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Energy and resources management systems for improved efficiency in the process industries

Title: Secure Management Platform for Shared Process Resources

Acronym: SHAREBOX

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Deliverable 6.3	On-site validation and impact assessment
Associated WP	WP6 *Field trials with real industrial conditions*
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Dissemination Level	Public (PU)

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Publishable Executive Summary

Deliverable 6.1 Validation Methodology established a methodology that was used to verify the impacts achieved form the synergies realised through the SHAREBOX project. That methodology specifies which impacts are measured, how they are calculated and it established a sign off procedure where companies would sign a form that included the details of the synergy together with the impacts themselves.

Overall, 17 high value synergies were verified, representing 73% of landfill diversion, 58% of carbon savings , 95% of increased sales and 67% of cost savings claimed within the project targets.

In addition to the validation methodology defined in Deliverable 6.1, we applied Life Cycle Assessment methodology to quantify benefits regarding primary energy consumption and mineral resource use in agreement with the SPIRE objectives “reduction in fossil energy intensity” and “reduction in non-renewable primary raw material input” as complementary indicator to greenhouse gas emissions.

The environmental benefits regarding primary energy consumption and mineral resource use as well as greenhouse gas emissions were quantified by comparing the original non-symbiotic industrial system with the industrial system using industrial symbiosis. The difference in the total resource inputs, material inputs, emissions and wastes between the two systems were connected to life cycle inventory databases in order to calculate the life cycle environmental benefits caused by the symbiotic industrial systems with Sharebox compared to the non-symbiotic industrial system without Sharebox. The analysis also included additional impacts of transports to enable the synergy or recycling. Other additional impacts like filtration or other beneficiation were not considered.

The total savings of greenhouse gas emissions across all synergies facilitated within Sharebox equal about 1.05 million tonnes of CO_2-eq. The total primary energy savings across all synergies equal about 10’990 TJ oil-eq which corresponds to about 2 million barrels of crude oil and the total mineral resource savings across all synergies equal about 5’590 kg Sb-eq which corresponds 2 tons of silver, 1800 tons of copper or 45 million tonnes of iron.

All synergies analysed caused positive net savings for at least two of the three analysed indicators after additional environmental impacts required to enable the synergy had been subtracted. One out of eleven synergies analysed in detail showed a trade-off meaning that the net savings for greenhouse gas emissions and primary energy were positive whereas the net savings of mineral resources were slightly negative. However, the savings for mineral resources are only slightly imbalanced whereas the net savings for greenhouse gas emissions and primary energy are very high.

The outcome of Task 6.4.1 and 6.4.2 shows that the synergies facilitated within the Sharebox project cause significant environmental as well economic benefits.

1. Introduction

This deliverable combines the outcomes of the Task 6.4.1 Verification and Task 6.4.2 Life Cycle Assessment, the report is structured accordingly with two parts, one for each task. The first part in chapter 2 describes the work done in Task 6.4.1 Verification and the second part in chapter 3 describes the methodology and calculations done for Task 6.4.2 Life Cycle Assessment.

The overarching goal of Task 6.4.1 and 6.4.2 was the quantification of the positive impacts of the Sharebox project including environmental, economic as well social aspects. To this end, the validation methodology defined in Deliverable 6.1 Validation Methodology (Woodcock et al., 2018) as well as Life Cycle Assessment methodology as described in this deliverable were applied. Task 6.4.1 focused on waste avoided, virgin resources, carbon savings, additional sales, cost savings, private investment and jobs, whereas the major focus of Task 6.4.2 was the expansion of the quantified environmental benefits to primary energy consumption and mineral resource use. With this expansion, the environmental assessment was broadened in order to address the SPIRE objectives, which also focus on a reduction in fossil energy intensity and non-renewable primary raw material input in addition to carbon savings (Tello & Weerdmeester, 2013).

In Task 6.4.1 sign off sheet with detailed information on the synergies facilitated within Sharebox were compiled. These sign off sheets were used for a more detailed assessment of the environmental impacts and benefits of the facilitated synergies in Task 6.4.2.

2. Verification of Completed Synergies

2.1. Sign off procedure

Seventeen high value synergies were chosen for verification, 14 in Turkey and three in the UK. These represented 73% of landfill diversion, 58% of carbon savings, 95% of increased sales and 67% of cost savings claimed within the targets of the project.

Each company involved in the synergy was visited and interviewed. From these interviews, sign off Documents were produced based on the template agreed in Deliverable 6.1 (Woodcock et al., 2018). The sign-off sheets are included in the confidential , which is only be shared within the consortium, as some of the details are financially sensitive.

The impacts that were to be verified were:

- Waste avoided (tonnes)
- Virgin resources saved (tonnes)
- Carbon dioxide equivalent saved (tonnes)
- Cost savings (€)
- Increased sales (€)
- Jobs created or safeguarded
- Virgin resources saved (tonnes)
- Carbon dioxide equivalent saved (tonnes)

During January 2019, representatives from Eskisehir Organised Industrial Zone, Eskisehir Chamber of Industry and International Synergies Limited visited the following companies to discuss the history and impacts of their synergies:

- Cimsa cement
- Anadolu Cam and Şişecam Çevre in a joint meeting
- Eti and Derin Kanatlı in a joint meeting
- EOIZ waste water treatment plant
- Aslan Susam
- Sanovit (Elit)

Each company was interviewed to confirm the origin of their synergies, how those synergies had progressed and the impacts that had been achieved from the synergies.

Following the interviews, sign-off sheets were produced that contained narrative together with the calculations of the impacts. These were then sent to the companies for confirmation, either through direct signatures or email confirmation.

This process was repeated with Alutrade in the UK where a total of three synergies with the company were signed off.

2.2. Verified impacts

The amalgamated verified impacts were as follows:

Table 2.1: Verified impacts of synergies facilitated within Sharebox

Metric	Project Target	Confirmed sign off	Forecast vs sign off
Waste avoided (tonnes)	500,000	375,700	-124,300
Virgin resources saved (tonnes)	750,000	495,800	-254,200
CO_2 saved (tonnes)	500,000	806,500	+306,500
Additional sales (€)	3 million	51.2 million	+48.2 million
Cost savings (€)	3 million	9.4 million	+6.4 million

In addition to the verified impacts, there were several, unverified synergies. For these synergies, the project had remained in contact with the companies via email and telephone, but no site visits were made to finalise the impacts. Once impacts from these synergies were included in the project results, the project results were adjusted to the following table:

Table 2.2: Impacts of synergies facilitated within Sharebox including unverified synergies

Metric	Project Target	Revised Forecast impact (Project life)	Forecast vs Target
Waste avoided (tonnes)	500,000	515,500	+15,500 (3 %)
Virgin resources saved (tonnes)	750,000	635,500	-114,500 (15%)
CO2 saved (tonnes)	500,000	1.38 million	+880,000 (176%)
Additional sales (€)	3 million	53.85 million	+50.85 million (1,667%)
Cost savings (€)	3 million	14.12 million	+11.12 million (366%)
Jobs created or safeguarded	20	74	+54 (270%)

As can be seen, the impacts achieved by the facilitated synergies have far exceeded the project targets bar for virgin resources saved. In addition, private investment of €4.45 million was stimulated by the synergies.

2.3. Examples of impacts

2.3.1. Cost savings

Synergies 2/16/28 - €4.23 million saving from sending 30,000 tonnes of aluminium for reprocessing versus landfill

Synergies 4/18 - €1.173 million saving from sending 21,000 tonnes dried sewage sludge to cement instead of paying to send it to RDF

Synergies 6/20 - €3.08 million saving from sending 29,600 tonnes of food waste to animal feed manufacture instead of landfill

2.3.2. Increased sales

Synergies 2/16/28 - €47.715 million sales from 30,000 tonnes of aluminium. Includes sales from waste producer to reprocessor and sales of reprocessed aluminium

Synergies 6/20 - €3.5 million from selling the new stock produced from the reprocessed food waste

2.3.3. Private investment

Synergies 2/16/28 - €3.5 million from buying of new land and equipment

Synergies 4/18 - €714,000 investment in new sewage sludge drying plant

Synergies 12/26 – €230,000 investment in separation technology to separate husks for supply to animal feed manufacturer

Total private investment stimulated

€4.45 million private investment stimulated

3. Life Cycle Assessment

3.1. Goal and method

SHAREBOX aims at reducing environmental impacts of the supported industrial network by transforming wastes to resources as illustrated in Fig. 3.1. The LCA task 6.4.2 assesses these environmental benefits caused by the SHAREBOX platform covering important environmental impact categories and using a life cycle based methodology. The assessment supports and addresses the environmental indicators and impacts listed in the deliverable D6.1 (Woodcock et al., 2018) as well as the Sustainable Process Industry through Resource and Energy Efficiency (SPIRE)[1] objectives in Tello & Weerdmeester (2013) and the recommendations regarding Life Cycle Sustainability Assessment (LCSA) from SPIRE MEASURE[2] in Kralisch et al. (2016) and Minkov et al. (2016). The SPIRE objectives are a reduction of 30 %, 20 % and 40 % in fossil energy intensity, non-renewable primary raw material input and greenhouse gas emissions (Tello & Weerdmeester, 2013).

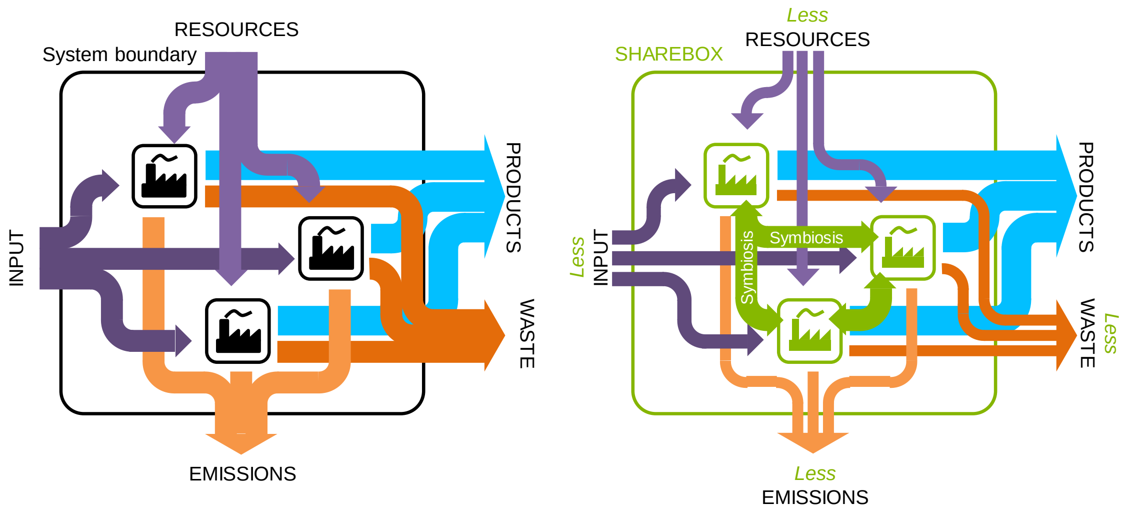


Fig. 3.1: **Schematic representation of the systems with (right) and without (left) SHAREBOX visualising the benefits of a less resource intensive, emission generating and waste producing circular system.**

The environmental benefits caused by specific symbiotic industrial networks were analysed in several studies using LCA methodology. Ardente et al. (2010) investigated industrial clusters in Sicily, Liu et al. (2011) looked at energy recovery from waste sludge in an industrial park in Shanghai, Sokka et al. (2011) analysed synergies in Finnish Forestry. Yu et al. (2015) analysed an industrial cluster with focus on aluminium processing in China and Zhang et al. (2017) focused on a chemical industrial park in Dalian (China). For the quantification of the environmental implications, we suggest the methodological approach illustrated in Fig. 3.2. The environmental benefits are quantified by comparing the original non-symbiotic industrial system with the industrial system using industrial symbiosis. The difference in the total resource inputs, material inputs, emissions and wastes with their corresponding life cycle environmental impacts are the

1 https://www.spire2030.eu/

2 https://www.spire2030.eu/measure

environmental benefits caused by the industrial systems. This approach avoids the allocation of specific impacts and benefits to the individual partners. This is a simple way to quantify the environmental benefits of a symbiotic industrial system, especially if the industrial symbiosis has more than two partners.

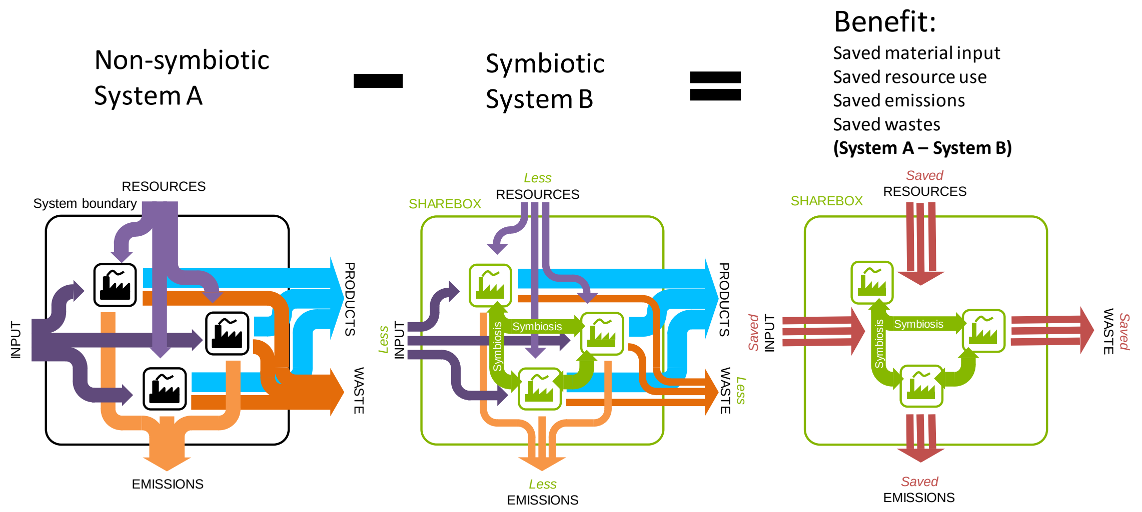
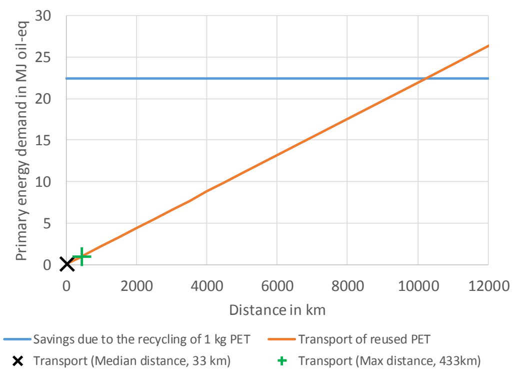


Fig. 3.2: **Schematic representation of LCA methodology applied for the quantification of environmental benefits of different synergies industrial systems.**

The calculation of the net savings also includes additional impacts caused by the implementation of the synergy, e.g. transportation Fig. 3.3 illustrates the reduction in the carbon savings caused by the additional transport between the partners of the synergy depending on the transport distance for polyethylene terephthalate (PET) and recycled concrete. Depending on the material and the transported distance, the net carbon savings can be reduced significantly. In the case of PET, the net savings are still very relevant even if the PET is transported more than 1000 km. In the case of recycled concrete granulate compared to conventional gravel only caused net savings if the transport distance for recycled concrete granulate is below 33 km.



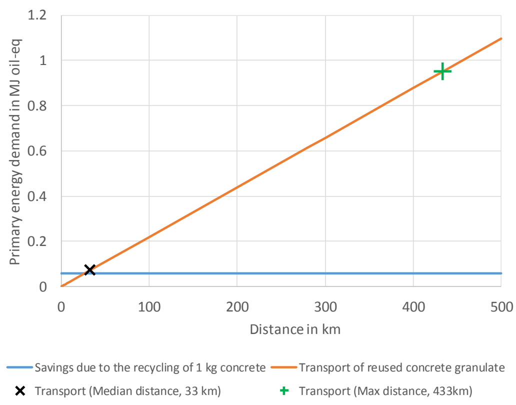


Fig. 3.3: Potential primary energy savings for recycled PET and concrete in MJ oil-eq compared to additional transport distance with median transport distance and maximum transport distance according to Jensen et al. (2011)

3.2. Life Cycle Impact Indicators

The selected life cycle impact indicators address and support the impacts on greenhouse gas emissions, primary energy consumption and mineral resource use as requested by the SPIRE objectives “30 % reduction of the fossil energy intensity” and “20 % decrease in non-renewable, primary raw material intensity” (Tello & Weerdmeester, 2013).

The methodology for the quantification of carbon savings defined in Deliverable 6.1 Validation Methodology (Woodcock et al., 2018) uses a life cycle based approach based on greenhouse gas emission factors. The calculations are based on various reports from DEFRA (DEFRA, 2006; DEFRA, 2007b; DEFRA, 2007a), ERM Group and Golder Associates (DEFRA & Golder Associates, 2005; ERM Group & Golder Associates, 2006a; ERM Group & Golder Associates, 2006b), WBCSD and WRI (WBCSD & WRI, 2004; WBCSD & WRI, 2005; WRI, 2007) as well as the WRAP programme (WRAP, 2006).

The core indicators for the SPIRE objectives focus on energy demand as well as resource use in addition to carbon savings. The SPIRE MEASURE Roadmap (Kralisch et al., 2016) recommends life cycle based approaches as far as possible in order to enable a balanced representation of drawbacks and advantages to cover holistic objectives of SPIRE. Therefore, we expanded the calculations from life cycle based carbon savings to life cycle based primary energy consumption as well as life cycle based mineral resource use using the life cycle impact indicators recommended by the Joint Research Council of the European Commission for the organisational and product environmental footprint (Fazio et al., 2018). With the expansion to these impact indicators, we addressed the SPIRE objective “30% reduction of fossil energy intensity” as well as “20% decrease in non-renewable primary material intensity” (Tello & Weerdmeester, 2013) with quantified life cycle based indicators. Fig. 3.4 shows an example for the mineral resource savings for PET recycling in g Sb-eq according to Oers et al. (2002).

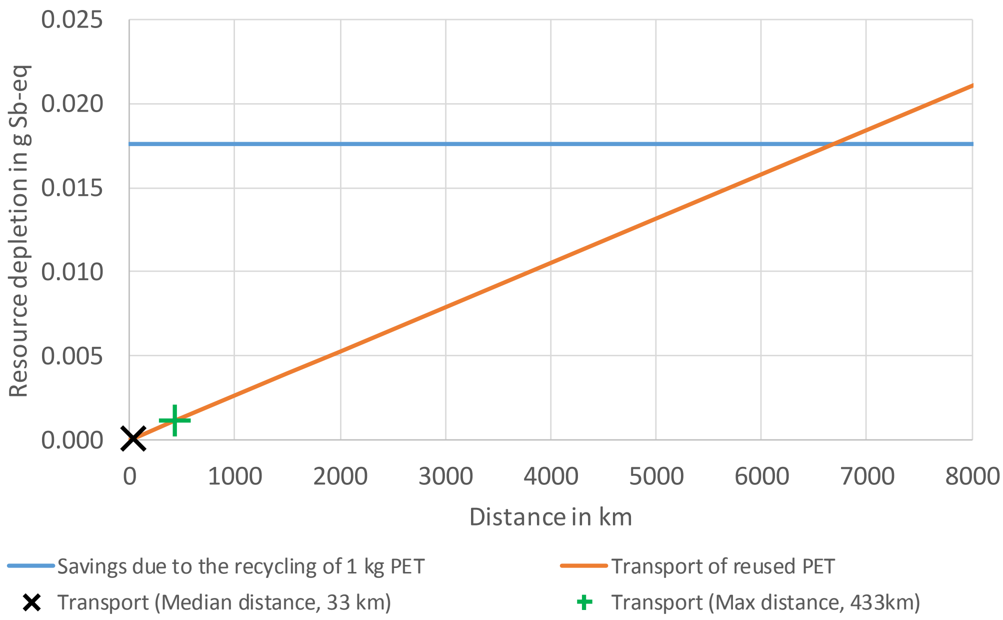


Fig. 3.4: **Potential mineral resource savings for recycled PET in g Sb-eq according to Oers et al. (2002) compared to additional transport distance with median transport distance and maximum transport distance according to Jensen et al. (2011)**

Furthermore, the analysis of the environmental impacts could be expanded to the complete indicator set recommended by Joint Research Council of the European Commission (Fazio et al., 2018; Hauschild et al., 2011) with 16 different life cycle based indicators. The expansion would include additional environmental impacts like water use, ozone depletion, particulate matter / air quality, human and eco-toxicity, ionising radiation, radioactive wastes, acidification, eutrophication and land use. The recommended indicators are listed in Table 3.1 with a short description. For a list of the extended indicator set recommended by the European Commission as well as a detailed description we refer to Hauschild et al. (2011) and Fazio et al. (2018).

The expansion to more life cycle impact indicators like primary energy or mineral resource use (van Oers et al., 2002) but also the full set of indicators recommended by Hauschild et al. (2011) and (Fazio et al., 2018) opens up the potential to trade-off between different indicators of the extender indicator set. This means that a potential outcome is that the synergy will decrease the impacts for one indicator and increase the impacts for another.

The assessment in this deliverable focuses on greenhouse gas emissions, primary energy and mineral resource use in agreement with the SPIRE targets. The additional indicators recommended by the Joint Research Council of the European Commission are not quantified in this deliverable.

Table 3.1: List of life cycle based impact indicators for task 6.4.2 Life Cycle Assessment

Indicator	Description	Source
Greenhouse gas emissions	Greenhouse gas emissions caused by the emission of climate forcing gases into the atmosphere (already used for carbon savings), addresses SPIRE objective “reduction of the fossil energy intensity” and the carbon savings.	(IPCC, 2013)
Resource use, energy carriers	Requirement of primary energy in MJ Oil-eq. This includes fossil fuels and biomass as well as nuclear, geothermal and wind energy, addresses SPIRE objective “reduction of fossil energy intensity”.	(van Oers et al., 2002; van Oers & Guinée, 2016)
Resource use, minerals and metals	Scarcity based characterisation of the use of different mineral resources based on the ratio of resource extraction and availability, addresses SPIRE objective “decrease in non-renewable, primary raw material intensity”.	(van Oers et al., 2002; van Oers & Guinée, 2016)
Environmental Footprint according to the Product Environmental Footprint	Recommendation by the Joint Research Centre of the European Commission for the calculation organisational and product environmental footprints. This is an extensive set of indicators including the three indicators listed above. Not all included midpoints specifically address the SPIRE objectives.	(Fazio et al., 2018; Hauschild et al., 2011)

3.3. Data requirements and collection

The main data requirements for the LCA task were the amount of saved materials and the transportation between the different partners of the synergy. Accordingly, the LCA task had a similar data requirement as the verification of impacts in Task 6.4.1.

3.4. Comparability, compliance and background data

The LCA methodology applied in Task 6.4.2 was in compliance with ISO 14040 and 14044 (ISO, 2006a; ISO, 2006b) using up-to-date background inventory data from the ecoinvent v3 database (ecoinvent Centre, 2016) in the LCA Software SimaPro (PRé Consultants, 2016) except for the external review of the results.

3.5. Assessment of environmental savings

The environmental impacts of the all synergies facilitated within Sharebox were assessed for the suggested indicators including greenhouse gas emissions (kg CO_2-eq.), primary energy demand (MJ oil-eq, PED) and mineral resource use (kg Sb-eq.). The environmental impacts of the individual synergies have been assessed using the ecoinvent database (ecoinvent Centre, 2016). The calculations of the environmental impacts were split in four parts

i) Saved environmental impacts due to the avoided production of primary materials,

ii) Saved environmental impacts due to avoided waste treatment.

iii) Additional environmental impacts due to transport between synergy partners

iv) Additional environmental impacts due to recycling

3.5.1. Savings due to avoided primary production

For each synergy, ecoinvent data (ecoinvent Centre, 2016) were used to assess the use of resources and the emissions arising from the production of 1 kg of the corresponding material. In order to know which input (and therefore which environmental production burden) was specifically avoided, it was necessary to be consider the intended use, respectively the substituted material. In Table 3.2, the synergies are listed with their corresponding material categories.

Materials of the category kitchen/food waste are mainly used as feed stuff for animals by the reference synergy partners. In order to assess the environmental impacts equivalent to the production of an appropriate amount of feed stuff, the specific calorific value of the used materials including whey, chocolate, liquid fruit peels and sesame peels was taken into account.

3.5.2. Savings due to avoided waste treatment

The environmental impacts of the disposal of specific materials were assessed separately from their production. For each synergy, the environmental impact linked with the treatment of 1 kg of a specific substance was evaluated, using the ecoinvent database (ecoinvent Centre, 2016). Since different treatment scenarios (e.g. incineration vs. landfill) lead to great differences in their impact results, these were assessed separately. Usually, the variant with lower savings was chosen, which can cause an underestimation of the saved environmental impacts.

3.5.3. Additional impacts due to transport between synergy partners

The additional environmental impacts of the transport of the materials between the synergy partners were assessed based on the address of the synergy partners and datasets for transport by lorry from the ecoinvent database (ecoinvent Centre, 2016).

3.5.4. Additional impacts due to recycling

The additional environmental impacts caused by the recycling of the material, e.g. remelting of aluminium or sorting and beneficiation of plastics based on the corresponding recycling datasets in the ecoinvent database (ecoinvent Centre, 2016).

3.6. Life Cycle Inventories Synergies

This chapter describes the compilation of Life Cycle Inventory models as well as the underlying assumptions. All the inventory models are based on the data in sign-off sheets in the confidential Appendix A. There is also a more detailed case study in the Appendix B, which focuses on one particular synergy in the ceramics sector, which is used by Keros and Kerafrit at their site in Nules, Spain. The same reasons for confidentiality apply for Appendix A as well as Appendix B.

We analysed eleven different synergies in detail, which were facilitated during the Sharebox project. In order to compare the savings for primary energy demand and mineral resource consumption, we established Life Cycle Inventory models for all individual synergies taking into account the saved primary materials as well as the saved disposal of the materials. The synergies facilitated within Sharebox include different material categories including non-ferrous metals, plastic, combustibles, kitchen and food waste, aggregate materials as well as wood. Table 3.2 shows the list synergies including category and Synergy ID and Table 3.3 shows the utilised life cycle inventories for avoided primary material and avoided disposal for each individual synergy.

All the process names in the tables below refer to the system model “cut-off/ recycled content” of the ecoinvent database and are not explicitly stated for the sake of readability.

Table 3.2: List of synergies

No	Name	Syn ID	Category
1	Alutrade – BSI	216	Non-ferrous metal (incl. Aluminium)
2	Recycled UK – Environment Agency	317	Plastic (dense)
3	Eti – Benli	828	Plastic (dense)
4	Bolu Cement – Eskisehir OIZ	4	Misc. Combustibles
5	Eti - Kanatli	6	Kitchen/food waste
6	Pinar - Bolvadin	11	Kitchen/food waste
7	Cimsa – Endel	9	Aggregate materials
8	Aslan – Doganer	12	Kitchen/food waste
9	Eti – Benli	721	Wood
10	Cimsa – Elit	10	Aggregate materials
11	Yardimci – Oguzlar	519	Kitchen/food waste

Table 3.3: Summary of the utilised life cycle inventories for avoided primary material and avoided disposal for each individual synergy; ecoinvent database cut-off / recycled content

Syn ID	Avoided primary material	Avoided disposal	Avoided amount in tonnes
216	Aluminium, wrought alloy {GLO}| aluminium ingot, primary, to market	Waste aluminium {GLO}| market for	47'465
317	Polyethylene, high density, granulate {GLO}| market for	Waste plastic, mixture {RoW}| treatment of waste plastic, mixture, municipal incineration	31'680
828	Polyethylene, high density, granulate {GLO}| market for	Waste rubber, unspecified {Europe without Switzerland}| treatment of waste rubber, unspecified, municipal incineration	20'400
4	Heat, district or industrial, other than natural gas {Europe without Switzerland}| heat production, at hard coal industrial furnace 1-10MW	Ash from paper production sludge {Europe without Switzerland}| treatment of ash from paper production sludge, residual material landfill	21'000
6	Energy feed, gross {GLO}| market for	Biowaste {RoW}| treatment of biowaste, industrial composting	29'581
11	Whey {GLO}| cheese production, soft, from cow milk	treatment, wastewater from dairy plant, to wastewater treatment, class 3/m3/CH”	55'300
9	Cimsa, aggregate materials, replaced based on clinker production | SHAREBOX	Waste brick {Europe without Switzerland}| market for waste brick	211'420
12	Energy feed, gross {GLO}| market for	Biowaste {RoW}| treatment of biowaste, industrial composting	900
721	EUR-flat pallet {GLO}| market for	Waste wood, untreated {RoW}| treatment of waste wood, untreated, municipal incineration	376
10	Cimsa, aggregate materials, replaced based on clinker production | SHAREBOX	Waste brick {Europe without Switzerland}| market for waste brick	3'240
519	Energy feed, gross {GLO}| market for	Biowaste {RoW}| treatment of biowaste, industrial composting	8

3.6.1. Alutrade – BSI (Syn ID 216)

The synergy between Alutrade and BSI is the transfer of expertise from BSI to Alutrade, which allowed Alutrade to increase their recycling activity. In total, this caused a net saving of 47’465 tonnes of aluminium that was recycled instead of disposed based on the final list of synergies provided by ISL[3].

We assumed that the recycled aluminium avoids the production of primary aluminium using the ecoinvent dataset “Aluminium, wrought alloy {GLO}| aluminium ingot, primary, to market” as well as the disposal of aluminium using the ecoinvent dataset “Waste aluminium {GLO}| market for”.

[3] Data provided by James Woodcock by email on 27 March 2019

The impacts for the aluminium recycling were modelled with the dataset “Recycling Aluminium, wrought alloy {RER}| treatment of aluminium scrap, new, at remelter”.

Additional transports were not included since there was no physical material that had to be transported. The transfer was only related to expertise.

3.6.2. Recycled UK – Environment Agency (Syn ID 317)

The synergy between Recycled UK and the Environment Agency is the transfer of expertise to enable the continuation of the activities of Recycled UK. With the continuation of the activities of Recycled UK a total amount 31’360 tonnes of plastic waste have been avoided.[3]

We assumed that the recycling of plastic avoids the primary production of the plastic with the ecoinvent dataset “Polyethylene, high density, granulate {GLO}| market for” as well as the disposal of plastic using the ecoinvent dataset “Waste plastic, mixture {RoW}| treatment of waste plastic, mixture, municipal incineration”. We assumed that incineration is the more likely method of disposal for plastic instead of landfill.

Additional transports were not included since there was no physical material that had to be transported. The transfer was only related to expertise.

Additional impacts for recycling were modelled with the dataset “Recycling Polyethylene, high density, granulate {Europe without Switzerland}| polyethylene, high density, granulate, recycled to generic market for high density PE granulate”.

3.6.3. Eti – Benli (Syn ID 828)

The synergy between Eti and Benli is the reuse of rubber waste for the production of rubber garlands. In total, this synergy avoided 20’400 tonnes of rubber waste.[3]

We assumed that the reuse of rubber waste plastic avoids the primary production of the rubber the ecoinvent dataset “Polyethylene, high density, granulate {GLO}| market for” as well as the disposal of rubber waste using the ecoinvent dataset “Waste plastic, mixture {RoW}| treatment of waste plastic, mixture, municipal incineration”. We assumed that incineration is the more likely method of disposal for plastic instead of landfill.

Recycling Polyethylene, high density, granulate {Europe without Switzerland}| polyethylene, high density, granulate, recycled to generic market for high density PE granulate | Cut-off, U

3.6.4. Basta - Eskisehir OIZ (Syn ID 4)

The synergy between Basta and the Eskisehir Organised Industrial Zone (OIZ) is the use of dried sewage sludge in the cement kiln of Basta. The sewage sludge is dewatered by Eskisehir OIZ via solar sludge drying system. The sludge is transported to Basta and used as alternative fuel source for cement production. The dried sludge has to be transported about 310 km from Eskisehir OIZ to Basta. In total, this synergy enable the reuse of 21’000 tonnes of dried sewage sludge in cement kilns.[3]

We assumed that the dried sewage sludge replaces hard coal as fuel for the cement kiln of Basta in Turkey. In order to calculate the amount of saved combustibles, we used a lower heating value of 10 MJ/kg for dried sludge (Stasta et al., 2006) and calculated the amount of hard coal saved which corresponds to 7’300 tonnes if we use a lower heating value of 28.9 MJ/kg for hard coal. The default disposal method for sewage sludge is a landfill (Turek et al., 2018). There is no dataset available in ecoinvent for the disposal of sewage sludge in landfills, therefore we used the ecoinvent dataset “Ash from paper production sludge {Europe without Switzerland}| treatment of ash from paper production sludge, residual material landfill” as approximation.

3.6.5. Eti – Kanatli (Syn ID 6)

The synergy between Kanatli and Eti is the reuse of expired biscuits and chocolate from Eti to produce animal feed. Eti produces biscuits, nuts, chocolate, cakes in six factories in the Eskisehir OIZ. Kanatli reused 29’581 tonnes of food waste from Eti but also uses wastes from other companies to produce animal feed.

The transport distance between Eti and Kanatli is very short due to both companies being located in the Eskisehir OIZ. We approximated the transport distance with 10 kilometres.

We assumed that the food waste will replace maize as feedstuff with an average nutritional value 18.85 MJ pro kg for maize feed (Qi et al., 2004). As a dataset for the replacement we used the ecoinvent dataset “Energy feed, gross {GLO}| market for” as well as the disposal of biowaste in industrial composting “Biowaste {RoW}| treatment of biowaste, industrial composting”.

3.6.6. Pinar – Bolvadin (Syn ID 11)

The synergy between Pinar and Bolvadin is the reuse of whey from Pinar by Bolvadin to produce whey powder. Bolvadin reused 55’300 tonnes of whey from Pinar, which otherwise would have been discharged to their wastewater treatment. The transport distance between Pinar and Bolvadin is 230 kilometres.

We used the ecoinvent dataset “Whey {GLO}| cheese production, soft, from cow milk” to model the replaced whey as well as the dataset “treatment, wastewater from dairy plant, to wastewater treatment, class 3/m3/CH” based on Eymann et al. (2015).

3.6.7. Cimsa Endel (Syn ID 9)

The synergy between Cimsa and Endel is the reuse of roof tiles from Endel in the cement kiln of Cimsa as Alternative Raw Materials. Cimsa produces mainly ordinary Portland cement (grey cement) in their production site in Eskisehir according to their Sustainability report p.16 (Çimsa cement, 2018, S. 16), Eskisehir Plant. Cimsa reuses 211’420 tonnes of roof tiles as Alternative Raw Material (ARM).

We approximated the input material mix for cement production of Cimsa based on the European clinker mix in ecoinvent “Clinker {Europe without Switzerland}| production”. The input material composition replaced by the Alternative Raw Materials used for the calculation is shown in Table 3.4 and mainly consists of lime, calcareous marl and clay. The production site of Cimsa in Eskisehir is not located in the OIZ and the material has to be transported about 40 kilometres.

Table 3.4: Replaced input material for cement production for Cimsa, Eskisehir Plant

Cimsa, aggregate materials, replaced based on clinker production | SHAREBOX	Amount in kg	Share
Calcareous marl {GLO}| market for	0.466	0.284
Clay {RoW}| market for clay | Cut-off	0.331	0.202
Lime {RER}| market for lime	0.841	0.513
Total	1.638	1.000

3.6.8. Aslan - Doğaner (Syn ID 12)

The synergy between Aslan Sesame and Doğaner Food is the reuse of sesame seed husks in the production of animal feed. Before the synergy, the husks were discharged to the sewer and caused problems at the receiving sewage treatment works. Doğaner Food uses 900 tonnes of sesame seed husk.

We assumed the sesame seed husks replace energy feed. As a dataset for the replacement we used the ecoinvent dataset "Energy feed, gross {GLO}| market for" as well as the disposal of biowaste in industrial composting "Biowaste {RoW}| treatment of biowaste, industrial composting". According to Abdullah et al. (2011) sesame hulls have a metabolisable energy content of 3.92 kcal or 0.016 MJ per kg. The transport distance between Aslan Sesame and Doğaner Food is very short due to both companies being located in the Eskisehir OIZ. We approximated the transport distance with 10 kilometres.

3.6.9. Eti – Benli (Syn ID 721)

The synergy between Eti and Benli is the reuse of wood pallets from Eti by Benli in wood crate production. 376 tonnes of pallets have been reused by Benli, with an average weight of 22 kg (Kellenberger et al., 2007) this corresponds to about 17'000 pallets.

We used the ecoinvent dataset "EUR-flat pallet {GLO}| market for" to model the avoided production of pallets and "Waste wood, untreated {RoW}| treatment of waste wood, untreated, municipal incineration" for the avoided disposal of the pallets.

The transport distance between Aslan Sesame and Doğaner Food is very short due to both companies being located in the Eskisehir OIZ. We approximated the transport distance with 10 kilometres.

3.6.10. Cimsa Elit (Syn ID 10)

The synergy between Cimsa and Elit is the reuse of gypsum waste from ceramics production from Elit in the cement kiln of Cimsa as Alternative Raw Materials. Cimsa produces mainly ordinary Portland cement (grey cement) in their production site in Eskisehir according to their Sustainability report p.16 (Çimsa cement, 2018, S. 16), Eskisehir Plant. Cimsa reuses 2'040 tonnes of gypsum waste as Alternative Raw Materials.

We approximated the input material mix for cement production of Cimsa based on the European clinker mix in ecoinvent "Clinker {Europe without Switzerland}| production". The input material composition replaced by the Alternative Raw Materials used for the calculation is shown in Table

3.4 and mainly consists of lime, calcareous marl and clay. The production site of Cimsa in Eskisehir is not located in the OIZ and the material has to be transported about 40 kilometres.

3.6.11. Yardimci – Oguzlar (Syn ID 519)

The synergy between Yardımcı Gıda and Oğuzlar Feed is the reuse of fruit peel in the production of animal feed. Oğuzlar Feed uses 8 tonnes of fruit peel.

We assumed the sesame seed husks will replace energy feed. As a dataset for the replacement we used the ecoinvent dataset “Energy feed, gross {GLO}| market for” as well as the disposal of biowaste in industrial composting “Biowaste {RoW}| treatment of biowaste, industrial composting”. We used the nutritional value for orange peel corresponding to 19.3 MJ/kg (Santos et al., 2015) for fruit peel.

The transport distance between Yardımcı Gıda and Oğuzlar Feed is very short due to both companies being located in the Eskisehir OIZ. We approximated the transport distance with 10 kilometres.

3.7. Life Cycle Impact Assessment

The synergies as described in section 3.6 were used to calculate the saved greenhouse gas emissions, the saved primary energy as well as the saved mineral resources with the Life Cycle Impact Assessment methods shown in Table 3.1. The net savings correspond to the sum of the savings due to avoided primary material use and avoided disposal minus the additional impact caused by the transport of the material between the synergy partners.

3.7.1. Avoided primary materials

The avoided greenhouse gas emissions, primary energy consumption and mineral resource use depend on the avoided material. Table 3.5 shows the saved environmental impacts for greenhouse gases, primary energy and mineral resources per kg of avoided primary material for the different synergies and material categories. The saved environmental impacts have a considerable variation depending on the material type, e.g. the greenhouse gas savings per kg of plastics are more than three times higher compared to kitchen or food waste. This leads to considerable higher or lower savings depending on the material category. The material category with the highest savings are non-ferrous metals, followed by plastics and combustibles.

Table 3.5: Avoided impacts per kg substituted of primary material

Category	Greenhouse gases	Primary energy	Mineral resources
	kg CO_2-eq per kg	MJ oil-eq per kg	kg Sb-eq per kg
Aggregate materials (Syn-ID-9)	0.0175	0.279	8.06E-08
Aggregate materials (Syn-ID-10)	0.0149	0.232	5.98E-08
Kitchen/food waste (Syn-ID-6)	0.606	4.11	1.34E-06
Kitchen/food waste (Syn-ID-11)	0.158	0.745	2.76E-07
Kitchen/food waste (Syn-ID-12)	0.000514	0.00349	1.14E-09
Kitchen/food waste (Syn-ID-519)	0.621	4.21	1.37E-06
Misc. Combustibles (Syn-ID-4)	1.1	9.6	6.71E-08
Non-ferrous metal (incl. Aluminium) (Syn-ID-216)	17.1	160	4.89E-05
Plastic (dense) (Syn-ID-317)	2.09	72.3	8.62E-05
Plastic (dense) (Syn-ID-822)	2.09	72.3	8.62E-05
Wood (Syn-ID-721)	0.349	6.28	1.15E-06

3.7.2. Avoided disposal

Similar to variation depending on the avoided primary material, there is a high variation of the avoided greenhouse gas emissions, primary energy consumption and mineral resource use for the avoided disposal of the reused material. Table 3.6 shows the saved environmental impacts for greenhouse gases, primary energy and mineral resources per kg of avoided disposal for the different synergies and material categories. The material category with the highest savings of greenhouse gases and mineral resources are plastics, whereas the category non-ferrous metals has the highest savings of primary energy per kg.

Table 3.6: Avoided impacts due to the reduction of disposed material

Category	Greenhouse gases kg CO_2-eq per kg	Primary energy MJ oil-eq per kg	Mineral resources kg Sb-eq per kg
Aggregate materials (Syn-ID-9)	0.0115	0.202	1.76E-08
Aggregate materials (Syn-ID-10)	0.0104	0.195	1.88E-08
Kitchen/food waste (Syn-ID-6)	0.0599	0.399	4.66E-08
Kitchen/food waste (Syn-ID-11)	0.000917	0.0147	9.16E-09
Kitchen/food waste (Syn-ID-12)	0.0599	0.399	4.66E-08
Kitchen/food waste (Syn-ID-519)	0.0599	0.399	4.66E-08
Misc. Combustibles (Syn-ID-4)	0.00807	0.282	1.04E-08
Non-ferrous metal (incl. Aluminium) (Syn-ID-216)	0.0425	0.643	3.26E-08
Plastic (dense) (Syn-ID-317)	2.38	0.459	5.99E-08
Plastic (dense) (Syn-ID-822)	3.16	0.469	6.59E-08
Wood (Syn-ID-721)	0.075	0.136	1.88E-08

3.7.3. Transport between synergy partners

In order to enable the synergy between the synergy partners, the material has to be transported. Table 3.7 shows the transport distance between the different synergy partners for each of the synergies analysed as well as the transported amount and the associated greenhouse gas emissions, primary energy demand and mineral resource use. For two synergies, the transport distance is zero because there was no physical flow of goods between the synergy partners but a transfer of expertise. The transport distance between the synergy partners is up to 300 kilometres. However, for most synergies the transport distance is very low because both synergy partners are located within the Eskisehir Organised Industrial Zone (OIZ).

Table 3.7: Transport distance and additional impacts caused by the transport of the material between the synergy partners for the different material categories and synergies

Synergy ID	Category	Distance	Waste avoided	GHG	Primary energy	Mineral resources
		km	tonnes	in Tonnes CO_2-eq	in MJ oil-eq	in kg Sb-eq
Syn-ID-9	Aggregate materials	40	211'420	1'105	17'271'151	3.14
Syn-ID-10	Aggregate materials	40	3'240	17	264'679	0.05
Syn-ID-6	Kitchen/food waste	10	29'581	39	604'127	0.11
Syn-ID-11	Kitchen/food waste	229	55'300	1'654	25'862'817	4.71
Syn-ID-12	Kitchen/food waste	10	900	1	18'381	0.00
Syn-ID-519	Kitchen/food waste	10	8	0	163	0.00
Syn-ID-4	Misc. Combustibles	314	21'000	860	13'452'496	2.45
Syn-ID-216	Non-ferrous metal (incl. Aluminium)	0	47'465	0	0	0.00
Syn-ID-317	Plastic (dense)	0	31'680	0	0	0.00
Syn-ID-822	Plastic (dense)	10	20'400	27	416'625	0.08
Syn-ID-721	Wood	10	376	0	7'679	0.00

3.7.4. Greenhouse gas emissions

With the avoided use of primary materials, the avoided disposal, the necessary transport between the synergy partners as well as the additional impacts for recycling, we calculated the net savings of greenhouse gas emissions. The net savings equal the difference between the saved environmental impacts due to avoided use of primary materials as well as avoided disposal and the additional environmental impacts due to the required transport and recycling.

In total, all the synergies facilitated within Sharebox and analysed with a detailed LCA saved 1.05 million tonnes of CO_2-eq. The saved greenhouse gas emissions are the highest for the synergy between Alutrade and BSI enabling the increased reuse of aluminium with 789’000 tonnes of CO_2-eq, followed by the synergy between Recycled UK and Environment Agency increasing plastic recycling with 117’000 tonnes of CO_2-eq.

Third highest greenhouse gas savings has the synergy between Eti and Benli transforming waste rubber to rubber garlands with 91’000 tonnes of CO_2-eq (see Fig. 3.5). The greenhouse gas savings mainly originate from the avoided production of raw materials except in the case of plastics where the avoided disposal causes the higher share of the savings than the avoided raw materials for production. The greenhouse gas savings show a high variance between the different synergies. The additional emissions due to the transport of the materials between the synergy partners does not cause a relevant reduction of saved greenhouse gas emission.

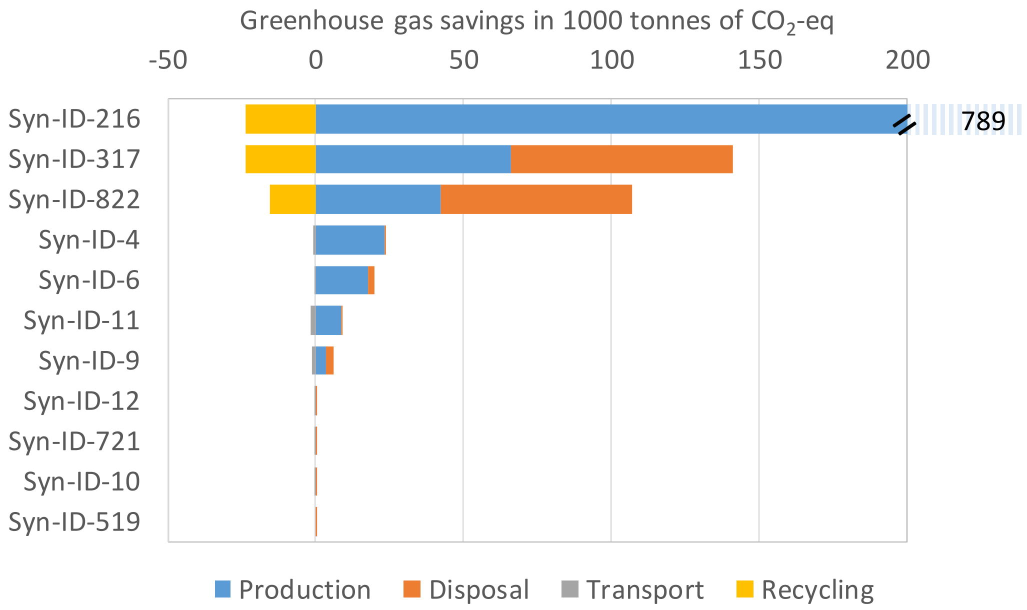


Fig. 3.5: Greenhouse gas savings by individual synergies in 1000 tonnes of CO_2-eq according to IPCC (2013)

3.7.5. Primary energy

In analogy to the net greenhouse gas savings calculation as described in the section above, we also calculated the net savings of primary energy. In total, all the synergies facilitated within Sharebox and analysed with a detailed LCA saved 10'990 TJ oil-eq. The saved primary energy is the highest for the synergy between Alutrade and BSI enabling with 7'300 TJ oil-eq, followed by the synergy between Recycled UK and Environment Agency with 1'990 TJ oil-eq as well as the synergy between Eti and Benli transforming waste with 1'300 TJ oil-eq (see Fig. 3.6). The primary energy savings mainly originate from the avoided production of raw materials. Less than one percent of the total primary energy savings of all synergies come from the avoided waste disposal. The primary energy savings show a high variance between the different synergies not only because of the different amounts of avoided wasted but also due to the material category of the saved primary material. The additional primary energy demand due to the transport of the materials between the synergy partners does not cause a relevant reduction of the primary energy savings.

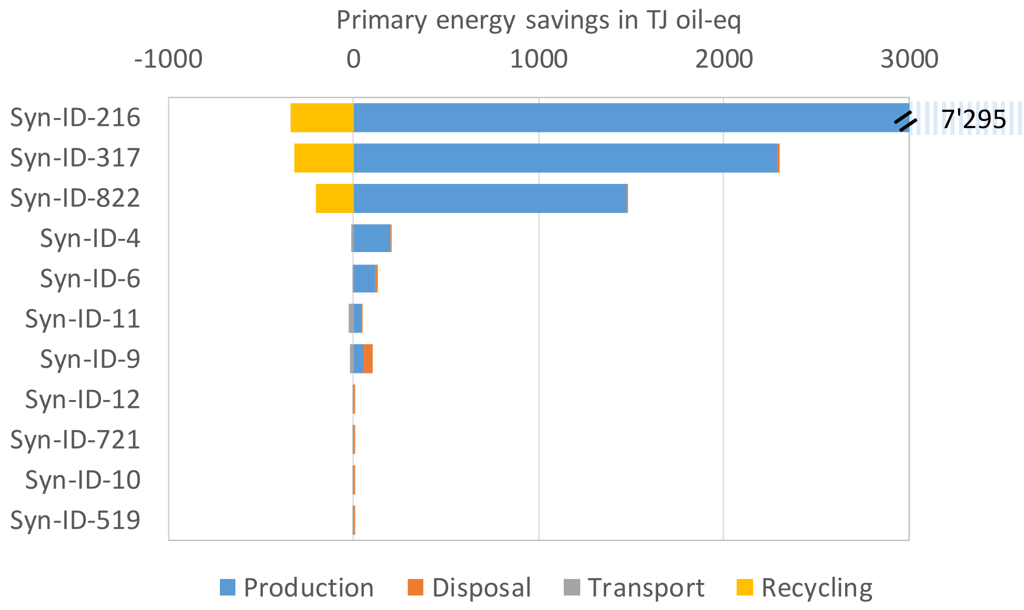


Fig. 3.6: **Primary energy savings by individual synergies in TJ oil-eq according to van Oers & Guinee (2016) and van Oers et al. (2002)**

3.7.6. Mineral resources

The third environmental impact under study was the use of mineral resources. In total, all the synergies facilitated within Sharebox and analysed with a detailed LCA saved 5’590 kg Sb-eq. The saved mineral resources are the highest for the synergy between Recycled UK 2’680 kg Sb-eq, followed by the synergy between Eti and Benli with 1’720 kg Sb-eq and the synergy between Alutrade and BSI with 2’680 kg Sb-eq (see Fig. 3.7). The mineral resource savings mainly originate from the avoided production of raw materials. Less than one percent of the total mineral resource savings of all synergies come from the avoided waste disposal. The difference between the aluminium and plastic saving synergies and the others synergies is even more pronounced for mineral resources compared to greenhouse gas or primary energy. The additional mineral resource use due to transport for the synergy Basta and Eskisehir OIZ is higher than savings due avoided production of primary material and disposal. However, the additional mineral resource use is about equal to the saved mineral resource use leading to only slightly negative net savings with the total of saved mineral resources being to 1.6 kg Sb-eq and the additional mineral resource use due to transport being 2.4 kg Sb-eq.

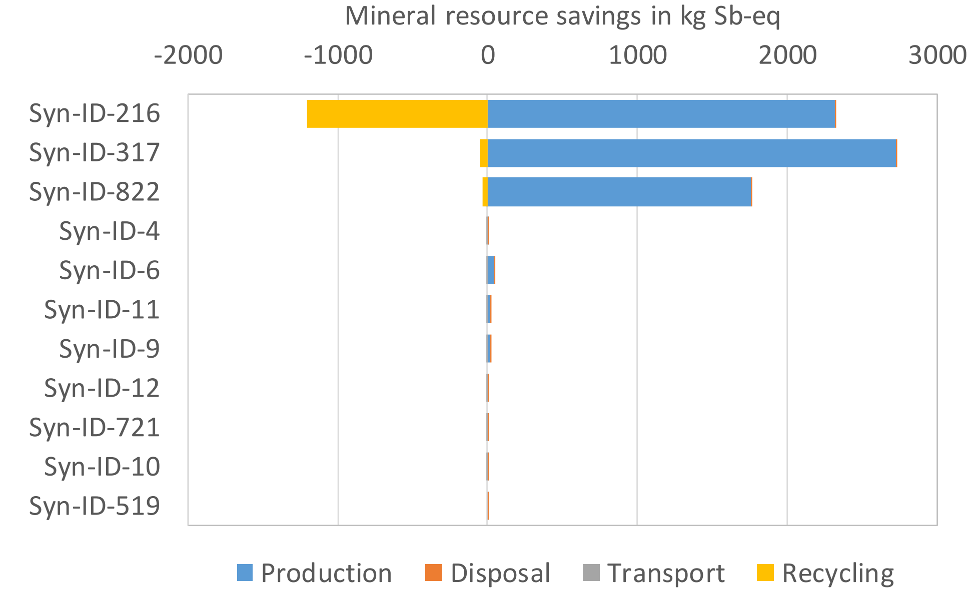


Fig. 3.7: **Mineral resource savings by individual synergies in kg Sb-eq according to van Oers & Guinee (2016) and van Oers et al. (2002)**

3.7.7. Savings according to material categories

The contribution of the individual synergies including categories to the total savings for greenhouse gas emissions, primary energy and mineral resources are shown in Fig. 3.8. Material categories with highest savings are non-ferrous metals, plastics and combustibles. The total savings of greenhouse gas emissions across all synergies equal about 3.5 billion kilometres driven by car. The total primary energy savings across all synergies equal about 2 million barrels of crude oil and the total mineral resource savings across all synergies equal 2 tons of silver, 1800 tons of copper or 45 million tonnes of iron.

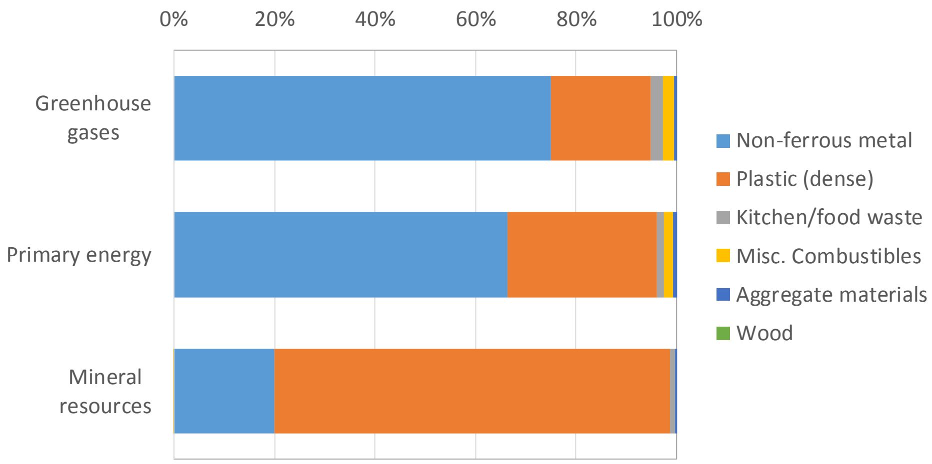


Fig. 3.8: **Summary of carbon, primary energy and mineral resource savings categories**

3.7.8. Summary and discussion of net savings

In order to summarise the results of the individual synergies, we merged the results from section 3.7.4, 3.7.5 and 3.7.6 in Fig. 3.9 . Fig. 3.9 shows the combined results for net savings of greenhouse gas emissions, primary energy and mineral resources grouped according to synergies for an easier comparison of trade-offs between greenhouse gas, primary energy and mineral resource savings. All synergies analysed cause positive net savings for at least two of the three analysed indicators, if additional environmental impacts due to transport and recycling are subtracted as shown in Fig. 3.9. The synergies with relevant transport distances are the synergies between Basta and Eskisehir OIZ, Pinar and Bolvadin as well as Cimsa and Elit.

The synergy between Basta and Eskisehir OIZ is the only synergy with a trade-off meaning that the net savings for greenhouse gas emissions and primary energy are positive whereas the net savings of mineral resources are negative. However, the savings for mineral resources are only slightly negative whereas the net savings for greenhouse gas emissions and primary energy are very high.

Additional impacts to enable the synergy except transports and recycling like filtration or some other sort of beneficiation were not considered.

The saved environmental impacts calculated in this deliverable differ from the savings calculated in Task 6.4.1 due to three major differences being:

1. Different levels of detailed for the individual synergies (average for categories vs specific materials)
2. Emission factors from different databases (ecoinvent v1.2 vs ecoinvent v3.5)
3. The consideration of required transport between the synergy partners
4. The consideration of the recycling process

The methodology used for the calculation of the carbon savings in the Task 6.4.2 Verification of environmental impacts is based on an older version ecoinvent v1.2 (ecoinvent Centre, 2005) and other sources. The different databases and methodology leads to different results for the carbon savings.

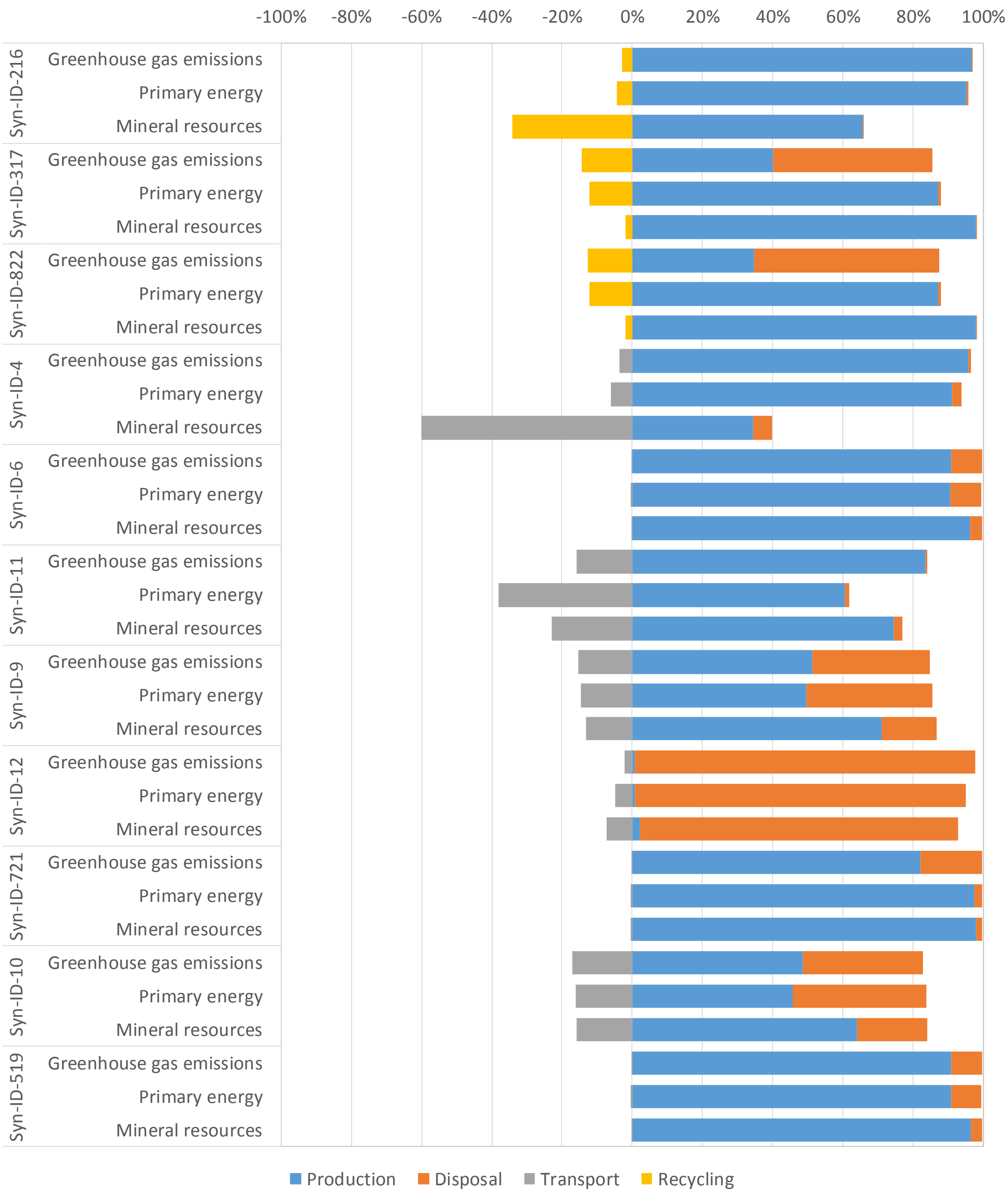


Fig. 3.9: **Comparison of carbon, primary energy and mineral resource savings categories for all synergies divided into the contribution from avoided production, avoided disposal, additional transport and additional recycling**

3.8. Outlook

Overall, the synergies facilitated within Sharebox have no relevant drawback and the synergies cause significant environmental benefits for all the analysed environmental indicators.

Although the environmental impacts of the saved primary materials and disposal are similar for the different material categories (see Table 3.5 and Table 3.6) there can be relevant differences regarding the savings within one material category. Especially for heterogeneous categories like non-ferrous metals which includes metals of different rarities as well energy demands for mining and smelting leading to differences of the saved impacts depending on the material.

In the case of the reuse of materials as alternative raw materials (ARM) or alternative fuel in cement kilns, it is very important to distinguish between the use as ARM or alternative fuel. An alternative fuel will likely replace fossil fuels leading to high greenhouse gas savings, whereas an ARM will very likely replace the environmental impacts associated with the mining activities needed to provide the raw material. This causes significantly lower greenhouse gas and primary energy savings compared to the use of alternative fuels.

The information compiled in the sign-off sheets provides sufficient information for a reliable approximation of the impacts. However, for a detailed assessment more information especially regarding heating or calorific values would be required.

The analysis of the eleven synergies in this report with four examples for kitchen / food waste, two examples for each plastics and aggregate materials each, as well as one example for combustibles, non-ferrous metals and wood does not allow for a generalisation of the saved environmental impacts per category. In order to make a somewhat reliable estimate, 10 or more examples or even more in case of very heterogeneous categories would be required.

As general recommendation, we suggest that all available information on the synergies from the sign-off sheets should be considered for the quantification of saved environmental impacts.

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