at the current rate until 2050 would result in an additional 90 Mtons of annual CO_2 emissions in addition to increased emissions due to growth in demand for plastics[51]. Together the effects of sustained demand growth, sustained incineration of plastics against the backdrop of decarbonising energy supply and increased production efficiency lead to an increase in total emissions from 132 Mtons today to 233 Mtons in 2050.

To date recycled plastics account for only 10% of the EU's plastic demand, for several reasons: low collection rates, 30 different types of plastics that are used commonly and these different types are collected altogether, which makes recycling difficult and expensive as it requires costly sorting technologies. As a consequence, only 60% of the plastics collected for recycling are actually turned into

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[47] Material Economics (2018) The Circular Economy – A powerful force for climate mitigation.
[48] *Ibid.*
[49] Material Economics (2018) The Circular Economy – A powerful force for climate mitigation.
[50] Material Economics (2018) The Circular Economy – A powerful force for climate mitigation.
[51] *Ibid.*

secondary plastics. Furthermore, in the design of many products different types of plastics are mixed or fused together making recycling virtually impossible. Another problem is that many plastics contain additives, some of which are difficult to remove rendering recycling unsafe or impossible. Currently, the poor sorting of plastics usually results in the production of low-quality secondary plastics, which reduces their economic value. Also, due to the low quality of the recycled plastics, the extent to which they can replace primary plastics is still limited.

Generally, if plastics are collected at a higher rate, sorting is improved, and design processes are adjusted so that mixing of different plastic types is minimised, and additives are used wisely, the supply of high-quality secondary plastics could go up substantially. Most plastics can be recycled mechanically and if mechanically recycled plastics replace primary plastics this reduces GHG emissions by 20%. Some types of plastics mechanical recycling are not possible, for these plastics chemical recycling is an option. However, to date the emissions from chemical recycling are still somewhat higher than for mechanical recycling. Performing mechanical recycling with low-carbon energy can reduce emissions to only 0.1 Mton CO_2/Mton plastic, a reduction of emissions by more than a factor 50 compared to primary plastics production today.

Increased recycling of plastics can reduce emissions from 233 Mtons of CO_2 emissions per year in 2050 to 117 Mtons, so a reduction of 116 Mtons of CO_2 emissions per year, which is a reduction of 15 Mtons CO_2-eq. compared to today's level of GHG emissions[52].

Circular economy actions in the built environment and construction and associated GHG impacts

The construction sector and built environment make a significant contribution to GHG emissions in Europe. The built environment accounts for approximately 40% of the EU's energy consumption[53] and the construction sector accounts for 50% of the raw material use[54] in the EU. In countries like Sweden where the energy efficiency of buildings is already very high, the impact of resource use on the total GHG impact of buildings has already increased to 50%.

In the EU, material use for construction accounts for around 250 Mtons CO_2-eq. emissions annually. The largest part of these emissions originates from the use of cement (30%), followed by steel (25%), aluminium (12%) and plastics (11%)[55]. Cement production generates 114 Mtons CO_2-eq. of GHG emissions in the EU each year, with around 60% of being process-related emissions form clinker production and the remaining 40% energy-related emissions from the production of cement. The relatively large impact of steel use is primarily caused by the fact that many buildings contain much more steel (on average twice as much) than is needed for their structural integrity. Reducing this so-called overspecification can thus be an effective method for reducing GHG emissions from construction.

There are several circular actions that can reduce the emissions of the construction sector. Emissions from cement can be reduced by recycling unreacted cement from demolished buildings, producing cement from clinker alternatives and substituting cement by alternative construction materials, including wood and plastics. Additionally, switching from demolition to deconstruction should increase the availability of components and secondary construction materials for reuse. Modular design of construction components that can easily be disassembled can aid this development.

[52] *Ibid.*
[53] EC DG Energy (2018) Official website - https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings
[54] Circle Economy (2018) The circularity gap report.
[55] Material Economics (2018) The Circular Economy – A powerful force for climate mitigation.

As the construction of buildings will have a larger impact on the lifecycle GHG impact of buildings it is important that buildings can be used longer. Several strategies can be employed to increase the lifetime of buildings. Modular design could also make it easier to adjust buildings internally, by replacing certain components to adapt them to new functional requirements, thereby avoiding the need to demolish the building and replace it with a new one. Another strategy that can reduce the demand for the construction of new buildings is to increase the implementation of sharing initiatives. Currently, office spaces are used for only 40% of the time on average, even during working hours[56]. Sharing initiatives could increase the utilization rate of such buildings. Towards the future, the amount of vacant office spaces is expected to increase further as digitalisation promotes practices like working from home and teleconferencing even more.

Several studies have assessed the potential GHG impact of implementing CE actions in the construction sector. The Material Economics assessed this potential by looking at the impacts of optimised material use (reducing overspecification, material substitution, reduced waste generation during construction) during construction, optimised use of buildings as well as improved cement recycling. This could be considered as a comprehensive assessment of the GHG emission reduction potential for the built environment and the construction sector. Overall, most actions assumed in the Material Economics study can be seen as ambitious, although feasible. However, a lack of explicit quantitative assumptions on decreased material use, increased reuse, etc. makes it difficult to assess what the actual ambition level of their scenario on the built environment is.

The Deloitte study also looked at the impact of improved material management and recycling. They made one scenario where the impact of increased use of secondary materials was assessed (60-95% depending on the material), where the overall use of recycled materials increases from the current 22% to 70%. This results in a GHG reduction of 17% compared to the current situation. In a second scenario, it was assumed that steel and aluminium reuse would increase to 50% and reuse of other construction, materials would increase to 30%. Together with the increases in recycling rates as modelled in scenario 1, this would lead to an overall emission reduction of 34% compared to the current situation. The aforementioned assumptions can be seen as quite ambitious, especially the high recycling and rates assumed in the Deloitte study. In reality, such a practice is likely to be limited by the availability of secondary materials with the right specifications and therefore this can only happen if changes in the sectors that produce these materials take place as well (e.g. in steel and aluminum industry). Also, to enable significant increases in the reuse of construction materials would require major shift from demolition to deconstruction.

The recent study by Cambridge Economics also assessed the building construction sector, taking into account CE actions such as increased sharing of space, modular design and improved materials managements (plastics, metals). However, the results of the study aggregate the GHG impacts for CE actions in five sectors, and GHG impacts are not differentiated between sectors as such (sectors were not modelled separately).

Overall, the aforementioned circular actions in the EU construction sector can reduce GHG emissions with 80 Mtons CO_2-eq. p.a. Of this abatement, 55 Mtons originate from improved material

[56] Ellen MacArthur Foundation (2015) Growth within: a circular economy vision for a competitive Europe.

use in buildings (e.g. more efficient material use for buildings, optimised building use through increased sharing of space) and increased cement recycling can reduce GHG emissions by an additional 25 Mtons CO_2-eq. by 2050 per year. Even when these circular actions are implemented the remaining GHG emissions from construction will be 150 Mtons per year[57]. Further lifetime extension of buildings beyond 2050 can deliver an additional 43 Mtons of annual GHG emission savings[58].

Circular economy actions in the biobased (e.g. food) sectors and associated GHG emission impacts

Currently, there are still many large inefficiencies in agriculture and across the food value chain. First of all, approximately 20% of all the food that is produced is not consumed but ends up as waste. Furthermore, diets in wealthy areas like Europe are very high in animal protein (meat, dairy products, fish etc.). The production of animal-based foodstuffs, such as meat and dairy products, requires much more land and resources than a vegetable-based diet and also leads to higher GHG emissions. Other important areas with circular economy potential relate to the closing of nutrient cycles and reducing fertilizer use and optimising the use of bio-waste.

Apart from the environmental impact of food production, the food value chain as a whole is still very wasteful. It is estimated that 20% of all the food that is produced in the EU ends up as waste[59]. Just over half of this waste is generated by consumers and the remainder is generated during food production, processing and distribution. In total it is estimated that a total of around 87 Mtons of food waste are generated each year[60], and with an average carbon footprint of 2-3.6 tons CO_2-eq./ton of food[61], this means food waste accounts for a total of about 245 Mtons CO_2-eq. per year in the EU. The Deloitte study on the GHG impacts of circular activities estimated that the GHG emission impact of reducing food waste could be in the order of 61 Mtons CO_2-eq. if the amount of food waste is cut by 50%[62]. The Ellen MacArthur Foundation has estimated that under the current development path, which focuses on resource efficiency improvements and waste reductions on the production side, a food waste reduction of 50% could be achieved in 2050. Implementation of more far-reaching circular economy actions could reduce food waste by as much as 80%. However, as 1/3-1/2 of the food waste is generated by consumers[63], achieving the ambitious food waste reductions mentioned before will require major behavioural changes. Therefore, it is questionable whether 50-80% reductions in food waste are attainable by 2050.

Apart from the fact that a large share of the food that is produced is wasted, European dietary patterns are also not sustainable. Europeans eat more meat, dairy and fish than is good for their health. As a result, the recommended intake of protein is surpassed by 70% and the intake of saturated fats is 40% higher than recommended by the WHO[64]. This vast consumption of animal-based food products does not only hamper our health, but also has significant environmental impacts. Livestock farming is responsible for 87% of the GHG emissions generated in agriculture in Europe, amounting to a total of 538 Mtons

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[57] Material Economics (2018) The Circular Economy – A powerful force for climate mitigation.
[58] *Ibid.*
[59] Stenmarck, A et al. (2016) Estimates of European food waste levels.
[60] *Ibid.*
[61] Tonini *et al.*, 2018. Environmental impacts of food waste: Learnings and challenges from a case study on UK.
[62] Deloitte (2016) Circular economy potential for climate change mitigation.
[63] Ellen MacArthur Foundation, Sun, and McKinsey Center for Business and Environment (2015[A]). Growth Within: A Circular Economy Vision for a Competitive Europe, Ellen Mac Arthur Foundation, Sun, and McKinsey Center for Business and Environment; Fusions (2016) Food waste quantification manual to monitor food waste amounts and progression.
[64] PBL (2011) The protein puzzle: the consumption and production of meat, dairy and fish in the European Union.

CO_2-eq. 70% of these emissions derive from beef and dairy production. Apart from the impact on GHG emissions, the high level of livestock production in the EU also has its repercussions for land use. The EU is currently using 20 million hectares of arable land outside Europe in order to supply feed for European livestock[65]. Reducing the amount of animal protein in European diets can thus significantly reduce land-use, fertilizer use (for producing feed) and GHG emissions. Within the EU, switching to a diet that complies with the WHO dietary recommendations, or substituting red meat (beef) by other types of meat could reduce livestock derived emissions by 400-1000 Mtons CO_2-eq. in the period from 2010-2030[66]. The avoided GHG emissions outside the EU would be even larger, namely 8000-11000 Mtons CO_2-eq. in that same period.

Agriculture in Europe uses 16.9 Mtons of mineral fertilizer each year[67]. The current use of fertilizers is not circular and not sustainable. Only a limited share of the nutrients applied to the land is recycled after the first application to the land. This is especially problematic for phosphorus as mineral phosphorus fertilizer is produced from mined from phosphate rock, a finite resource, which is expected to run out in 300 to 400 years at the current rate of consumption[68], while phosphorus is a nutrient that cannot be substituted by something else. Nitrogen fertilizers can be produced from atmospheric nitrogen, but this process which consumes natural gas generates significant GHG emissions. The combination of production and use of nitrogen fertilizers in the EU amounts to around 104 Mtons of CO_2-eq[69].

Agricultural innovations like precision farming, where fertilizers and pesticides are only applied locally, can help reduce the demand for fertilizers. The same holds for new farming practices like hydroponic and aquaponic farming, where nutrients are controlled in a closed system so that run-off is prevented. Innovative microbiological technologies, like the nitrogen-fixing bacterial strains that can live inside crop tissues and provide the crops with nitrogen, can help reducing the demand for nitrogen fertilizer by 30-50% and sometimes even more[70]. The Deloitte study only looked at increasing nutrient recycling and they estimate that this could yield a 3-4 Mton CO_2-eq. emission reduction compared to the emission level at the time of writing.

The biobased sectors together with consumers produce a vast amount of organic waste each year, amounting to 118-138 Mtons[71]. Currently, a large part of this organic waste is landfilled, resulting in high levels of methane emissions (around 150 Mton CO_2-eq.). This organic waste could be used in much more valuable ways. Many organic waste streams contain valuable components such as proteins, pigments or natural pesticides. Such components can be extracted from organic streams in biorefineries. Next to that, several types of organic waste can be used as animal feed directly or converted into animal feed, e.g. by breeding insects on the organic waste and producing feed from these insects. The remaining streams of organic waste can be used for biogas production, through

[65] PBL (2011) The protein puzzle: the consumption and production of meat, dairy and fish in the European Union.
[66] The emission abatement in this study was calculated using the combination of the LEITAP and IMAGE model as well as the combination of the IMPACT and IMAGE model. The LEITAP model is a CGE model, the IMPACT model an agricultural commodity trade model and the IMAGE model is an integrated assessment model.
[67] Fertilisers Europe (2017). Securing the future – fertilisers and the food chain. Overview 16/17.
[68] Blanco (2011). Supply of and access to key nutrients NPK for fertilisers for feeding the world in 2050.
[69] Based on data from: Fertilisers Europe (2008). Energy efficiency and greenhouse gas emissions in European nitrogen fertiliser production and use.
[70] Azotic (2014) http://www.azotictechnologies.com/index.php/news-and-insight/latest-news/nitrogen-fixation-trials/ ; Azotic (2017) http://www.azotictechnologies.com/assets/Uploads/Azotic-Koppert-Rice-Information.pdf
[71]EC COM(2010)235 final https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52010DC0235&from=EN

anaerobic digestion or gasification. However, the latter would fall under renewable energy generation and is therefore considered to be outside the scope of this study.

Taking together all the aforementioned CE actions, the food sector and associated sectors seems to possess significant GHG abatement potential. The Ellen MacArthur Foundation states that there is a large potential for GHG abatement in the food value chain[72]. They estimate that even under a scenario where current developments (more resource efficient farming, waste reduction in the supply chain) are sustained, a GHG reduction of 11% compared to 2012 levels could be attained in 2030 and a 20% reduction in 2050. If further circular economy measures are taken, such as dietary shifts, a shift to closed-loop farming and increased implementation of peri-urban farming, these emission reductions can grow further to 35% in 2030 and 61% in 2050 compared to 2050 levels. It should be noted though, that implementation of the actions included in the latter scenario involves major systemic change in how food is produced and consumed, so this scenario reflects a very high ambition level. The Deloitte study took a narrower approach in their quantification of the emission reduction potential in the food sector as they only included food waste reduction and increased nutrient recycling[73]. The study estimates that achieving the 50% food waste reduction goal that has been formulated by the UN, could lead to a GHG emission reduction of 52-60 Mtons CO_2-eq. Additionally, they estimated that increased nutrient recycling could induce a saving of 3-4 Mtons CO_2-eq. The Cambridge Econometrics study[74] also analysed CE actions in the food sector, but the GHG results were only quantified at an aggregate level (CE actions per sector were not modelled separately for each sector, but together in one scenario).

The total GHG emission reduction potential from reducing food waste by 50% is in the order of 61 Mtons CO2-eq[75] based on current food waste levels. Shifts to healthier diets with less red meat could reduce emissions with around 20-50 Mtons CO_2-eq. per year[76]. The total of these actions if summed up, which do not include improved nutrient management and biorefinery, could lead to a total emission reduction in the order of 81-111 Mtons CO_2-eq. per year[77].

The GHG impacts of collaborative actions

In the last five years, the collaborative economy more commonly known as the sharing economy has seen tremendous growth[78]. The collaborative economy mostly involves 'sharing' transactions between peers that are facilitated by online platforms. There are also collaborative economy activities that occur from business to business or from consumer to business, but the studies analysed in this literature review mainly focused on peer-to-peer transactions and to a limited extent also on business-to-consumer transactions.

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[72] Ellen MacArthur Foundation, Sun, and McKinsey Center for Business and Environment (2015[A]). Growth Within: A Circular Economy Vision for a Competitive Europe, Ellen Mac Arthur Foundation, Sun, and McKinsey Center for Business and Environment.
[73] Deloitte (2016) Circular economy potential for climate change mitigation. https://www2.deloitte.com/content/dam/Deloitte/fi/Documents/risk/Deloitte%20-%20Circular%20economy%20and%20Global%20Warming.pdf
[74] Cambridge Econometrics, Trinomics and ICF (2018). Impacts of the circular economy on the labour market. For the European Commission, Luxembourg: Publications Office of the European Union. Available at: https://publications.europa.eu/en/publication-detail/-/publication/fc373862-704d-11e8-9483-01aa75ed71a1/language-en
[75] Deloitte (2016) Circular economy potential for climate change mitigation.
[76] PBL (2011) The protein puzzle: the consumption and production of meat, dairy and fish in the European Union. These numbers are based on an equal distribution of the cumulative emission abatement between 2010 and 2030 estimated in the study over the individual years.
[77] Assuming stable food consumption levels.
[78] EC (2018) Study to monitor the economic development of the collaborative economy at sector level in the 28 EU Member States.

The collaborative economy has an environmentally friendly image, but the number of studies that analysed the climate change and/or environmental impacts of the collaborative economy has been limited up to now. The environmental potential of collaborative transactions lies mainly in the fact that they increase the utilization of assets through shared use, thereby reducing the overall demand for these assets. Existing studies on the climate and environmental impacts of the collaborative economy focused mainly on activities in the transport sector, the accommodation sector and goods sharing. Another large branch of the collaborative economy is the area of peer-to-peer services, but the environmental impacts of such activities were not assessed in the studies reviewed.

In the transport sector, collaborative economy activities include carsharing, either via peer-to-peer or by business-to-consumer transactions (platform-mediated form of traditional car rentals), ridesharing (carpooling mediated by a platform). Lifecycle Assessments have shown that ridesharing has the largest potential for reducing GHG emissions[79]. A study among Dutch carsharing members found that car sharing reduces the emissions from car use on average by 280 kg per person per year, due to a reduction in the overall distance travelled by car[80]. Additionally, car sharing was estimated to reduce the emissions from car ownership (production and end-of-life treatment) by 87-175 kg per person per year. When this was extrapolated to all the people in the Netherlands that engage in carsharing this means that a total of 20.7-28.8 ktons CO_2-eq. of GHG emissions were avoided because of carsharing. Another study, which modelled the GHG impacts at the EU level[81] through input-output modelling estimated that by 2030 an increase in collaborative modes of transport can reduce emissions with 1 Mtons CO_2-eq. when the rebound effect is included and 7.5 Mtons when a rebound effect is absent[82]. The study performed by Material Economics assumed higher uptake of carsharing than the DG ENV study, namely 64% of the cars would be operated as shared cars and as a result the emission reductions resulting from reduced material use are considerably higher in this study. The study estimates that increased car occupancy due to car sharing can reduce emissions by 9 Mtons CO_2-eq. per year, and car sharing can also be an enabler for having a car fleet with smaller (average) car size and changes in car design that lead to an increased lifetime of cars, leading to emission reductions of 21 and 9 Mtons CO_2-eq. per year, respectively [83].

In accommodation, the collaborative economy involves renting out entire homes or rooms to peers and home swapping. At the macro-economic level, the GHG benefits of collaborative accommodation were estimated to be rather limited[84]. Overall, sustained growth of collaborative accommodation was estimated to reduce EU GHG emissions in 2030 by 18 to 22 ktons, depending on whether or not the rebound effect was included.[85] The fact that the GHG impact of collaborative accommodation is so limited is because although the emissions per stay might be slightly lower than in ‘traditional’ accommodation, the lower price of collaborative accommodation options also creates additional demand for accommodation. It should be noted that the rebound effect in the aforementioned figures was assumed to result from increased spending in all consumer categories. However, in reality cheaper

[79] EC (2017) Environmental potential of the collaborative economy.
[80] PBL (2017) Effecten van autodelen op de mobiliteit en CO_2-uitstoot.
[81] EC (2017) Environmental potential of the collaborative economy.
[82] In the scenario with rebound the total emission reduction is lower as people spend the money saved through the use of collaborative transport forms on other consumption, which also creates emissions. In the scenario without rebound it is assumed that the cost savings are not spend but kept as savings.
[83] Material Economics (2018) The Circular Economy – A powerful force for climate mitigation.
[84] Collaborative accommodation was modelled in the input-output model by reducing the demand for services from the ‘traditional’ accommodation sector, combined with an increase in income for the IT services sector and increased income for households.
[85] EC (2017) Environmental potential of the collaborative economy

holiday accommodation might specifically induce people to travel more often or over larger distances. In that case the rebound effect might even result in a net negative impact of GHG emissions due to collaborative accommodation. To what extent this is the case needs to be investigated further.

Another area of the collaborative economy for which the GHG impacts have been assessed is goods sharing/renting. Via platforms people can borrow or rent all kinds of goods from neighbours, e.g. tools, travel gear, party items, gardening equipment etc. Goods sharing can have GHG benefits, by increasing the utilisation rate of product thereby reducing the relative impact of the production phase on the overall environmental impact of the product. However, the net GHG impact of goods sharing is strongly affected by the transport mode people use to pick up the item and return it to its owner as well as the travel distance. Also, increased cleaning and maintenance rounds in-between uses by different users can increase the environmental impact. Currently, the number of people that participate in peer-to-peer good sharing/renting activities is very low. Even when the number of people involved in such activities would increase substantially, the GHG impact at the EU level in 2030 would be rather limited (only 40-120 ktons CO_2-eq.).[86]

The table below shows the GHG abatement estimates by different studies. The difference in size largely depends on the assumptions made with regard to the uptake of collaborative economy in the EU. Moreover, studies that used LCA methods, e.g. Trinomics (2017) study, global impacts were considered.

Table 4-3 – GHG impacts of collaborative economy activities. The estimates from the sources are given

Circular activity	Sector	EU GHG emission reduction potential (CO_2-eq.)	Source
Extending smartphone use from 2 to 6 years	Electronics	0.7 Mtons p.a.[87]	CE Delft (2016)
Switch from traditional accommodation to collaborative accommodation	Accommodation	0.018-0.022 Mtons p.a. by 2030 at the EU level	Trinomics, Cambridge Econometrics, VVA & Vito (2017)
Increased use of collaborative economy transport modes	Transport	1-7.5 Mton p.a. by 2030 at EU level	Trinomics, Cambridge Econometrics, VVA & Vito (2017)
Increased sharing of consumer durables	several sectors, including clothing, electronics, electronic equipment, sports equipment, etc.	0.040 -0.120 Mton p.a. by 2030 at EU level	Trinomics, Cambridge Econometrics, VVA & Vito (2017)
Carsharing (GHG emission reduction from material savings only)	Transport	9 Mton (direct emission reduction) by 2050 at EU level + 30 Mton p.a. (indirect) emission reduction	Material Economics (2018)

The collaborative economy and other inner loops of the circular economy hold a large potential for material savings and associated emission savings as these actions fall within the highest levels of the waste hierarchy, namely refuse and reduce. However, currently the participation in collaborative economy activities is still rather limited in most sectors. This means that the potential total emission savings can be very substantial, but only if collaborative economy actions like car sharing become part of mainstream economic activity. Material Economics estimated that if two

[86] EC (2017) Environmental potential of the collaborative economy
[87] 4.1 Mtons in a period of 6 years.

thirds of the car travel would be done using a shared car fleet this could lead to an emission reduction of 43 Mton by 2050, resulting only from reduced resource use in car manufacturing[88].

The GHG impacts of improving waste management

Currently, the waste management sector in Europe is still responsible for significant amounts of GHG emissions, although significant progress has been made during the last decade. From all non-ETS sectors, the waste management sector reduced its GHG emissions at the highest rate in the period from 2005 to 2013. However, significant potentials for improvement are still remaining.

Today, 31% of the municipal waste in Europe still ends up in landfill, which is not only a waste of precious resources but also generates substantial amounts of methane emissions[89]. In the short-term, switching from landfilling to incineration with energy recovery appears to be an attractive way to reduce emissions in the waste sector. However, greater GHG benefits can be achieved when the municipal waste is recycled rather than incinerated. The benefit of recycling is that the recovered materials can replace virgin raw materials, thereby reducing dependence on imported raw materials but it also avoids the emissions that would have been generated from raw material production. When considering the avoided emissions from reduced landfilling, it should be noted that different models allocate the moment of emission differently. The EU reference model on municipal waste allocates all landfill emissions to the year of disposal, whereas some other models use first-order decay trajectories to better reflect the actual moment of emission.

Up to now recycling policies in Europe have often focused on increasing collection rates. Although achievement of high collection rates is desirable, the story does not end here. It is essential that collected waste is recycled and that recycling is organised in such a way that materials are recovered at a high quality. As an example, more than 40% of the plastics that are collected are currently not recycled[90]. Also, downgrading is common practice for many materials. Recycled plastics often are of a low quality and the value of these plastics is often only 50% of the value of primary plastics, or even less. As explained above, downgrading is also a big issue in aluminium recycling as mixing different types of alloys leads to production of lower quality wrought aluminium. As an example, only around 8% of the steel recycled from vehicles is again used for that purpose. Therefore, waste policies should not only set targets for collection rates, but also for levels of high-quality secondary materials produced. Ensuring production of high-quality secondary materials would require improved collection methods, with more differentiated waste streams as well as product designs that allow for easier dismantling and separation of different materials.

Due to its importance for circular economy, the waste management sector has been assessed in terms of GHG impacts in several studies. When assessing the impact of circular economy actions in a wide range of sectors it is often difficult to include the waste sector as well, as this poses the risk of double-counting the effects of recycling activities. Still, several studies have tried to assess the impacts of improved waste management and increased recycling on GHG abatement. The WRAP (2016) study looked at the emission reduction of the entire waste sector according to the digit 2 NACE Rev 2 classification, but in this study all CE actions were modelled together and therefore no specific GHG

[88] Material Economics (2018) The Circular Economy – A powerful force for climate mitigation.

[89] CE Delft (2016) The circular economy as a key instrument for reducing climate change.
[90] Material Economics (2018) The Circular Economy – A powerful force for climate mitigation.

emission reduction from improved waste management and increased recycling can be given. The same holds for the recent study on the labour market impacts of the circular economy modelled CE actions in the waste sector by reducing landfilling, increasing recycling activities and increasing investments in recycling facilities[91]. The Eunomia study (2014) assessed only municipal waste using the EU Reference model on Municipal waste, which takes an LCA approach. They estimated that increased recycling of municipal waste can result in emission reductions from 107-443 Mtons CO2-eq. between 2014 and 2030.

Increasing the recycling rate of municipal waste to two-thirds of the volume can already generate a GHG emission reduction of 180 Mtons CO_2-eq. in the EU, based on the current amount of waste. A large part of this (150 Mtons) originates from avoided methane emissions from the degradation of organic waste[92]. It is estimated that a combination of restricting landfilling and increasing waste collection and recycling rates can generate annual emission reductions of 20-62 Mtons CO_2-eq. in the EU by 2030[93]. The latter estimate from Eunomia refers to the emissions from landfilled waste allocated to the year of disposal. The latter also uses an LCA-based method, and as such might take into account global impacts.

Table - GHG impacts of circular economy actions in waste management. The estimates from the sources are given and where needed extrapolations to the EU level were made (indicated in red).

Circular action	Sector	GHG impact (Mton CO_2-eq.)	EU GHG impact (Mton CO_2-eq.)	Source
Recycling 2/3 of all MSW	Waste sector	180 Mtons		CE Delft (2016)
Shift from recycling to increased reuse and repair, and additionally increased recycling of items that are currently not recycled	Metals, Electronics and electronic appliances	0.747 Mtons (NL only)	17.4 Mton[94]	TNO (2013)
Biogas production from organic waste	Waste sector, agriculture, industry	0.15 Mton (NL only)	3.5 Mton[95]	TNO (2013)
Shifts from recycling to increased repair and reuse in the metals, electronics and electric appliances sectors. Higher value use of biogenic residues, e.g. to produce high value products in biorefineries or by producing biogas and organic fertilizers.	biobased sectors and the metals, electronics and electronic appliances sectors	17.15 Mton (NL only)	398.8 Mton[96]	TNO (2013)
Increasing recycling rate of municipal waste to 60, 65 or 70%	Waste sector	23, 32, 39 Mton CO_2 eq. pa by 2030 in the EU		Eunomia (2014)
Increased collection and recycling of packaging waste	Waste sector	20-24 Mton CO_2 eq. pa by 2030 in the EU		
Limiting landfilling to a maximum of 5% of the total waste volume	Waste sector	13 Mton CO_2 eq. pa in the EU by 2030		
Combining the 3 options mentioned above	Waste sector	44-62 Mton by 2030		
Improved waste management - landfill ban	Waste sector	78 Mton in 2020 compared to 2008 (EU + Norway and Switzerland)		EEA (2011)

[91] Cambridge Econometrics, Trinomics and ICF (2018). Impacts of the circular economy on the labour market. For the European Commission, Luxembourg: Publications Office of the European Union. Available at: https://publications.europa.eu/en/publication-detail/-/publication/fc373862-704d-11e8-9483-01aa75ed71a1/language-en

[92] CE Delft (2016) The circular economy as a key instrument for reducing climate change.

[93] Eunomia (2014) Impact Assessment on Options Reviewing Targets in the Waste Framework Directive , Landfill Directive and Packaging and Packaging Waste Directive ” Final Report Report for the European Commission DG Environment.

[94] It was assumed that the sectoral composition of the EU average is similar to that of the entire EU, so the GHG savings potentials were upscaled as a function of GDP. The Dutch economy was assumed to have a 4.3% share in the EU economy, based on the EC (2016) EU Reference scenario 2016.

[95] It was assumed that the sectoral composition of the EU average is similar to that of the entire EU, so the GHG savings potentials were upscaled as a function of GDP. The Ducth economy was assumed to have a 4.3% share in the EU economy, based on the EC (2016) EU Reference scenario 2016.

[96] Ibid.

Non-climate related environmental impacts of the circular economy

When implementing environmental policies, it is always important that all different types of environmental impacts are monitored, so that reductions in one type of environmental impact do not result in worsening of other impacts. Therefore, it is important that the impacts of circular economy activities apart from GHG impacts are properly assessed. In our literature review we did not find any quantification of major trade-offs between implementation of circular economy actions and environmental impacts. Generally, circular actions tend to lower environmental impacts as reducing resource use does not only reduce the emissions, but also the local environmental impacts (e.g. pollution, biodiversity loss etc.) resulting from resource extraction.

One trade-off that could occur would be increased impacts on land-use change and biodiversity due to increased use of biomass for the production of materials and biochemicals. However, increased use of biobased materials does not need to increase environmental impacts when managed in a proper way. First of all, circular economy actions aimed at reduction of food waste and shifting dietary patterns should lead to increased availability of arable land for the production of products other than food, including biomaterials, biobased chemicals and bioenergy. The philosophy of the circular economy is that resources are always used at the highest value possible. This means that the use of biomass for food, materials and production of chemicals is preferred over the use of biomass for energy. Therefore, a circular bioeconomy agenda should not focus only on increasing biobased materials alone, but rather take a holistic approach aiming at optimised utilisation of the arable land available for the production of those products that are most valuable in a particular context (depending on local soil quality and relative prices of different products).

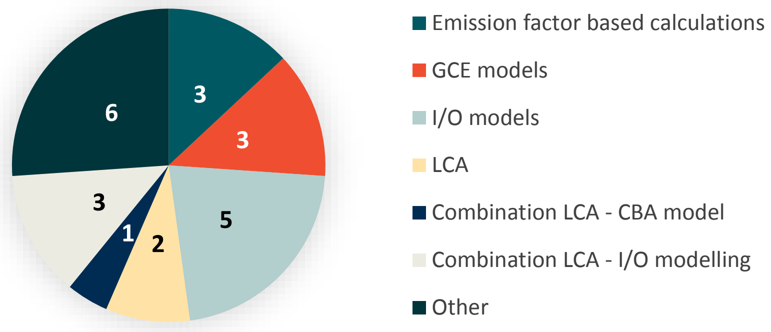
4.3 Selection of five cases for an in-depth review

4.3.1 Methodological characterisation of analysed literature

This section gives an overview of the methodologies used in the reviewed studies to quantify the impact of circular economy activities on GHG emissions. From the 23 studies that quantified this impact, eight used macro-economic modelling techniques, including Computable General Equilibrium (CGE) modelling (3) and input-output models (5). Five of them either used a Life-Cycle Assessment (LCA) (2) or approach based on changes in emission factors and activity volumes (3) (referred to in the figure below as ‘Emission factor-based calculations’)[97]. Three studies used a combination of methods, namely LCA together with Input-output modelling (2) and LCA combined with Cost Benefit Analysis (CBA) modelling. Lastly, six studies used other types of methods. Figure 4-2 depicts the overview of these methods.

[97] This is a collection of studies that used relatively simplistic calculation methods to make rough estimates on emission savings potentials by combining changes in material flows by emission factors per ton, we dubbed the term emission-factor based calculations to these studies. However, we consider these methods too limited to give a realistic picture of GHG emission impacts from circular activities as such methods do not consider GHG emission impacts throughout the entire value chain, nor the emissions resulting from the circular processes that replace the original process. Lastly, these calculations do not take into account any of the economic impacts resulting from the efficiency gains that accompany circular actions, e.g. rebound effects.

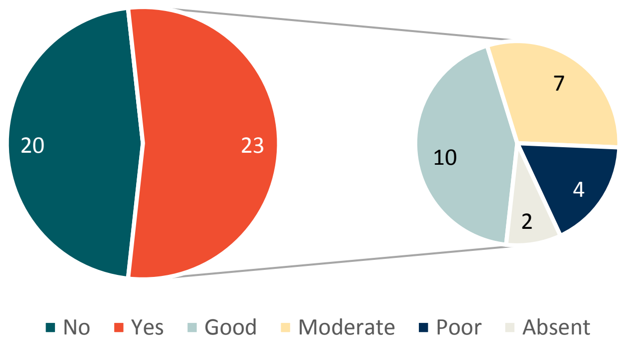
Figure 4-2 Methods applied to assess GHG impacts of circular economy activities



4.3.2 *Approach to case selection and selection criteria*

As mentioned above, out of the 43 studies reviewed, 23 studies contained quantitative estimates on the impact of the circular economy on GHG emissions. For all these studies we have assessed the quality of the description of the methodology, data sources and assumptions used, and we qualified the descriptions as 'good', 'moderate', 'poor' or 'absent' (Figure 4-3) based on our expert judgement.

Figure 4-3 Assessment of the methodological descriptions of the studies that assessed GHG impacts of CE actions.



Elimination factor 1: Quality of the description of the methodology poor or absent

From the 23 studies assessed, six studies were excluded based on the fact that the description of their methodology was poor (4) or absent (2). The details of these papers and their scoring are still included in the literature overview table delivered as part of Task 1. Consequently, we ended up with a long list of 17 studies from which five were selected for in-depth analysis in Task 2.

Elimination factor 2: Old publication date (> 5 years)

To reach the target of five studies for further analysis, we first ranked the papers in terms of their **publication date**. We preferred more recent studies over older studies as the thinking about the circular economy has evolved rapidly in the past five years and we would like the definition of the circular economy in the selected studies to be as much as possible aligned with the definition of the circular economy used in this study. As a result, three studies were removed from the long list, namely ECN (2011), OECD (2012) and Club of Rome (2011), whose definition of the circular economy was considered too different from the definition used in this study.

Elimination factor 3: Variety of methods and topics

As we aimed to create a final selection of studies that represent the variety of methods to estimate GHG emissions, the next selection criterion we applied focused on the **type of methodology** used by the papers. We strived to select a set of cases that at least includes:

- One CGE model
- One Input-Output model
- One LCA
- One combined methodology

These methodologies were identified to be exhaustive of the types of methods used to quantify the impacts of the circular economy in Task 1.

We also aimed to make the final selection of studies to cover a broad range of circular economy actions. Our aim was to have methodologies that apply to a larger number of CE actions across the lifecycle phases in order to be able to apply them to as many CE actions as possible. However, this does not mean that some specific important CE actions should not be covered, for example collaborative economy or waste management, as these activities form an important role in the current circular economy discourse. However, we did avoid the inclusion of studies that take a more conventional resource efficiency approach. By this we mean studies that assume an arbitrary percentage of resource efficiency improvement, without being linked to concrete actions that underlie the modelled improvement, and then proceed to the estimation of the resulting GHG emission reductions. For this reason, we excluded Hatfield-Dodds *et al.* (2017) and AMEC (2013). The latter study also contains a limited number of quantifications and these are all based on WRAP (2016), where the latter will be reviewed as one of the five case studies. Hatfield-Dodds *et al.* (2017) did a detailed assessment on the effects of resource efficiency innovations, resource taxes and policy-driven demand reductions on GHG impacts, but these measures were not linked to concrete circular economy actions.

LCA based methods

There were three studies that analysed the environmental impacts of specific collaborative economy activities (a part of the circular economy). These studies therefore deliberately had a narrow focus on certain (or one) economic activities and most of them used LCA to assess the impacts of these specific activities. In addition, there was a study that analysed the environmental impact of waste management practices, which also followed an LCA approach. Table 4-5 presents all the studies considered under this methodological category. The study by Trinomics (2017) analysed certain collaborative economy using LCAs and input-output modelling with the E3ME model for effects at the macro-level. This study has the advantage that the methods are explained very explicitly. The study also combines both LCAs with a macroeconomic input output model to estimate the impacts of several circular actions at EU level. PBL also did an elaborate study on the GHG impacts of car sharing in the Netherlands, combining empirical data from a survey with an LCA. However, they focus on the impact of sharing today, rather than also looking forward to what the impact might be. There has also been a study for the Nordic Council of Ministries on the environmental impacts of the collaborative economy, but this study might be less fit for the development of the EEAs analytical framework as it mainly reviewed assessments from other studies which it then uses to make some rough order of magnitude estimates on impacts for the Nordic countries. Lastly, there is the Eunomia (2014) study, which analysed the GHG emission impacts of a number of various waste management scenarios derived by EU's main waste management policies. This study has taken an LCA approach using the 'European Reference Model on Municipal Waste

Management', which is able to make projections on waste generation and management for the period 2010 to 2035 in all Member States and the EU.

Among the sharing economy studies, **Trinomics (2017)** has the advantage of having a broader scope and combining both LCA and input-output modelling, as well as containing a forward-looking element. In addition, this broad approach does not limit the establishment of linkages between specific circular actions and methodologies used, which is advantageous for Task 2 where the methodology for quantifying GHG emissions of each study needed to be well-linked to a specific CE action. **Eunomia (2014)** has the advantages of analysing the impact of waste management practices, one of the most important types of circular economy actions and combining an LCA based method with modelling that allows the prediction of future waste generation and management impacts on GHG emissions. Moreover, this study has added practical value, since it is based on the EU's main waste management policies. **We therefore proposed to select both of these studies for Task 2.**

Table 4-4 Studies using Computable LCA based methods to quantify GHG emission reductions, selected in grey

Title	Author	Year	Quality of description methods	Circular actions covered
Environmental potential of the collaborative economy	Trinomics	2017	Good	Multiple collaborative economy actions (incl. car sharing)
Effecten van autodelen op de mobiliteit en CO_2-uitstoot	PBL	2015	Good	Car sharing
Environmental impacts and potential of the sharing economy	Nordic Council of Ministers	2017	Good	Sharing, renting
Impact Assessment on Options Reviewing Targets in the Waste Framework Directive, Landfill Directive and Packaging and Packaging Waste Directive" Final Report for DG Environment.	Eunomia	2014	Good	Waste management practices

Computable General Equilibrium models

There were two studies that have translated circular economy actions into modelling inputs for a computable general equilibrium model, both of which were fit to be analysed as cases in task 2 (methodologies well explained). Table 4-6 presents all the studies considered under this methodological category. One is the Denmark case study made by the Ellen MacArthur Foundation, that analysed circular actions in five sectors, including a service sector, which is a unique feature of this study. The disadvantage of this study is that the methodology is not sufficiently clear to assess. The other one is a study done this year by TNO to analyse the GHG impacts of the Dutch circular economy policy programme. The interesting feature of this study is that the analysis is strongly policy driven. Where many studies assess the impacts of hypothetical circular economy actions, the TNO study assessed the GHG impacts of circular economy actions that are mentioned with quantified targets in the circular economy policy. The disadvantage of the latter study is that it has been written in Dutch and therefore may not be used as easily within the EEA. Since it however approaches the modelling of the circular actions very specifically by modelling policy targets, **we proposed to analyse more in-depth the TNO study for Task 2.**

Table 4-5 Studies that used Computable General Equilibrium models to quantify GHG emission reductions

Title	Author	Year	Quality of description methods	Circular actions covered
Potential for Denmark as a Circular Economy - A case study from: DELIVERING THE CIRCULAR ECONOMY – A TOOLKIT FOR POLICY MAKERS	Ellen MacArthur Foundation	2015	Moderate	A broad range of actions
Effecten van het Rijksbrede Programma Circulaire Economie en de Transitieagenda' s op de emissie van broeikasgassen	TNO	2018	Good	A broad range of actions

Input Output models

There are three recent studies with sufficiently detailed methodologies that have used input output modelling to assess the GHG impacts of circular actions, namely WRAP (2016), Cambridge Econometrics (2018) and Deloitte (2016). Table 4-7 presents all the studies considered under this methodological category. The first covers a range of actions across lifecycle stages, ranging from recycling, to increased reuse, repair and increased uptake of service-based business models. The advantage of the study is that as an I/O model, it covers each Member State, and the results are available for different levels of implementation per Member State. The disadvantage of the study is that the study lacks sectoral detail, leading to relatively rough estimates. The Deloitte study analysed a number of sectors, by looking at the sectors from the perspective of circular actions, which were translated to modelling inputs for an input-output model, but the assumptions are not explained very clearly. A similar approach was used in the study done by Cambridge Econometrics, Trinomics and ICF. However, the focus of this study was not to assess the GHG impacts of the circular actions, but the impacts on the EU labour market. Still, the GHG impacts of the circular actions covered were calculated by the model, although the results are not available per sector but only at the level of the entire economy. **Weighing these pros and cons, we propose to select the WRAP (2016) study for assessment in Task 2.**

Table 4-6 Studies that used Input Output models to quantify GHG emission reductions

Title	Author	Year	Quality of description methods	Circular actions covered
Extrapolating resource efficient business models across Europe	WRAP	2016	Moderate	Increased recycling, repair, remanufacturing and servitisation
Impacts of the circular economy on the labour market	Cambridge Econometrics	2018	Good	Broad set of actions in food sector, construction, electronics, waste sector and passenger car sector
Circular economy potential for climate change mitigation	Deloitte Sustainability	2016	Moderate	Broad set of actions

Combined methods

Another study that gave very important insights on the GHG impacts of circular economy actions is the recent study done by **Material Economics (see** Table 4-8). This study analysed circular economy actions in four material supply chains and two related value chains. The strength of this study is that it combines trends and models on material demand with circular actions on the production side as well as specific actions to modulate demand. **This study is definitely a useful study to include as a case for further assessment in Task 2**, because it provides great detail on the actions as well as a holistic approach to the developments taking place in the sectors.

Table 4-7 Studies that used Combined methods to quantify GHG emission reductions

Title	Author	Year	Quality of methodological description	Circular actions covered
The circular economy - A powerful force for climate mitigation	Material Economics	2018	Moderate	A broad range of actions

Based on the discussion above, Table 4-9 presents a summary overview of our five selected cases. Full description of the case studies can be found in Annex B.

4.3.3 Integration into GHG Inventory calculations

As part of the analysis of case studies, we have also investigated the potential integration of the methods assessed and their results into GHG inventory calculations. In particular, the methods were assessed against potential compatibility with the GHG Inventory source categories (for a list of source categories, please see Annex D and for individual assessments of methods, please see relevant section in the case studies in Annex B). However, in broad terms, there is scope for these approaches to derive useful data for consideration within national GHG inventories and emission projections. For example, the further research and consultation that will be needed around the development of the new methodology could inform assumptions regarding the split of activity across, for example, different modes of transport, now and into the future. Information from the methodology development and related policy appraisal could be helpful to sense-check the assumptions (e.g. of national stock models for buildings, vehicles) applied in inventories and projections.

In terms of direct impact and linkages to GHG inventories, however, the degree to which CE policy impacts are reflected directly in national inventories and projections will depend on the data and methods applied in each country for the source sectors where policy impacts are expected to act. The current inventories are unlikely to be practicable to assess the effect of individual CE actions, as the inventory methods are typically “top-down” with multiple policy actions leading to changes in national activity and emissions within a specific source category.

As a GHG inventory primarily captures the emissions in the past, the level of detail in the inventory is the main parameter determining the possibility to capture any individual CE action. The more detailed the source sub-division can be made (and the activity data and specific emission factors can be defined and monitored), the better the GHG effects of CE actions can be captured (and distinguished in the inventory). Developing such a pronounced source sub-division in the inventory will also open opportunities to improve GHG projections (taking into account any specific proposed CE actions) based on data in the inventory. Such development would allow to forecast and quantify the responses from GHG inventories to a specific CE policy.

Table 4-8 Proposal for the selection of cases

	Title	Author	Year	Method used	Quality of methods description	Circular actions covered	Assets
1	Extrapolating resource efficient business models across Europe	WRAP	2016	I/O model	Moderate	Closed and open loop recycling, repair of machinery & electronics, reuse, renting & leasing activities, remanufacturing	- High-level model expressing potential results for all of Europe - Results available by member state for different levels of implementation - Five different circular actions evaluated - High-level model expressing potential results for all of Europe - Results available by member state for different levels of implementation - Five different circular actions evaluated - The project team has contacts with the authors, which makes it easier to dig deeper into the methodology and its potential upscaling.
2	Impact Assessment on Options Reviewing Targets in the Waste Framework Directive, Landfill Directive and Packaging and Packaging Waste Directive" Final Report for the European Commission DG Environment.	Eunomia	2014	LCA based method	Good	Waste management practices	- Municipal waste management is important circular action, in particularly at EU level, and has relatively good EU statistics provided by Eurostat - The EU waste reference model was developed and applied for DG ENV and EEA, hence, these bodies are already familiar with it - Combines LCA with cost benefit assessment modelling to assess environmental impacts, including GHG impact. - Based on actual EU waste flows and policies - Drawback that currently it applies only to municipal waste management, and cannot be replicated to other CE actions - Very data intensive
3	The circular economy - A powerful force for climate mitigation	Material Economics	2018	Combination of methods	Moderate	CE actions in steel, cement, aluminium, plastics, mobility and buildings	- Approaches circular economy from a material and value chain point of view - Accounts for future changes in demand - Emphasises demand-side activities as well as production-side resource efficiency improvements - Very comprehensive study, looking at EU as well as global GHG impacts and potentials - Applies a tailored methodology (dynamic materials flow analysis, microeconomics) to each material and value chain - Definitely a key study on this topic.

	Title	Author	Year	Method used	Quality of methods description	Circular actions covered	Assets
4	Effecten van het Rijksbrede Programma Circulaire Economie en de Transitieagenda' s op de emissie van broeikasgassen	TNO	2018	CGE	Good	Circular actions in the biobased sectors (e.g. increase nutrient recycling, lower consumption of animal-based products, improved use of organic waste), increased recycling of plastics, implementation of circular strategies in the construction sector e.g. (increased reuse of materials, lighter constructions) and increased recycling of municipal waste.	- Takes actual circular economy policies and their targets as a starting point, a top down approach rather than a bottom up approach as in other studies - Highly compatible method with GHG reporting inventories - Has a well-described methodological description and TNO is part of the project team, hence ease of access to experts and methodology - Drawback that the study is in Dutch, less accessible.
5	Environmental potential of the collaborative economy	Trinomics, VITO, Cambridge Econometrics, VVA	2017	LCA, LCA & I/O model	Good	Collaborative economy in transport, accommodation & consumer goods sectors	- Unique study measuring environmental impacts, incl. GHG emissions, of collaborative economy in the EU, covering 3 main sectors - LCA method to assess current situation GHG impacts - E3ME macroeconomic model to assess future potential - Since Trinomics led this study, we are very familiar with the methodology and impacts. Important to have collaborative economy actions in the scope as it is an important part of circular economy with a very high potential in some sectors.

5 Options for a European Methodological Framework

This chapter analyses what we can learn from the case studies to inform the EEA's development of a framework to estimate the GHG benefits of circular economy activities. It starts by defining what is meant by a 'framework' in this context, and identifying its key aspects, which are then addressed in turn in the sections that follow. In the final 'synthesis' section, we reflect on what has been learned and suggest some possible ways forward.

5.1 Overview and Definition of a Framework

Conceptually, there might be several approaches to examining the GHG benefits of the circular economy. At the simplest level, it might be possible to study all of the CE impacts at once across all of Europe. The alternatives all disaggregate this approach to look at smaller scopes with the aim to later aggregate them to a total picture. The next level of options include looking at one country at time, one sector at a time, one CE action at a time, and then combining the results to arrive at the total assessment. Further levels of disaggregation (such as looking at each CE action sector-by-sector) are also plausible, but the complexity and data requirements escalate with disaggregation.

The EEA is open-minded about what approach might be most appropriate, and the relevant advantages and disadvantages of each. Accordingly, the goal of this project was to develop a framework to assist the EEA with assessing the alternatives and deciding what to do next. In this context, the framework required is a stepwise procedure to take forward the work. There are more ways than one to move forward, so the framework should help the EEA to appraise those options and identify its most approach pathway. The key aspects of the framework are listed below, and discussed in detail in the sections that follow.

- **Defining the study focus**
  The choice of the most appropriate approach will depend to a large extent on what focus is to be set for the analysis. Different approaches are preferred depending on what question needs to be answered, and this has important other implications. Therefore, defining the study focus is first step in the framework approach.
- **The scope of the analysis**
  The report has demonstrated that the circular economy is wide-ranging, with impacts across most sectors, cross-cutting across sectors, life cycle stages and geographies. The scope of EEA's analytical framework is not yet determined and will be discussed further internally at EEA.
- **The tools, methods and approaches available**
  The report has reviewed a number of methods used in other studies, some underpinned by bespoke analytical tools. The EEA might adopt one of these or devise a new method, and if a new method, might calculate the results from new or seek to optimise the combination of the studies already performed.
- **Data characteristics and availability**
  Closely tied to the choices around approach are questions of data characteristics and availability. This section will look at what data could inform the EEA's chosen framework.

5.2 Defining the Question to be Answered

The framework that the EEA will adopt depends on the question to be answered. Therefore, this section reviews how the answers to certain considerations assist with that clarification, by revealing which of the available approaches might be better suited to those sorts of requirements.

5.2.1 Past or Future?

A modelling framework whose focus is on past accounting needs to have an adequate database of past data from which to draw its conclusions, making interpolations if necessary, to cover data gaps. However, by focussing on future impacts, the EEA clarified that it would like to be able to make projections. This reduces the significance of acquiring past data, though some will inevitably still be required, and places more emphasis on forecasting how key parameters will evolve over years to come. This requirement may favour LCA models, which tend to be more limited and 'simple' in their scope, inasmuch as they often look at one product at a time and pay less regard to feedback loops. In comparison, macro-economic models are more mathematically complex, and any feedback loops are likely to cause parameters to diverge more quickly than the more linear LCA models.

If the EEA chooses a framework that simply aims to build the best possible compilation of existing studies' data and results, the question of past and future is less critical, as it will only really be possible to use whatever is in those reports. This is discussed in more detail in Section 5.4.5.

5.2.2 Actions, Policies or Targets?

In this project's context, a framework can examine three fundamental considerations, associated either with investigating how the changes that an activity or a policy effects may impact upon the world, or looking at what needs to happen for certain targets to be achieved.

- **CE actions**
  If the goal is to model different take up rates of a particular CE action (or set of activities), scenarios are developed to model the different levels of up-take in the relevant sector(s) of interest, without the need to assign those changes to their causes – they might be due to policy changes, technological changes or simply evolving cultural attitudes. The modelling looks at the direct impacts arising from the different levels of up-take, considering all the affected sectors. This would typically be done on a sector-by-sector basis, using LCA to inform the analysis. These sector-by-sector perturbations can then (in theory, at least) be mapped using high-level models to anticipate the wider possible impacts. Case studies 1 (WRAP) and 5 (collaborative economy) used this form of analysis.
  With its straightforward analytical approach, the results of such modelling are relatively easy to interpret. The downside is that, simply looking at the activities, there is no causal link to demonstrate what is causing the modelled changes.

- **CE policies**
  The lack of causal link can be critical, so it is not surprising that an alternative approach seeks to model CE policies instead. Here, scenarios describe different levels of policy ambition (and/or implementation), and the modeller must explicitly choose what policies to model, which activities will result in which sectors, and how to model the impacts and interactions

(often using LCA). Once again, the sectoral impacts can then (theoretically) be mapped using high-level models to extrapolate to wider possible impacts. Case study 4 (TNO) and case study 2 (Eunomia) have aspects of this approach.
The key benefit of this methodology is that it does seek to show the results that are driven by the policies modelled. However, this can only be as good as the underlying modelling, and there are inevitably in-built assumptions and uncertainties around how the policy changes translate to impacts. A less significant issue is that it would be problematic to combine the results from separate policy modelling exercises, to estimate their combined impact, since interactions (both synergies and conflicts) between the policy impacts would not be captured.

- **Achieving targets**
  The third approach is to explore what needs to happen in order for a certain target to be achieved. A target such as "divert 75% of plastic from energy recovery and landfill by 2030" is likely to require actions in many different sectors and at many if not all points of the value chain, from design right through to waste management. The methodology has to be able to arrive at an estimation of the current level of performance, and then reflect how perturbations in the underlying parameters can contribute together towards achieving the new target.
  It is difficult to envisage a methodology that could readily explore achieving any target, given the sheer breadth of possible targets ("reduce traffic pollution by 5% using car sharing" would need a very different approach to the previous example). Therefore, it is tough to see how this approach could work across the CE, but it might be tenable for specific investigations.

5.3 The Scope of the Analysis

5.3.1 Coverage

Section 3.3 of this report provides an overview of the different classification systems of circular economy actions, as well as a list of CE actions for each lifecycle phase of a product. The analysis there demonstrates the considerable variety of circular economy actions, as exemplified by the actions that have arisen in studies investigated in this project. None of the methodologies identified in those studies has attempted to quantify GHG benefits across all the potential CE actions (see section 4.2.2 for details). Instead, they focused either on a subset of the groupings (such as the Eunomia model's target of municipal waste management, or 'value recovery') or particular material or product flows (e.g. the Material Economics study).

This aligns with the analysis in Section 5.6 that concluded certain ideal characteristics are incompatible. Acknowledging its available resources, the EEA has accepted that **there are many circular economy actions and any developed methodology would not be able to cover all of them**. Rather, the focus should be on those bringing in the highest GHG benefits.

5.3.2 Prioritisation of Actions

Having concluded that covering all actions is unrealistic, it makes sense that the EEA's framework should attempt to focus on the most significant actions. As discussed in Section 3.3, circular economy actions can be classified in several different ways. Correspondingly, it might be possible to develop different approaches that attempt to estimate the GHG benefits of the actions according to those different classification methods. The case studies for example revealed that circular actions can be quantified using economic sector, circular strategy or material flow classifications. However, as discussed in more detail below, the ready availability of data is another key factor for the EEA. The best data on GHG emissions are classified according to the IPCC reporting guidelines, using a sectoral hierarchy (see also section 5.5 and Annex D for UNFCCC Sectoral Classification). Therefore, we **recommend that, if the EEA wishes to explore a new methodological approach, it should look to quantify circular economy actions on a (sub-)sectoral basis** (noting that it would probably be necessary to go to a greater level of granularity than presented in Annex D, which only reports the top two (of nine) levels). By looking at a (sub-)sectoral level, this does not necessarily mean that cross-sectoral impacts of CE actions are not captured. As discussed in section 4.2.2, macro-economic models often take into account these cross-sectoral impacts as these models have embedded linkages between sectors and supply chains, hence modelling CE action gives direct, indirect and induced impacts. These cross-sectoral impacts can be also explicitly modelled. However, when using other methods, such as e.g. LCA, such cross-sectoral linkages are captured only via lifecycle stages of a product. Judicious selection of the studied sectors could ensure that the majority of the impacts are captured.

Choosing a sectoral approach would involve some data collection from official statistics, such as Eurostat, which uses NACE sector classification system, and comparison with reporting data from GHG inventories according to UNFCCC source classification. Moreover, many forward-looking methods, such as CGE or I/O models, have sectoral classification that can be mapped against Eurostat or other formally collected data sources. The issue here will be to disaggregate some of the sectors where only proportion of activities can be classified as circular actions, for example in the manufacturing sector.

To prioritise the sectors of interest, it makes sense to refer back to Table 4-2 and the analysis provided in section 4.2.2 for the different sub-sectors, which compiled the potential GHG impacts estimated in previous reports, to see which sectors are revealed as likely to be the most important. Although the system boundaries for the different studies are not consistent (different methodologies, different level of ambition assumptions), and so the results should not be directly compared, it is nevertheless reasonable to use them to identify which sectors repeatedly appear to be making the biggest contributions to GHG reductions. Those sectors are:

- Materials (notably plastics, but also metals and cement)
- Food (reduction, improved packaging, nutrient recycling)
- Construction (material substitution, modular design, smart crushers, space-sharing, prolong lifetimes, deconstruction and reuse instead of demolition)
- Waste management sector
- Automotive (car sharing, durability, improved end of life).

Please refer to details on actual GHG reductions in section 4.2.2 and 5.4.5.

5.4 The Tool/Methods Available

5.4.1 Ideal Characteristics

When considering what is available to perform the analysis, it is beneficial to start with the characteristics of the ideal approach, to avoid accidentally ruling out possibilities by assuming that certain things cannot be done:

- **Uses a limited set of data**
  It would be preferable if the framework relied on data that are already collected and reported.

- **Simplicity**
  Whilst some complexity is inevitable, whatever can be done to simplify the framework, without wholly compromising the results, will be desirable.
- **Robust**
  The framework should generate results that are, within its scope, sufficiently reliable to be used for assessment and reporting purposes.
- **Non-proprietary**
  It would be preferable to adopt a framework that does not require a proprietary model.
- **Detailed (accurate)**
  Ideally, the framework will be able to accurately quantify the GHG reductions of each CE action.
- **Comprehensive**
  It would include the entire range of potential CE actions.
- **Easily aggregated**
  At the same time, it should be simple to scale-up individual CE actions to see their impact across Member States and the EU.
- **Synergistic**
  In assessing multiple CE actions, the ideal framework would be able to accommodate synergies and conflicts between the actions.

Reviewing this list reveals that some of the criteria conflict with one another; it is difficult to conceive of a framework that is accurate and comprehensive and, at the same time, less data demanding and simple. A framework whose individual calculations are easily aggregated to arrive at an overall result is less likely to be synergistic as well and be able to account for conflicts and positive feedback (though some level of this may be possible). This leads to conclude that, in reality, there must be some compromise between the ideal characteristics.

This is supported by findings from the case studies. The Material Economics case study (no. 3) delivered relatively comprehensive analyses of the sectors investigated, but required a lot of data and complex methods in order to arrive at its assessment. In contrast, the WRAP study (no. 1) adopted a high-level and relatively simple modelling approach using limited yet robust statistics, but had to rely on imprecise mapping approximations that constrained the possible accuracy of the results. The Eunomia study (no. 2) was very data intensive and quite accurate about the activities modelled, but was far from comprehensive in examining the range of CE actions.

5.4.2 EEA Priorities within those Characteristics

Faced with these conflicts, the EEA expressed its preferences where the conflicts arose. The EEA's priorities are to develop a framework that is robust and practical and that gives insight into the potential contribution that circular economy actions can bring to reducing the total GHG emissions. In this context, it is worth reiterating the definition of the circular economy for this study, which excludes actions around energy efficiency and renewable energy sources that are already covered by current climate change mitigation policies and impact studies.

In contrast, high levels of precision are not paramount, nor need the framework necessarily cover all sectors, as long as it considers those that can provide a relatively significant emission reduction potential by 2030 and 2050. Finally, although the EEA would prefer not to be tied to a proprietary model, this was not thought (at this stage) to be an absolute exclusion criteria.

5.4.3 The Expert Workshop

During the expert workshop, we collected feedback on the potential framework from participants, particularly with regard to what a bespoke methodology might comprise. There was broad consensus on a few design considerations:

- A hybrid-forward looking method that combines macro-economic analyses with detailed bottom-up data is likely most optimal;
- Focusing on a subset of circular actions seems to be most feasible and this might be done by looking for where the largest GHG emission reduction potentials are;
- Preliminary work on where the biggest potential for GHG emission reductions might be needed to specify for example the key climate-relevant CE actions or sectors;
- It is key that the methodological framework can make use as much as possible of existing data sets, e.g. from national registries, LCA inventories, official statistics;
- The fitness of the methodologies is dependent on the modelling objectives and questions to be answered;
- It is important that interlinkages and interdependencies between sectors are taken into account and therefore methods that take a consumption perspective may be preferred;
- Modelling of Circular Design can be done implicitly, through modelling the increased recycling rates, remanufacturing rates, improved fuel efficiency during use phase, etc., which is enabled by the changes in design. However, some other consequences may not be captured, such as lower manufacturing activities in countries exporting the goods to the EU and the associated reduced transport burdens.

Beyond these points, opinions differed:

- Most assumed a bottom-up approach (LCA feeding CGE or I/O) would be preferable, but a top-down approach was also suggested.
- Many thought rebound effects should be included, but others thought them being too difficult to be incorporated.

5.4.4 Calculation Method

The EEA's approach to tools/method in the new framework can broadly take one of two pathways, looking either to adopt a calculation method, discussed here, or perform a meta-analysis of existing data and studies, discussed in Section 5.4.5.

With regard to a calculation method, a question that needs to be addressed is whether a set of different tools/methods is needed to estimate different CE actions. For example, do we need another method to estimate the GHG impacts of CE design actions compared to estimating the GHG impacts of recycling? The answer to this based on the studies reviewed is most likely to be a no, as the method is chosen based on the type of 'question' (see section 5.2) rather than the type of CE action. For example, a CGE or an I/O model is able to pick up and model theoretically any type of CE action, but CE actions that link more closely to the predefined economic sectors in the model (e.g. recycling activities in the waste sector) are easier to model than CE actions that are less defined (e.g. collaborative economy) or which span across a number of economic sectors (e.g. remanufacturing). A more micro-level method, such as an LCA is able to theoretically look at any CE action if the functional

unit is well defined. Hence the choice of a method again depends more on 'what question' – at micro- or macro-level - we want to estimate rather on 'which CE action' we want to estimate.
The literature review identified two broad levels of analysis: the detailed, product- or action-specific level of LCAs and Material Flow Analyses (MFAs); and the high-level, economy-wide perspective of techniques such as I/O and CGE. They are characterised in Table 5-1.

Table 5-1: Typical characteristics of methodological approaches

Detailed methods such as LCA and MFA	High-level methods such as I/O and CGE
• **Data-intensive** Rely on large, tailored datasets • **Simple, transparent models** Although varied, LCA models can be relatively simple and transparent • **Detailed** Each intervention modelled individually, enabling specific estimations • **Hard to aggregate** Extrapolating LCA results for a MS or the EU needs scaling parameters that may be hard to acquire • **Erroneous to aggregate** Moreover, the aggregation cannot evaluate synergies or conflicts that might contradict the simple additivity of actions	• **Less data demanding** Often rely on existing published statistics • **Complex, opaque models** Models are frequently proprietary and less transparent • **Broad** Acting at MS- or EU-level, these methods need little or no up-scaling • **Synergistic** Used well, can deal with synergies and conflicts between individual actions, estimating net impact of a suite of actions • **Often lack granularity** These models assess impacts of often aggregated sectors. These are sometimes difficult to disaggregate and capture impacts of specific CE actions.

This analysis quickly concludes that a methodology wholly based at just one of the two identified broad levels will be able to deliver some of the ideal characteristics but is unlikely to manage others. Just using a CGE or an I/O model would struggle to provide the granularity to isolate benefits of the circular economy actions. Just using LCA is theoretically possible, but requires a separate model for each intervention, which quickly becomes far too onerous.

Based on this, one solution might be to adopt a sequential approach. Initially, a high-level method would help identify where circular economy actions might have the most significant GHG benefits. That analysis would then be put to one side and need not be repeated unless there is reason to believe that its analysis may have become obsolete. Thereafter, a detailed method would be employed to quantify those particular reductions more accurately.

The alternative option is to explore combining the best of the two alternatives in what becomes a hybrid approach.

Hybrid methodology

A hybrid methodology would seek to combine the best of the two approaches, to optimise coverage of the ideal characteristics. As stated above, most of the workshop stakeholders thought that a hybrid model would be the best approach. However, opinions differed on whether the hybrid approach should be "top-down" or "bottom-up":

- **A "bottom-up" methodology** uses CGE/I/O techniques, in its second stage, to scale up individual effects evaluated by LCA in its first stage, in order to estimate what their effects might be when applied to a wider economy. By doing so, it starts at the detailed, granular level and then seeks to extrapolate results to cover the whole economy, hence the term bottom-up. Such an approach (with LCA delivering GHG impacts per tonne of raw material) was used by WRAP in its REBM work (case study 1 in this report). That study revealed several challenges that would need to be overcome, as follows:
  - getting the data at the micro-level to complete the LCA
  - determining the upscaling factors
  - integrating the outputs of LCA as inputs into the macro-economic model and
  - the potential dilution of impact through rebound effects.

  This approach is likely to require a fair amount of detail in order to inform the LCA development of modelling coefficients, which are then applied in the macro-economic model. Mapping is an issue, as it is often not possible to allocate the CE actions to the discrete sectors within the CGE/I/O tool. It is also difficult to link both methods in the transition from micro to macro scale. Indeed, the authors of the collaborative economy study (case study 5) were unable to find a way to integrate the results of the LCA analysis into the I/O model in a sufficiently linked way.

- **A "top-down" methodology** starts with a macro-economic model (CGE or I/O) at its default (high) level of aggregation. It then seeks to use LCA results and cost data (such as the fraction of total sector spend on each of its sub-sectors) to subdivide individual sectors within the model to a higher level of detail, so that the circular economy actions can be disaggregated from other activities in the sector – thereby going from high-level data to more detail, hence top-down. In essence, the goal is to create what is still the high-level model but with more categories, particularly in the areas of most interest. Ideally, all sectors would be split to the same deeper level of disaggregation, to encourage internal consistency, but this is not often feasible in practice. Although it is difficult to estimate the error that may be introduced by such disaggregation, practitioners anticipate that any error such error is smaller than the error made by working with the industry average (i.e. at the higher level of aggregation originally in the model) if it is not representative of a specific subsector.

  Compared with the "bottom-up" alternative, this approach is likely to be less data intensive, but correspondingly less accurate in its results.

Conclusion on calculation method

From the above, we conclude that there are two broad levels (either detailed or high level) of calculation. Moreover, **a method that relies solely on calculations at one level is unlikely to be suitable** (either too high-level to reveal CE benefits, or so detailed requiring resources which are not available at EEA). Therefore, **a hybrid method is recommended**. Whether it should be "bottom-up" or "top-down" is discussed further in Section **Error! Reference source not found.**.

5.4.5 Meta-analysis of existing studies

The previous section reviewed the options for developing a bespoke methodology for estimating the GHG benefits of the CE. An apparently far simpler alternative approach would be to perform a meta-analysis of already existing studies. Here, the challenge is to identify the right studies to use, and to understand how to combine their information in an internally consistent way. The literature review revealed many sector-specific analyses, which offer the tantalising prospect of being able to combine their results to generate an analysis, albeit a one-off snapshot, of the bigger picture. Unfortunately, reviewing this information, and the greater detail in the analysis of the case studies provided in Annex B, reveals several significant challenges with this more simplistic approach.

This section tries to provide guidance on how findings from existing studies can be interpreted and compared. Chapter 4 of this report showed that several insightful studies into the impacts of the transition to a circular economy have been done already, but comparing the findings from these different studies is challenging.

Choice of a method

The study method chosen presents a real problem for the meta-analysis approach. A study based on LCA looks at impacts from cradle to grave, and the raw material extraction and manufacturing may well be done outside the EU. A macro-economic market-based assessment of CE actions in Europe will have a very different system boundary, and might not include production impacts outside Europe. A meta-analysis would look to combine and thereby compare the results from the two studies, and this is simply not going to be valid.

Studies with different scopes

Many of the studies identified in the literature review are country-specific. Their findings would need to be extrapolated to cover all of Europe, and that extrapolation is likely to be imperfect, though possible nonetheless.

More problematic would be genuine conflicts of scope. If one study included rebound effects (to reflect how money saved might be spent on GHG-emitting activities in other sections) but a second study excluded those same effects, their results cannot practicably be compared.

The Eunomia case study (no 2) focuses on waste management scenarios. Its results could not be combined with the sector-specific CE actions examined in the Material Economics case study (no 3), because of the overlap in waste management considerations. Moreover, even if different studies looked at the same sector, e.g. construction, they modelled/ assessed specific CE actions or policies within that sector which might not be comparable across different studies.

Studies with different assumptions

A similar issue concerns studies with different assumptions. Nearly all of the analyses need to take account of the carbon impacts of producing electricity, but the carbon intensity of grid electricity varies by country and by year. For those that look to the future, grid intensities in future years may be based on national government estimates, European average data or even be pegged to current values with no anticipated (or, at least, modelled) improvements.

Where a significant fraction of the benefits of a CE action arise from reduced energy consumption, it becomes more important that these factors are modelled consistently across the studies used.

Interpreting the results

Figure 5-1 shows other main differences between the existing studies on circular economy impacts, being differences in purpose (research question), the detail-level of the results, the baseline used, the ambition level chosen and the output format in which the results are presented.

First of all, the studies analysed differ in their purpose, that is **the research question** that they tried to answer. Although some of the studies analysed aimed at specifically analysing the GHG impact of circular economy activities, most of them had other purposes, predominantly the assessment of employment impacts or economic impacts. The kind of research question is one of the leading determinants for which type of methodology is chosen, as explained in section 5.2. This means that in some cases the methodology used was not optimal for the quantification of GHG impacts, as that was simply not the aim of the study.

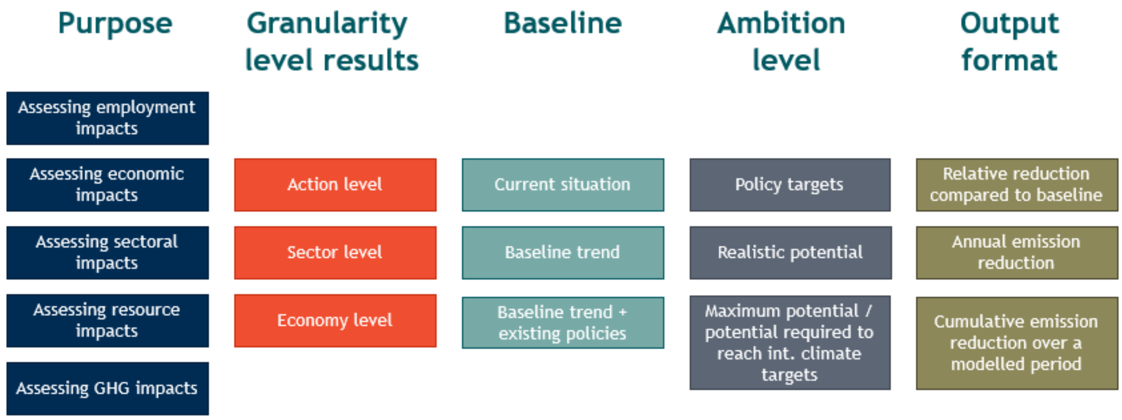
Secondly, studies differ in **the granularity level** at which GHG impacts are reported. Some studies assess GHG impacts at the detail level of individual GHG actions, whereas others report the results on sector level or even only on the aggregate economy-wide level. Some macro-economic studies for example, do use sector-specific circular actions as input parameters for their modelling, but outputs are only given at the level of the entire economy. As a consequence, the findings of such studies cannot be compared to studies that do report on the impacts per sector.

A third difference between studies is the **baseline situation** to which the implementation of a circular action or a set of circular actions is compared. Some studies compare the impact of circular economy actions to the current impact level, based on the most recent historical data. However, preferably forward-looking studies use a baseline scenario where some business as usual improvement takes place. However, even these baseline scenarios can differ in the types of baseline trends they cover. For instance, some baseline scenarios explicitly include the effects of existing policies, whereas others do not. Some of these different bases are easier than others to align to a common method, and some might simply not be possible – for example, it is not possible to arrive at absolute emissions reductions from a dataset that only reports changes versus a baseline.

A fourth, very essential difference between the studies is how **ambition levels** are approached. Some studies simply assess the effects of achieving certain policy targets, without assessing the feasibility of achieving those targets. Other studies try to make an expert judgement on the ambition level that can be realised within a certain timeframe. An alternative strategy is to analyse the impacts in case the maximum potential of a certain action or policy is utilised.

Last, the studies differ in the **format** in which the findings are presented. Some present the results based on an absolute annual emission reduction or a relative change in emissions in a specific year, compared to a baseline. Others report cumulative emission savings over a certain period. Studies looking at detailed actions using LCAs often express impacts per functional unit of used or per amount of product.

Figure 5-1 Key dimensions in which existing studies reporting on GHG impacts of CE actions differ



In Table 5-2 below, we have classified the analysed studies in relation to the differences outlined above.

Table 5-2 Characterisation of reviewed studies according to the dimensions outlined in Figure 5-1.

Study	Findings	Purpose	Granularity level	Baseline	Ambition level	Output format
Club of Rome (2011)	Emissions in 2030 compared to baseline: -4% for Finland, -5% for Sweden and France, -3% for the Netherlands, and -10% for Spain.	Assess the economic and environmental impacts of improving resource efficiency	Economy level	Undefined business as usual scenario that is fossil-fuel dominated	Ambitious	Relative abatement (%) in target year (2030) compared to the BAU scenario
Material Economics (2018)	GHG abatement in 2050 in Mton CO_2-eq.: 41 (steel), 117 (plastics), 26 (Aluminium), 25 (Cement), 19 (passenger cars), 55 (buildings), overall impact 296	Analysing the GHG impacts of CE actions	Action, sector and economy level	Demand forecasts per material, decarbonisation of the energy supply, baseline innovations	Maximum potential	Absolute abatement compared to baseline in target year (2050)
Deloitte (2016)	33% cut in GHG emissions related to the consumption and production of goods	Analysing the GHG impacts of CE actions	Sector level	Current GHG impact of the sector (from lifecycle perspective)	Ambitious (incl. some policy targets)	Relative abatement (%) compared to current GHG impact
Cambridge Econometrics (2018)	GHG abatement compared to the baseline: 60 Mtons CO_2-eq. in 2030, 83 Mtons CO_2-eq. by 2035	Analysing employment impacts of the circular economy	Economy level	Business as usual (continuation of historical trends; legislation adopted by MSs until December 2014 included in forecasts	1 scenario: Realistic potential, 1 ambitious	Absolute emission reduction in target year (2030) compared to the baseline
Trinomics (2017)	An GHG emission reduction of 1.5-6.9 Mton CO_2-eq. in total (based on combined effects of collaborative activities in transport, good sharing and accommodation)	Assess the environmental impact of collaborative economy activities	Action level (only for LCAs), sector and economy level	Baseline: no further collaborative economy growth	1 scenario: Realistic potential, 1 ambitious	Absolute emission reduction in target year (2030) compared to the baseline
Ellen MacArthur (2015[A])	Emission reductions related to food production and consumption in 2030: -35% compared to 2012, in 2050: -61% compared to 2012.	Assess the economic impact of implementing CE action	Sector level	Current development scenario that already includes certain CE policies	Ambitious	Relative emission reduction compared to base year (2012) for CE scenario and current development scenario
PBL (2011)	A cumulative emission reduction of 400 - 1000 Mtons in the period 2010-2030 (based on 40% lower consumption of red meat than in the baseline)	Analysing the environmental impacts of animal protein consumption and production in the EU	Action level	Extrapolation of trends in demand for animal protein and baseline yield improvements	Realistic potential	Cumulative abatement over modelled period (2010-2030)
CE Delft (2016)	180 Mtons CO_2 eq. (when 2/3 of solid municipal waste is recycled)	Analysing the GHG impacts of CE actions	Sector level	Current GHG impact	Realistic potential	Absolute abatement based on current waste levels
Eunomia (2014)	20-62 Mtons CO_2-eq. in the EU by 2030 (depending on the ambition level chosen)	Analysing the economic and environmental impact of different waste policy options	Sector level	Full implementation of existing policies combined with projections of future waste generation	Various policy options (targets)	Absolute abatement in 2030 compared to a baseline (full implementation of existing policies))
WRAP (2016)	92-154 Mton CO_2 eq. (depending on scenario chosen)	Analysing employment impacts of the circular economy	Economy level	Scenario that assumes no new policies for stimulating resource efficient business models are adapted	1 ambitious and 1 very ambitious scenario	Absolute emission reduction achieved in target year (2030)

Future analysis

Finally, as noted in Section 5.2.1, the EEA stated during the Workshop that its primary interest is in evaluating the future benefits of the CE. A notable limitation of the meta-analysis approach is the impracticality of trying to reproduce the study in the future. Most of the studies reviewed were one-off analyses, so that, even if a framework could be established to bring together previous studies in an acceptably consistent and coherent way, it would not be possible to reproduce the analysis again after a period of time, to explore progress.

Conclusion on meta-analysis

For all of the reasons above, **we think that a meta-analysis of the currently available literature offers limited value as most of the results of the studies cannot be compared to each other nor combined to derive some estimates of the GHG benefits of the CE. However, we provided a structure on how to interpret any existing or future results.**

5.5 Data Characteristics and Availability

The design of the framework to be developed should be closely linked to the availability of data to support it, if the work is to be more than a simple thought-piece. Through conversation with the EEA and the workshop delegates, it became clear that there are several important characteristics that the framework's required data should exhibit (some of which have clear parallels in the list in Section 5.4.1):

- **Already collected and publicly available**
  The datasets should already be available in the public domain, so that they are familiar to the audience and can be independently corroborated, also meaning that the data are transparent
- **Robust**
  The data should be sufficiently reliable and of high quality to be used for reporting purposes, generating plausible results
- **Consistent**
  The basis by which the data are generated should be consistent between Member States, between sectors, over time, etc.
- **Regularly updated**
  The EEA would like the framework to be used regularly, so that the evolving picture of CE effects can be derived, and this means that the underlying data need to be regularly (though not necessarily annually) updated

5.5.1 Eurostat datasets and National GHG inventories

Two datasets that are almost certainly useful for the framework and that comply with these requirements are as follows:

- **Eurostat database**
  Eurostat regularly collects and publishes extensive datasets of information that can support the framework. Firstly, there are the trade data and structural business statistics from every Member State, reporting in some detail the levels of trade between Member States. These data could form the foundation for an I/O model of trade flows between Member States. Secondly, the various waste and recycling statistics gathered under the Waste Statistics Regulations (and other legislation such

as the revised Waste Framework Directive) provide what should be consistent and useful information about waste arisings and fates across the EU. A third exemplar is the circular monitoring framework developed by ESTAT, together with JRC, which provides a raft of information specifically on circular economy activities (although it has limitations, including a lack of information on product-related CE actions, eco-design activities and collaborative consumption).

- **National GHG inventories**
  Member States annually report their national inventories of GHG emissions to the UNFCCC. Emissions are reported against a 10000-row hierarchy of sectors, grouped in six major categories of Energy, Industrial Processes and Product Use, Agriculture, Land Use, Land Use Change and Forestry, Waste and Other (see Annex D), representing a substantial database of useful data. If a circular economy action is anticipated to influence the GHG emissions in a particular (sub-)sector or group of (sub-) sectors, the national inventory would provide the evidence to reveal whether those influences translate into changes in emissions. There is also the potential to combine the sectoral emissions data with trade information to develop emission intensities that can underpin the development of environmental extension factors for I/O models.

Aligning CE actions with GHG reporting

The national GHG inventories represent a large and potentially valuable source of emissions data, which could be used to monitor the outcomes from CE actions (though without necessarily proving the causal link). For that reason, the EEA requested an examination of how well aligned CE actions are with the GHG inventory categories. Table 5-3 below reproduces Table 3-1 but with an extra set of columns, identifying possible inventory sectors where changes would appear.

Table 5-3 The alignment between circular economy actions and national GHG inventories

Phase	Circular Economy action	Possible inventory sectors of interest[98]								
		§1	§2.A	§2.B	§2.C	§2.E	§2.G	§2.H	§3	§5
Design	Material exchange		✓	✓	✓	✓	✓	✓		
	Increased durability		✓	✓	✓	✓	✓	✓		
	Modular design		✓	✓	✓	✓	✓	✓		✓
	Facilitate repair		✓	✓	✓	✓	✓	✓		✓
	Minimise in use impacts	✓								
	Material recovery at end of life		✓	✓	✓	✓	✓	✓		✓
	User friendliness (see consumption phase)									
Production	Resource use optimisation		✓	✓	✓	✓	✓	✓		
	Automation, 3D printing, etc.	✓	✓	✓	✓	✓	✓	✓		
	Use of bio-materials and recycled materials		✓	✓	✓	✓	✓	✓		
Distribution	Prevent losses	✓	✓	✓	✓	✓	✓	✓		✓
Consumption / use phase	Sharing/ renting/ leasing business models	✓	✓	✓	✓	✓	✓	✓		
	Reduce consumption		✓	✓	✓	✓	✓	✓		✓
	Prevent/ minimise waste (including food)		✓	✓	✓	✓	✓	✓	✓	✓
	Virtualisation		✓	✓	✓	✓	✓	✓		✓
Reverse logistics	Reuse	✓	✓	✓	✓	✓	✓	✓		✓
	Remanufacturing	✓[99]	✓	✓	✓	✓	✓	✓		✓
	Refurbish		✓[100]	✓[100]	✓[100]	✓[100]	✓[100]	✓[100]		
End-of-life stage	Recycling		✓[100]	✓[100]	✓[100]	✓[100]	✓[100]	✓[100]		
	Waste-to-energy (AD and EfW)	✓								✓

[98] The named sectors represent:
- §1 Reduced energy consumption
- §2 Reduced material consumption, leading to reduced industrial production:
  §2.A = minerals; §2.B = chemicals; §2.C = metals; §2.E = electronics; §2.G = other products; §2.H = other
- §3 Reduced agricultural production
- §5 Reduced waste

[99] Remanufacturing may be more or less energy intensive (than original production)

[100] Reductions seen at global level. If product is manufactured outside the EU but refurbished or recycled locally, EU material and energy consumption will increase not decrease

Table 5-3 quickly reveals that the beneficial impacts of the different CE actions are likely to be reported in many different GHG inventory sectors. Furthermore, it should be noted that the high-level sectors named have many sub-sectors, as detailed in Annex D (e.g. there are 1049 subsectors within §1 “Energy”, and 355 within §2.B “Chemical Industry”). However, in reality it may be possible to narrow down the impact of a particular action to fewer reporting categories.

For example, if we imagine a CE action that has the sole effect of reducing the demand for aluminium, Figure 5-2 reveals that the benefits (if production were in Europe) would appear as a reduction within sector 2.C.E “Aluminium production” (disaggregating this further into 2.C.E.a,b,c would not help any further). The challenges with this sort of approach are likely to be that:

- Many if not most CE actions are likely to influence multiple GHG inventory categories
- Even for unilateral actions, there is still the challenge to disaggregate the impact of the CE action from any other activities that might have influenced emissions during the period of analysis

Figure 5-2: Taxonomy of GHG reporting of Aluminium Production

Category	Level 2	Level 3	Level 4
1. Energy			
2. Industrial Processes and Product Use			
	2.A Mineral Industry		
	2.B Chemical Industry		
	2.C Metal Industry		
		2.C.1 Iron and Steel Production	
		2.C.2 Ferroalloys Production	
		2.C.3 Aluminium Production	
			2.C.3.a CO_2 Emissions
			2.C.3.b By-Product Emissions
			2.C.3.c F-gases used in foundries
		2.C.4 Magnesium Production	
		…	
	2.D Non-energy Products from Fuels and Solvent Use		
	…		
3. Agriculture			
…			

It is also important to acknowledge the architecture of the national GHG inventories. They are explicitly designed to produce a summative methodology, in which there is no double-counting of emissions, between sectors or countries. This production-based approach dictates that every emission calculation must only consider what is happening in country at that point in the life cycle. For that reason, the life cycle emissions for a single product are never all contained within one data point:

- Every raw material will have a production burden in its country of origin and electricity is reported separately from production
- Components may be assembled, and then the product manufactured, in other countries, generating discrete production and electricity burdens
- The transport of the product may cross several countries and involve several modes (rail, ship, truck, car)
- Retail energy emissions have their own sub-sector (1.A.4.a – see Annex D for context)
- The product may or may not create in-use emissions, in the country of use
- The end of life scenario may involve a range of processes, in more than one country

- The European GHG inventory cannot by definition capture the complete (global) effect of (European) CE actions.

An LCA seeks to identify the emissions associated with a product throughout its lifecycle. Typically, results are partially disaggregated into life cycle stages – raw materials, production, retail, use and end of life – but there is often no consideration of impacts across different components or countries (so imports and exports are not highlighted), nor any differentiation between production and electricity burdens.

High-level CGE and I/O models also tend to include the whole life cycle impact of products. Unlike LCA, the locations of the emissions are considered, but the product's impacts are aggregated into large sectoral results.

Moreover, GHG inventories always look back into time, and effects of CE actions would show up only after a minimum of two years after introduction. If one is interested in looking forward and one wants to know what the possible impact of a proposed CE action will be, then one is bound to modelling approaches.

This lack of alignment between the GHG inventories, CE actions and methodologies makes it difficult to use the data from GHG inventories to monitor CE actions, but not impossible. The approach would need to be tailored to the particular CE action being investigated, and identify which country/sector combinations in the GHG inventories would be expected to see the greatest impacts from the action. Eurostat import and export data could be used to identify which sectors retain the most production in the EU, versus those that rely more heavily on imports. The general position is certainly that, over the past decade or so, many value chains have become increasingly global. This must be taken into account when evaluating the GHG benefits of CE actions, and may well involve drawing upon GHG inventories from countries outside the EU.

5.5.2 Other available databases

During the review of the five selected cases and the expert workshop, several other important databases were pointed out, including:

- **Exiobase database -** EXIOBASE is a global, detailed Multi-regional Environmentally Extended Supply and Use / Input Output (MR EE SUT/IOT) database. It was developed by harmonizing and detailing SUT for a large number of countries, estimating emissions and resource extractions by industry, linking the country EE SUT via trade to an MR EE SUT, and producing an MR EE IOI/OT from this.[101] It is being used by several partner organisations in their macro-economic models.
- **UN Environment International Resource Panel Global Material Flows Database** – The International Resource Panel provides a comprehensive understanding of linkages between the world economy, population and material use for more than four decades based on an authoritative database of global materials extraction and materials trade. This dataset covers most countries of the world. It presents direct and consumption-based material flow indicators for seven world regions and for individual countries, covering total usage, per capita use, and material use per US$. It also provides details for different groups of materials and relates

[101] EXIOBASE website, https://www.exiobase.eu/index.php/about-exiobase

indicators to human development outcomes. It provides similar information for each of seven world regions and about 150 countries to support informed decision-making by policy and business communities.[102]

- **Life Cycle Data Network (LCDN)** – the EC JRC's LCDN aims to provide a globally usable infrastructure for the publication of quality assured LCA dataset (both life cycle inventories and life cycle impact assessments) from different organisations, that can be consistent with the International Reference Life Cycle Data System (ILCD) handbook and/or the new Product and Organisation Environmental Footprint (PEF and OEF) initiatives. As such, it is one repository of LCA data that can be used to estimate the GHG impacts of CE actions such as product changes.
- **ecoinvent -** The Swiss ecoinvent Association is a not-for-profit association that manages another international life cycle inventory database, holding nearly 15,000 different datasets.

5.5.3 Other potential, less desirable but needed data sources:

Besides the existing databases mentioned above, there are several other means of collecting data that were used in different studies to fill data gaps but are less desirable:

- **MS surveys** – some methods, such as Eunomia's waste model relied on MS questionnaires on waste flows. The approach was highly data-intensive and so would not be popular to repeat (as MSs already receive many questionnaires to fill in).
- **Ad hoc evidence from literature and scientific studies** – whilst such data can provide useful information and are often needed due to data gaps on CE in official databases, their ad hoc nature make them unsuitable for the EEA's purposes.
- **Commercial databases, industrial associations data** – these datasets can be accurate, if quite specific, but are typically proprietary and so may not be available in the future.

Whilst none of these potential data sources would be particularly desirable to update, because of the effort that would be involved, their existing information might still be valuable as a means to fill specific existing data gaps.

5.5.4 Practicalities of using existing datasets related to CE

Own experience with modelling CE actions as well as the review of studies in this report showed that there is a general data gap with regard to data relevant to CE actions, including GHG impacts of such activities. This is primarily due to the fact that CE actions span across different economic sectors and are not properly captured by existing datasets. Moreover, some CE actions are innovative, e.g. circular business models, which are not yet fully captured either.

Strengths and limitations of Eurostat data

As the WRAP case study (no. 1) demonstrated, the Eurostat datasets represent a potentially very useful reference base for analysing CE actions. However, a key limitation of using Eurostat data to assess circular actions is that circular actions span across NACE sector classification and across sectors in general. Whilst some NACE sectors at 2-digit level can be considered entirely as circular sections (for example, waste recycling), for many other sectors some disaggregation is necessary. This could be mitigated by trying to estimate the share of the sector that could be considered circular, for example,

[102] UN Environment International Resource Panel website, http://www.resourcepanel.org/global-material-flows-database

the % share of manufacturing subsectors which relates to remanufacturing, as has been done in the WRAP 2016 study reviewed as Case Study 1. The WRAP study took a simple assumption on this share, however, **a more robust method to derive the circular economy shares of economic sectors could be explored.** For example, a study[103] could provide insight into the value of CE actions within a sector, and that value (as a fraction of the total sector value) be used as the basis to scale the impacts. This would be highly relevant for the use of CGE and I/O models to model GHG impacts of circular actions, as these models often map their sector classification with the Eurostat NACE sectors. Related to this is the issue that sectoral data in Eurostat datasets are often at a higher level of aggregation than that of the macro-economic models that use the data. Once again, some effort of disaggregation is needed to overcome this limitation.

A separate issue with Eurostat data is that, although they might be by some distance the best available statistics, this does not automatically mean that the data themselves are very accurate. Some datasets, such as certain parts of the waste statistics, are known to be based on relatively poor information, so this needs to be taken into consideration, where possible. Also, the level of detail in waste statistics is too limited to do accurate calculations on the impacts of CE actions. For instance, there is no data on the volume of organic waste that is created in Member States. Furthermore, there are gaps in the datasets where information is either reported as unknown or is otherwise withheld to protect confidentiality.

Eurostat is also currently working on developing indicators for collaborative economy actions. One or two questions related to collaborative economy, or rather digitalisation, have already been incorporated in MS questionnaires, however, these questions do not fully capture the impact of collaborative economy. Further work in this area is planned, however, progress is slow.[104]

Limitations of national GHG inventories

A key limitation with the national GHG inventories is the varied level of data aggregation employed by each MS. Although the available 10000 rows of hierarchy suggests a great richness of data granularity, MSs in reality report their inventories at a far higher level of aggregation. This makes good sense practically[105] but means that data may well not be available at the same level of disaggregation (and therefore specificity to the CE action of interest) for every MS.

In addition, like the Eurostat datasets, although the national GHG inventories may be the best available data, there may still be significant uncertainties about the values reported.

Finally, being still based on emissions production, the national GHG inventories for the EU naturally only cover emissions produced in the EU, thereby missing the embedded emissions in goods arriving from around the world. Many CE actions, including those that prolong lifetime or promote second lives, act to reduce the rate of consumption of goods produced outside the EU, reducing emissions in the source countries. These benefits are entirely missed by the EU national GHG inventories.

[103] Such as this previous WRAP report: "The Economic Impacts of Resource Efficient Business Models", WRAP, RBM200-009, March 2013, available at http://www.wrap.org.uk/sites/files/wrap/Economic%20impacts%20of%20resource%20efficient%20business%20models%20final%20report.pdf

[104] Discussion with Eurostat

[105] For example, there are two further levels of disaggregation in the section '1.B.1.a Coal Mining and Handling', but there is little point in a MS with minimal coal mining to disggregate its data to these extra levels of detail.

Strengths and limitations of Exiobase

Exiobase is the database with economic and environmental variables and parameters that are used by the EXIOMOD model. The strength of Exiobase is that it covers 43 countries and compared to other input-output databases is has a relatively high level of detail with regard to sectors, products (200) and materials (48). However, for proper modelling of many CE actions an even more granular sector structure and product detail would be required. As an example, for the food sector, Exiobase only distinguished between grains, meat products and dairy products. A geographical limitation of Exiobase is that it doesn't include any data on Croatia, as the latest data update has been done before Croatia became part of the European Union. Also, due to the infrequent updating of data and parameters, many parameters such as specific GHG emission factors (e.g. for steel production) are outdated. These parameters can be changed manually (in locally downloaded versions of the database), but this is not preferable as this hampers reproducibility of findings by other researchers.

Strengths and limitations of LCA databases

Databases should as LCDN and ecoinvent provide a potentially rich source of life cycle data to inform the analysis of CE actions. The practical challenges of this sort of approach are likely to concern ensuring that the datasets have the appropriate system boundary for the desired analysis, and accounting for the fact that a CE action may affect multiple products, requiring some form of aggregation of LCA results.

5.6 Synthesis

5.6.1 Quantifying GHG impact of circular actions remains a challenge

As can be seen from the above analysis, trade-offs need to be made when developing a framework to quantify the GHG impacts of CE actions and if possible, link them to the GHG inventories. Forecasting approaches will require significant modelling resources, not directly available at the EEA today. This would mean, the EEA has to rely on a proprietary model and outsource modelling to a third party rather than develop a model itself. There also need to be some choices made with regard to the selection of CE actions to be included, as covering most CE actions is not feasible. Substantial data limitations, in particularly from official statistics, mean that considerable resources would need to be allocated to data collation and collection before any modelling can be done. Alternatively, one has to rely on assumptions and try to improve those.

The alternative to developing a modelling approach is to devise a framework to meta-analyse information already available. As discussed in Section 5.4.5, this was judged to be impracticable because of the likely numerous differences between the various previous studies.

5.6.2 Our suggestions

Despite the challenges mentioned above, there is an option to go forward with one or two existing methods and adapt them. Both "top-down" and "bottom-up" approaches of a hybrid model appear to be feasible, so it makes sense to look at how they would sit with the other considerations discussed. Probably the most significant is the EEA's desire to focus on forecasting GHG benefits rather than accounting for past benefits. Section 5.4.4 concluded that LCA methods are expected to be more stable when looking at future projections, since they only deal with a few considerations at a time. This allows the modeller to consider a defined progression in the benefits of a circular economy action, that the macro-economic model to which it is coupled could then scale up to look at wider system boundaries. Coupling LCA to macro-economic models still remains a challenge and needs to be researched further as an LCA offers a micro-level analysis that does not always translate into inputs that can be used by a macro-level model. One example discussed during the workshop was to use an LCA to define better emission factors that could be used as coefficients in the macro-level model. This would appear to be a better solution than attempting to forecast future trends initially in the macro-economic model and then using projected LCA and purchasing data to disaggregate the analysis.

On this basis, the methodological framework we would propose to the EEA would be to adopt a bottom-up approach. The WRAP REBM case study could be a template for the methodology, or the EEA might prefer to adopt a CGE model such as TNO's EXIOMOD -depending on the question to be answered (see Section 5.2). Using LCA, emission factors would be developed for circular economy actions in the key sectors (automotive, construction, food, materials), and these would be applied to an I/O or CGE model. This would either be EXIOMOD, or (following WRAP REBM) a new model underpinned by Eurostat data detailing the value of trade between sectors in the model, and perhaps using GHG inventory reporting data to help inform its environmental extension information.

This approach would achieve the EEA's goals of relying largely on already existing data (just needing the extra LCA data for the chosen sectors and circular economy actions) and of being transparent and replicable. What is less clear is the extent to which the methodology will be plausibly robust. It would share many of the shortcomings of the WRAP study – notably the weakness of the assumption that one or more certain sectors can be a reasonable proxy for the circular economy activities of interest. However, this could be solved by initiating preparatory studies to estimate in a robust way the share of circular economy in the selected sectors.

One option for the EEA might be to pursue the development of the methodology with an initial focus on just one of the identified key sectors. This would limit the amount of new data that would be needed to drive the modelling, whilst still being able to generate data that can be compared against the previous studies identified that have sought to estimate impacts in the chosen sector. This in turn has the potential benefit of enabling the EEA to finesse and tune the methodology so that its results are well aligned, before replicating the approach for other sectors.

5.6.3 Further research needs

To advance the methodology, a plausible next step would be to explore some of the identified gaps, to determine if cost-effective solutions can be developed.

Exploring ways to link LCAs to macro-economic models

In the Collaborative Economy case study (no. 5), the authors were ultimately unable to link LCA data on the circular economy to their macro-economic models. This is clearly a fundamental requirement in order to leverage the benefits of a hybrid approach, which has worked in other instances and so is presumably technically feasible.

Improve CE-relevant datasets

Whilst several useful datasets (including those from Eurostat and national GHG inventories) exist that could be used to inform the methodology, some further investment into CE-relevant data collection and harmonisation/standardisation of data could be beneficial in order to improve the foundations on which the calculations are made.[106] This work would be best if coordinated with relevant parties, such as ESTAT, Exiobase and JRC.

Research into splits and coefficients

An identified limitation at present is the inability to get to the required level of granularity from macro-economic models. The EEA could commission preparatory studies aimed at improving assumptions and coefficients to model circular actions, including the fractional share of model sectors and subsectors that are circular activities. This might also extend towards modelling circular design, though see also the next section.

Example of how some CE actions can be translated into modelling parameters:

The Cambridge Econometrics (2018) study assessed the impact of CE actions in five sectors using an I/O model. The table below shows how different CE actions are translated into modelling inputs.

Table 5.4 E3ME modelling inputs

Type of modelling inputs	Modelling method in E3ME
Increase in alternative materials and energy sources, e.g. recycled materials and biofuels	Changing input-output structure of the relevant sectors
Reduction in the consumption of virgin materials, e.g. metals, plastic and petrol	Changing input-output structure of the relevant sectors (reducing purchases from sectors producing raw materials and increasing purchases within the sector or from the waste sector)
Increase in repairing activities	Changing input-output structure of the relevant sectors (assuming that repairs occur within the same sector)
Collaborative economy	Reduction in demand for traditional business products (less buying), increase in demand within the household sectors (sharing), small increases in demand for collaborative economy platforms
Investment in recycling facilities	Exogenous additional investment by the recycling sector
Changes in the labour intensity of recycling activities compared to traditional waste management	Exogenous increase in employment in the waste management & recycling sector (same sector)
Cost reductions from the more efficient use of resources or production methods (e.g. modular design)	Exogenous reduction to industry costs

Source: Cambridge Econometrics (2018)

The table below shows an example of how CE actions in the construction sector were translated into modelling parameters for the two CE scenarios (moderate and ambitious). An elaborate explanation

[106] Harmonisation is key to get EU aggregated results from modelling. Lessons learned on harmonisation and standardisation of activity data and emission factors from the inventory and statistical community should be taken on board.

on how the assumptions and quantitative model inputs were derived can be found in the full sector profile in Annex C of the published report.

Table 5.5 Translation of circular activities in the construction sector into E3ME modelling inputs.

Circular economy action	Implications for E3ME modelling	CE scenarios
Recycling, reuse, waste reduction, and recycling of Construction and Demolition waste (C&D)	Increase in construction demand from recycling (buying more recycled materials) (I/O) Reduction in minerals demand (cement, sands, glass, ceramics etc.) by construction sector (I/O)	5% (moderate) or 15% (ambitious) additional purchases from the waste & recycling sector compared to the baseline * -5% (moderate) or -15% (ambitious) compared to the baseline
Sharing, efficient use of empty buildings	Households letting out spare rooms resulting in reduction on demand for traditional accommodation (e.g. hotels) (exogenous reduction in consumer spending on traditional hotels and accommodations) Small payment to collaborative platforms such as AirBnB (exogenous increase in consumer spending on miscellaneous services) Assume households spend money from P2P (peer-to-peer) activities on other goods and services (reallocation of consumer spending)	Consumer spending on traditional models of accommodation reduced by €6.4bn (moderate) or €18.4bn (ambitious) compared to the baseline €1.05bn (moderate) or €3.03bn (ambitious) compared to the baseline
Modular design	Lower construction sector costs per unit of output from non-labour related efficiency gains (exogenous reduction of unit cost in the construction sector) Increase in labour productivity of new construction per unit of output (exogenous reduction in construction labour demand)	3% (moderate) or 9% (ambitious) lower cost for new buildings in 2030 compared to the baseline *-5% (moderate) or *-10% (ambitious) of labour requirement for newbuilds compared to the baseline

Source: Cambridge Econometrics (2018)

Note: * own estimation

Networking/ learning from Member States and other initiatives

Even though it was constrained to look at studies with a GHG accounting angle, the literature review revealed that there are many studies and initiatives examining the circular economy. Certain countries (such as the Netherlands) and organisations (such as the Ellen McArthur Foundation, EXIOBASE or JRC) are identified as leaders in the area. The EEA could look to liaise with these leaders and provide a forum to share ideas and best practices.

5.6.4 An Alternative Way Forward

The previous section outlines how the EEA could move forward with the development of a new methodological framework, based on the learnings from this project. Nevertheless, it should be reiterated that it will be genuinely challenging (in terms both of complexity and resources required) to develop a methodology for estimating the GHG benefits of the circular economy, and even more challenging to apply such method with reliable results. Likewise, a meta-analysis approach faces significant difficulties harmonising data and results from different studies. In this light, it might be reasonable for the EEA to pause and consider exploring an alternative course of investigation, focusing on particular circular actions to which limited attention has been paid up to now.

One possible option would be to investigate the GHG benefits of circular "design" actions. The literature review has revealed that these particular GHG benefits have been poorly studied to date, so the EEA would have the opportunity to open up a new avenue of analysis, to feed into policy development. As discussed at the workshop, quantifying design benefits is far from straightforward, because a better designed product might:

- use fewer damaging materials
- consume less energy during production (which might be outside the EU)
- consume less energy during use
- be more efficiently used during its life
- last for longer (extended 'durability')
- be better designed for reuse/remanufacture/etc at the end of its first life

In reality, it is unlikely that all of these options will occur simultaneously, especially as some appear more naturally to be alternatives – light weighting often reduces in-use impacts by using more environmentally damaging materials, and more durable products tend to be made of more and/or stronger materials (if such things were not the case, the interventions would have been non-contentious and therefore already made).

Given the conclusion that the design improvements are more likely to be alternatives, the natural question that arises is, "what is the best design approach to reduce a product's impact?". The EEA could embark on a study to explore this question, with more than one way of scoping the work, best exemplified by first considering the most comprehensive approach.

This would involve first of all identifying a range of exemplar products, chosen to cover some of the most environmentally significant products (because of their materials of construction, their energy consumption, their European sales, etc).

For each product, the study would determine (through life cycle assessment) the life time impacts of the product against a range of environmental impacts, not just global warming, to ensure that any improvements later identified are not simply shifting burdens to other environmental impacts.

Finally, the study would then look in some detail at how each of the aforementioned design interventions might change the environmental impacts of each of the products. This would lead to conclusions about how the different design improvements lead to different environmental performances for different products, enabling the EEA to identify where the best options lie for each exemplar product.

A study of this scope would be extremely revealing, but is also very resource intensive. If the EEA wanted to limit the scope, several options exist:

- reduce the number of products studied

- limit the analysis to global warming potential
- base the analysis on perturbations to existing, published, peer-reviewed LCAs
- reduce the number of design interventions assessed

Even if the most comprehensive study could not be commissioned, this type of investigation into the benefits of a more circular product design would be a valuable contribution to circular economy policy development.

6 Conclusions

A shift to a low-carbon and circular economy are two of the EU policy priorities. While many synergies exist between the two through energy and material flows, and many studies suggest a large GHG abatement potential of circular economy, there has been relatively little quantification available so far of the extent to which CE can contribute to climate change mitigation. Moreover, this potential has been hardly integrated into climate change mitigation policies and targets. As has been pointed out - there is a difference between EU GHG benefits and global GHG benefits. Some of the CE actions reduce emissions outside the EU, e.g. in producing countries like China, India and USA, and hence never show up in EU GHG inventories.

This study investigated the aforementioned research gap by first identifying and reviewing existing literature and methodologies which assessed the GHG impacts of circular activities and by giving an overview and analysis of the findings. From the list of existing studies and reports, five studies were selected for a more in-depth analysis of their methodologies:

- **Case study 1 by WRAP (2016):** Extrapolating resource efficient business models across Europe
- **Case study 2 by Eunomia (2014):** Impact assessment on options reviewing targets in the Waste Framework Directive, Landfill Directive and Packaging and Packaging Waste Directive', based on the European Reference Model on Municipal Waste
- **Case study 3 by Material Economics (2018):** The circular economy - A powerful force for climate mitigation
- **Case study 4 by TNO (2018):** Effects on greenhouse gas emissions of the Government-wide Circular Economy Program and Transition agendas
- **Case study 5 by Trinomics *et al* (2017):** Environmental potential of the collaborative economy.

The methodologies and assumptions of these studies were further discussed in an expert workshop with the authors of the studies and other participants.

Developing a generalised methodology for assessing GHG impacts of CE actions is challenging

The second aim of the study was to propose options for the development of a European methodological framework which allows for the quantification of the GHG impacts of CE actions and their possible integration into climate change policies. The key aspects of the framework included defining the question, the scope of the analysis, the tools, methods and approaches available and data characteristics and availability. Ideas on such options for a framework were based on the analysis of five case studies, feedback from the EEA and brainstorming with workshop participants as well as the literature review performed in the first part of the study. The results of the analysis show that developing a single European methodological framework to quantify GHG impacts of circular actions is very challenging, because of:

- The diverse nature of the circular economy makes evaluating its full impact on GHG emissions complex and expensive.
- A general lack of robust readily available and regularly updated circular economy-related data.
- Limited ressources available at EEA

Based on this, there have been two main options identified as a potential way forward for the EEA. One is to focus on developing a modelling framework, the second being performing a meta-analysis of existing data and studies.

Directions for future quantitative assessment of GHG impacts from CE actions

If the EEA decides to pursue the development of a methodology to estimate the GHG benefits of circular economy actions in the future, the ideas and analysis presented above lead to some conclusions that may form the framework for the next phase of work:

1. Since a comprehensive coverage of CE actions is challenging, the scope should be limited to the most significant circular economy actions in a number of sectors rather than trying to cover all range of CE actions. The fact that specific sectors were assessed does not necessarily mean that cross-sectoral impacts were not taken into account. The light meta-analysis of existing studies has identified the following sectors and CE actions where CE actions have led to considerable GHG reduction potential:
    a. Materials (notably plastics, but also metals and cement)
    b. Food (reduction, improved packaging, nutrient recycling)
    c. Construction (material substitution, modular design, smart crushers, space-sharing, prolong lifetimes, deconstruction and reuse instead of demolition)
    d. Waste management sector (recycling – overlap to some extent with recycling activities in other sectors)
    e. Automotive (car sharing, durability, improved end of life).

2. The nature of existing GHG reporting requirements collected by EEA and official statistics collected by Eurostat suggests that the methodology would work best if it sought to evaluate impacts on a (sub)sectoral basis – i.e. being aligned as much as possible to existing databases using economic or other sector classifications, for example, looking at construction, food sector, etc., so that aligned data would be readily available at least to some extent. In general, improving CE-related data is one of the important future research needs.

3. The EEA's desire to forecast future benefits (rather than account for past ones) sets a scope for the methodology to be able to take current data and project how matters will evolve over time. There are broadly two types of methodological approaches that can be used to assess the GHG impacts of any CE action (theoretically) – detailed level methods such as LCA and MFA, or high-level methods such as a CGE or I/O model. Given their greater simplicity and smaller scope, LCA and MFA analyses are expected to diverge from each other less quickly than macro-economic models which are more likely to use different assumptions.

Guidance for meta-analysis of existing studies

If the EEA decides to pursue a meta-analysis of already existing studies, the identified challenges with using such an approach and the guideline provided to interpret the results leads to the following conclusions:

4. The existing literature currently allows only for a very light meta-analysis of results due to the following key challenges: use of different methodologies, scopes of CE and assumptions,

in particularly on the level CE ambition which makes comparison and combination of results difficult.

5. If such an interpretation of results is nevertheless undertaken, the following five elements should be considered when using the findings:
   a. **The purpose and research question analysed in the study** – not all studies that assessed GHG impacts of CE actions had this as their primarily purpose. As such, the results are often aggregated (i.e. not per CE action) or the methodology chosen might not have been optimal to estimate the GHG benefits.
   b. **The studies differ in the granularity level at which GHG impacts are reported.** This is often related to the purpose (point a), i.e. some studies looked at individual CE actions while others looked at macro level impacts of the economy as a whole.
   c. **The baseline to which the GHG benefits were compared also differed greatly**. Some used comparison to current data as their baseline, others developed their own baseline situations.
   d. **The level of ambition - i.e. the level of uptake of CE assumed** – also greatly determines the size of the GHG benefits. While some studies looked at the maximum potential, others took a more conservative approach based on how likely the CE actions are expected to evolve given historical trends.
   e. Lastly, **the format of reporting GHG impacts** varied from presenting annual reductions to cumulative savings over a certain time period to a relative change compared to a specific year.

6. All this shows that currently, a meta-analysis offers a limited value for the EEA as a framework to make comparable estimates on the relative GHG reduction potentials in different sectors and of different CE actions. However, the proposed framework does offer guidance on the elements that need to be considered when interpreting and comparing the findings of studies that use different methods and approaches to quantify GHG impacts.

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8 Annex A - Excel Database of Literature Review

8.1 Template

Document details							Scope						Preliminary methodological details								
Title	Author	Organi-sation/ journal	Year of publica-tion	Link to document (if available)	Summary	How are CE and GHG emissions linked?	Activities examined fit within our CE scope	Are GHG of the CE activities assessed?	Geogra-phical scope	Scale-level of circular action	What kind of CE actions are covered?	Who is the stake-holder imple-menting?	method used quali-tative/ quanti-tative	Type of quanti-tative method used (if applica-ble)	Quality of methodo-logical description	List overall quanti-tative estimates	Did the study use methods for upscaling?	Did the study take into account rebound effects?	Mention of non-climate related impacts	Description of qualitative impacts	Is this case relevant to be assessed further in task 2 and why

8.2 List of reviewed sources

	Title	Author(s)	Organisation/journal	Year of publication
1	The circular economy as a key instrument for reducing climate change	Bijleveld, Marijn; Bergsma, Geert; Nusselder, Sanne	CE Delft	2016
2	Opportunities for a Circular Economy in the Netherlands	Bastein, Ton; Roelofs, Elsbeth; Rietveld, Elmer; Hoogendoorn, Alwin	TNO	2013
3	Effecten van het Rijksbrede Programma Circulaire Economie en de Transitieagenda ' s op de emissie van broeikasgassen	Rietveld, Elmert; Boonman, Hettie; Chahim, Mohammed; Bastein, Ton; Hu, Jinxue	TNO	2018
4	"Impact Assessment on Options Reviewing Targets in the Waste Framework Directive, Landfill Directive and Packaging and Packaging Waste Directive" Final Report for the European Commission DG Environment	Eunomia, Dominic Hogg; Eunomia, Tim Elliott Cri, Christian Fischer; Öko-, Georg Mehlhart	Eunomia, Oeko and Copenhagen Resource Institute - study for DG ENV	2014
5	The Circular Economy and Benefits for Society: Jobs and Climate Clear Winners in an Economy Based on Renewable Energy and Resource Efficiency	Wijkman, Anders Skånberg, Kristian	The Club of Rome	2011
6	Implementing circular economy globally makes Paris targets achievable	Blok, Kornelis; Hoogzaad, Jelmer; Ramkumar, Shyaam; Ridley, Andy; Srivastav, Preeti; Tan, Irina; Terlouw, Wouter ; Wit, Marc de	Ecofys & circle economy	2016

	Title	Author(s)	Organisation/journal	Year of publication
7	Circular economy potential for climate change mitigation.	Didier-Naoro, F.;Olivier, J.; Hestin, M.; hanoine, A.; Croison, F.; Menten, F., Berwald, Lecerf, I.	Deloitte Sustainability	2016
8	Circular Economy in Europe Developing the Knowledge Base	Reichel, Almut; De Schoenmakere, Mieke; Gillabel, Jeroen; Martin, Jock; Hoogeveen, Ybele	EEA	2016
9	The circular economy - A powerful force for climate mitigation	Not mentioned	Material Economics, Sitra, European CLimate Foundation, Climate KIC, Energy transitions commission, Ellen MacArthur Foundation, MAVA Foundation, ClimateWorks Foundation	2018
10	Growth within: a circular economy vision for a competitive Europe	many	Ellen MacArthur Foundation	2015
11	Mitigating Climate Change and Waste Recycling : Household Packaging Case Study	Dépoues, Vivian; Bordier, Cécile	CDC Climat	2015
12	Effecten van autodelen op de mobiliteit en CO_2-uitstoot	Nijland, Hans; Van Meerkerk, Jordy; Hoen, Anco	PBL	2015
13	Environmental potential of the collaborative economy	Rademaekers, Koen; Svatikova, Katarina; Vermeulen, Jurgen; Smit, Tycho; Baroni, Laura; Hausemer, Pierre; Dagulin, Marius; Chewpreda, Unnada; Politt, Hector; Boonen, Katrien; Vercalsteren, An; Gillabel, Jeroen	Trinomics, Cambridge Econometrics, VITO and VVA for DG-ENV	2017
14	Impacts of the circular economy on the labour market	Chewpreecha, U.; Pollitt, H.; Colin, H; Svatikova, K.; Williams, R.; Vermeulen, J.; Smit, T.	Cambridge Econometrics, Trinomics, ICF	2018
15	Study on modelling of the economic and environmental impacts of raw material consumption	Not mentioned	Cambridge Econometrics & bio Intelligence Service	2014
16	The MATTER Project - Intergrated energy and materials systems engineering for GHG emission mitigation	Kram, T.; Gielen, D.J.; Bos, A.J.M., De Feber, M.A.P.C., Gerlagh, T., Groenendaal, B.J.; Moll, H.C.; Bouwman, M.E.; Daniëls, B.W. ; Worrel, E., Hekkert. M.P.; Joosten, .A.J.;Groenewegen, P. and Goverse, T.	ECN	2001
17	Greenhouse gas emissions and the potential for mitigation from materials management within OECD countries	Evans, C.; Brundage, A.; Lizas, D.;Kennedy, V.; Nadkarni, N.; Rowan, E.; Freed, R.	Working Group on Waste Prevention and Recycling, OECD	2012
18	Decarbonisation of industrial sectors: the next frontier	De Pee, A.; Pinner, D.; Roelofsen, O.; Somers, K.;Speelman, E.; Witteveen, M.	McKinsey & Company	2018
19	Modelling Milestones for Achieving Resource Efficiency: Economic Analysis of Waste Taxes	Not mentioned	Cambridge econometrics for DG ENV	2013

	Title	Author(s)	Organisation/journal	Year of publication
20	Opportunities to Reduce Greenhouse Gas Emissions through Materials and Land Management Practices	Not mentioned	EPA	2009
21	Environmental pressures from European consumption and production	Not mentioned	EEA	2013
22	Waste opportunities - past and future climate benefits from better municipal waste management	Not mentioned	EEA	2011
23	The circularity gap report: our world is only 9% circular	De Wit, Marc; Hoogzaad, Jelmer; Ramkumar, Shyaam; Friedl, Harald; Douma, Annerieke	Circle economy	2018
24	Beyond the circular economy package	Molho, N.; Feming-Williams, V.	Aldersgate Grouup	2017
25	Businesses call for greater circular economy support	Roberts, N.	ENDS Europe	2017
26	Transport has the largest green impact on the circular economy	Delpero, C.	ENDS Europe	2017
27	Experimenting and public procurement among the priorities in the Action plan for a circular economy	Herlevi, K.	Ministry of Agriculture and Forestry (Finland)	2017
28	Circular economy in the Nordic construction sector - Identification and assessment of potential policy instruments that can accelerate a transition toward a circular economy	Sand, Henrik; Høibye, Linda	Nordic Council of Ministers	2018
29	Spain launches circular economy consultation	Gyekye, L.	ENDS Europe	2018
30	Dematerialization—A Disputable Strategy for Resource Conservation Put under Scrutiny	Müller, F.; Kosmol, J.; Keßler, H.; Angrick, M.; Rechenberg, B.	resources (journal)	2017
31	Policy and action standard - Waste Sector guidance	Davis, S.; Lerpiniere, D.; Mitra, A.; Roe, S.; Van Brunt, M.; Vieweg, M.	Greenhouse Gas Protocol & World Resources Institute	2015
32	With resource use expected to double by 2050, better natural resource use essential for a pollution-free planet	Horz, M.B.	UNEP	2017
33	Environmental impacts and potential of the sharing economy	Sjelvil, J.M., Erlandsen, A.M. & Haavrardsholm, O.	Nordic council of ministers	2017
34	Assessing global resource use	Stefan Bringezu, et al.	UNEP International Resource Panel	2017
35	Milieu-impact en -kansen van de deeleconomie	Van de Glind, P.; Slijpen, J.; De Jong, P.	ShareNL for the Dutch Ministry of Environment and Infrastructure	2015
36	The opportunities to business of improving resource efficiency	Lawton, K.; Carter, C.; Lee, J.; Tan, A.; de Prado Trigo, A.; Luscombe, D.; Briscoe, S.;	AMEC Environment & Infrastructure and Bio Intelligence Service	2013
37	Potential for Denmark as a Circular Economy - A case study from: DELIVERING THE CIRCULAR ECONOMY – A TOOLKIT FOR POLICY MAKERS	many	Ellen MacArthur Foundation	2015
38	Policies and Consumption-Based Carbon Emissions from a Top-Down and a Bottom-Up Perspective	Kirsten S. Wiebe, Simon Gandy, Christian Lutz	Low Carbon Economy	2016

	Title	Author(s)	Organisation/journal	Year of publication
39	Assessing global resource use and greenhouse emissions to 2050, with ambitious resource efficiency and climate mitigation policies	Hatfield-Dodds, S.; Schandl, H.; Newth, D.; Obersteiner, M.; Cai, Y.; Baynes, T.; West, J.; Havlik, P.;	Journal of Cleaner Production	2017
40	Extrapolating resource efficient business models across Europe	James, K., Mitchell, P., Mueller, D.	WRAP	2016
41	A resource efficient pathway towards a greenhouse gas neutral Germany	Günther, J., Lehmann, H., Lorenz, U., Purr, K.	German Ministry of Environment	2018
42	Development of a Modelling Tool on Waste Generation and Management	Gibbs, A.; Elliott, T.; Vergunst, T.; Ballinger, A.; Hogg, D.; Gentil, E.; Fischer, C.; Bakas, I.	Eunomia, Copenhagen Resource Institute	2014
43	Circular by design - Products in the circular economy	De Schoenmakere, M.; Gillabel, J.	EEA	2017

9 Annex B - Case Studies

9.1 Case study 1 by WRAP

Case study	Resource Efficient Business Models (REBMs)
Basic information	
Author(s), Organisation	James, K., Mitchell, P., Mueller, D. WRAP
Title of the study	Extrapolating resource efficient business models across Europe
Year	2016
Link to the document	http://www.rebus.eu.com/wp-content/uploads/2017/07/Extrapolating-resource-efficient-business-models-across-Europe.pdf
Summary	This report examines how the large-scale adoption of resource efficient business models (REBMs) that have been piloted through the course of the REBus project could have significant economic and environmental benefits across Europe. The adoption of REBMs involves the use of more labour and fewer resources (greater resource productivity) to broaden economic activity while increasing production efficiency. The model used to identify and quantify the economic and environmental impacts of large-scale adoption of REBus Models in terms of Gross Value Added, job creation, raw material demand, and GHG emissions was developed in another study (WRAP, 2015. Employment and the circular economy – job creation in a more resource efficient Britain) and they use data from the REBus pilot companies, Eurostat and the UKMRIO database. The authors created three different scenarios each illustrating a different level of adoption of these models. They then estimate how the up-scaling of these models will result in different economic and environmental benefits.

Circular Economy actions covered	The study covers four circular economy activities, which it models using sector proxies from Eurostat:
	• Recycling
	    ○ Closed & open loop recycling activity is proxied by GVA in the wholesale of waste and scrap sectors and the waste and recycling sector
	• Re-use
	    ○ Employment in retail of second-hand goods
	• Repair
	    ○ GVA in repair activities by repair of machinery and equipment and repair of electrical and electronic and household products
	• Servitisation
	    ○ Servitisation is proxied by GVA in the rental/ leasing sectors

Geographical scope	EU
Link between CE and GHG emissions	Study assesses the raw material equivalent impact of activities to assess materials avoided and diverted. This is used to calculate GHG benefits.
Contact for the study	Keith James | Government Account Manager | WRAP

	Direct: 01295 819642 Email: keith.james@wrap.org.uk
Key findings	
The study builds on previous reports from WRAP and the experience of the REBus project to suggest that REBMs could increase employment, reduce raw material consumption and, connected to this, reduce GHG emissions. The REBus project piloted actions aimed at facilitating REBMs. The annualised results from the pilot projects, in terms of tonnes of resource avoided, tonnes of GHG avoided and financial benefit are used, in conjunction with the calculated GVA of circular economy activities, to model three different REBM uptake scenarios. These scenarios reported against a baseline contribution from REBM activities (a proxy indicator of GVA and resource use constructed from Eurostat data) and assumed varying degrees of increased REBM uptake. The first scenario assumed that no new REBM initiatives were undertaken but some further advancement in REBM activities. This suggests a reduction in material demand of 7 million tonnes through extending product lifetimes and a further 20 million tonnes of material diverted through reuse, repair and recycling. The study suggests this equates to a 21 million tonnes CO2e reduction. The second scenario assessed a continued trend in REBM take-up and found a 63 million tonne reduction in material demand and a further 77 million tonnes diverted, equating to 82 million tonnes of CO2e. The third scenario considered extensive uptake in REBM activities, reducing material demand by 184 million tonnes, diverting 172 million tonnes and reducing GHG emissions by 154 million tonnes.	
CE action 1 – Recycling	The study assessed EU GHG reductions up to 2030 across three scenarios: no new initiatives, current development and transformational. The study assessed the supply chain implications, calculating the raw material equivalents avoided and diverted, and the subsequent GHG emissions avoided. • Scenario 1 = 19Mt CO2e • Scenario 2= 43Mt CO2e • Scenario 3 = 59Mt CO2e
CE action 2 – Repair; CE action 3 – Rental/Leasing; and CE action 4 - Remanufacturing – Repair	The study assessed EU GHG reductions up to 2030 across three scenarios: no new initiatives, current development and transformational. The study assessed the supply chain implications, calculating the raw material equivalents avoided and diverted, and the subsequent GHG emissions avoided. It is not possible to disaggregate the results presented to understand the individual implications of the three measures listed beside.

	• Scenario 1 = 2Mt CO2e • Scenario 2= 39Mt CO2e • Scenario 3 = 95Mt CO2e
Methodology description	
Short description of the methodology applied	The study uses an Input/Output method to model the GHG savings from sectors used as proxies for CE actions.
Geographical scope of analysed GHG emissions	It is not explicitly stated, but the model expresses material avoided in raw material equivalents to model emissions throughout the supply chain. Moreover, the I/O model includes market exchanges throughout the world, so we infer the scope is indeed global.
CE action 1	Recycling
Methodology used	Input Output model
Scale of the method	EU, Wholesale of waste & scrap; and waste & recycling
Assumptions used	Eurostat sectors were used as proxies to model closed loop and open loop recycling. Assumptions are made regarding the weight of raw materials per GVA. Modelling GVA in the proxy sector enables the raw materials diverted to be calculated with its accompanying GHG saving.
Data sources used	1. Eurostat (2014) Material flow accounts - flows in raw material equivalents http://ec.europa.eu/eurostat/statistics-explained/index.php/Material_flow_accounts_-_flows_in_raw_material_equivalents 2. Eurostat (2015) Resource Productivity Statistics http://ec.europa.eu/eurostat/statistics-explained/index.php/Resource_productivity_statistics
Degree of independence of activity	The analysis is undertaken at a sector level. While it may be fair to assume growth with recycling sectors will prevent raw material use, it is not a direct measure of raw material prevention.
CE action 2, 3 &4	
Methodology used	Input Output model
Assumptions used	Similar to CE 1, Eurostat sectors were used as proxies to model repair, reuse and servitisation. Assumptions are made regarding the GVA per manufacturing job and the raw materials used per GVA. This enables a GHG savings to be calculated by taking the jobs displaced by REBM to derive a GVA value, which can be used to calculate raw materials avoided. Unlike recycling, the study cannot disaggregate the benefit from repair, rental and remanufacturing. Indeed, on p8 it comments that “it is not

	really possible to separately identify remanufacturing or servitisation with any confidence".
Data sources used	3. Eurostat (2014) Material flow accounts - flows in raw material equivalents http://ec.europa.eu/eurostat/statistics-explained/index.php/Material_flow_accounts_-_flows_in_raw_material_equivalents 4. Eurostat (2015) Resource Productivity Statistics http://ec.europa.eu/eurostat/statistics-explained/index.php/Resource_productivity_statistics
Degree of independence of activity	There is little independence of activity under this method since the three activities cannot be separated and, similarly to activity one, there may be other drivers which increase sector GVA that may not displace raw materials.
Upscaling and replicability potential	
Upscaling	Data are reported at Member State and summed to provide a total for the EU.
Replicability	The methodology uses Eurostat data and can be easily used to report savings across all Member States.
Data source needs	Eurostat
Potential of integration into existing GHG inventory calculations	The GHG savings calculated via this method are more indirect than consumption-based methods. It must be assumed that growth within the proxy sectors occurs in place of traditional linear activities. Such assumptions will be present in any assessment of circular economy GHG savings. However, this methodology is not directly aligned with CE actions, rather GVA growth in relevant sectors. This presents drawbacks, but the calculations are performed on respectable data that are equally applicable throughout the EU. It should be possible to integrate this methodology with existing inventory calculations, however a methodology to avoid (or account for) double counting would need to be developed. **CE action: Recycling, Re-use, Repair** **Primary impact on inventory source categories** - *changes in waste management, energy & process emissions from manufacturing and transport of materials associated with manufacture of products where recycled materials replace raw materials* *Relevant sources* 5A1a Solid Waste disposal to land 5B Biological treatment of solid waste 5C1 Incineration of MSW 1A1a Power generation (from EfW plant)

	1A2gviii Stationary combustion in manufacturing industries and construction (*e.g. due to changes in mining, manufacturing, construction*) 1A2a / 2C1 Iron and steel production 1A2b / 2C3 Non-ferrous metal production / Aluminium production 1A2f / 2A Mineral products (*e.g. production of cement, glass, ceramics*) 1A2c / 2B Chemical production (*e.g. production of plastics, key feedstock chemicals such as ethylene*) 2C Metal production (*e.g. magnesium, lead, zinc, other..)* 1A2gvii Mobile combustion in manufacturing industries and construction (*e.g. fuel use in mobile machinery associated with mining, construction and waste management*) **Secondary impact on inventory source categories** -*changes in transport related to the provision of ancillary services and materials, transport of goods and waste* *Relevant sources* 1A3bi Road transport (Cars) 1A3bii Road transport (LGVs) 1A3biii Road transport (HGVs and buses) 1A1, 1B Combustion and fugitive emissions associated with upstream energy sector provision of fuels and feedstocks
Assessment of the method	
Strengths	The strength of this methodology is its use of readily available data for each member state. Its assumptions that growth in the proxy sectors are synonymous with raw material prevention are easy to measure and report against.
Weaknesses	However, the methodology does report on sectors rather than CE actions. By implementing a macro approach, it is not possible to be certain that measures are happening or are directly responsible for GHG reductions. Moreover, it is hard to allocate the benefits of said activities beyond the proxy sectors.
Conclusion	This study uses macro-economic data at a Member State level, as published by Eurostat, to identify the GVA within sectors targeted as proxies for circular economy activities. Growth within these proxy sectors is assumed to displace traditional manufacturing and avoid virgin materials, which consequently delivers net reductions in GHG. Due to its macro-economic approach, the method is very easy to scale; indeed, it already reports at a Member State level. It relies on data that are readily available, making it easy to roll out across Member States and report alongside other mechanisms. While the method's use of sector proxies risks wrongly tagging growth that is unrelated to the circular economy as the circular economy, this is not an unsurmountable obstacle. Indeed, its methodology is relatively transparent

	compared to other input-output macro-economic models assessing GHG benefits. The method appears to rely on quite crude emission factors to estimate the potential benefits. Combining this method with an LCA approach could provide more robust figures for GHG savings which are applied to the raw materials avoided by growth in the proxy sectors. We recommend taking this study forward for consideration when developing a CE GHG saving methodology, perhaps in combination with an LCA method.

9.2 Case study 2 by Eunomia

Case study	Key targets
Basic information	
Author(s), Organisation	Hogg, D. (Eunomia); Vergunst, T. (Eunomia); Elliott, T. (Eunomia); Elliott, L. (Eunomia); Fischer, C. (CRI); Kjaer, B. (CRI); Mehlhart, G. (Oeko); Kuchen, V. (ARGUS)
Title of the study	Impact Assessment on Options Reviewing Targets in the Waste Framework Directive, Landfill Directive and Packaging and Packaging Waste Directive.
Year	2014
Link to the document	http://ec.europa.eu/environment/waste/pdf/target_review/Targets%20Review%20final%20report.pdf
Summary	The aim of this study was to evaluate the impact of more ambitious targets for the recycling and landfill of municipal waste and packaging waste in EU 28. The authors modelled several policy options that incorporated various waste targets for the revision of the Waste Framework Directive, the Landfill Directive and the Packaging and Packaging Waste Directive, such as increased recycling for municipal solid waste (MSW) and restrictions to landfilling. The policy options identified were further scrutinized in terms of their financial, environmental- including GHG emissions - and social costs and benefits by comparing them to a baseline and to a scenario representing the full implementation of already existing targets. To estimate the costs and benefits of all policy options, the study utilized the 'European Reference Model on Municipal Waste Generation and Management'.
Circular Economy actions covered	Replacement of landfilling and waste incineration with recycling.
Geographical scope	EU
Link between CE and GHG emissions	The main GHG benefits arise due to reduced methane emissions from landfilling, and from avoiding emissions by replacing virgin materials and energy with recycled materials and energy recovery from waste.
Contact for the study	D. Hogg (CEO of Eunomia)
Key findings	

<table>
<tr><td colspan="2">The authors developed nine policy options, each including different waste management targets. The greatest reduction in GHG emissions is delivered by Option 3.4.c in which the target of 70% recycling/preparation for reuse of MSW combined with increased targets for recycling of packaging waste and limiting landfilling at Category B landfills to 5% by 2030 could reduce GHG emissions in the EU by 443 Mton CO_2-eq by 2030 compared to the 'full-implementation' scenario. The full-implementation scenario refers to reaching the targets arrayed in the Waste Framework Directive, the Landfill Directive and the Packaging and Packaging Waste Directive that Member States are already obliged to implement.</td></tr>
<tr><td rowspan="2">CE action 1 – Increasing recycling rate of MSW to 60%, 65%, and 70%</td><td>All these three recycling targets, which constitute three different options in the report, are assumed to be progressively reached in 2030 and are assessed against the 'full-implementation' scenario. The 60% recycling rate will result in GHG emissions reduction of 23 Mton CO_2 eq. in 2030 in the EU once the target is met. The 65% recycling rate would lead to 32 Mton CO_2 eq. lower GHG emissions in the EU in 2030 and the 70% target would reduce GHG emissions in 2030 by 39 Mton CO_2 eq. Reaching these annual reductions by 2030 will result in 107, 166, 214 Mton CO_2 eq. total GHG emissions reduction respectively from 2014 to 2030 in the EU (accumulated).</td></tr>
<tr><td>Scale: The total GHG emissions in the EU28 in 2016 were 4,440.8 Mton CO_2 eq. from which 3% is attributed to waste management. This means that around 133 Mton CO_2 eq. were emitted in the EU in 2016 from the waste sector. This indicative figure can be used to put the values of the above-mentioned GHG emissions reductions estimated under this option in perspective, but are not directly comparable, since the emission reductions are estimated against the 'full implementation' of the EU waste legislation scenario, and because the modelling takes a life-cycle approach which takes into account GHG emission reductions in other sectors, triggered/enabled through better waste management.</td></tr>
<tr><td rowspan="2">CE action 2 – Increase collection and recycling of packaging waste</td><td>There are two options in this category of actions in the report. Both assume great increases in the collection and recycling of packaging, but the second option distinguishes between ferrous and non-ferrous metals, while the first does not. Both options assume that 60% of plastic, 90% of all metal, 90% of glass, 90% of paper, and 80% of wood packaging will be collected and recycled by 2030. This would result in 20 Mton CO_2 eq. reduction of GHG emissions compared to the 'full-implementation' scenario and in 24 Mton CO_2 eq. reduction in 2030 in the EU if different targets are set for the two types of metals. These annual reductions of GHG emissions would result in 183 and 250 Mton CO_2 eq. reduction of emissions respectively from 2014 to 2030 in the EU.</td></tr>
<tr><td>Scale: Same as CE action 1</td></tr>
<tr><td rowspan="2">CE action 3 – Limiting landfilling to 5% of the total waste</td><td>This option assumes that by 2030 all Member States will progressively have limited the landfilling of residual waste to 5%. This action would reduce the GHGs emitted in the EU compared to the 'full-implementation' scenario by 13 Mton CO2 eq. in 2030. This is translated into 49 Mton CO_2 eq. total GHG emissions reduction from 2014 to 2030.</td></tr>
<tr><td>Scale: Same as CE action 1</td></tr>
</table>

CE action 4 – Combination of the three actions mentioned above	This category of CE actions includes three distinct options developed in the report that all combine different attributes of the abovementioned options. By combining 70% of MSW recycling/preparation for reuse option, increased packaging recycling targets, and limiting landfilling to 5%, the GHG emissions in the EU would be 44 Mton CO_2 eq. lower compared to the 'full-implementation' scenario. The same combination of attributes but differentiating three groups of EU countries, which reach these targets in different timing according to their capacity, would have the same level GHG emission reductions in 2030. The last option formulated in this category is the one with the greatest GHG emissions reduction potential and consists of the target of 70% recycling/preparation for reuse of MSW combined with increased targets for recycling of packaging waste and limiting landfilling at Category B landfills to 5% by 2030. This option would result in 62 Mton CO_2 eq. reductions in the EU in 2030 compared to the 'full implementation' scenario. These three options would generate 308, 320, 443 Mton CO_2 eq. GHG emissions reductions respectively compared to the 'full-implementation' scenario from 2014 to 2030.
	Scale: Same as CE action 1
Methodology description	
Short description of the methodology applied	The estimation of the financial, environmental – including GHG emissions - and social impacts of the developed options presented above, were estimated by the European Reference Model on Municipal Waste Generation and Management. The assessment of the environmental impacts of the different waste management practices is modelled by the combination of two methods. Climate change impacts, expressed in tonnes of CO_2 eq., are considered using the Life-Cycle Assessment method. The core of the model is based on waste flows reported by MS through a questionnaire, and for the analysis of the impact in changing waste management policies it takes a lifecycle perspective. The environmental impact module is the part of the model that calculates the GHG impacts. Emission reductions are based on emissions avoided compared to a baseline development. In case of recycling avoided emissions from avoided production of new materials, emission data is obtained from the Eco-invent database. For waste incineration the level of avoided emissions, are different depending on the presence and type of energy recovery taking place and of the energy mix that is replaced. In addition to waste treatment types, the model also takes the fuel consumption related to waste collection into account. The GHG data combined with data on the emission of air pollutants, such as NOx and PM emissions, are monetized and considered using the Cost Benefit Analysis (CBA) approach, in order to be compared with financial costs.
General assumptions used	The technical assumptions used in the modelling concern the various waste management methods considered in the study and they mainly involve energy consumption and GHG emissions during different types of waste treatment and GHG intensity of avoided material production and energy generation. Moreover, since the impacts of the examined waste management methods on GHG emissions occur at different times and a CBA approach is followed, the model has to

	account for these different time periods. To do that, the European Reference Model applies a social discount rate of 4%.
Geographical scope of analysed GHG emissions	The model considers direct and avoided emissions at the EU-level.
Detailed methodology per CE action	
CE action 1	**Increasing recycling rate of MSW to 60%, 65%, and 70%**
Methodology used	LCA based modelling built around a Cost-Benefit framework
Scale of the method	**Geography**: EU **Sector**: Waste sector with knock-on effects on other sectors **Lifecycle stage**: End-of-life
Assumptions used	To quantify the climate change impacts (GHG emissions) derived from different waste management practices, the authors made assumptions for the following parameters, based on information available in literature: • Emissions generated per tonne of MSW for each waste management type and specified by waste composition type; • Electricity requirements for waste treatment, for all different waste management options; • A universal maximum capture rate for landfill gas is assumed; • All GHG emissions from landfill are allocated to the year of the landfilling activity; • For anaerobic digestion an average efficiency is assumed and it is assumed that all the nutrients in the digestate are used to replace inorganic fertilisers; • For waste collection regional averages are used for the distance travelled between waste collection and the waste treatment site and a general average fuel consumption per km is assumed; • The current and future electricity mix for each Member state as well as GHG intensities per generation type (to calculate avoided emissions achieved by waste incineration with energy recovery). The latest version (2017) of the model has assumptions on the average electricity mix as well as the marginal mix and one can select to use either of these depending on the kind of study. For detailed information regarding the values used in the model for each waste management option, please check Appendix 4.0, of the report (prepared as a separate document).
Data sources used	The data sources used in the study were derived by: • The literature • The Member States • Eurostat
Degree of independence of activity	There is a clear independence between the actions considered here and other interventions. Each waste management option results in a specific amount of GHG emitted. However, the combination of different CE actions within the model is not the sum of the independent CE actions but calculated by the model in an integrated way.
CE action 2	**Increase collection and recycling of packaging waste**
Methodology used	Same as action 1

Scale of the method	Same as action 1
Assumptions used	Same as action 1
Data sources used	Same as action 1
Degree of independence of activity	Same as action 1
CE action 3	**Limiting landfilling to 5% of the total waste**
Methodology used	Same as action 1
Scale of the method	Same as action 1
Assumptions used	Same as action 1
Data sources used	Same as action 1
Degree of independence of activity	Same as action 1
CE action 4	**Combination of the three actions mentioned above**
Methodology used	Same as action 1
Scale of the method	Same as action 1
Assumptions used	Same as action 1
Data sources used	Same as action 1
Degree of independence of activity	Same as action 1
Upscaling and replicability potential	
Upscaling	Not applicable. It already applies to the EU as a whole.
Replicability	The model used in the study is specifically made to investigate the financial, environmental and social impacts of municipal and packaging waste generation and management in the EU, assessing at the same time the impact of the targets of specific pieces of European legislation. Having said that, the replicability of this method to other non-waste-related actions is considered very limited. However, it should be noted that other methods do not cover well the GHG impacts of the waste sector, which are often underreported (e.g. in the UNFCCC reports). This method can be very easily used to quantify the impact of the municipal and packaging waste at different levels, from regional to the EU. It is expected that the model will be made publicly available somewhere in 2019.
Data source needs	The model used for this study is quite data-intensive. The data required for this method consists of information on municipal waste generation, waste composition (types of waste), the distribution of municipal and packaging waste among the different waste management practices, the national energy mix, energy consumption of the different types of waste management, various data indicators on the municipal waste collection procedures, and on top of this, data are also required for including future projections of the development of all the above categories.

Potential of integration into existing GHG inventory calculations	The method is not designed to be linked to the UNFCCC reporting. Linking them would require a range of assumptions, including about shares of recyclables from municipal solid waste exported, share of materials produced within/outside Europe, and others. The landfill modelling would need to be adapted as well. Since the GHG emissions reductions of the different CE actions presented in the report refer to the EU municipal waste sector and since the reported emissions are well-linked to the source of emission, there is a high potential for the results of these methods to be integrated into existing GHG inventory calculations. CE action: Increased recycling Primary impact on inventory source categories –changes in waste management, transport and provision of ancillary services and materials *Relevant sources* 5A1a Solid Waste disposal to land 5B Biological treatment of solid waste 5C1 Incineration of MSW 1A1a Power generation (from EfW plant) 1A3bi Road transport (cars) 1A3bii Road transport (LGVs) 1A3biii Road transport (HGVs and buses) 1A2gvii Mobile combustion in manufacturing industries and construction (e.g. fuel use in mobile machinery associated with waste management) Secondary impact on inventory source categories –changes in energy & process emissions from manufacturing and transport of materials associated with manufacture of products where recycled materials replace raw materials *Relevant sources* 1A2gviii Stationary combustion in manufacturing industries and construction 1A2a / 2C1 Iron and steel production 1A2b / 2C3 Non-ferrous metal production / Aluminium production 1A2f / 2A Mineral products (e.g. production of glass, ceramics) 1A2c / 2B Chemical production 2C Metal production (e.g. magnesium, lead, zinc, other..) 1A1, 1B Combustion and fugitive emissions associated with upstream energy sector provision of fuels and feedstocks
Assessment of the method	
Strengths	• The methodology can establish a strong link between circular economy actions at the end-of-life phase and GHG emissions reduction; • The EU waste reference model was developed and applied for DG ENV and was in 2015 transferred to the EEA who has hosted it for DG ENV with support of the ETC/WMGE, hence, these bodies are already familiar with it.

Weaknesses	• It applies only to waste management and in this form, it does not allow for replication to other CE actions • Very data-intensive methodology
Conclusion	This methodology can directly attribute GHG emission mitigation to specific circular economy actions, and because of that can be very useful for assessing the impact of the municipal waste sector on GHG emissions. However, this methodology has been developed in such a way that cannot be easily modified to be applied to circular economy actions other than those at the end-of-life stage. However, the waste sector is thoroughly covered compared to other methods, and as the calculated GHG emission impacts are relatively large, the sector is gaining increased attention in the decarbonisation debate.

9.3 Case study 3 by Material Economics

Case study	Decarbonisation potential of circular economy in heavy industry
Basic information	
Author(s), Organisation	Material Economics, Sitra, European CLimate Foundation, Climate KIC, Energy transitions commission, Ellen MacArthur Foundation, MAVA Foundation, ClimateWorks Foundation
Title of the study	The circular economy - A powerful force for climate mitigation
Year	2018
Link to the document	http://materialeconomics.com/material-economics-the-circular-economy.pdf?cms_fileid=340952bea9e68d9013461c92fbc23cae
Summary	This study shows that the commitments in the Paris Agreement can only be achieved if climate mitigation of the energy go along with a transition to a circular economy. Without a circular economy, the vast increases in demand for raw materials would result in a level of emissions that would exceed the levels needed to keep well below 2 degrees of temperature rise, even in when the energy system is fully decarbonised. Three chapters primarily have a strong focus on materials, namely steel, plastics and aluminium and the actions investigated in these chapters mostly focus on supply-side measures. The chapter on construction and mobility takes a more mixed approach. The latter focuses on intensive car sharing, combined with electrification and automation of passenger cars as well as an optimisation of car design to extend the lifetime of cars and reduce their weight. Each chapter uses a combination of methods, to estimate future demand, model technological developments and calculate the GHG impacts of those developments.
Circular Economy actions covered	• **Steel sector:** 1) increased recycling and more high-quality recycling of steel (and especially reduced pollution with copper); 2) reduced losses in materials cycle (scrap formation, melting losses, etc.); 3) improved materials efficiency and resulting reduced demand through strategies such as high-strength steel, increased re-use of steel components, reduced over-specification, longer lifetimes, etc. • **Plastics**: 1) Increased mechanical recycling through changes to materials choice, product design, increased collection rates, improved

	purity of flows, new sorting and recycling technologies; 2) chemical recycling techniques; 3) re-use. • **Aluminium:** 1) increased high-quality recycling by preventing mixing of different aluminium types, including improved sorting by alloy type, reduced number of alloy specifications, changed product design for recycling, additional closed loops; 2) reduced losses through increased collection, less scrap formation, etc. • **Cement**: 1) Re-use of structural segments through local markets; 2) recovery of unreacted cement from end-of-life concrete; • **Mobility:** The study draws out the implication of a scenario with high levels of car sharing, where cars are designed for intensive use in professionally managed fleets. Strategies following form this include 1) longer lifetimes by enabling higher-durability materials, predictive maintenance, modular design and remanufacturing, increased re-use of components, longer-intrinsic durability of electric drivetrains; 2) light weighting through automation and less spare capacity (variability of sizing to trip requirements); 3) increased intensity of use through increased occupancy and changed ownership model. • Construction sector: more modular design of buildings to allow for easier refurbishment/disassembly, recovery of unreacted cement, reduce materials use during construction, reduce waste of materials on the construction site, sharing of buildings to increase utilization rates; longer building lifetimes through increased rebuilding / renovation;
Geographical scope	Results are provided on EU and global level.
Link between CE and GHG emissions	The study links circular economy to GHG emissions by showing that materials use is responsible for a very large share of our energy consumption. Additionally, it shows that circular actions can optimise resource efficiency in production, but more importantly can help to significantly reduce the demand for resources, which will make climate mitigation less costly.
Contact for the study	Per-Anders Enkvist pa.enkvist@materialeconomics.com
Key findings	
We report here only on EU findings. Cumulative GHG emission reduction potential of the four sectors and two value chains examined (the authors note that this represents 70% of 'heavy industry') is 296 Mtons of CO_2 eq. per year by 2050 in the EU. They examine circular economy opportunities aimed at reducing resource demand and minimising production emissions. These 296 Mtons represent a 56% reduction compared to their estimated baseline emissions in 2050. Baseline emissions are estimated by the authors through detailed development of demand scenarios within a setting of increased production efficiency and a decarbonised wider energy system (but not including radical changes to industrial processes)but the specific decarbonisation scenario that was used as baseline is not explicitly mentioned. selected three CE actions out of the studied six, those having the highest GHG abatement potential. Besides the three CE actions listed below, the findings for the other three actions and 'other category' were the following:	

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For aluminium industry - Reduced collection losses; increased alloy separation (to keep quality of secondary material); reduce scrap during production generate abatement potential of 26 Mtons of CO_2-eq. pa by 2050
For cement industry - Increased development of smart-crushers to increase recovery of cement in construction; develop markets for reuse of structural segments generate abatement potential of around 25 Mtons of CO_2-eq. p.a. by 2050.
For mobility value chain - Increase product lifetime; vehicle size adjustments (the average passenger car could be smaller when a shared car fleet is used) generate abatement potential of around 19 Mtons of CO_2-eq. pa by 2050.
Others – related to machinery, transportation - light-weight materials for products; local markets for building component reuse; prolonged lifetimes; leasing model to increase utilisation generate abatement potential of around 13 Mtons of CO_2-eq. p.a. by 2050.

</td></tr>
<tr><td rowspan="2">CE action 1 – improved circularity of plastics - production, end of life stage</td><td>Product design measures to facilitate recycling; specialised recycling operations; technology development for sorting, automation, and chemical recycling generate abatement potential of 116 Mtons of CO_2-eq p.a. by 2050.</td></tr>
<tr><td>Their baseline scenario estimates 233 Mt of CO_2 emissions in 2050. This means that their circular plastics scenarios abate around half of CO_2 emissions in the plastics sector.</td></tr>
<tr><td rowspan="2">CE action 2 – improved circularity in buildings, all lifecycle phases</td><td>Material saving during construction (steel and cement use drops by 20-30%, reduce waste to 5% during construction, 15% of structural building components are reused, cement reuse is widespread); light-weight materials for engineering; local markets for re-use of building components; decrease floor space by 5% (through space-sharing) generate abatement potential of around 80 Mtons of CO_2-eq pa by 2050 (this includes 55 Mtons for improved material use for buildings and 25 Mtons related to cement recycling and reuse).</td></tr>
<tr><td>The baseline scenario estimates around 230 Mt CO_2 per year by 2050, hence the circular scenario for buildings would decrease GHG emissions by 34%.</td></tr>
<tr><td rowspan="2">CE action 3 – improved circularity in the steel sector – production, end of life stage</td><td>High-quality secondary production; Avoiding copper contamination; Increased collection of post-consumer scrap; reduced fabrication scrap generates abatement potential of around 41 Mtons of CO_2-eq pa by 2050.</td></tr>
<tr><td>The report presents a reference case in which emissions remain at 104 Mtons CO_2 per year in 2050. This is substantially lower than today, largely because it includes a shift towards a higher share of secondary production. In the circular scenario, this is taken further, and the stand-alone emissions abatement potential in the steel sector is 47 Mtons per year. When accounting for overlaps with other actions (reduced demand in value chains), the net abatement potential is 41 Mtons.</td></tr>
<tr><td colspan="2">Methodology description</td></tr>
<tr><td>Short description of the methodology applied</td><td>A large part of the potential consists of incremental improvement of current practices (e.g., increase collection rates), but it also includes more ambitious changes (e.g., major changes to product design to enabler higher levels of mechanical plastics recycling). Notably, in the mobility value chain, the picture painted is one of a major reorganisation of the ownership model for transportation.</td></tr>
</table>

	The potentials are taking the perspective of what is needed in order to achieve GHG emission reductions needed to meet the Paris Climate targets. This means that large parts of the scenarios represent an ambitious disruptive change from the current business as usual with largely linear supply chains to much more circular supply chains. The methodology is based on a variety of approaches documented in the literature, including stock-based demand forecasts and dynamic materials flows models for metals, and detailed microeconomic activity levels for mobility and buildings.
General assumptions used	The report uses an underlying set of assumptions for population, GDP, etc. that build on other major studies for EU energy and transport systems. It also assumes that the energy sector decarbonises following the trajectory in the EU 2050 Roadmap scenarios (which assume a >95% GHG emission reduction in the energy sector). In this way, the GHG impacts highlight the potential within a setting of a decarbonising economy and avoid double-counting with other studies (as the reductions only result from resource demand reductions, materials efficiency improvements etc. and not from decarbonisation of the energy sector).
Geographical scope of analysed GHG emissions	The report is concerned with the emissions resulting from meeting EU demand. Where materials are imported, emissions reductions therefore can happen outside the EU. The report outlines that this is a minor consideration for steel, plastics, and cement, where most materials consumption is from domestic production. For aluminium, more of the emissions reductions would take place elsewhere, as the EU imports a large share of its primary metal. The emissions covered are those from materials production, including secondary materials (such as steel or plastics recycling). In addition, end-of-life emissions are covered.
Detailed methodology per CE action	
CE actions 1 Plastics	
Methodology used	The study uses a model of plastics demand split by plastics type and use sector, as well as production route (primary and secondary), and end-of-life treatment. A range of sources from the literature were used to estimate the emissions from different plastics categories and production routes, including recycling, and from end-of-life treatment.
Scale of the method	***Geography:*** EU and global ***Sectors:*** packaging, building & construction, automotive ***Lifecycle stages:*** production, end of life phase
Assumptions used	Exhibit 3.9 shows the different components of a circular scenario for EU plastics, all of them contributing to significant reuse of end-of-life plastics and substitution of primary plastics with secondary materials. Key features of this scenario include:

	• Increase the collection rate for mechanical recycling to 73%. The rate varies by value chain and plastics type but is underpinned by collection up to 85% of the five most common plastic types. • Collection rate remains as low as 30% for other, smaller-scale plastics, which although often very valuable, often also entails small volumes that make the economics of recycling difficult. • The non-collected portion of 27% also includes a large share of thermosets, which can be chemically but not mechanically recycled. • Significant yield improvements in sorting and recycling to 76%: The share of plastics that are collected for recycling but not turned into secondary materials falls from more than 40% today to 24%. Combined with a 73% collection rate, this means that the output from re-use recycling is 56% of total end-of-life plastics volumes. • Chemical recycling of 25% of remaining flows. This focuses on the remaining 44% of plastics that are difficult to handle through mechanical recycling. Thus, 11% of total end-of-life plastics are chemically recycled.
Data sources used	• Plastics Europe • Consultancy reports • Scientific papers • International Energy Agency • For full list see end notes ch. 3 (pp. 166).
Degree of independence of activity	The impacts of the different actions in the plastics sector have been calculated independently, allowing for an assessment of the GHG impacts of individual actions. Note that in this context actions mean things like increasing the rate of mechanical recycling to 73%. To achieve this, a variety of (policy) and industry actions will be needed.
CE action 2 Buildings	
Methodology used	Similar to plastics, to estimate CO_2 emission reduction potential, a circular scenario is developed with the gradual adoption of a wide-ranging circular opportunities in buildings by 2050. The analysis shows that CO_2 emissions from materials in buildings could be reduced by 34% by 2050 and by 53% beyond 2050 (Exhibit 6.7). The method follows a micro-economic approach at the building level and investigates the potentials resulting from improvements in cement production and circular use of buildings. • For cement the focus is put on the production phase as most GHG emissions are generated • For buildings as a whole, the method focused on actions throughout the different lifecycle stages. As a baseline for the 2050 scenario the baseline growth in building area (m^2) was taken into account as well as baseline demolition and renovation rates. The circular scenario represents the reduction potential compared to this baseline.
Scale of the method	***Geography:*** EU-only

	Sectors: steel, plastics, aluminium, cement applied in the construction sector. ***Lifecycle stages:*** design, production, use, end-of-life phase
Assumptions used	Exhibit 6.8 lists measures that were assumed in the circular buildings' scenario: • Materials recirculation – tonnes CO2 per tonne materials cutting the average CO2-intensity of cement production by 23%, from 0.62 to 0.48 tonnes CO2 per tonne cement. • Building materials efficiency – tonnes materials per m2 - The materials efficiency strategies reduce the amount of new building materials that are required, from an average of 2.45 tonnes of materials for each square metre of building, to 1.92 tonnes. To achieve this, waste during construction is reduced to 5%, while steel and cement use falls by 20-30%, as a result of reduced over-specification and use of higher-quality materials. • 15% of structural building components are reused. • Circular business models – useful service from each m2 - for each year of service from a building, the materials input is one-third lower in the circular scenario. • The baseline scenario used for cement production assumes 0% cement recycling and derives cement demand from the compiled buildings stock model, which is based on baseline growth in building area and demolition and renovation rates.
Data sources used	• Eurostat • Scientific literature • Industry reports • Independent consultancy reports
Degree of independence of activity	The impacts of different actions are calculated independently.
CE action 3 Steel	
Methodology used	The study used a dynamic material flow model that was developed and described in Pauliuk *et al.* (2013).[107] Steel demand is modelled in four end-use sectors and 11 world regions. Historical steel stocks are based on Pauliuk, Wang and Müller (2013), while future stock turnover is modelled with different lifetimes of products in each end-use sector following a normal distribution. The steps of the steel supply chain and use cycle are directly modelled, including losses in production, new scrap formation, the remelting process, and collection of post-consumer scrap. The model also tracks inmixing of copper in the steel stock, and the limitations this places on use. It further represents degrees of international trade in scrap, and the dilution of steel scrap with primary steel. Note the difference between demand, which denotes the requirements for steel in final products, and

[107] Pauliuk, S., Wang, T. and Müller, D. B. (2013). Steel all over the world: Estimating in-use stocks of iron for 200 countries. Resources, Conservation and Recycling,
71. 22-30. DOI:10.1016/j.resconrec.2012.11.008.

	production, which is the amount of crude steel required to service this demand. However, the report also mentions that the authors constructed a scenario for steel which estimates CO_2 emission savings from reduced losses of steel and technology improvements to reduce contamination of copper and enabling wider use of secondary steel. From this scenario they find that CO_2 emissions could be reduced by around 50% by 2050 in the EU (to 116 Mtons).
Scale of the method	***Geography:*** EU and global ***Sectors:*** steel ***Lifecycle stages:*** production, use, end of life phase
Assumptions used	There is a need to go back to Pauliuk et al. (2013) to understand the assumptions. Some potential assumptions from the report: • Baseline scenario – Steel recycling continues with the same collection rates, loss levels and practices as today. Continued dependence on Basic Oxygen Furnace process, with rapid implementation of Best-available technologies. As a consequence, the CO2 intensity of primary steel production falls by 17% by 2050. • Demand in each sector and region is modelled with a stock-based approach, with population forecasts based on UN Population Prospects 2017, and per-capita saturation is largely completed by 2100. • The circular materials scenario includes …. • The circularity products scenario combines the circular materials scenario with additional decreases in demand for steel due to optimised steel use in the transport and construction sector • Emissions from the mining and production of iron ores are not included in any of the scenarios.
Data sources used	• Scientific literature • Consultancy reports • World Steel Association
Degree of independence of activity	Yes, see actions 1 and 2.
Upscaling and replicability potential	
Upscaling	The results apply to EU level.
Replicability	The report can be replicated later on for data updates or for more detail in particular areas. However, with regard to circular actions, the methods have been tailored for the specific materials investigated. This means that for other materials the methodology has to be adjusted although the same general approach can be applied.
Data source needs	This method is very data intensive as it requires detailed data on specific material flows. This means that regular updating will be time-consuming and thus resource-intensive.

Potential of integration into existing GHG inventory calculations	Since the methodology gives emissions at material/ sector level, there seems to be a potential to integrate into existing GHG inventory calculations. **CE action: Circular Economy Strategy in Heavy Industry** **Primary impact on inventory source categories** -*changes in energy & process emissions from manufacturing and transport of materials associated with manufacture of products where recycled materials replace raw materials* *Relevant sources* 1A2gviii Stationary combustion in manufacturing industries and construction (*e.g. due to changes in mining, manufacturing, construction*) 1A2a / 2C1 Iron and steel production 1A2b / 2C3 Non-ferrous metal production / Aluminium production 1A2f / 2A Mineral products (*e.g. production of cement, glass, ceramics*) 1A2c / 2B Chemical production (*e.g. production of plastics, key feedstock chemicals such as ethylene*) 2C Metal production (*e.g. magnesium, lead, zinc, other..)* 1A2gvii Mobile combustion in manufacturing industries and construction (*e.g. fuel use in mobile machinery associated with mining, construction*) **Secondary impact on inventory source categories** -*changes in waste management and transport related to the provision of ancillary services and materials* *Relevant sources* 5A1a Solid Waste disposal to land 5B Biological treatment of solid waste 5C1 Incineration of MSW 1A1a Power generation (from EfW plant) 1A3bii Road transport (LGVs) 1A3biii Road transport (HGVs and buses) 1A1, 1B Combustion and fugitive emissions associated with upstream energy sector provision of fuels and feedstocks
Assessment of the method	
Strengths	• Approaches circular economy from a material and value chain point of view, could potentially be used for other value chains using these materials. • Accounts for future changes in demand • Emphasises demand-side activities as well as production-side resource efficiency improvements.

	• Very comprehensive study, looking at EU as well as global GHG impacts and potentials. • Possibility to see the effects of individual actions • Clear separation of the effects from decarbonising energy supply and implementing circular actions
Weaknesses	• The method is very detailed and requires a vast range of different data sources which might make regular updating challenging. • The current methodology does not comprehensively assess the economic impacts of implementing the described circular economy actions (e.g. rebound effects) and knock-on effects on other sectors. • The method does not show the economic or political feasibility for most of the circular actions that are being proposed.
Conclusion	The study is definitely an important study on the topic. It illustrates the potential of a wide range of circular economy actions to contribute to GHG abatement with a relatively high level of detail. However, the lack of a detailed overview of all the assumptions and parameters used to arrive at the presented results makes replicability challenging. With respect to the results it is important to take into account that the study looks at potential actions and what is needed to achieve climate targets, not at what is likely to happen based on current trends or existing policies.

9.4 Case study 4 by TNO

Case study	Effects of the Circular Economy programme on GHG emissions
Basic information	
Author(s), Organisation	Elmer Rietveld, Hettie Boonman, Mohammed Chahim, Ton Bastein & Jinxue Hu, TNO
Title of the study	Effecten van het Rijksbrede Programma Circulaire Economie en de Transitieagenda's op de emissie van broeikasgassen (Effects of the nation-wide programme on Circular Economy (CE) and the transition agendas on greenhouse gas emissions)
Year	2018
Link to the document	https://www.tno.nl/media/8551/tno-circular-economy-for-ienm.pdf
Summary	This study has quantified the GHG emission mitigation impacts of implementing the national CE programme in the Netherlands, using a CGE model. The study estimates that together these policies can contribute to approximately one sixth (7.7 Mton) of the required annual GHG emission reduction in 2030 and 18% (13.3Mton) to the achievement of the emission reduction target for 2050. The uncertainty bandwidth of the outcomes for 2030 and 2050 are 1 and 2 Mtons, respectively. The study only modelled the impacts of CE measures for which effects/targets were actually quantified, opposed to merely described in text. Therefore, the results are expected to represent an underestimation of the potential impacts of CE policy. The model, being a macroeconomic CGE exercise, also calculated rebound effects, and the cost savings brought about by the circular economy actions are spent again on consumption with an equal spread over all sectors.

	Together, the existing energy transition policies and the circular economy policies are not yet enough to achieve the GHG emission reductions needed to meet the commitments made in the Paris Agreement. Additional interventions to fulfil the NDC for the Netherlands are required.
Circular Economy actions covered	All the quantified targets (around 27 in total) mentioned in the Dutch national programme on circular economy (Rijksprogramma Circulaire Economie) and transition agendas. Most targets relate to circular interventions in the biobased/food sector (e.g. nutrient recycling, dietary shifts towards less animal protein, biogas production) and plastics recycling. One or two targets are also set for the construction sector, the metal products manufacturing sector and waste sector respectively.
Geographical scope	The Netherlands
Link between CE and GHG emissions	The study has used quantified policy targets as modelling inputs. In other words, the Environmental Extensions (from Exiobase), notably GHG, can be linked to interventions for which quantified targets were set.
Contact for the study	Elmer Rietveld - elmer.rietveld@tno.nl

Key findings

The study estimates that together these policies can contribute to approximately one sixth (7.7 Mton CO_2-eq.) of the required annual GHG emission reduction in 2030 and 18% (13.3Mton CO_2-eq.) to the achievement of the emission reduction target for 2050. The uncertainty bandwidth of the outcomes for 2030 and 2050 are 1 and 2 Mtons, respectively. The study only modelled the impacts of CE measures for which effects/targets were quantified. Therefore, the results are expected to represent an underestimation of the potential impacts of CE policy.

The study modelled three scenarios, namely:
1. Impacts of national CE program (RPCE) only
2. Impacts of circular actions in transition agendas only
3. Combined scenario RPCE and transition agendas

The baseline scenario of the study proved to be highly significant. As efforts from the energy transition autonomously change the Environmental Extensions for GHG, the possible gains of circular strategies will become less over time. At the same time, it means that targets from a circular economy perspective can be regarded as truly additional, without overlap to other policy efforts.

The results of the scenarios were as follows:
Scenario 1: 2.4 Mton CO_2-eq emission red. in 2030 and 2.6 in 2050 (only in NL). 2.8 and 3.6 Mton CO_2-eq. emission reduction in 2030 and 2050 in the entire supply chain (i.e. effects in the worldwide system).
Scenario 2: 5.7 Mton CO_2-eq emission red. in 2030 and 11.6 in 2050 (only in NL). 6.1 and 12.3Mton CO_2-eq emission reduction in 2030 and 2050 in the entire supply chain.
Scenario 3: Combined scenario RPCE and transition agendas: 7.7 Mton CO_2-eq emission red. in 2030 and 13.3 in 2050 (only in NL). 7.8 and 14 Mton CO_2-eq emission reduction in 2030 and 2050 in the entire supply chain.

CE action 1	Results are only published at the aggregate level. Background data discerning scenarios and transition agendas is available on request.
CE action 2	
CE action 3	

Methodology description	
Short description of the methodology applied	The methodology that has been applied was to first identify circular actions with quantified targets. The changes in material flows are put into the model as inputs. The EXIOMOD model is an extended input-output model, meaning that it has the sectoral details of an input-output model, but it can be extended with a computable general equilibrium module to simulate market clearance. Emissions are calculations made by the model are made according to the UNFCCC standards, which means that the estimates give an underestimation compared to the actual emissions as reported in the Dutch national GHG accounts, as short-cycle CO_2 emissions are omitted from UNFCCC reporting[108]. Furthermore, the emission impacts are split up in emission effects in ETS sectors and emission effects in Effort Sharing sectors.
General assumptions (non-exhaustive – summary of most important ones)	• The study assumes that improvements in material efficiency and emission reductions will also take place in the reference scenario, which reduces the net impact of circular economy policy actions. The baseline scenario in this modelling study was based on 'WLO laag[109]' ("low") pathway that is generally used by the Dutch national government (an externally defined scenario). Emission reduction targets that need to be achieved were set more ambitious, in line with the 'WLO hoog' ("high") pathway. This approach of 'reverse cherry picking' reduces the risk of overestimating the additional effect of circular economy policies compared to other climate change mitigation policies. • The demand trends for raw materials are assumed to be homogeneous across sectors. • Changes to be achieved in target years are spread equally over the years as fixed percentage changes. • Changes in raw material consumption are not modelled as changes in material use coefficients, but rather as substitutions of materials among each other. • In addition to the aforementioned assumptions, there is a number of specific assumptions per scenario, these can be found in annexes A3.3-3.6 of the report.
Geographical scope of analysed GHG emissions	The model determines the domestic impacts, both in terms of economic variables as well as in terms of emissions. Next to this it calculated the impacts that occur in interlinked parts of the global supply chain. Which market is chosen as the 'domestic' market can be chosen, so the model can also be used to model any given quantified target on the EU level, instead of the Netherlands.
Detailed methodology per CE action (3 actions are selected as examples)	
CE action 1	**Increased recycling of nitrogen (60-70%) and phosphorus (95%) for fertiliser production (production phase/waste phase)**

[108] https://www.clo.nl/indicatoren/nl0170-de-co2-emissie-verklaard
[109] From the Netherlands Bureau of Economic Policy Analysis https://www.cpb.nl/en

Methodology used	Extended input-output model (EXIOMOD)
Scale of the method	**Geography:** EU **Sectors:** waste sector and agriculture **Lifecycle stages:** Waste stage and production stage
Assumptions used	Annual reduction in the use of virgin nitrogen and phosphorus fertilizers with 0.3 Mton
Data sources used	Quantified targets from the national circular economy projects. The data sources used to implement the target was EXIOBASE.
Degree of independence of activity	The degree of independence of this action from other interventions is quite high, but when multiple actions are modelled simultaneously, the impacts of individual actions cannot be determined independently. This is inherent to the method and not related to this specific circular economy action.
CE action 2	**Increased use of bioplastics.**
Methodology used	Extended input-output model (EXIOMOD)
Scale of the method	**Geography:** EU **Sectors**: chemical sector and plastics manufacturing sector **Lifecycle stages:** production phase
Assumptions used	Annual reduction of fossil-based plastics with 0.113 Mton.
Data sources used	Quantified target from the national circular economy projects.
Degree of independence of activity	See action 1.
CE action 3	**Recycling of asphalt**
Methodology used	Extended input-output model (EXIOMOD)
Scale of the method	**Geography:** EU **Sector:** construction **Lifecycle stages:** production phase/ waste phase
Assumptions used	Annual reduction in the use of new asphalt with 6.5 Mton
Data sources used	Quantified target from the national circular economy projects.
Degree of independence of activity	See action 1.
Upscaling and replicability potential	
Upscaling	The results of the study do not need to be scaled up as geographical scope of the model can be chosen, so the entire EU can be covered. The database used identifies all individual EU MS, as well as the other fifteen largest and/or relevant national economies in the World. Other parts of the world are represented in continental aggregated entities.
Replicability	Modelling of circular activities via this approach requires development of CE scenarios and inclusion of the particular material categories concerned in the model. All of these definitions need to be compatible with standard classifications used in official statistics (such as NACE and CPA).
Data source needs	Data is needed on the impact of the circular actions on material savings. As such data is often only available for actions on a limited scale, assumptions and/ or extrapolation of those material savings might be needed to arrive at

	modelling inputs that fit the geographical scope of the model. The challenge here is that such assumptions and extrapolations often introduce a larger error margin. This is a common drawback of hybrid LCA approaches that enable process innovations on a specific level to be upscaled to macroeconomic models.
Potential of integration into existing GHG inventory calculations	This method holds great potential for integration in GHG inventory calculations as the EXIOMOD model already generated the GHG emission outputs in a format that is compatible with UNFCCC standards. **CE action:** Dutch CE interventions in the biobased/food sector (e.g. nutrient recycling, dietary shifts towards less animal protein, biogas production); plastics recycling; construction sector; the metal products manufacturing sector and the waste sector. **Primary impact on inventory source categories** -*changes in agriculture, food & drink sector, waste management, energy & process emissions from manufacturing and construction* *Relevant sources* 3A Enteric fermentation and 3B Manure management (e.g. changes in livestock numbers to reflect dietary shifts) 3D Agricultural soils (e.g. from changes in agricultural land use, use of fertilisers and so on to reflect dietary shifts 1A2e / 2H2 Food and drink industry 5A1a Solid Waste disposal to land 5B Biological treatment of solid waste 5C1 Incineration of MSW 1A1a Power generation (from EfW plant) 1A2gviii Stationary combustion in manufacturing industries and construction (*e.g. due to changes in mining, manufacturing, construction*) 1A2a/2C1 Iron and steel production 1A2b/2C3 Non-ferrous metal production / Aluminium production 1A2f / 2A Mineral products (*e.g. production of cement, glass, ceramics*) 2B Chemical production (*e.g. production of plastics, key feedstock chemicals such as ethylene*) 2C Metal production (*e.g. magnesium, lead, zinc, other..)* 1A2gvii Mobile combustion in manufacturing industries and construction (*e.g. fuel use in mobile machinery associated with mining, construction*) **Secondary impact on inventory source categories** -*impacts on transport* *Relevant sources* 1A3bi Road transport (cars) 1A3bii Road transport (LGVs)

	1A3biii Road transport (HGVs and buses)
Assessment of the method	
Strengths	• Impacts in both the domestic market (e.g. the EU) and the other parts of the global value chain can be obtained • The model is able to simulate rebound effects • The model has a high number of product categories and sectors • Impacts can be shown per Member State. • The CGE module allows for the analysis of the impact of fluctuating prices on the GHG impacts • The approach taken allows for the modelling of actual policy targets
Weaknesses	• The CGE models such as EXIOMOD give outputs per sector and for the economy as a whole which makes it fairly impossible to track down the effects to one particular action, unless only one action is modelled (but this is very resource intensive) • Material savings need to be known, this might mean that a combination with LCAs can be an attractive strategy to explore, following commonly accepted and implemented hybrid LCA techniques. • As with all economic models, the results depend on the assumptions made. Hence, the assumptions should be credible and acceptable. • The exiobase database contains many disputable parameter values, e.g. for specific emission factors, and therefore urgently requires updating
Conclusion	This method is very well suited to calculate economy-wide effects of circular economy activities and for a macro-economic model its product structure is quite detailed. However, the approach used in this TNO study requires that the impact of a circular economy target (or intervention) on material requirements in macroeconomic product groups is accurately modelled. Furthermore, if multiple actions are modelled together, reporting modelling results could become a sizeable task in case one wants to disentangle the impacts of the individual actions. Impacts can be seen per sector/product level akin to either NACE/CPA 2 or NACE/CPA 3, and per Member State.

9.5 Case study 5 by Trinomics et al.

Case study	GHG impacts of collaborative economy
Basic information	
Author(s), Organisation	Katarina Svatikova, Jurgen Vermeulen, Tycho Smit, Koen Rademaekers, Laura Baroni (Trinomics), Hector Pollitt, Unnada Chewpreecha (Cambridge Econometrics), Katrien Boonen, An Vercalsteren, Jeroen Gillabel (VITO), Marius Dragulin, Pierre Hausemer (VVA).
Title of the study	The environmental potential of the collaborative economy.
Year	2017
Link to the document	https://publications.europa.eu/en/publication-detail/-/publication/8e18cbf3-2283-11e8-ac73-01aa75ed71a1/language-en

Summary	The aim of this study was to investigate the environmental impacts (incl. the GHG emissions) of the collaborative economy in Europe. The study analysed the environmental impacts at two scale levels. The current situation analysis was done at the transaction level where collaborative transactions were compared to transactions from 'traditional economy' alternatives using LCA approach. These results were then upscaled to sector level. The impacts of the collaborative economy were also analysed at a macro-economic level for 2030, using a macro-economic model (E3ME model). The study focused on collaborative economy activities in three sectors, namely transport, accommodation and goods sharing. The main conclusions from the study were that the net environmental impact of collaborative economy activities strongly depends on the alternative to which the activity is compared. On a transaction level, most collaborative economy activities had an environmental impact that was lower or similar to that of the 'traditional economy alternative'. At a macro-level however, the net environmental impact of the collaborative economy showed very limited, due to rebound effects.
Circular Economy actions covered	***In the transport sector:*** ride sharing, car sharing and ride-hailing ***In the accommodation:*** Room renting, home renting, home-swapping ***Durable goods***: goods-renting – power drill, ladder
Geographical scope	European Union
Link between CE and GHG emissions	The study does not make an explicit link to circular economy. GHG impacts of collaborative actions were assessed using a bottom-up approach by analysing the specific characteristics of collaborative activities. For the macro-economic analysis these actions were then upscaled from the transaction level to the entire economy, based on data found in literature and assumptions used in the scenario build up. GHG impacts (or climate change impacts) were just one of the environmental impacts analysed.
Contact for the study	Katarina Svatikova – katarina.svatikova@trinomics.eu
Key findings	
The LCA analysis was performed on a functional unit level for each of the sectors, and through assumptions upscaled to sector level. The published report shows only relative results of LCA, i.e. a relative comparison (in %) of collaborative economy and the traditional alternative. In the accommodation sector, the results show that the current environmental impact of staying one night at a collaborative economy accommodation is comparable to staying at a budget hotel. The impacts are lower compared to a mid-scale or luxury hotel. The current environmental impact of travelling with collaborative economy transport is generally smaller than or equal to travelling with the traditional transport mix. Ride-sharing generally has the lowest environmental impact. When compared with the impact of a kilometre travelled in your personal car (the most common alternative), the collaborative business models typically have a significantly lower environmental impact. In the consumer durables sector, the environmental impact was linked to the transport impacts of the good. So, sharing goods within a short radius had a significantly lower environmental impact than buying a good where people might need to drive longer distances. However, the number of trips to share the good were also an important factor.	

On the economy-wide level all the collaborative economy activities combined (all three sectors) yielded a total GHG emissions reduction level of around 2.2 Mton CO_2-eq. in a moderate scenario without rebound effects in 2030 compared to the baseline and around 1.5 Mton CO_2-eq. reduction compared to the baseline with rebound effects. In an ambitious scenario, the total GHG emissions reduction increased to 7 Mton CO_2-eq. (including rebound) in 2030 compared to the baseline. The moderate and ambitious scenarios were modelled based on the extrapolation of current activity levels and an assumed increased uptake of collaborative economy activities (5% higher uptake in the moderate scenario, 10% in the ambitious scenario, compared to the baseline). Hence, this does not constitute an overly ambitious scenario. As such, the GHG impacts are relatively low.	
CE action 1 – Ride sharing (e.g. Blablacar), ride-hailing (Uber), Car sharing (Zipcar), all life cycle phases	***LCA results:*** Ride-sharing is the only type of collaborative economy transport for which a reduction of the carbon footprint (impact category climate change) is achieved compared to the traditional transport mix (the GHG impact of ride-sharing is around 60% compared to using own car). When choosing ride-sharing instead of traditional car driving, 1,75 km can be driven rather than 1 km, with the same effect on climate change. Car-sharing and ride-hailing do not perform better than the traditional transport mix for climate change because the traditional transport mix includes transport types with a low to very low carbon footprint, such as train and tram, bicycle and walking. But they do perform better than personal car use. With regard to car-sharing, as one example mentioned in the report, 64% of the climate change impact (GHG emissions) is due to emissions generated while driving, hence the use phase, 15% due to car production, and 14% due to fuel use. ***Macro-economic impact of all collaborative economy activities in the transport sector:*** In the scenario assuming moderate development of the collaborative economy the GHG impact amounted to just over 1 Mton CO2-eq. in 2030 compared to the baseline, and in the scenario assuming ambitious developments the impacts amounted to around 7.5 Mton CO2-eq.
	Compared to the emission impacts of other collaborative economy sectors, the impact of activities in the transport sector are much larger than in the other two sectors analysed. However, compared to overall emission levels in 2030, the emission reduction effects are very limited.
CE action 2 – home renting, all life cycle phases	***LCA results:*** On a transaction level, a collaborative accommodation transaction (e.g. staying in an Airbnb apartment) has a GHG impact that is approx. 40-60% of that of a midscale-priced hotel (assuming 30% and 100% occupancy rates, respectively) and around 15-20% of a luxury hotel. The impact is very similar to that of a low-budget hotel. Electricity and heating are the two main contributors to the climate change impact of collaborative accommodation (with 30% occupation rate), 35% and 44% respectively. Building (construction and end of life) contribute with around 15% to the climate change impact.

	Macro-economic impact of all collaborative economy activities in the accommodation sector: In the scenario assuming moderate development of the collaborative economy the GHG impact amounted to a GHG emissions decrease of 18 Kton CO2 eq. in 2030 compared to the baseline and in the scenario assuming ambitious developments the impacts amounted to an increase in emissions of 22 ktons. The increase in the ambitious scenario is due to the rebound effects – increased use of oil demand in transport (i.e. more travelling) which outweigh the environmental benefits of sharing.
	The net impacts of collaborative accommodation activities are relatively low, primarily because the reduction in 'traditional tourist accommodation' (hotels, B&B's etc.) is compensated by an increase in household income which results in increased spending across economic sectors, which also generates GHG emissions.
CE action 3 – consumer durables – sharing power drill and a ladder, all life cycle phases	***LCA results:*** On a transaction level, the GHG benefit compared to a 'traditional economy transaction', i.e. buying lies between 90% and 40% lower depending on how the shared good is transported (car or bike/foot, respectively) and on the distance that has to be travelled to obtain the shared product. Two products were analysed, namely a power drill and a ladder. For a power drill transported by car, 84% of the climate change impact comes from the transport, 13% from production. For a power drill transported by bike/on foot, 87% of the climate change impact comes from production, 7% from energy use. For ladder, similar results apply, 72% of climate change impacts are due to transport (by car) and 28% due to production. ***Macro-economic impact of all collaborative economy activities in the consumer durables sector:*** In the scenario assuming moderate development of the collaborative economy the GHG impact amounted to 40 Ktons of CO2-eq. in 2030 compared to the baseline, and in the scenario assuming ambitious developments the impacts amounted to 120 Kton CO2-eq.
	GHG emission reductions from good sharing were calculated to be very low. This is primarily caused by the fact that the number of people engaging in good sharing is relatively low.
Methodology description	
Short description of the methodology applied	The environmental impacts, including the GHG impacts of collaborative economy activities were investigated in this study using two different methods, namely attributional Life-Cycle Assessment and Input-output modelling (a macroeconomic model called E3ME). LCA was used to analyse the impacts of the collaborative economy activities at transaction (and sector) level, by comparing them to alternative activities in the 'traditional economy' for the situation today. For example, comparing carsharing with an individual car ride, taking public transport, and biking.

	In order to model future potential impacts of the collaborative economy at the macro-economic level, the E3ME macroeconomic model was used. In order to model the impact of very specific collaborative economy actions at such an aggregate scale, a set of assumptions was made for each type of collaborative activities by adjusting for example the consumer expenditures on certain products or services. For the modelling exercise two scenarios were made, one assuming moderate growth of collaborative economy activities (5% additional uptake compared to the baseline) and one with ambitious growth (10% more uptake compared to the baseline). Both scenarios were based on extrapolation of current activity levels.
General assumptions used	For the rebound effect: • No differences in spending between income groups were assumed • It was assumed that all cost savings due to collaborative activities are spent, equally spread across household expenditure categories.
Geographical scope of analysed GHG emissions	LCA: not applicable, analysis on a functional level, extrapolated to sector, but along the life cycle phases of a product. The E3ME model can assess impacts on Member State and EU level. Not sure how the model calculates emissions, probably takes into account global emissions.
Detailed methodology per CE action	
CE action 1	Carsharing, ride-sharing, ride-hailing
Methodology used	LCA and Input-output model
Scale of the method	Geography: LCA: transaction level (functional unit per person-km) I/O modelling: Macro-economic impacts for entire EU, can be disaggregated per MS (not published) Sectors: transport Lifecycle phases: all
Assumptions used	LCA: see annex 10 to the published report for all the assumptions. The environmental impact of car sharing (vehicle-renting), ride-sharing and rides on demand is analysed by calculating the environmental impact of a kilometre travelled with those platforms compared with the average environmental footprint of the current mix of transport modes in the EU (the share that people travel by car, motor bike, bicycle, bus, train, airplane, ship and walking) and with a kilometre travelled in a personal car. • Transport mix assumed based on EU transport figures • Average occupancy rate 1.6 person for traditional transport and ride- and car-sharing, 2.8 for ride sharing • Service life of the car = 150 000km same for ride sharing, more for ride-hailing (300 000km) such as for taxis and 225 000km for car sharing.

	• Use of road infrastructure per km driven – 7x lower for ride sharing, 17x lower for car sharing. Input-output analysis: see annex to the published report. • Carsharing reduces the overall distance travelled by car by 30%; • A reduction in household expenditures is assumed; • A slight reduction in demand for cars is assumed.
Data sources used	• A mix of data sources Scientific literature, Ecoinvent, data from platforms, Eurostat data • Own assumptions
Degree of independence of activity	It is difficult to ascribe one-to-one the changes in mobility behaviour between carsharing users and private car owners one-to-one to carsharing. As the current group of carsharing users is relatively small the differences in mobility patterns can maybe be partly explained by differences in personal characteristics between them and car owners. As an example, the lower amount of total distance travelled by car that is often observed for carsharing users might not be applicable if car sharing is mainstreamed to a much larger portion of the society. Also, the effects from carsharing cannot always be distinguished from other ongoing trends in the transport sector, e.g. increased accessibility of public transport.
CE action 2	Apartment renting (Airbnb)
Methodology used	LCA and Input-output model
Scale of the method	Geography: LCA: transaction level (functional unit per person night) I/O modelling: Macro-economic impacts for entire EU, can be disaggregated per MS (not published) Sectors: hotels and holiday stays (accommodation) Lifecycle phases: all
Assumptions used	LCA: The environmental impact of collaborative accommodation is assessed at the level of a person staying for one night in a peer-to-peer rented property (a private residence) compared to a one night at a hotel (traditional economy model). Assumptions are made for the differences as to: • Facilities offered • Materials used in construction • Energy use – electricity and fuels • Water use • The use of toiletries • The waste created - waste water, packaging and excess products for guests • Infrastructure maintenance - production, maintenance and end of life of hotels and houses • Occupancy rate – 44% for hotels (Eurostat), assumed 30% and 100% for collaborative accommodation.

	Annex 10 in the published report lists all the assumptions. Model: see annex to the published report. • Increased income for households • A reduction of household expenditures on accommodation • Increased income for ICT services (because of the increased income of online platforms)
Data sources used	• A mix of data sources • Scientific literature, Ecoinvent, data from platforms, Eurostat data • Own assumptions • Tourist statistics
Degree of independence of activity	Several assumptions had to be made in the LCA and modelling as data is scares. There is for example no separate category for online platforms, therefore the income for the entire ICT services sector was increased, but this will also happen through increased activity in other online (collaborative economy) platforms.
CE action 3	(Goods renting)
Methodology used	LCA and Input-output model
Scale of the method	Geography: LCA: transaction level (functional unit – a product) I/O modelling: Macro-economic impacts for entire EU, can be disaggregated per MS (not published) Sectors: electronic goods and household goods Lifecycle phases: all
Assumptions used	LCA: In a collaborative economy, consumers can choose to borrow a power drill or a ladder, compared to buying one. Assumptions were made on: • % consumers who buy, who rent, % consumers who share using a car, or by bike/ on foot • Power drill life time and use • Ladder life time and use • Assumption on the number of km driven to use a sharing platform (15km return to buy, 7.5km to borrow by car, 5km on foot/ bike) Annex 10 in the published report lists all the assumptions. Model: see annex to the published report. • Increased income for households; • A reduction of household expenditures on several good categories; I • Increased income for ICT services (because of the increased income of online platforms)
Data sources used	A mix of data sources: • Data from Peerby (Europe's largest good sharing platform) • Scientific literature • Collaborative economy think tanks • Eurostat

Degree of independence of activity	In general, there is lack of data, hence large part of the analysis was based on evidence-based assumptions. The same limitations hold for good sharing as those described for collaborative accommodation. Also, there are several other circular economy actions that could reduce expenditures on new products, including repairs and second-hand product sales. Differentiation between such activities is quite difficult with the aggregation level of an I/O model.
Upscaling and replicability potential	
Upscaling	LCA: difficult to upscale as there is a general lack of data on these activities. Upscaling made sense in this case only to sector level. If better data, upscaling could be possible. But a general drawback with LCAs is that the analysis only compares two 'functional units', so LCAs can provide better material or emission factors that can be used in other methods, which are more fit to upscale, such as input output models. Model: upscaling possible. In order to come up with modelling inputs at the EU level, figures from literature on local, regional or national activity levels were upscaled. This is done in different ways, depending on the nature of the figures that are available for the lower scale level and the kind of activity concerned.
Replicability	This method is quite replicable, as action-specific assumptions can be made to develop model inputs that are specific for that particular circular action. However, some actions can be more easily translated into direct modelling inputs, while for other actions this is more difficult due to the low granularity level of input-output models. The E3ME model does for example only contain a single category for food products, which makes it relatively difficult to model things like a shift from animal products to more vegetable products. Whether an action can be modelled in an input-output model needs to be determined on a case by case basis.
Data source needs	Data on the monetary effects of circular actions or data to couple changes in material flows to changes in economic flows. Alternatively, one could change the material use and/or emission multipliers per EUR spent in a specific sector, but that was not done in this study.
Potential of integration into existing GHG inventory calculations	The methodologies applied, LCA and macroeconomic modelling should be possible to integrate with existing inventory calculations. However, as mentioned already, LCAs only compare two situations with each other. They will need to be use with other methods to derive aggregate GHG emissions on a larger scale. Based on the CE studies and their analysis of expected policy impacts, it is possible to indicate the GHG inventory source categories (using the IPCC source category nomenclature as used by all national GHG inventories) where the CE policies are expected to have an impact. For most CE policies, there are clear "primary" source categories where impacts can be expected, and then a series of "secondary" source categories where impacts may also be expected. Examples are:

	CE action: Car-sharing and Ride-sharing **Primary impact on inventory source categories** -*changes in vkms, fuel use by different vehicle types* *Relevant sources* 1A3bi Road transport (cars) 1A3biii Road transport (HGVs and buses) **Secondary impact on inventory source categories** -*changes in energy & process emissions from manufacturing and transport of materials associated with vehicle manufacture* *Relevant sources* 1A2gviii Stationary combustion in manufacturing industries and construction 1A2a / 2C1 Iron and steel production 1A2b / 2C3 Non-ferrous metal production / Aluminium production 1A2c / 2B Chemical production 1A1, 1B Combustion and fugitive emissions associated with upstream energy sector provision of fuels and feedstocks **CE action: Apartment renting** **Primary impact on inventory source categories** -*changes in energy consumption, materials used in construction of buildings* *Relevant sources* 1A4a Commercial / Institutional Combustion 1A4b Residential stationary Combustion 1A2gviii Stationary combustion in manufacturing industries and construction **Secondary impact on inventory source categories** -*changes in waste management and provision of ancillary services and materials* *Relevant sources* 5A1a Solid Waste disposal to land 2F1 Refrigeration and air conditioning equipment 1A3bii Road transport (LGVs) 1A3biii Road transport (HGVs and buses) 1A1, 1B Combustion and fugitive emissions associated with upstream energy sector provision of fuels and feedstocks **CE action: Goods renting**

	Primary impact on inventory source categories - *changes in transport fuel use, changes in energy & process emissions from manufacturing and transport of materials associated with goods manufacture* *Relevant sources* 1A3bi Road transport (cars) 1A3bii Road transport (LGVs) 1A3biii Road transport (HGVs and buses) 1A2gviii Stationary combustion in manufacturing industries and construction **Secondary impact on inventory source categories** -*changes in energy & process emissions from manufacturing of materials associated with goods manufactured* *Relevant sources* 1A2a / 2C1 Iron and steel production 1A2b / 2C3 Non-ferrous metal production / Aluminium production 1A2c / 2B Chemical production 1A1, 1B Combustion and fugitive emissions associated with upstream energy sector provision of fuels and feedstocks
Assessment of the method	
Strengths	• Input-output models have the advantage that they also show the indirect and induced effects of the circular economy activities in other sectors; • Input-output models allow for the quantifying of impacts on aggregate levels and per Member State; • Potentially, it is possible to adjust emission coefficients using results from LCAs. • The scenarios are built on a baseline scenario containing ongoing trends, so that the effects of the modelled activities can be separated from general developments in the economy.
Weaknesses	• Potential lack of data to do LCAs of innovative circular economy activities • LCAs are analyses on a micro level, difficult to aggregate results, to upscale • If multiple activities are put into the model simultaneously it is not possible to see the effects of individual actions. • The translation of low-scale activities into sector-wide inputs introduces are likely to introduce large error margins due to lack of data and the need for assumptions. • Although the rebound effect has a large influence on the modelling outcomes, it is difficult to make accurate assumptions on how additional income is spent.

Conclusion	The study is the first study in the EU analysing the environmental impacts of collaborative activities. The study combines LCA method with a macroeconomic modelling, however, this combination proved difficult due to the different outputs and inputs of the methods. LCAs are a good means to understand the GHG impacts on a micro level and can be used to better calibrate the model and alter some of its coefficients to calculate macro level impacts. Macroeconomic models are a good means to calculate GHG impacts on aggregate levels, use regularly updated databases, but the results are driven largely by its assumptions.

10 Annex C - Participants in the Expert Workshop

Participants:

Stephanie Schilling, Climate change mitigation, energy and transport (EEA)
John van Aardenne, Climate change, energy and transport (EEA)
Almut Reichel, Sustainable Resource Use and Industry (EEA)
François Dejean, Head of group 'Climate change mitigation, energy and transport' (EEA)
Peter Mitchell (Valpak/ WRAP)
Ann van der Linden (VITO - partner in the ETC/WMGE)
Katrien Boonen (VITO)
Elmer Rietveld (TNO)
Stijn van Hummelen (Cambridge Econometrics)
Beatriz Vidal-Legaz (JRC)
Edgar Hertwich (Yale University/International Resource Panel)
Simon Gandy (Ricardo) – Lead methods development
Katarina Svatikova (Trinomics) – Project manager
Tycho Smit (Trinomics) – support
Per Klevnäs (Material Economics) – audio
Adriana Gomez (IIASA) – audio
Fabien Porcher (European Commission, DG Grow) - audio

11 Annex D - UNFCCC Sectoral Classification

The table below reproduces the top two levels of the UNFCCC sectoral classification for GHG reporting. The full table (available at http://rt.unfccc.int/locator) contains nine levels and over 10,000 rows.

1. Energy	1.AA Fuel Combustion - Sectoral approach
	1.AB Fuel Combustion - Reference Approach
	1.AC Comparison of CO2 Emissions from Fuel Combustion
	1.AD Feedstocks, reductants and other non-energy use of fuels
	1.B Fugitive Emissions from Fuels
	1.C CO2 Transport and Storage
	1.D Memo Items
2. Industrial Processes and Product Use	2.A Mineral Industry
	2.B Chemical Industry
	2.C Metal Industry
	2.D Non-energy Products from Fuels and Solvent Use
	2.E Electronics Industry
	2.F Product Uses as Substitutes for ODS
	2.G Other Product Manufacture and Use
	2.H Other
3. Agriculture	3.1 Livestock
	3.C Rice Cultivation
	3.D Agricultural Soils
	3.E Prescribed Burning of Savannas
	3.F Field Burning of Agricultural Residues
	3.G Liming
	3.H Urea Application
	3.I Other Carbon-containing Fertilizers
	3.J Other
4. Land Use, Land-Use Change and Forestry (LULUCF)	4(IV) Indirect N2O Emissions from Managed Soils
	4.1 Land Transition Matrix
	4.A Forest Land
	4.B Cropland
	4.C Grassland
	4.D Wetlands
	4.E Settlements
	4.F Other Land
	4.G Harvested Wood Products
	4.H Other
5. Waste	5.A Solid Waste Disposal
	5.B Biological Treatment of Solid Waste
	5.C Incineration and Open Burning of Waste
	5.D Wastewater Treatment and Discharge
	5.E Other
	5.F Memo Items
6. Other	not assignable otherwise
	Other non-specified
	Smoking
7. Kyoto Protocol LULUCF	4(KP)
	NIR-1
	NIR-2

	NIR-2.1
	NIR-3

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