CIRCULAR IMPACTS

Insights from the CIRCULAR IMPACTS case studies

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Abstract

This report summarizes the results of the case studies in the CIRCULAR IMPACTS project and derives some main lessons from these case studies. The case studies are on concrete recycling, phosphorus recycling, car sharing, and recycling of batteries from electric vehicles. The case studies and the methodology for the case studies are discussed more extensively in the deliverables 4.1 through 4.5 of the CIRCULAR IMPACTS project.

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Executive Summary

This report summarizes the results of the case studies from the CIRCULAR IMPACTS project and derives several main lessons therefrom. The case studies address the topics of concrete recycling, phosphorus recycling, car sharing, and recycling of batteries from electric vehicles (EV). The case studies and a report on the case-study methodology are available as deliverables 4.1 through 4.5 of the CIRCULAR IMPACTS project.

The case studies were conducted according to the stepwise approach developed in Deliverable 4.1 of the CIRCULAR IMPACTS project. This methodology focuses on comparing circular business opportunities with baseline developments, consequences for changes in the key sector and other parts of the economy, systematically investigating the impacts on the environment and society at several levels of analysis, broadening the perspective by exploring alternatives for the analysed business opportunity, and an analysis of policy options to realize the circular business opportunities.

Concrete recycling in France was chosen as a case-study topic because construction and demolition waste (CDW) constitutes one of the heaviest and most voluminous waste flows in the EU, with France producing a large amount of CDW (including concrete) that is mainly used for backfilling operations and recycled as aggregates for road construction. The case study shows the limitations of using recycled concrete aggregates (RCA) in ready-mix concrete: fresh cement will always be required, even if the former is incorporated into the mix. The chemical process of cement production cannot be reversed, even though it is responsible for most of the greenhouse-gas emissions associated with concrete production. An LCA study shows that RCA has minor positive effects on health and resource use compared with quarried aggregates. Furthermore, producing RCA to replace quarried aggregates in ready-mix concrete can only be beneficial in a regional or local context from an economic and environmental perspective, because these benefits of recycling are closely related to the transport distances of the materials.

Uncertainties about quality issues remain, and only 15% of aggregates in structural concrete are allowed to be made of recycled materials according to the European standard. Additional research could increase the understanding of how to maximize the potential of concrete recycling.

Phosphorus recycling from manure was chosen as a case-study topic because phosphate rock is on the EU list of critical raw materials and over-application of phosphorus on land creates environmental problems. Current legislation on manure in combination with the regional concentration of the livestock sector generates local excess supply of manure, with negative manure prices as a result. The BioEcoSIM process was selected as a point of focus since it splits manure into useful components that can be easily transported over long distances, saving on transport costs as well as reducing the negative environmental effects of manure storage and transport. This provides benefits to the intensive livestock sector, partially at the expense of local arable farmers for it reduces the negative manure price.

The BioEcoSIM process has no or marginal effects on phosphate rock demand since in the baseline, phosphorus is already recycled and the phosphorus storage in the soil is mainly determined by environmental, manure and fertilizer regulation. The business case is only profitable in case of a negative manure price, implying that if the intensive livestock sector would be reduced in regions with excess manure supply the BioEcoSIM process would become irrelevant. Such a reduction of intensive livestock in regions with excess manure supply may be achieved in the future due to more advanced circular economy policies or because of requirements to reduce greenhouse gas emissions in the livestock sector in the context of the Paris agreement on climate. An important barrier for phosphorus recycling from manure or other sources is the acceptance of recycled phosphorus fertilizers as substitute for mineral phosphorus fertilizers. Therefore, as with secondary aggregates for concrete, also for phosphorus fertilizers standardisation and certification are crucial.

Recycling of electric vehicles (EV) batteries was chosen as a case-study topic because it is expected that in the short-term, the market share of electric vehicles will increase significantly, generating an opportunity for recycling the critical raw materials contained in the batteries reaching their end of life. Recycling will take place in the future, as the expected average lifetime of EV batteries is 8 years, and an additional 10 years in a second life for stationary applications of the batteries is possible. Nevertheless, current decisions on battery use in electric vehicles will affect the future recycling of EV batteries.

In the current Battery Directive (2006/66/EC) 50% of the weight of the battery in the category “other batteries”, which includes EV-batteries, has to be recycled. Since the main benefit of recycling is recovering high value, high supply-risk materials or materials whose environmental production costs are high, policy targets should be set on the most important materials with regard to their security of supply and environmental footprint. Where possible, these targets must be neutral with respect to technology, so the industry can find the best technologies to reach them.

EV-battery recycling is a long-term process and therefore does not require a specific policy from a macroeconomic point of view. The case study concluded that increasing the collection and recycling efficiency rates of EV batteries in the EU could mitigate dependence on imported materials and help to retain the value of recovered materials in the EU economy. Furthermore EV battery recycling has environmental benefits and jobs are created in the lithium-ion recycling sector for the collection, dismantling and recycling of EV batteries which, however, implies a shift in employment, but not an increase in aggregate employment.

A serious consideration to take into account is to what extent the recycling industry will develop in the EU. It may be that some batteries will be exported outside the EU before their end of life, or that batteries at the end of their life can be more efficiently recycled outside the EU.

Car sharing was selected as an interesting example of "product as a service", by becoming an increasingly viable alternative to the private ownership of cars. The transportation sector is responsible for a large portion of energy consumption and greenhouse gas emissions. The focus is on Germany, since it is one of the world's major automobile-producing countries and simultaneously, it is amongst the world leaders in adoption of car sharing.

The car-sharing case shows how difficult it is to predict the consequences of some circular opportunities. For this reason a Circular "Green" 2030 scenario has been defined where car sharing is used to replace car ownership implying a reduction in the car fleet and also a reduction in passenger kilometres because car sharing makes the variable cost per km travelled higher. However, it may also be that car sharing is additional to car ownership and partly replaces the use of public transport. This is especially the case if shared cars would become self-driving in which case more people can have transport (you don't need a driving licence) and the shared cars are used for easy trips within the city. The net effect of this Circular "Grey" 2030 scenario is that people drive even 2% more than in the Business As Usual scenario (BAU) and the car fleet is 1% larger. In summary, the greenhouse gas emissions in Circular "Green" 2030 scenario are 10% smaller and in the Circular "Grey" 2030 scenario 1% higher than in the BAU.

In the car-sharing scenario, it is argued that a specific circular opportunity like car sharing should be interpreted in the context of a broader system of multi-modal transport. Therefore, policies should be focused on an integral approach of this multi-modal system next to pricing of externalities. Another issue that has been made explicit in the car sharing study is that many circular opportunities are not as new as sometimes suggested. Public transport is for example an old and very effective method of shared transport.

Based on our experiences with the case-study analyses, we draw some conclusions with respect to the circular economy and the case-study methodology. In none of the case studies did we find clear GDP or employment benefits of the circular economy. This shows how difficult it is to draw clear conclusions on economic benefits. However, in some transitions, like the transition towards wind energy cost benefits compared with fossil energy have been generated that are caused by rapid technological change. The change in location and skill requirements of the energy transition may require structural labour market policies (Weterings et al. 2018), which is highly relevant from the perspective of the European Semester. The European Semester serves as the policy background for the CIRCULAR IMPACTS project and therefore also for this report.

Although it is very uncertain to what extent the circular transition will generate benefits for GDP or employment, benefits from a broader welfare perspective are much more plausible. The purpose of the circular economy is mainly environmental and resource-use driven, and when these benefits are included in the welfare concept, benefits of the circular transitions can be calculated as is, for example, done in the case study on phosphorus recycling. However, the case studies also showed that what is described as circular opportunities is not always beneficial from an environmental perspective. The Circular "Grey" 2030 Scenario of the car-sharing case shows that it may happen that sharing has negative consequences for the environment. This doesn't show that targeting for a more circular economy is not relevant, but that careful analysis of the circular opportunities in a broad perspective is needed.

Most case studies showed the importance of analysing material flows in combination with supply and demand. Material flows can help to identify what part of material demand can be satisfied by secondary materials and what the most important losses are in the material cycle, thereby serving as inspiration to search for the best circular opportunities.

Additionally, most case studies showed the importance of quality guarantees through certification and legislation, and the need for regulation to ensure the quality of secondary materials. However, the quality of secondary materials is not automatically comparable with primary materials, as was shown for the use of waste-derived aggregates from concrete.

Circular opportunities may be interdependent and depend on technological developments. For example, IT and GPS made car sharing much easier, while autonomous cars may further increase the benefits of car sharing. The more intensive use of cars due to car sharing may increase the uptake of electric cars, as they have higher fixed and lower variable costs than their fossil-fuel counterparts. However, the circular "Grey" 2030 scenario shows also that car sharing is not automatically beneficial for the environment.

All case studies demonstrated how important it is to pose the fundamental question: what alternatives are relevant? If problems are solved through new technologies that become obsolete when the economy becomes more circular, investments in these new technologies, as well as the capital and human-capital investments, may become stranded assets. Therefore, taking a broad perspective for each analysis is important.

With respect to methodology, the stepwise approach helps to ask the right questions and as mentioned before, in particular the question concerning the available alternatives is a useful thought exercise. Additionally, tracing causal links in the scenario analysis of the case studies is important, and in order to make this possible it is important to keep case studies as simple as possible and simulate all different components of a scenario separately. Furthermore, it may be useful to analyse more than one possible scenario in order to grasp the uncertainties in future dynamics of the economy or the dynamics of the case that is investigated.

1 :: Introduction

This report summarizes the results of the case studies from the CIRCULAR IMPACTS project and derives several main lessons therefrom. The case studies address the topics of concrete recycling, phosphorus recycling, car sharing, and recycling of batteries from electric vehicles. The case studies and a report on the case-study methodology are available as deliverables 4.1 through 4.5 of the CIRCULAR IMPACTS project.

The purpose of the case studies is to get an idea of the costs and revenues of circular business opportunities. The analysis goes beyond direct impacts at sectoral level or on the production chain, and also includes potential influences on society as a whole. The economic and societal effects of the current situation are used to create and investigate a business as usual scenario and a circular scenario. Furthermore, barriers and enabling factors for the implementation and upscaling of the circular business models are identified. Finally, it is analysed how policies may influence the latter's implementation. All case studies are based on a desktop literature review, expert interviews, and a workshop with experts to check and refine the outcomes.

1.1 The selection of case studies

The case studies are on concrete recycling, phosphorus recycling, car sharing and recycling of EV batteries.

Phosphorus recycling has been chosen because phosphate rock is on the EU list of critical raw materials. The element phosphorus (P) is essential for life and, therefore, for the agricultural sector. It is irreplaceable, but recyclable. In the Netherlands, phosphorus is mainly recycled from manure. Phosphorus in manure has two sides: on the one hand phosphorus is an important fertilizer for the agriculture sector, on the other hand over-application of manure causes eutrophication, which is a severe treat to the environment. For decades, oversupply of manure has been an issue in the Netherlands.

Concrete recycling was chosen because the European Commission identifies construction and demolition waste (CDW) as one of the "heaviest and most voluminous waste streams generated", responsible for 25% - 30% of all waste generated in the EU.[1] The focus is on France, since it is one of the largest producers of CDW in Europe, which is mainly used for backfilling operations and recycled as aggregates for road construction (Bougrain, Moisson, & Belaïd, 2017).

[1] http://ec.europa.eu/environment/waste/construction_demolition.htm

Car sharing was selected as an interesting example of “product as a service”, by becoming an increasingly viable alternative to the private ownership of cars. The transportation sector is responsible for a large portion of energy consumption and greenhouse gas emissions. The focus is on Germany, since it is one of the world’s major automobile-producing countries and simultaneously, it is amongst the world leaders in adoption of car sharing.

The case of EV-battery recycling was selected because demand for electric batteries is expected to increase significantly, due to an increased uptake of electric vehicles. Another motivation is the current policy agenda of the European Commission and national governments. The European Battery Alliance has been initiated by Maroš Šefčovič, with the goal to establish a full battery value chain in Europe, with large-scale battery cell production facilities and the circular economy at its core.

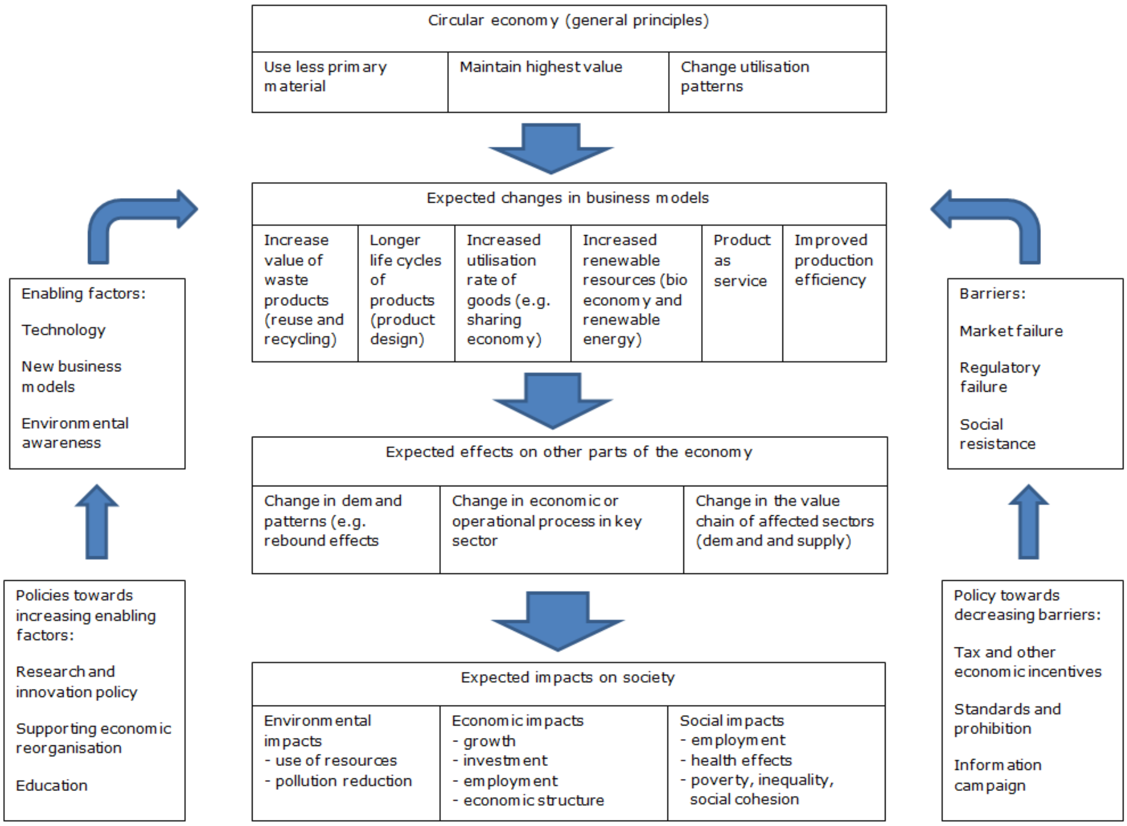
1.2 Methodology for the case studies

Deliverable 4.1 from the CIRCULAR IMPACTS project describes a methodology that makes the case studies comparable with a focus on the overall impact of the circular economy.

The methodology is developed around a framework (which in turn is based on a scheme from Deliverable 2.1) as depicted by

Figure 1. This framework shows the line of reasoning from the general principles behind the concept of a circular economy towards the expected impact of a circular transition on society.

Figure 1: Framework to describe the circular economy transition



Source: Deliverable 4.1 of the CIRCULAR IMPACTS project

In the case studies, we start with describing the current (linear) business model, which is the baseline, to subsequently do the same for the new (circular) business case. To describe why the new business case fits within the concept of a circular economy, the general principles of a circular economy can be used (see first row of Figure 1) together with the business models for a circular economy (see second row). The new business model is feasible thanks to enabling factors, e.g. technological improvements, but also faces several barriers, such as regulations which may have been useful in a linear economy but are counterproductive in a circular economy (see blocks on the right and left). These enabling factors and barriers are often the point of departure for policy formulation. We describe direct and indirect effects of the new business case on the sector and on the society as a whole, with an emphasis on the environmental, economic and social impacts.

The methodology consists of the following steps:

- **Step 1: Defining the baseline:** what is the current business situation?
- **Step 2: Defining the new business case:** what is the circular alternative and what are its enabling factors and barriers?

- **Step 3**: **Changes in the key sector**: what changes are expected in the key sector when the new business case is implemented, i.e. what are the direct effects of the business case?
- **Step 4**: **Effects on other parts of the economy**: what are the indirect and rebound effects of the new business case?
- **Step 5**: **The impact on the environment and society**: the economic, environmental and social impacts are analysed, thereby distinguishing between physical and monetary flows.
- **Step 6**: **Are alternatives available?** One should note that besides the current and the described circular business case, other business opportunities may be available. Furthermore, it may be that when the circular economy principles are applied to the whole economy, circular business opportunities that are relevant under current circumstances are not relevant anymore in a more circular economy. For example, if the livestock sector in regions with excess manure would be reallocated to other sectors, technologies for manure processing may become irrelevant.
- **Step 7**: **Policy options**: which policies are required to increase enabling factors, and to decrease barriers?
- **Step 8**: **Overall conclusions**: what did we learn about the new business case, and its environmental, social and economic impacts?

Since the focus of the CIRCULAR IMPACTS project is on societal and macroeconomic consequences of the circular economy, special emphasis will be put on these aspects. In all case studies, a comparison is made between a type of baseline scenario and a scenario where the circular opportunity has been implemented.

The CIRCULAR IMPACTS project aims to get a better grasp on the circular economy and methodologies used to analyse its societal and macroeconomic consequences. Because methodology development is one of the goals of the project, we decided to have some flexibility in methodology used for the case studies, starting from the stepwise approach developed in Deliverable 4.1 as described above. In this report, we summarize the main results of the case studies and in the last chapter, we highlight some of the key insights that we gained therefrom.

2 :: Concrete recycling in France

2.1 Introduction

The European Commission identifies construction and demolition waste (CDW) as one of the "heaviest and most voluminous waste streams generated", as it is responsible for 25%–30% of all waste generated in the EU (European Commission, 2016a). Directive 2008/98/EC, also known as the Waste Framework Directive, describes the basic concepts and definitions related to waste management. Article 11.2 introduces a 2020 target for Member States to prepare 70% (by weight) of all non-hazardous CDW for re-use, recycling and other recovery, excluding natural occurring material as defined in category 17 05 04 of the European List of Waste (European Commission, 2016b).[2]

In France, around 300 million tonnes of Construction and Demolition Waste (CDW) are produced each year (IREX, n.d., (a)), which is predominantly used for backfilling operations and recycled as aggregates for road construction (Bougrain, Moisson, & Belaïd, 2017). Overall CDW recycling and material-recovery rates differ greatly amongst Member States, from less than 10% to more than 90% (European Commission, 2016c).

2.2 The baseline

The production process of one tonne of Portland cement requires approximately 4,882 megajoules of energy (Struble & Godfrey, 2004), and releases nearly 1 tonne of carbon dioxide. Most of the carbon dioxide released in concrete production comes from cement production (Collins, 2013). The chemical process is irreversible, meaning that new cement will always be required to produce concrete, even if recycled concrete aggregates (RCA) are incorporated into the mix.

Concrete is mainly made up of aggregates, most of which are extracted via quarrying. Aggregates contribute 13-20% of the carbon emissions for concrete (Nazari & Sanjayan, 2016). Overall, concrete production contributes 6-7% of global carbon dioxide emissions (Imbabi, Carrigan, & Mckenna, 2012; Meyer, 2009). In 2015, the total production of aggregates in the EU-28 and European Free Trade Association (EFTA) countries was 2.66 billion tonnes, including 277 million tonnes of recycled, re-used and manufactured aggregates, of which around 45% was used for different concrete applications (UEPG,

[2] The category "natural occurring material" is defined as soil and stones; it excludes soil and stones containing dangerous substances.

n.d.(a)) Concrete sludge, which is waste water produced during the construction and demolition of concrete, is extremely hazardous due to its high alkalinity (Aggregates Business Europe, 2011).

In 2012, the concrete sector in France had a value added of €20 billion and employed 394.000 people. In that same year, the French ready-mix concrete sector had a turnover of about €4 billion.[3] The case study focuses on ready-mix concrete, because it is the most common type of concrete.

2.3 The new business case

Recycled concrete aggregates can be used not only for road construction, but also for structural concrete applications (The Cement Sustainability Initiative, 2009). It should be noted that this business case is not entirely new, as the European aggregates industry has been recycling aggregates for many years, with an increasing amount becoming available on the market over time. A lack of confidence in the quality of CDW recycled materials is often perceived as a barrier to increased recycling rates. This lack of confidence also applies to RCA. The European Aggregates Association (UEPG) states that the use of recycled aggregates should be promoted only where "economically, environmentally, and technically feasible respecting the given technical standards (UEPG, n.d., b)."

The Waste Framework Directive forms an important part of the European policy context by setting for Member States a target for 2020 to prepare 70% (by weight) of all non-hazardous CDW for re-use, recycling and other recovery, and determinining the requirements for end-of-waste criteria. As a result of its 2018 revision, it now urges Member States to take measures to: "[...] promote sorting systems for construction and demolition waste for at least the following: wood, aggregates, metal, glass and plaster" and to "reduce waste generation in processes related to industrial production, extraction of minerals and construction and demolition, taking into account best available techniques" (European Commission, 2015).

In 2016, the European Commission launched the EU Construction and Demolition Waste Management Protocol, which is part of the Circular Economy Package and fits within the Construction 2020 strategy. The non-binding guidelines as laid down in the Protocol are a proposal to the industry and have the goal to strengthen the confidence in CDW management. This is to be achieved by:

- Improved waste identification, source separation and collection

[3] Table 7 of the case study on concrete recycling

- Improved waste logistics
- Improved waste processing
- Quality management
- Appropriate policy and framework conditions (European Commission, 2016d).

On the national level, Article 79 of the French Energy Transition for Green Growth Act from 2015 lays down a regulatory framework to promote the recycling of aggregates for road construction.

2.4 Changes in the key sector

The key sector of the analysis is the aggregates industry. In 2015, recycled aggregates accounted for about 8% of total aggregates production in France.[4] To identify opportunities, one should be aware that transport costs are high and quickly rise over increased distances, as well as the environmental impacts. Therefore, the distances that aggregates travel should not be increased due to recycling. Accordingly, the EU Construction and Demolition Waste Management Protocol encourages the recycling of CDW in densely populated areas, because it is here that supply and demand come together (Ecorys, 2016).

With regard to the scenario analysis, 12% from the RCA is used in ready-mix concrete in the business as usual scenario and 25% in the circular scenario. In both cases, the average percentage of RCA in the mix is 15% (and so 85% of total aggregates are quarried aggregates). This implies that the share of ready-mix concrete with RCA incorporated is doubled from 10.9 to 22.8 million tonnes, whereas the share of ready-mix concrete without RCA is more or less halved from 27.1 to 15.3 million tonnes.

Environmental impacts are calculated by using the results of an LCA study for three concrete samples, each with different compositions but the same compressive strength (Serres, Braymand, & Feugeas, 2016). Based on the outcome thereof, and in combination with other key data and assumptions for France, it is concluded that the circular scenario compared to the business as usual scenario reduces abiotic depletion and energy with around 2%, and lowers greenhouse gas emissions and water consumption by a little more than 1%. Eutrophication, air pollution, water pollution, ozone layer depletion and photochemical oxidation are down with around 2% as well. Only acidification increases with around 2%, presumably due to the use of additives. This implies that, in this particular case, the increased use of RCA in ready-mix concrete has minor positive effects

[4] Aggregates re-used on site and the recycled mobile aggregates production are not included in this figure due to a lack of data.

on health and resource use. For ecosystem quality the results remain inconclusive. The extent of the environmental benefits are closely linked to the transport distances of the aggregates; it is important to note that the transport distances in the LCA study were shorter for RCA.

With respect to economic consequences, it is concluded that it is very difficult to get insights into profitability and other economic factors, because the market is so dependant on regional and local circumstances. Nevertheless, significant investments would be needed to pay for the new machinery that would be used to clean up and process concrete waste. Due to the extremely short distances between suppliers and buyers in the aggregates sector, any jobs that would be lost or gained would remain regional and local in nature.

2.5 Effects on other parts of the economy

Other sectors using waste-derived aggregates may be influenced by an increased use of recycled concrete aggregates. For example, if RCA is used more for ready-mix concrete production, would that mean that as a result more quarried aggregates would be used to build roads? If the total demand for aggregates does not decrease, then this might very well be the case. Therefore, having a good material flow analysis is essential, wherein losses and quality differences are taken into acccount (Schiller et al. 2017).

Also the construction sector may be influenced. However, it proves to be very difficult to identify the knock-on effects of an increased focus on concrete recycling for the construction sector. It is likely that the consequences are marginal.

2.6 The impact on the environment and society

The foreseeable impact on French society would be small, and it appears the economic and social consequences would be as well. One must be aware that, according to the numerical analysis, even if all RCA in France would be incorporated into ready-mix concrete still only 35% of aggregates would come from RCA as the demand for concrete (and therefore aggregates) is higher than the amount of waste-derived aggregates that can be recovered from CDW.[5] The environmental impact of ready-mix concrete production would be reduced in that case with about 10-15 percent.[6]

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[5] Paragraph added compared with case study document

[6] Based on a rough calculation with the numerical analysis that has been developed for the project

However, as indicated before, the LCA study that forms the foundation of the numerical analysis used shorter transport distances for the RCA than the quarried aggregates. Since in reality transport distances differ, it is very likely that incorporating all RCA into ready-mix concrete would not be attractive from an economic or environmental point of view, or even undesirable.

2.7 Are alternatives available?

By placing concrete recycling in a broader perspective, one may consider other options to reduce the use of quarried aggregates, for example, to what extent wood could be a substitute building material to concrete. However, this is not feasible on a large scale, because of the performance characteristics of concrete compared to wood. Additionally, large-scale wood use would have important consequences for land use and greenhouse emissions. Other options to consider would be to reduce building activities, for example through more sharing and more efficient use of available space, or to reuse concrete in its original form.

2.8 Policy options

The Netherlands provides a good example of how policy and natural circumstances generated a market for the recycling of waste-derived aggregates. Limited resources and land availability combined with high population density and groundwater levels naturally restrict the Dutch from mining and landfilling, and reduces the potential for illegal dumping. The Netherlands began implementing waste legislation in 1972, leading to the adoption of a ‘waste hierarchy’ in 1979. This eventually led to waste legislation enacted in 1994 that currently bans landfilling for 45 types of waste, including mineral CDW and mixed CDW. Additionally, recycled CDW must comply with a Soil Quality Decree, which prioritises the safe removal of asbestos and safe removal, disposal, and storage of materials such as asphalt, hazardous waste, and gypsum, as well as enforcing chemical limits regarding leaching potential (Cuperus & Broere, 2017).

It should be noted that the Dutch economy is open to the import and export of hazardous and tradable waste. This greatly contributes to the high success rate of recycling of CDW in the Netherlands, as this allows materials to be processed in locations with greater capabilities for recycling (Baldè, 2016).

According to the EU Construction and Demolition Waste Management Protocol, landfill restrictions are a prerequisite for creating a market for CDW recycled materials, but should be supplemented by additional measures (European Commission, 2016e). Landfill taxes are an instrument that can ensure that landfilling is no longer the least expensive option for how to deal with CDW; however, the tax structure and levels should fit the local situation and the specificities of the wastes involved (European Commission, 2016e).

A study from the European Environment Agency (EEA) on the effectiveness of environmental taxes stated that "[a] tax on aggregates, if properly designed and combined with other instruments, could have positive effects on the environmental impacts of aggregates and construction" (EEA, 2008). However, it depends on the local situation whether a tax on quarried aggregates may be an option (European Commission, 2016e).

2.9 Conclusions

Judging by the outcome of the numerical analysis, it can be concluded that, in this particular case, increasing the percentage of RCA in ready-mix concrete by 2030 to 25% could mildly reduce the environmental impacts of the French concrete sector. The transport distances plays a significant role in shaping the results, with the recycled materials travelling shorter distances compared to the quarried materials.

Additionally, when looking at a bigger picture that also incorporates the aggregates sector, it remains unclear if total demand for aggregates would be affected by an increased use of RCA. There is a risk that the total environmental impact of the French aggregates and concrete sectors might not be meaningfully reduced. RCA used for structural concrete could displace quarried aggregates in concrete, but those raw materials may merely be shifted to lower-value applications that RCA had previously been used for (e.g. road building).

Since there is still not much information available on the cost aspect of recycling concrete compared to quarrying for aggregates, it remains challenging to say anything regarding the potential socio-economic impacts. As mentioned before, this is mainly due to the significance of regional and local conditions. Nevertheless, as described, the recycling process will not significantly change the broader French economy or society.

Based on the results of the case study, the following policy recommendations are relevant for France and could also be considered for other EU Member States, as well as the EU as a whole:

- **Seek to capture the benefits of recycling concrete, but be realistic about its limitations.** Using recycled concrete aggregates instead of quarried aggregates has the potential to achieve environmental benefits. The distances that aggregates travel should not be increased due to recycling as this quickly increases the costs and cancels out the environmental benefits of recycling. Also, it is important to keep in mind that there is always a need for new cement (the vast bulk of concrete's CO_2 emissions) when producing concrete, even if RCA are incorporated. Quarried aggregates will always be needed to meet the total demand for aggregates. Policymaking should be based on an understanding of the net impact of shifting flows of recycled concrete from one application to another (e.g. from roadbeds to new concrete).

- **Keep investing in making concrete more sustainable.** There is not a single building material that comes close to the popularity of concrete. Improvements to the sustainability of concrete can have large-scale impacts as new techniques are implemented around the globe. The French research project RECYBETON provides a good example of an investment in improving the knowledge base for concrete recycling.
- **Ensure that concrete containing RCA is not regarded as an inferior product.** Introducing quality standards and labels could raise market confidence in recycled concrete. Additionally, clear end-of-waste criteria for waste-derived aggregates should be developed, not only for the purpose of building roads. This could be done on an EU level if the uniformity of Member States' regulatory frameworks would offer economic and environmental advantages. Increased public procurement of concrete containing locally available RCA could help establish its respectability in the market.
- **Define liability and keep reporting/permit requirements to a minimum.** Since the French construction sector is predominantly made up of SMEs, these businesses need to have certainty regarding who is liable for what when choosing to work with RCA. Furthermore, their small size makes it especially important to keep burdens of reporting and permitting manageable. This also relates to the implementation of end-of-waste criteria for waste-derived aggregates.
- **Consult all relevant stakeholders in the policymaking process.** The different sectors that are involved in the production and consumption of concrete, such as the cement industry, the aggregates industry and the construction sector, should all be asked to share their views before any major political decisions are made, as they have the expertise and experience to contribute to the debate. Public consultations provide a good means to collect such input.
- **Improve statistical knowledge of the market.** More detailed statistics on markets for the re-use and recycling of CDW would help guide policymakers and businesses seeking to create circular-economy opportunities that have combined economic and environmental benefits.

3 :: Phosphorus recycling in the Netherlands

3.1 Introduction

The element phosphorus (P) is essential for life and is used to make phosphate fertilizer, one of the three main mineral fertilizers being phosphorus, nitrogen and potassium. Phosphate rock forms an irreplaceable component in modern agriculture and is on the EU list of critical raw materials. The EU phosphorus flows show that the main losses of phosphorus in the food sector occur through sewage sludge, other waste water and food waste. Losses from the fields or from stables are relatively minor, but they have a high environmental impact.

3.2 The baseline

EU phosphorus flows: van Dijk et al. (2016) analyse phosphorus flows for the EU27 in 2005. Agricultural land is fertilized with 1389 KT (kiloton) of phosphorus, 1749 KT phosphorus from manure, and 157 KT phosphorus from other recycling. Of this input of 3295 KT phosphorus 842 KT goes into food processing, 1460 KT into animal feed (of which 1023 KT roughage), and 924 KT is stored in the soil. 84 KT is lost, half by leaching and drainage, half by runoff and erosion. Accordingly, loss on agricultural soil accounted only for 2.5% of total phosphorus input in 2005. Accumulation of phosphorus, mainly in regions with excess supply of manure, has a negative impact on the environment. Stricter fertilizer and manure regulation has been implemented to reduce these problems.

Dutch phosphorus flows: Since the Netherlands has a phosphorus oversupply, looking at the Dutch phosphorus flows in-depth is an interesting exercise, again for 2005 based on Van Dijk et al. (2016). Twenty-two KT is imported as fertilizer, 23 KT as animal feed (net imports), 7 KT as mineral feed additives and 3 KT as inorganic food additives. Seventy-four KT of phosphorus in manure is recycled from animal production to crop production, and 3 KT of phosphorus is recycled from food processing and consumption into crop production. Forty KT of phosphorus goes from food processing and consumption to the animal sector (of which 38 KT compound feed: see Smit et al. (2015)). Through net imports of crop-based products the Netherlands imports 45 KT phosphorus, and through net exports of animal based products exports 4 KT phosphorus plus 6 KT of manure. Accumulation in soil was about 30 KT in 2005, but was reduced to 2 KT in 2014 (Eurostat).

Dutch manure problem: Prior to around 1970 manure was perceived as a useful source for fertilisation in the Netherlands. Since the 1970s, manure is perceived as waste instead. Although problems with pollution as a consequence of manure were already recognized in 1972, mineral accounts with regulatory tariffs were introduced only just in the 1990s. EU legislation restricted the use of manure further and as a consequence several regions saw an excess supply of manure. This generated business cases for manure processing.

3.3 The new business case

The BioEcoSIM consortium developed a concept to process pig manure into mineral fertilizers, i.e. phosphorus and nitrogen, and biochar. According to the project coordinator, Dr. Jennifer Bilbao, the "overall process uses energy-efficient technologies and works on the principle of circular economy." The explicit target of the project is to "valorise pig manure into high value products that can be easily handled, transported, and applied back into agriculture" (Fraunhofer 2016, sheet 7). The application of the technique reduces energy-intensive ammonia production for nitrogen fertilizer by producing a substitute, reduces EU dependency on phosphate fertilizers, increases water efficiency and reduces the cost of manure disposal for farmers (Smeets et al. 2016, p. 7).

The BioEcoSIM process consists of four steps, of which the last step is production of biochar. When this last step is skipped, a soil improver with a small phosphorus and nitrogen content can be used, instead of biochar.

Enabling factors and barriers: The main enabling factor for the BioEcoSIM concept to become a success commercially is the negative price for pig manure in several regions. This negative price is the result of concentration of animal production in certain regions, combined with legislation, which limits the maximum use of manure on cropland and pasture and requires that manure is used productively.

Current legislation on fertilizers is also a restriction to the BioEcoSIM business concept because currently the fertilizer made from biodegradable pig manure waste is not accepted as being equal to fossil fertilizer and is counted as part of the manure application to land. The revision of the Fertilizer Regulation in 2013 emphasised harmonising the access to the EU market for biodegradable waste as an input for fertilizers and soil improvers. In 2016, the European Commission published a proposal that aims to further update rules concerning the approval of fertilizers, with a focus on allowing fertilizers on the market made from secondary resources such as manure.

3.4 Changes in the key sector

In this case study, the key sector is the phosphorus sector. However, it should be noted that the BioEcoSIM consortium focused on the valorisation of manure, and therefore the key sector could also be the manure processing sector. One could also see the livestock sector as the key sector, because this sector has to get rid of manure. However, the main problem of excess manure is the amount of phosphorus contained in the manure, and this phosphorus has to be exported. This is an important reason why the phosphorus sector may be the best approach to understand the value of BioEcoSIM.

For the scenarios below, we do some calculations.

Scenario 1: The baseline. The situation in 2017. Oversupply of manure in several European regions with intensive livestock production, pigs in particular. The manure surplus is transported to regions with less livestock and more crop production. Because of high transport costs, transport distances are minimized (i.e. within the legislative framework). As far as legislation is effective, phosphorus fertilization is more or less balanced.

Scenario 2: The BioEcoSIM concept or a comparable approach to manure processing is scaled up to all regions with excess pig manure in the EU. We develop this specifically for the Netherlands as an example of such a region, because the focus of the European Semester is on national policies. In this case, only limited effects are expected with respect to total phosphorus fertilizer use, because secondary phosphorus fertilizer will replace manure products, and in both cases the total phosphorus amount brought to land remains the same. Only when secondary phosphorus fertilizer has a higher nutrient use efficiency than standard manure products, there will be an effect.

The economies of scale are small. When the manure-processing factory is positioned on the farm, transport costs are low. When a larger factory is built on a central place, transport and storage cost from the farm to the factory will increase, and this will compensate for the scale benefits of the larger production facility.

Scenario 3: Phosphorus is recycled not only from manure, but also from sewage sludge, food waste, slaughter waste and other biomass. If a large share of these phosphorus losses would be recycled, the import needs of phosphorus into the EU would be reduced significantly. Changes in the phosphorus sector are already taking place. In 2011 ICL and the Dutch Authorities agreed on a covenant to replace 15% rock by 2015 and up to 100% in 2025 (Langeveld 2016). This means that in 2025 the entire phosphorus rock feedstock, amounting for 0.5 Tg/year, should be replaced with secondary phosphorus, initially from human wastewater (Metson et al. 2015; Withers et al. 2015). However, this requires further processing of struvite into more useful fertilizers products, or mono-incineration of phosphorus sludge. The BioEcoSIM concept produces high quality, ready for use, fertilizer products.

3.5 Effects on other parts of the economy

Recycling of manure will change, of course, the manure market. Change from direct manure use to recycling phosphorus from manure with the BioEcoSIM concept results in:

- More choices for the livestock producers: sell the manure to a crop farmer or sell it to a recycling plant;
- Less transport of manure (the manure is processed at a short distance from the farm);
- Decrease of the negative price of manure in certain regions (as far as the BioEcoSIM technique is cheaper than the alternatives).

Furthermore, the manure market is highly influenced by government regulation, both on the supply and demand side, but also concerning conditions for trade of manure. To organize manure processing, this legislation must be adjusted.

As far as the BioEcoSIM concept reduces the negative manure price, the implicit financial advantage for the crop sector is reduced. However, the effect on the crop sector is marginal. In the EU27 about 0.4% of total crop production cost is related to phosphorus fertilizer (globally 1%), and 1.6% on all fertilizers together (including horticulture; when excluded, 0.5% respectively 2.1%).[7]

In case the BioEcoSIM concept is implemented, the consequence for the transport sector will mainly be that international transport of secondary fertilizers is increased, whereas the regional transport of manure is reduced.

3.6 The impact on society and the environment

To analyse the impact of the BioEcoSIM concept, we created a scenario wherein BioEcoSIM is mainstreamed for all phosphorus in pig manure that is exported from the Netherlands in 2015 (scenario 2). In the baseline (scenario 1) 40% is exported by means of long distance transport and 60% through manure separation.

Given a cost reduction of €5 per tonne of pig manure (which is an estimate made by the BioEcoSIM consortium), GPD increases by €15 million. However, GDP effects are only a

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[7] Based on MAGNET data of 2007.

small part of the total welfare effects. According to the Life Cycle Analysis (LCA) of BioEcoSIM, the main environmental benefits of the BioEcoSIM concept are reductions in greenhouse gas emissions and particulate matter formation. The estimated decrease of GHG emissions is 144,600 ton CO_2eq, which generates an estimated welfare increase of €8.68 million. The estimated decrease of particulate matter formation is 1,488,000 kg PM10eq, which results in a welfare benefit of €66.96 million. That makes the total estimated welfare increase €90.64 million. When the BioEcoSIM process would be used for all manure that has to be exported, 31,800 tonne oil equivalents of energy would be used. Based on the numbers on differences in fossil-fuel depletion from the BioEcoSIM LCA and a crude oil price of €60 per barrel, it can be calculated that the net imports of fossil fuels will increase with €0.26 million, which is a marginal amount.

A next economic indicator is the amount of investment needed. Depreciation and therefore replacement investment will be about €4.5 million per year, while the BioEcoSIM concept will require an investment of about €45 million more compared to the alternative processes. The employment effects will be small. The processes are automated to a large extent and therefore will not generate a significant amount of jobs. Based on the change in transport costs for manure, the loss of income for the transport sector will be about €25 million, whereas other sectors will increase their sales. With respect to the livestock sector, the equilibrium price of manure will be reduced with the same amount, generating a benefit for all traded manure for the livestock sector of €55 million. Forty million is a change in price for manure sales to the crop and extensive livestock sector, which is just a transfer of income from the crop sector to the livestock sector. The difference, €15 million, is the cost reduction for the export of manure, and equals the increase in GDP.

The benefits of the BioEcoSIM concept depend on the assumption that the current situation is the correct starting point. If, for example, the Netherlands has to reduce its livestock sector in order to reduce greenhouse gas emissions because of the Paris Agreement, less manure will be produced in the Netherlands. In that case, the business case is no longer profitable.

3.7 Are alternatives available?

As far as the purpose of manure recycling is a reduction in fossil fertilizer use, the alternative is to increase the efficiency of phosphorus use. There are several possibilities to reduce fossil fertilizer use (Schoumans et al. 2015; Withers et al. 2015), for example through precision farming for crops and grassland, but also by reducing phosphorus in feed additives (EC 2013, p. 16).

If less meat would be consumed, livestock production would be reduced, as well as phosphorus use. Furthermore, manure production would go down, reducing the need for advanced manure processing techniques. According to the United Nations World Health Organization (WHO), people in the EU eat 70% more meat and dairy products than is known to be good for their health, thereby generating diseases. From this perspective, a reduction in livestock production through decreased consumer demand for meat and dairy products would positively affect health and related costs, greenhouse gas emissions and the pressure on nutrient resources.

Even if global livestock production would remain the same, having a better regional tuning between livestock and crop production could be an alternative. Then all manure produced in a region could be used within the region on cropland and grassland, while manure would be valued for its nutritional value.

What would the consequences be for Dutch GDP if the size of the pig-farming sector would be reduced? The average income per labour year for unpaid labour in the pig farming sector over 2001-2017 is €28,000[8], i.e. far below the modal income of €37,000 in the Netherlands, with pig farmers not only supplying labour, but also capital to the farm. Therefore, it seems plausible that they can earn a higher income if they would switch jobs while using their capital for other investments. However, if pig farmers cease business, others save on cost for manure processing and therefore their income will increase. As a result, it seems as if the former prefer to stay active in the pig farming sector.

Because the Netherlands is both a net exporter of manure and pig meat, a smaller pig farming sector would have consequences for the net trade balance.

3.8 Policy options

Existing regulation has a major impact on the use of phosphate. Phosphate use per hectare in the EU has been reduced significantly between 1980 and 2016 by stricter EU and national fertilizer, manure and detergent regulation. Regulation concerning fertilizer industry, farms, food, the water treatment sector and more are in place, both at European, national, regional and local level. According to Buckwell & Nadeu (2016, p. 11) it is important that the consistency of these regulations is carefully analysed and made consistent with recycling.

[8] See Agrimatie: https://www.agrimatie.nl/binternet.aspx?ID=4&bedrijfstype=5

An important argument for public involvement is externalities in the form of greenhouse gases and pollution. Additionally, the recycling industry for nutrients will probably be very dispersed and inexperienced, making it difficult to compete with the centralized fossil fertilizer companies. Also social attitudes have to change, and therefore investment in the new facilities may be risky (Buckwell & Nadeu 2016, p. 73).

A possible approach of stimulating nutrient recycling is to set voluntary targets through green deals or otherwise. These approaches will only work out in case of win-win situations. The targets may stimulate the search for win-win solutions and may help to communicate about barriers towards implementation of nutrient recycling techniques.

However, if the current situation is not profitable, stricter regulation is needed. The case of BioEcoSIM shows how important it is that processing of manure is obligatory, because the process is only profitable at negative manure prices. Blending targets for fertilizers and requirements to recycle also sewage sludge and bone meal may be examples of regulations that could be implemented to make recycling more profitable than in the past. Currently, such regulations are already partially implemented.

Another approach is to finance R&D, including demonstration plants and initial investments on a large scale. The European Commission is doing this through FP7 and Horizon2020 projects and also investment, start-up and innovation grants. The subsidy for BioEcoSIM provides an example of the latter. One may also give subsidies per unit of recycled nutrient, i.e. a feed-in tariff may stimulate the spread of nutrient recycling technologies.

What are the barriers for a successful introduction of the BioEcoSIM concept and how can these be solved? The fundamental cause of externalities related to nutrient use and manure production is that no prices exist for these externalities. One may try to internalize these through taxation. This implies that the waste flows or the inputs or outputs generating the externalities are priced. For example, in Denmark a tax on fertilizer has been introduced. However, this tax was not effective (Hees et al. 2012) because the tariff was low (and for households, not for agriculture). If a tax on fossil fertilizers would be high enough, this would stimulate the use of recycled fertilizers.

Buckwell & Nadeu (2016, p 11) suggest that the quality of recycled fertilizer is not necessarily the same as that of fossil fertilizers. A good-quality certification system is important, especially because the recycling sector is dispersed compared to the fossil fertilizer sector, and consumers, traders and farmers may have doubts about the quality and safety of using the recycled nutrients.

Stability and predictability of legislation is an essential condition to reduce investment risk. For example, if it is not certain that large-scale livestock in the areas with currently excess manure supply will continue to exist for some time, the investment in projects like BioEcoSIM may be too risky.

3.9 Conclusions

On BioEcoSIM: On the one hand, a business case like BioEcoSIM is mainly a technology that reduces transport cost and therefore saves money for the intensive livestock farmers. On the other hand, BioEcoSIM provides benefits with respect to greenhouse gas emissions and particulate matter emissions. Additionally, it does make more precise and therefore more efficient nutrient application possible, potentially reducing phosphate accumulation in the soil and eutrophication of water. Furthermore, the BioEcoSIM process may reduce greenhouse gas emissions and other emissions of manure transport and storage. However, since manure is already recycled in the baseline (i.e. used on arable and grassland), the BioEcoSIM concept has limited effect on conservation of phosphorus.

A requirement for profitability of BioEcoSIM is a negative manure price, i.e. the existence in certain regions of large-scale intensive animal production. Another solution to the excess of manure supply could be a situation where arable and animal farming are more in equilibrium.

On manure and phosphorus recycling: Phosphorus depletion will not pose a significant problem in the coming decades, but because stocks, production and exports are concentrated in a small number of regions and the EU depends almost completely on imports, geo-political uncertainties are an important argument to reduce dependency on primary phosphorus sources. As mentioned, the effect of BioEcoSIM on preventing phosphorus depletion is limited. However, if other types of biomass, like sewage sludge, are recycled, the effect on phosphorus depletion will be significant.

The case on manure recycling shows that legislation restricting manure application on land combined with requirements to process excess manure resulted in less phosphorus application on land in Western Europe, with as a consequence less phosphorus accumulation in the soil. The legislation created a negative price for manure and therefore business opportunities for manure processing. Because legislation can be such a decisive factor in this regard, implementing it with a long-term vision in mind is of the essence. Investors need to be sure that the regulatory framework does not change drastically in the short term.

On impact: As far as the BioEcoSIM business case brings down the cost of manure processing, the negative price of manure in several regions of Western Europe will be reduced. This implies lower cost for intensive livestock farmers and lower benefits from manure supply for the crop farmers in the neighbourhood of intensive livestock farmers. With respect to the environment, BioEcoSIM has a (restricted) positive impact on reduction of greenhouse gas emissions and particulate matter formation.

With respect to social impacts, one should note that the new technique is not labour intensive and it not expected that there would be a significant change of employment. As far as there are fewer dangerous materials like cadmium in secondary fertilizers compared to fossil fertilizers, health and ecosystems may be improved.

Policy recommendations: Standardisation and certification are crucial with regard to the markets for secondary fertilizers, and regulatory barriers have to be solved. Another issue is innovation policy. As shown, innovation policy for manure processing mainly reduces transport cost and potentially increases opportunities for better fertilizer efficiency. Also for other waste streams that contain phosphorus, innovation policy may help to develop better and cheaper technologies. Targets and feed-in tariffs may also help.

4 :: Car sharing in Germany

4.1 Introduction

The mobility sector is currently undergoing a series of fundamental changes, including a shift towards non-fossil fuels, autonomous driving and to mobility as a service. Car sharing is a crucial part of this mobility-as-a-service sector.

In this case study, three scenarios of car sharing development in Germany through 2030 are developed: a business-as-usual (BAU) scenario with lower levels of car sharing and two circular scenarios with significantly higher levels of car sharing. All 2030 scenarios are based on a set of underlying assumptions wherein the passenger-vehicle sector achieves greenhouse-gas emission reductions at levels in line with the German government's climate commitments under the Paris agreement (based on Agora Verkehrswende, 2018). In addition, in all 2030 scenarios, the number of electric vehicles on German streets reaches 5 million by 2030. Achieving these ambitious assumptions is contingent on corresponding and effective policy interventions in Germany and the EU. With this common substrate to all the 2030 scenarios, the specific effects of car sharing can be better analysed.

While the default case-study methodology developed for CIRCULAR IMPACTS calls for comparing a single circular scenario to the BAU scenario, a second circular scenario was developed for this car-sharing case study to address uncertainties regarding potential future technological and behavioural developments that could significantly affect the impacts of this circular-economy transition.

4.2 The baseline

The two business models compared in this case study co-exist in both the baseline and circular scenarios. The scenarios are distinguished from one another by the differing degrees to which car sharing is used vis-à-vis private vehicles.

In the predominant business model of private motorised transport, the car manufacturer supplies a vehicle to a retailer and the retailer then sells the vehicle to the end consumer. In this model, the consumer takes care of all maintenance costs, such as insurance, taxes and repairs, which are frequently provided by independent garages. In this linear model, the car may be used by several consumers sequentially (via resale of the used vehicle to a new private owner), but the use intensity of the vehicle is relatively low. Eventually, the car is sold or scrapped, in which a portion of the material stream is recycled while the other portion is permanently disposed.

In the BAU 2030 scenario, car sharing continues rapidly growing, reaching a level in 2030 where it constitutes 0.5% (one half of 1%) of passenger-kilometres covered by motorised passenger vehicles. This is a level five times higher than today's share of about 1/10th of 1% and corresponds to a compound annual growth rate of about 12%. In this scenario, car sharing's effects on vehicle use and ownership are within the mid-range of recent empirical studies carried out in Germany regarding these effects.

4.3 The new business case

In the car-sharing business model, the car remains in the ownership of the mobility service provider, which could either be the car manufacturer or a service provider. Hence, the maintenance costs are undertaken by the service provider, which is likely to cooperate with a pre-determined set of garages for repairs.

Car sharing means organised, shared use of vehicles by a larger number of people (Pieper et al 2013). This study focuses on two types: station-based car sharing and free-floating car sharing. With station-based car sharing (e.g. Cambio, Stadtmobil), a driver picks up the car at fixed locations (i.e. stations) and typically brings it back to the same station after use. In Germany, station-based providers now have 10,050 car-sharing vehicles at about 5,000 stations throughout Germany (BCS, 2018). With free-floating car sharing (e.g.DriveNow, Car2Go), a driver finds the car-sharing vehicle by mobile phone, drives it to his or her destination, and simply parks the vehicle nearby. Free-floating providers in Germany now provide 7,900 vehicles serving several large urban centres (BCS, 2018). Hiring and renting cars amongst individuals who do not know each other is known as peer-to-peer car sharing. The mediation between the private car owner and the person searching for a car is provided by a platform (e.g. drivy), where one can typically register without any cost. For the use of this mediation service, and often insurance, the platform usually charges a fee. Peer-to-peer car sharing is not explicitly examined further in this case study due to the limited data available at present.

In the first circular-economy scenario (titled Circular "Green" 2030), car sharing experiences disruptive growth while acting as a catalyst for reducing private-vehicle ownership and use. In the second circular-economy scenario (titled Circular "Gray" 2030), the disruptive growth of shared mobility tends to attract users from public transport, while the dynamics associated with autonomous vehicles (lower costs and high convenience) lead to an increase in the number of motor vehicles and motor-vehicle passenger-kilometres. In both circular scenarios, there is disruptive growth, with 2.5% of the passenger-kilometres in motorised passenger vehicles taking place via car sharing (“shared mobility” in the Circular “Gray” scenario due to the convergence of car sharing and ride sharing).

Table 1: Assumptions used in the scenario analysis

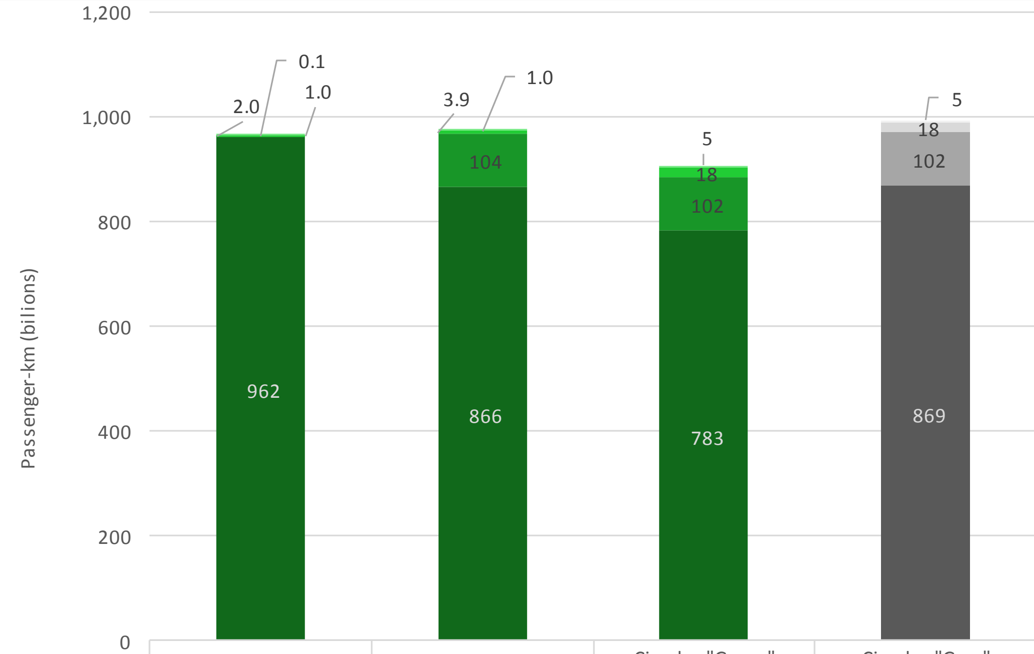
Assumption	BAU 2030	Circular "Green" 2030	Circular "Gray" 2030
Percentage of passenger motor-vehicle passenger-kilometres covered by car sharing	0.5% covered by car sharing	2.5% covered by car sharing	2.5% covered by shared mobility
Net reduction of passenger vehicles per car-sharing vehicle	Reduction of 2 vehicles	Reduction of 2 vehicles	Vehicle increase of 10% (0.1 vehicles)
Net reduction in total pkm of motor vehicles per pkm covered by car sharing	Reduction of 3.7 pkm	Reduction of 3.7 pkm	Pkm increase of 10% (0.1 pkm)

4.4 Changes in the key sector

To analyse the impacts of the scenarios, the case-study team undertook a numerical analysis using a large number of parameters and projections related to motor-vehicle travel, emissions data, new-vehicle production, the vehicle stock, and vehicle lifespans.

Figure 2 shows the case-study results for the annual passenger-km travelled in Germany by motor vehicles in 2030, breaking them down by use application (private car or car sharing) as well as energy source (fossil fuel or electric). Including the base year of 2017 allows a comparison to today's situation. In the Circular "Green" 2030 scenario, the total passenger-km of motorised passenger vehicles is reduced by 7% compared to the BAU scenario, whereas the Circular "Gray" scenario drives an increase of 2% in passenger-km.

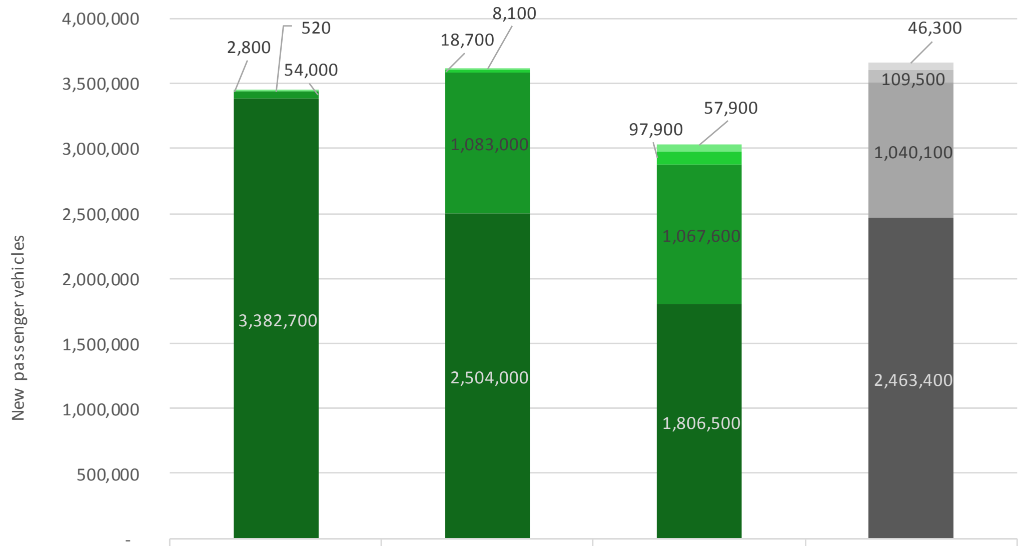
Figure 2. Annual passenger-km in Germany (motorised passenger vehicles)



	Base Year (2017)	BAU Scenario 2030	Circular "Green" Scenario 2030	Circular "Gray" Scenario 2030
Car sharing (electric)	0.1	1.0	5	5
Car sharing (fossil-fuel)	1.0	3.9	18	18
Private electric cars	2.0	104	102	102
Private fossil-fuel cars	962	866	783	869

The most dramatic sectoral change relates to the production of new vehicles. In the Circular “Green” 2030 Scenario, car production for the German market falls 16%, while 5% of new-car production is for the car-sharing market. In contrast, car production actually increases slightly (by 1%) in the Circular “Gray” Scenario.

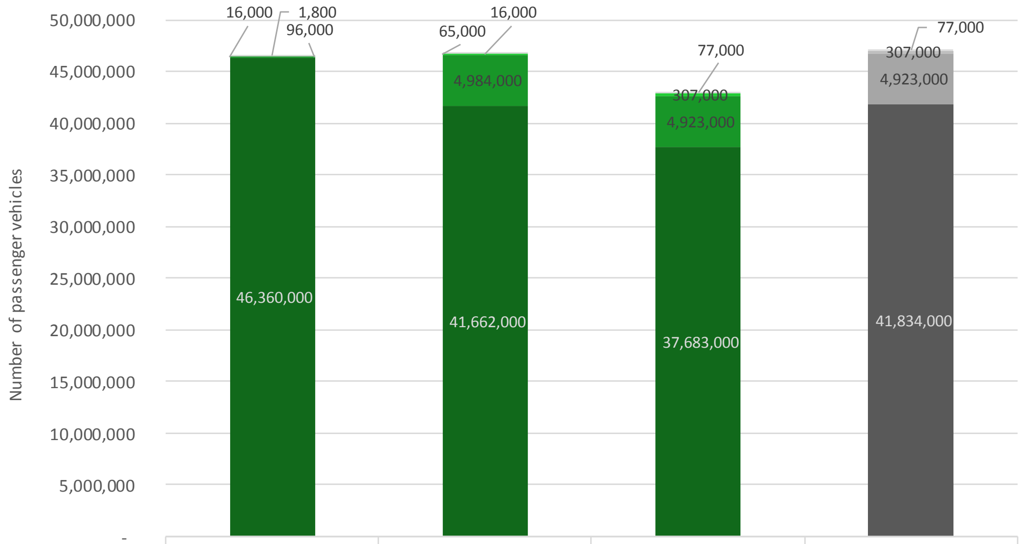
Figure 3. New passenger vehicles in Germany



	Base Year (2017)	BAU Scenario 2030	Circular "Green" Scenario 2030	Circular "Gray" Scenario 2030
Car-sharing cars (electric)	520	8,100	57,900	46,300
Car-sharing cars (fossil-fuel)	2,800	18,700	97,900	109,500
Private cars (electric)	54,000	1,083,000	1,067,600	1,040,100
Private cars (fossil-fuel)	3,382,700	2,504,000	1,806,500	2,463,400

The circular scenarios differ significantly from the BAU scenario in the way that increases in car sharing could alter the make-up of the vehicle fleet (Figure 4). In the BAU scenario, without a significant share of car sharing and barring changes in usage rates of passenger vehicles, the number of cars would increase by 0.5%, in line with the expected increase in passenger-km. By design, all scenarios have the same electric vehicle fleet (BEV and PHEV) of five million units while in the two circular scenarios the car-sharing fleets are of equivalent size. In the Circular “Green” 2030 scenario with a high replacement ratio, the fleet of fossil-fuel vehicles is reduced quite substantially by 2030, by over 9% compared with BAU. However in the Circular “Grey” 2030 scenario with its low replacement ratio the car fleet even slightly increases with a little bit less than 0.1% compared with BAU.

Figure 4: Passenger-vehicle stock in Germany



	Base Year (2017)	BAU Scenario 2030	Circular "Green" Scenario 2030	Circular "Gray" Scenario 2030
Car-sharing cars (electric)	1,800	16,000	77,000	77,000
Car-sharing cars (fossil-fuel)	16,000	65,000	307,000	307,000
Private cars (electric)	96,000	4,984,000	4,923,000	4,923,000
Private cars (fossil-fuel)	46,360,000	41,662,000	37,683,000	41,834,000

4.5 Effects on other parts of the economy

The total number of new passenger vehicles in Germany is 16% lower in the Circular "Green" 2030 scenario than it is in the BAU scenario. In addition to the effects of this drop in new-car sales, a significant diversion of new vehicles into car-sharing applications would have dramatic implications for the automobile market and the business models of automobile manufacturers and retailers. Since the mobility sector is subject to different dynamic trends, it is challenging to forecast future economic responses to car sharing. For scope reasons, it was not possible to do a numerical analysis of these effects at the same level of detail as for the data presented above.

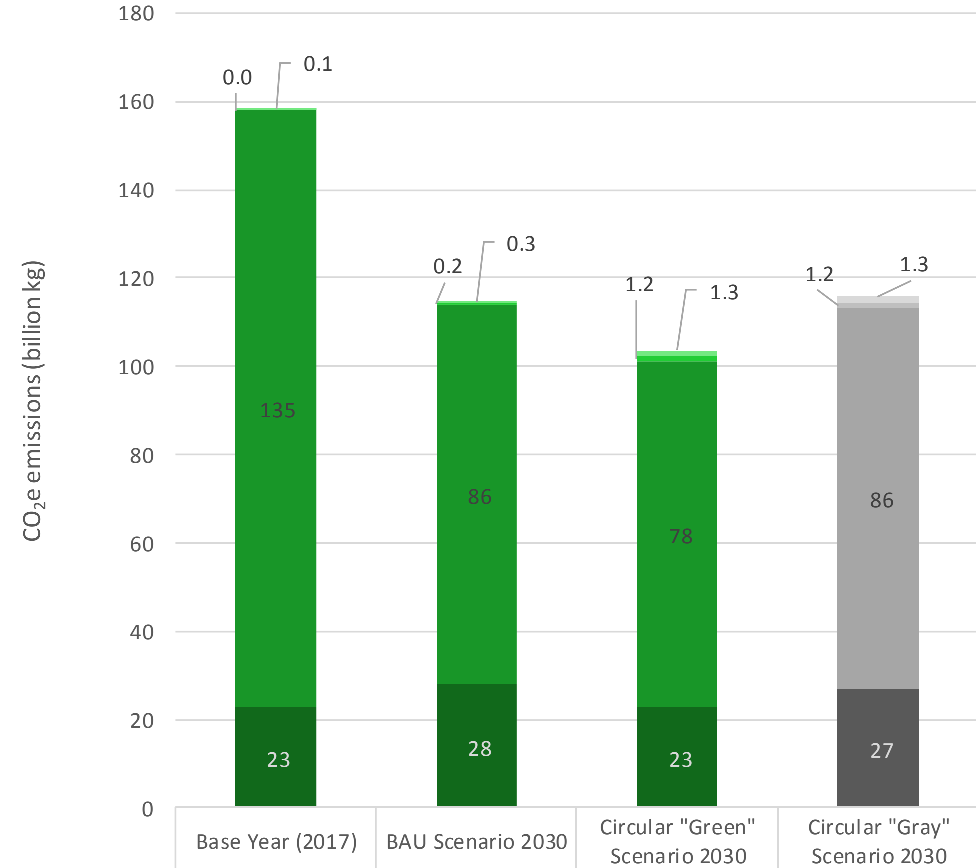
However, there do exist different estimations and projections of vehicle sales and emerging business opportunities, including the impacts on sales, revenue and opportunities arising from the different business models. BCG estimated car sharing would decrease the number of European vehicles sold by some 182,000, or about 1% (BCG, 2016). The company also estimated that car sharing would increase business opportunities (also for car manufacturers, who may provide mobility services). BCG expected Europe to be the region generating the greatest amount of car-sharing revenue in 2021 (€2.1 billion), followed by Asia-Pacific (€1.5 billion) and North America (€1.1 billion) (BCG, 2016). McKinsey estimated that car sharing would lead to opportunities beyond selling mobility services or building purpose-built vehicles, including gaining customer data, testing new technologies and ensuring fleet emission compliance (via electric vehicles) (McKinsey, 2017).

4.6 The impact on the environment and society

The social impacts from car sharing can be positive or negative. Since many of them are socio-economic effects, they are highly linked to business models and overall changes in the mobility sector. These social impacts included issues of accessibility of car-sharing services (by region, income class or socio-demographic profile), health impacts (whether car sharing influences overall mobility behaviour) and social cohesion (to a very limited extent).

Also with regard to environmental impacts, car-sharing can have several positive or negative environmental impacts related to the composition of the car-sharing fleet, changes in car ownership and respective implications for the modal split or total demand for mobility. When analysing the greenhouse-gas emissions for this case study, significant reductions in greenhouse-gas emissions are evident in both the BAU and the two circular scenarios. The calculation includes both production-related and use-related greenhouse-gas emissions. The most important factor behind the significant drop in emissions from present-day levels is the rise in the average energy-efficiency of vehicles and the increased use of electric vehicles. The increased use of electric vehicles explains the relatively large increase in production related emissions in the BAU scenario. Greenhouse gas emissions are reduced with almost 10% in the Circular "Green" 2030 Scenario compared with the BAU, while greenhouse gas emissions even are a little bit larger in the Circular "Grey" 2030 Scenario (see Figure 5).

Figure 5: CO_2e emissions from passenger vehicles in Germany



	Base Year (2017)	BAU Scenario 2030	Circular "Green" Scenario 2030	Circular "Gray" Scenario 2030
Car sharing cars (use)	0.1	0.3	1.3	1.3
Car sharing cars (production)	0.0	0.2	1.2	1.2
Private cars (use)	135	86	78	86
Private cars (production)	23	28	23	27

With regard to the replacement of private cars due to car sharing, the literature studies identify a range of replaced private vehicles due to present-day car sharing of between 3 and 20 cars. Such replacement of private cars leads to several beneficial environmental impacts, such as a decreased demand for parking space. Since car-sharing users have to pay the full operational costs of vehicle use, while for the use of private cars many costs are "hidden", there is an incentive to drive less by car. Hence, car sharing could potentially help trigger multi-modal mobility, including the use of public transport or bikes. However, whenever shared mobility models (car sharing and ride sharing) attracts people from public transport, it generally leads to negative impacts related to the use of public transport. Several studies assessed station-based car sharing to be more environmental friendly than free-floating car sharing schemes.

4.7 Are alternatives available?

For many types of trips, alternatives to car sharing are public transport, pedestrians, bicycles and autonomous and connected mobility. The types of mobility available and the number of business models behind its delivery have increased significantly in recent years.

Itself an example of the sharing economy, public transport is perhaps the premier alternative. Public transport is relatively low cost and accessible for most people (including people who would be excluded due to the digital divide); it is suited to the urban context (like car sharing) and can move more people within dense cities than any other mode. Over small distances, walking is a good alternative for car sharing due to its positive social effects (e.g. health impacts) and environmental effects (low emissions, etc.). Cycling can cover larger distances than walking and is beneficial both environmentally (less resource intensive) and socially (positive health impacts, cost-effective). Globally, there is an increasing use of pedelecs and bicycles in general. Autonomous and connected mobility could potentially transport a large number of people with a limited amount of vehicles. However, there is a risk that the use of such vehicles induces additional traffic, since costs are potentially cheap and no license is required for an individual to use an autonomous vehicle (UBA, 2017).

4.8 Policy options

In order to achieve a transition in the traffic sector, a policy mix that is effective, technology-neutral, predictable, cost-effective and enforceable is preferable (Damert & Rudolph, 2018). Only such a policy mix would take into account that also environmental beneficial transport modes can have negative externalities (e.g. ride sharing) or not be suitable to replace less beneficial transport modes completely (e.g. bikes). A policy mix, which is including these negative externalities, without picking a specific technology or mode of transport, first reduces or eliminates subsidies to the transport sector that are environmentally harmful. As a second step, the undesired outcomes should be avoided by pricing their underlying drivers. In case of congestion and lack of parking lots, this could be, for example, congestion pricing. As a third step, it is important to provide transport modes that are environmentally beneficial. This includes providing bicycle lanes, good public transport services and potentially parking lots for car sharing. With respect to car sharing, station-based schemes seem to be environmentally more beneficial, which is why they should be preferred. As a fourth step, monitoring and ongoing adaption of the policy mix are necessary to cope with future challenges in the transport sector. These challenges might include a dissolution of the boundaries between pure car sharing, public transport and partly privately owned cars, since these business models seem to be getting more similar as technology progresses. The key question for policy makers is either to embrace new transport services and to combine their services with those from public transport, or strengthen the boundaries between the two transport schemes. Generally, car sharing leads to the most environmental benefits when it is linked to other modes of transport, not only including public transport, but also bicycle and pedestrian traffic. To exploit these synergies, support for multi-modal transport is necessary—it is not sufficient to support only car sharing.

4.9 Conclusions

Car sharing is one part of a broad and diversifying multi-modal transport regime. The overall growth of car sharing and the extent of its impacts are highly dependent on its interlinkages with and effects on other transport modes, especially public transport. The environmental and social benefits of car sharing are higher when it acts as a catalyst for the increased use of environmentally friendly modes of transport. Therefore, policies addressing car sharing need to be well embedded in the overall transport-policy landscape. Thus, policies providing free parking spaces for car-sharing vehicles should be aligned with policies that address the externalities of unsustainable transport (e.g. via tolls for cars or withdrawing subsidies for private cars) while facilitating the development of multi-modal transport systems that can move high numbers of people in environmentally friendly ways (e.g. by financing bicycle lanes and public transport).

The car-sharing case study also points to broader conclusions about circular-economy transitions, especially ones related to the sharing economy. Public transport is a form of shared mobility itself, one that long predates the advent of smartphone-enabled car-sharing services. The case has helped to make it clear that understanding the full impacts of circular-economy transitions requires examining a broader set of effects than product- or service-specific replacements of a linear process with a circular one.

5 :: End-of-life batteries from electric vehicles

5.1 Introduction

Battery-powered electric vehicles (EVs) are among the key technologies for decarbonising road transport (EEA, 2016). At present, lithium-ion batteries are the most common type of battery used in these vehicles (EEA, 2016). The manufacturing of these batteries requires several different raw materials, of which, some have a high economic importance and face supply risks (Lebedeva et al., 2017). The anticipated increase in EV sales will also increase demand for lithium-ion batteries and the materials needed for their manufacturing (IEA, 2017). To this end, the questions of what will happen to the large number of lithium-ion batteries that will reach at some point the end of their life cycle and how their valuable materials can be recovered and recycled will become increasingly important. These questions are very relevant for Europe which is lacking a strong domestic battery cell manufacturing[9] base (Lebedeva et al., 2017) and is considered to have a good potential to become a global leader in recycling (Steen et al., 2017).

The case study investigates the consequence of two scenario options to recycle batteries from electric vehicles in the year 2030 and beyond. There is a high degree of uncertainty beyond 2030, but given that a significantly higher volume of EV batteries would be at their end of life in years later than 2030, the years 2035 and 2040 have also been analysed applying the same assumptions developed for 2030.

5.2 The baseline

Lithium-ion battery improvements in the last decade have been significant. The price has been steeply decreasing over the past five years (Shankleman, 2017) and it is likely to continue to do so. In 2015, the price of EV batteries ranged from $320-460/kWh and many predict that by 2030 the price will fall to $50-90/kWh (Berckmans et al., 2017; European Commission, 2016e; Curry, 2017).

As the price of cobalt increases, it is predicted that there will be a continued shift towards NMC and NCA blended lithium-ion batteries that need much less cobalt and therefore are more economical, while still achieving a good performance (Battery University, 2017).

[9] According to Lebedeva et al. (2017), cell manufacturing is one of the six segments of the automotive lithium-ion battery, for more details see section of this paper on technological development and the battery value chain.

By 2025, Shunmugasundaram et al. (2017) predict that less than 20% of cells will use the more traditional LCO technology while more than 40% will use NMC cathodes.

As the EV industry grows, battery recycling will become crucial and is a key sector where value can be created through jobs and materials (Lebadeva et al., 2016). Europe has an advantage being among the market leaders, particularly for the recycling of lithium-ion batteries (ibid). Although there is huge opportunity for EU industry and already some companies[10] are recycling these batteries, the lithium-ion battery recycling industry is not yet adequately developed to meet the expected volumes in years to come. The majority of EV batteries that have entered the market in recent years have not yet reached their end-of-life cycle. Therefore, the baseline for this case study is not available and instead the research team has developed two future scenarios to compare the economic, societal and environmental impacts of shifting towards a circular economy, with one scenario being more ambitious.

5.3 The new business case

Recycling of batteries is especially important to recover critical raw materials (CRMs). CRMs are defined as raw materials that have both a high economic importance for the EU and are vulnerable to supply disruptions (European Commission, 2017b). Currently, cobalt is considered one of the twenty-seven critical raw materials, while lithium, nickel and aluminium are all within the candidate critical raw materials (European Commission, 2017b).

This case study applies two types of variables that have been determined through a review of secondary sources and validated through a workshop and interviews with experts in the field. Scenario 1 is less ambitious, with a relatively low collection/take back and recycling efficiency rates and Scenario 2 is the more ambitious scenario. Collection/take back rates have been taken from the European Commission's SET-Plan Action No.7 (European Commission, 2016e), while target rate and recycling efficiency rates have been taken from the Lebadeva et al. (2016) report by the JRC on the lithium-ion battery value chain that shows two technically different recycling processes. These are shown in Table 2.

[10] For example, Umicore, Accurec, Recupyl and SNAM.

Table 2: Scenario variables

Battery Recycling	Scenario 1	Scenario 2
Collection/take back rate for recycling within the EU	65%	85%
Cobalt recycling efficiency rate	94%	99%
Nickel recycling efficiency rate	95%	97%
Aluminium recycling efficiency rate	98%	98%
Lithium recycling efficiency rate	57%	94%

5.4 Changes in the key sector

The electric vehicle battery-recycling sector can be defined as the key sector for this analysis. Relevant for the development of this sector is first the supply of batteries to be recycled. Based on projections for electric vehicle sales and the use of batteries in second life applications[11], it is projected that in 2030 46,540 MWh of batteries reach their end of life, 103,844 MWh in 2035 and 215,200 MWh in 2040. Depending on the type of batteries that have been used, the amount of raw materials in the batteries can be calculated.

Based on the collection/take back rates and the material recycling efficiency rates of the two scenarios combined with estimates of the amount of batteries that reach their end-of-life in 2030, 2035 and 2040, the amounts of cobalt, nickel, aluminium and lithium produced can be calculated. By multiplying those by the price (because of large uncertainties in future prices, current prices are used) the consequences of high efficiency recycling compared with low efficiency recycling can be calculated. Revenues from sales of the secondary materials (cobalt, nickel, aluminium, lithium) included in the

[11] An effective first lifetime of EV batteries in the vehicle is assumed to be 8 years on average and when a second-life is included, an extra life-time of 10 years has been added.

study increases from €408 – 555 million in 2030. In 2040, the total revenues from sales of the secondary materials included in the study increases from €1.9 – 2.6 billion. See Table 3 for more results.

Table 3: Amount and value of materials recovered

	Scenario 1	Scenario 2	Scenario 1	Scenario 2	Scenario 1	Scenario 2
	2030		2035		2040	
Amount of recovered material (tonnes)						
Cobalt	2,922	4,058	6,519	9,054	13,509	18,763
Nickel	10,604	13,535	23,662	30,200	49,035	62,584
Aluminium	31,826	39,783	71,013	88,766	147,163	183,954
Lithium	1,162	2,421	2,593	5,401	5,373	11,193
Value of recovered material (million €)						
Cobalt	213	295	475	659	983	1,366
Nickel	123	157	274	350	569	726
Aluminium	57	71	126	158	262	328
Lithium	15	32	34	71	71	148
Total	**408**	**555**	**909**	**1,238**	**1,885**	**2,568**

These numbers give an idea of the value of the key materials within the EV battery-recycling sector, which is in the order of magnitude of €500 million in 2030 and €2,600 million in 2040. The table above gives some insights into the revenues that may be generated in the recycling sector, but costs are not further investigated. However, there are indications that current recycling processes are profitable at current prices (Richa et al. 2017).[12]

The consequences of the two scenarios for direct employment are the following, for 2030 2,618 jobs would be created in Scenario 1 and 3,272 in Scenario 2 (collection, dismantling and recycling only, so excluding construction and development of recycling facilities). In 2035, 5,841 jobs would be created in Scenario 1 and 7,302 jobs in Scenario 2, and in 2040, these figures would be significantly higher as many more batteries would

[12] See also https://elektrischeauto.com/techniek/recyclen-van-batterijen/.

each the end of their life cycle: 12,105 jobs would be created in Scenario 1 and 15,131 in Scenario 2.

5.5 Effects on other parts of the economy

The benefits of recycling and second life use of batteries may change the cost of driving electric cars because depreciation of batteries becomes less when second life use of batteries makes old EV batteries valuable or when recycling of the batteries becomes profitable. However, it should be kept in mind that there is a high degree of uncertainty regarding these benefits because they are in the far future and thus will probably not influence the current market for electric vehicles within the next decade.

The extra supply of recycled materials will imply a reduction in demand for primary materials, mostly imported from outside the EU. As we have seen, in 2030 this effect will be small with respect to the change from a low towards a high-efficiency scenario (assuming that when batteries are exported they will also be recycled in the end), but in the baseline the supply of the recycled batteries may become significant for some materials, especially cobalt and lithium. As we move towards 2035 and 2040 with more batteries reaching their end of life the impact is larger and the difference between the two scenarios is much higher.

5.6 The impact on the environment and society

First, recycling of EV batteries is a development that should be in the baseline because it is consistent with current policies on battery recycling and because in many cases it seems even profitable by 2030. In the baseline, the employment and investment generated by the sector will be relatively small and there is no evidence that it is significantly different from traditional employment. Therefore, it is unlikely to influence macroeconomic dynamics significantly.

With regard to recycling, the results from the case study show that it has an effect on trade, particularly for the later years. For cobalt in 2030 the production value is €213 million for Scenario 1 and €295 million for the more ambitious Scenario 2. Around 4,060 tonnes of cobalt could be recovered in the year 2030, which is over 41% of all cobalt imports into the EU in 2012. In the year 2035, €659 million of cobalt could be recovered from end-of-life EV batteries in Scenario 2; while in 2040, applying current prices, this figure could reach almost €1.4 billion for Scenario 2, almost 40% more than in Scenario 1.

For nickel, taking the more ambitious Scenario 2, the value of nickel that could be recovered in 2030 is approximately 9% of the value of net EU imports in the year 2015, for 2035 it comes to 21% and 2040, 44%. In Scenario 1, approximately 20% less nickel is recovered from the end-of-life EV batteries when compared to the more ambitious Scenario 2.

For aluminium, although found in higher quantities than other materials in EV batteries, particularly for the battery cell casing, recycling end-of-life EV batteries in 2030 will generate between €57 (Scenario 1) and €71 million (Scenario 2), which is under 1% of the net import value in 2015. In 2040, the aluminium that can be recovered from end-of-life EV batteries could reach up to €262 (Scenario 1) and €328 (Scenario 2), going up to around 3% of the net import value in 2015.

With regard to lithium, results from the scenarios show that the EU could recover up to €32 million of lithium from the end-of-life EV batteries in 2030. By 2040, this increases to €71 million (Scenario 1) and €148 million (Scenario 2), with Scenario 2 providing approximately 50% more recovered lithium than Scenario 1.

In summary, the effect on the current account of battery recycling may have some significance, with Scenario 2 providing a greater effect on the trade balance, although this effect varies for each material assessed.

With respect to the environment, the consequence for greenhouse gas emissions is estimated as a reduction of 1 kg CO_2-eq per kg of recycled batteries, partly as a consequence of the high energy intensity of primary aluminium production (Romare & Dahllöf, 2017). This implies that in the less ambitious Scenario 1, 174,525 ton CO_2-eq is saved by EV battery recycling in 2030, while in the more ambitious Scenario 2, 218,156 ton CO_2-eq is saved. In 2040, these figures reach 807,000 tonne CO_2-eq (Scenario 1) and 1,008,750 ton CO_2-eq saved (Scenario 2). The net savings of over 1 million tonnes of CO2-eq in 2040 (Scenario 2) are equivalent to the CO_2 emissions of producing 261,000 tonnes of aluminium, which is comparable to the annual production of two primary aluminium smelters.

5.7 Are alternatives available?

As discussed, the alternative considered in the case study paper is the opportunity for EV batteries to have a second-life in stationary applications. In the scenario analysis, it is assumed that 30% of the EV batteries will have a second-life where the average second lifetime is an additional 10 years. If the fraction of EV batteries having a second-life would be larger, perhaps because of the development of higher quality batteries, the supply of batteries for recycling would be smaller. Richa et al. (2017) calculate that cascaded use may generate significant profits and therefore may increase also the second hand value of EV batteries.

At the start of the 1990s, innovation of Li-ion batteries developed very quickly. More recently, nickel has become a partial substitute of Cobalt in Lithium-ion batteries, especially for batteries that have large capacities. The future scarcity of some materials may encourage the development of new battery technologies using less of these materials. The assumption is that batteries are recycled in the EU. However, an alternative scenario would be that the batteries are exported to low labour cost countries like India. This has impact on these countries (labour conditions, safety, environmental pollution), but has also consequences for the calculations made above.

At the moment, 50% of cars end their life outside the EU. For electric vehicles, this may be much less because one needs infrastructure for these types of vehicles. However, if policies in developing countries would change, it may be that a large part of batteries in electric vehicles end their life outside the EU, implying that fewer batteries would become available for recycling in the EU, unless they would be subject to extended producer-responsibility rules. This would mean that the battery component materials and their value would not be retained in the EU economy.

5.8 Policy options

Currently, there is no regulation available explicitly for lithium-ion batteries in the EU. It is important that regulations and policies are developed given that the market is expected to expand rapidly in the coming decades. That said, lithium-ion batteries are regulated non-explicitly with other batteries in a number of Directives and there is scope for these batteries to be regulated further in updates to EU legislation.

In the current Battery Directive (2006/66/EC), 50% of weight of the battery in the category "other batteries" under which the EV batteries fall, has to be recycled. Because the main benefit of recycling is recovering high value, high supply risk materials or materials whose environmental costs in production are high, targets could be set on the most important elements from a resource supply certainty and environmental point of view. When possible, the targets should be neutral with respect to technology, so the industry can find the best processes to reach the targets.

Although the market may generate automatically better recycling technologies and technologies that allow for easier recycling, fundamental public research into new technologies that may be relevant for battery improvement must not be neglected. Physical and chemical research may be focused for example on better materials, solving cost and other problems with solid state batteries or batteries with a much higher energy density such as lithium-air batteries. However, it always remains difficult for government institutions to pick the winning technologies.

5.9 Conclusions

Currently, recycling of lithium-ion batteries is taking place in Europe at a very limited scale due to, among others, the small number of batteries that have reached their end of life. However, as sales of EVs grow, it is anticipated that in the coming years a large number of batteries will enter the market and reach at some point their end of life, raising questions about what will happen to these batteries. It is clear from our analysis that achieving high rates of recycling of EV batteries in Europe can mitigate dependence on imported materials and help retain the value of recovered materials in the EU economy.

Decisions on battery use in electric vehicles have consequences for future recycling of EV batteries. Because EV batteries are relatively large, recycling is required by law and seems to be profitable, thus it is plausible that recycling happens in the baseline. Therefore, the choice is more on the collection and recycling efficiency targets for recycling. If policy wants specific materials to be recycled with a high efficiency rate, it is important to set specific recycling targets for these materials. The possibility for efficient recycling is already in the design of the batteries, and therefore ecodesign requirements may be a useful instrument to steer future recycling quality.

The development of battery recycling will not have a very large influence on the economy in the short term until 2030. However, moving beyond 2030 and as many more batteries will reach their end of life; the impact would be much more significant. This raises questions about whether the recycling industry will develop in the EU or to what extent end of life batteries will be exported outside the EU after their end of life. More refined recycling technologies may increase environmental performance and recovery efficiencies.

6 :: Main lessons from the case studies

In this chapter, we focus on the lessons we may learn from the case studies. We organized those lessons in two categories: the circular economy, and the case-study methodology.

6.1 Circular economy

None of the case studies shows direct evidence that large benefits for employment or GDP can be expected. For example, although the EV case study shows that developing a viable value chain for recycling of lithium ion batteries in Europe generates some employment in the new sector, this does not imply that employment for the whole economy is increased. This requires detailed insights in the dynamics of the labour market and the balance of payments which shows how difficult it is to draw clear conclusions on economic benefits. However, in some transitions, like the transition towards wind energy cost benefits compared with fossil energy have been generated that are caused by rapid technological change. The change in location and skill requirements of the energy transition may require structural labour market policies (Weterings et al. 2018), which is highly relevant from the perspective of the European Semester. The European Semester serves as the policy background for the CIRCULAR IMPACTS project and therefore also for this report.

Although it is very uncertain to what extent the circular transition will generate benefits for GDP or employment, benefits from a broader welfare perspective are much more plausible. The purpose of the circular economy is mainly environmental and resource use driven, and when these benefits are included in the welfare concept benefits of the circular transitions can be calculated. For example, manure recycling results in less greenhouse gas emissions, which helps to mitigate climate change, while for example recycling of aggregates from concrete may generate some additional benefits. Also recycling of electric vehicle batteries may generate environmental benefits. In the car sharing case it has been argued that it may give benefits for the environment, but that car sharing may also take people out of public transport or that car sharing is additional to car ownership, in which case car sharing increases the number of kilometres driven and the number of cars may even increase. The case studies also show that recycling does not always generate positive outcomes on all aspects related to environmental issues or resource efficiency. BioEcoSIM manure processing, for example, requires more energy sources than alternative processes, while the use of recycled concrete aggregates can lead to increased acidification due to the use of additives in the mix, though the effect is minor.

Re-use instead of recycling proves to be more efficient in some cases. Re-using manure (without processing it the BioEcoSIM way), or re-using buildings (without a need to recycle concrete) may sometimes be the better solution. For concrete waste, it may also be that downcycling for road construction is more attractive than recycling, because otherwise primary raw materials (e.g. gravel) are potentially used to this end.

For two case studies, i.e. phosphorus recycling from manure and aggregates recycling from concrete, transport cost constituted an important factor. The high transport costs of manure made a business case for manure processing into phosphorus fertilizer in order to transport only the component of manure for which there is a local excess supply. For aggregates recycling, transport cost determines the maximum distance at which recycling is profitable.

The circular economy may be seen on a global scale, but many argue that it is preferable to have circularity on a local or regional scale. In the case study on electric vehicle batteries, it is assumed that they are recycled within the EU, but it may also be that the recycling happens in other countries, such as India, because it is cheaper. With respect to phosphorus recycling, it may be better to reduce livestock density in regions with excess manure supply with the aim to close local cycles, instead of processing manure into phosphorus fertilizers to be transported over a long distance.

Most case studies show the importance of analysing material flows in combination with supply and demand. For phosphorus, the material flows indicate where the leakages are that may be remedied to increase circularity, and reveal that there is an excess supply of phosphorus from manure in the Netherlands. With respect to recycling aggregates from concrete, it is demonstrated that demand for concrete is much higher than can be supplied with aggregates from secondary sources. However, because the aggregates market is very much regionally and locally oriented due to high transport costs, some regions may have more supply of aggregates from construction and demolition waste than can be used in a profitable and environmentally beneficial way. So, not all aggregates from construction and demolition waste can effectively be used.

Most case studies demonstrate the importance of quality guarantees through certification and legislation, and the need for regulation that guarantees the quality of secondary materials. The latter's quality is not automatically comparable with primary materials, as is shown for the use of concrete to produce waste-derived aggregates. For phosphorus recycling from manure, hygienic issues are important for international trade, and this is for a good reason. Therefore, internationally agreed quality standards and certifications are even more important for international trade than for national use.

Circular developments may be interdependent, making a good argument for discussing structural changes. For example, since electric cars have high fixed and low variable cost compared with conventional cars, they could be (once adequate charging infrastructure is in place) better suited for car sharing because of increased use. Relatively disruptive changes due to other sharing-economy models (e.g. ride sharing) may give unexpected effects. For example, Uber led to increased congestion in United States cities as taxi services became cheaper compared to public transport. Also in our car-sharing case study, a gray scenario has been developed that increases pollution and congestion. Therefore, the effect of circular opportunities is not automatically positive, and should be evaluated carefully case study by case study.

There is a relationship between technological development and new circular opportunities. For example, car sharing is made much easier by Internet and GPS technologies, while it may become even more attractive if cars become self-driving.

All case studies demonstrated how important it is to pose the fundamental question: what alternatives are relevant? If problems are solved through new technologies that become obsolete when the economy becomes more circular, investments in these new technologies, as well as the capital and human-capital investments, may become stranded assets. Therefore, taking on a broad perspective for each analysis is important. There is a tendency to focus on steps from the current situation, preferably with few taxes and limited restrictive use of legislation. However, if these taxes and legislation are needed for the circular transition, an erroneous selection of projects may have been made. Analysing to what extent new circular opportunities become more or less profitable when externalities are priced through taxes, subsidies, quota, changes in property rights, among others, is very relevant to assess the robustness of new business cases.

6.2 Methodology

With respect to methodology, we conclude the following. Firstly, the stepwise approach did help to pose questions to take on a broader perspective. In a circular economy, waste of one sector is an input for another sector. Sectors depend on each other and there is not always a clear key sector. Therefore, posing the question on the key sector helped to focus on the most important issues of the circular opportunities. However, asking the question what the consequences are for the rest of the economy did help to think through the consequences for the sectors that deliver inputs, sectors that receive outputs, and the sectors that are substituted as well as consumers.

The impacts on the environment and society was a crucial topic, where the framework developed in deliverables 2.3 and 5.1 from the CIRCULAR IMPACTS project provided useful input. The case studies also show that the circular opportunities are not always better when all environmental aspects are taken into account. The question on the alternatives available stimulated further thinking on other ways to reach the goals, such as changing the livestock sector instead of solving their manure problems. An important thing to consider regarding the stepwise approach is at which moment the policy options should be put forward. If the consequences of process changes are independent from the policies that realize them, the discussion on policy options can be delayed until the end. However, to the extent that the business case depends on policies in a broad perspective the policies have to be taken into account during earlier steps.

Secondly, the scenario approach is not without difficulties. An important target is clarity; a reader must understand where all the figures come from. The idea to create full scenarios is in that context not very fruitful. It is much clearer if the effects of specific policies or process changes are investigated. For that reason, the case studies all investigated small changes keeping the other variables the same. Another issue is uncertainty on the specific effects of the chosen opportunities. For this reason, it may be good to evaluate more scenarios. For example, in the car sharing case two scenarios have been developed where only one factor, i.e. the replacement ratio of shared cars, is different.

The challenge of the case studies was to create a link between low (business or local) level and the macroeconomic level. This is a challenge, and in the description of the case study, this is not always easy to distinguish. Because the chosen transitions are relatively simple (recycling of concrete for aggregates, recycling of batteries from electric vehicles, replacement of direct manure application by an advanced process to create artificial fertilizers from manure) the consequences can be calculated through simple upscaling. However, for a case like car sharing, this was much more difficult due to the dynamic nature of the market.

Furthermore, having very focussed case studies makes it more difficult to put them into broader perspective. This is accounted for by including an explicit step urging to think about alternative options. We did find out that posing the question for a broader perspective and available alternatives is essential to get a good insight into the case studies.

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