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Carbon Footprints of Recycled Solvents

Study for the European Solvent Recycler Group (ESRG)

August 2013

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Title of the study: Carbon footprints of recycled solvents

Client: European Solvent Recycler Group (ESRG)

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Project carried out by: ETHOS Research

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Executive summary

This study presents the results of the carbon footprinting study of six recycled solvents – mixed solvents, acetone, tetrahydrofuran (THF), methyl ethyl ketone (MEK), triethylamine (TEA) and perchloroethylene (PERC) – produced by some of the members of the European Solvent Recycler Group (ESRG). The study has been carried out by ETHOS Research.

The main goal of the study has been to estimate the carbon footprint of six recycled solvents from 'cradle to gate' or 'business to business' considering transport of waste solvents to the recycling plant, the solvent recycling process and the subsequent transport of recycled solvent to the user. Credits for energy recovery are also considered where process wastes are incinerated with heat recovery.

The study is based on the functional unit (unit of analysis) defined as '1,000 kg (1 tonne) of recycled solvent'.

As shown in Figure 1, the average carbon footprint of recycled solvents ranges from 156–798 kg CO_2 eq./t. The main contributor to the total carbon footprint for all six solvents varies. For example, the recycling process is the main contributor for acetone, THF, MEK and TEA, while transport and raw materials are the main contributors for mixed solvents and PERC. For mixed solvents and PERC, the carbon footprint results are sensitive to system credits for heat recovery from waste incineration.

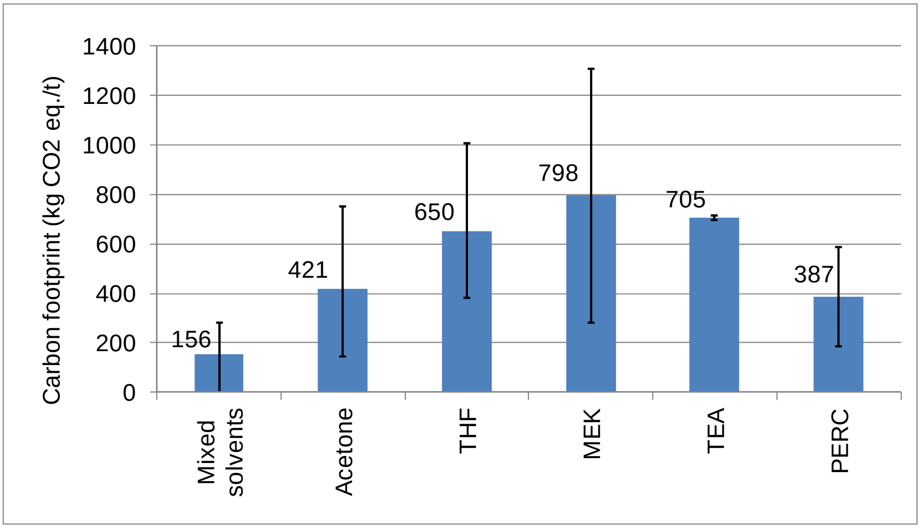

Figure 1 Carbon footprints of all solvents per 1,000 kg of recycled solvent
[The error bars indicate the minimum and maximum values where available. The height of each bar indicates the average value. All figures rounded off.]

Figure 2 compares the average carbon footprint of recycled solvents with their respective virgin solvents. As indicated, recycling of these solvents leads to significant savings of greenhouse gas emissions (ranging from 46-92%) compared to the virgin solvents. However, it should be noted that, although the data for the virgin solvents represent industry averages, they are secondary data taken from databases while the data for recycled solvents are primary data obtained directly from manufacturers. Therefore, the comparisons between the virgin and recycled solvents should be interpreted with this in mind. Nevertheless, as the differences in the carbon footprints are relatively large, the confidence intervals are high enough to render the comparisons robust.

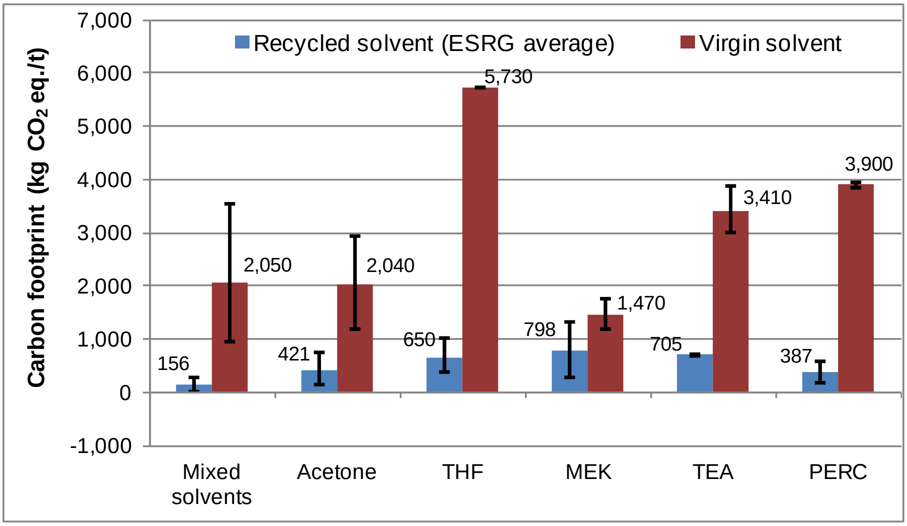

Figure 2 Comparison of the carbon footprints of recycled and virgin solvents
[The error bars indicate the minimum and maximum values where available. The height of each bar indicates the average value. All figures rounded off.]

1 Introduction

This carbon footprinting study has been commissioned by the European Solvent Recycler Group (ESRG) to assess the carbon footprint of recycled solvents produced by some of its members.

This report presents the carbon footprint for six recycled solvents produced by members of the ESRG: mixed solvents, acetone, tetrahydrofuran (THF), methyl ethyl ketone (MEK), triethylamine (TEA) and perchloroethylene (PERC).

Life Cycle Assessment (LCA) has been used to estimate the carbon footprint, following the ISO 14044 [1] methodology. CCaLC V3.0 [2] has been used to model the system and estimate the carbon footprint.

The generic LCA methodology is outlined briefly below. The results of the study for each solvent are presented in Sections 4–9, respectively, and the conclusions are drawn in Section 10.

2 Generic LCA methodology

LCA is conducted by:

- compiling an inventory of relevant inputs and outputs in the life cycle of the system under study; these include materials and energy used in the system and emissions to the environment;
- evaluating the potential environmental impacts associated with those inputs and outputs (e.g. carbon footprint, acidification, etc.); and
- interpreting the results with respect to the goal and scope of the study.

As shown in Figure 2-1, this process comprises four steps [1]:

- Goal and scope definition, in which the intended purpose of the study, the functional unit (unit of analysis) and the system boundaries are defined;
- Inventory analysis which involves collection of data related to the inputs of materials and energy and outputs of emissions to the environment in each life cycle stage considered in the study;
- Impact assessment, in which the inputs and outputs are aggregated into a smaller number of environmental impacts (e.g. carbon footprint, acidification, etc.); and
- Interpretation, in which the LCA results are analysed and opportunities for improvements are identified.

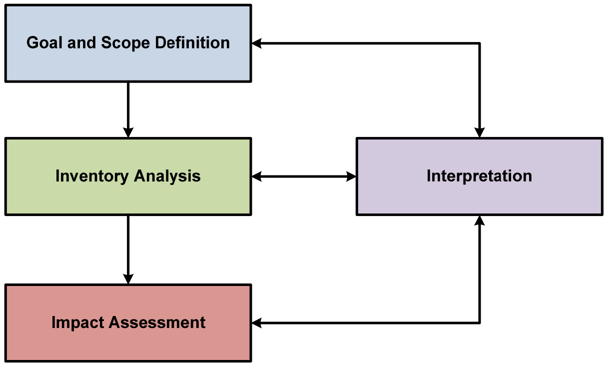

Figure 2-1 The LCA methodology according to the LCA standard ISO 14044 [1]

3 Goal and the scope of the study

The main goal of this study is to assess the carbon footprint of recycled solvents produced by ESRG members. The unit of analysis or functional unit of the study is defined as 1,000 kg (1 tonne) of recycled solvent. The system boundary of the study is from 'cradle to gate' or 'business to business', considering transport of the waste solvent and other raw materials to the solvent recycling plant, the solvent recycling process (including consumption of utilities – electricity, heat/steam and water), waste management of in-process waste streams as well as transport of recycled solvent to the final user.

Figure 3-1 shows a general diagram of the life cycle stages and processes considered for all recycled solvents. The carbon footprint results for each recycled solvent are discussed in the next sections.

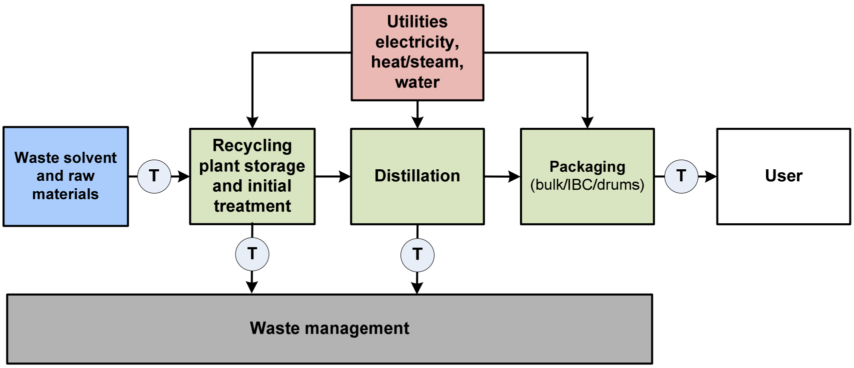

Figure 3-1 Scope of the study and system boundaries for recycling of different solvents

[Use of recycled solvent is not considered]

4 Carbon footprint of recycled mixed solvents

4.1 Inventory analysis

The inventory data for the recycling of mixed solvents have been supplied by some of the ESRG members. The carbon footprint data have been obtained from the CCaLC V3.0 [2] and Ecoinvent V2.2 [3] databases. The following summarises the data used in the study and the assumptions made for filling the data gaps:

- ***Waste solvent, auxiliary raw materials and packaging:*** The data for the waste solvent and raw materials used in their recycling processes as specified by the participating companies are shown in Table 4-1. The waste solvent is transported to the recycling plants in bulk or in different types of packaging, such as drums and IBC (see Table 4-2).
- ***Energy:*** The average data for electricity and steam consumption provided by individual companies are presented in
- Table 4-3. Electricity is assumed as medium voltage from the corresponding national grid while steam is generated using either natural gas or waste solvent. Carbon footprint data for the production of electricity have been sourced from Ecoinvent V2.2 [3] and for the steam from CCaLC V3.0 [2].
- ***Process waste and emissions:*** The inventory for process waste and emissions represents the emissions of solvents from recycling processes, wastewater, packaging waste and other waste such as residues. The average data provided by different companies are summarised in Table 4-4.
- ***Transport:*** The transport modes and distances for delivery of the waste solvent to the recycling plant and recycled solvent to the user have been provided by individual companies. The average transport data are shown in Table 4-5. Other transport data such as transport of raw materials to the recycling plants and waste streams to the waste management facilities have been assumed. The carbon footprint data for transport have been obtained from CCaLC V3.0 [2].

Table 4-1 Data for waste solvent and raw materials (all LCA data from [2])

Raw material	Amount -average- (kg/functional unit)	Amount -ranges- (kg/functional unit)	Comments
Waste solvent (mixed solvents)	1,680	1,210 – 3,030	
Water	2,620	0 – 14,800	Cooling water
Chemicals	0.6	0 – 1.5	H_2SO_4, NaOH, filter aid, etc.

Table 4-2 Data for packaging materials (all LCA data from [2])

Packaging material	Amount -average- (kg/functional unit)	Amount -ranges- (kg/functional unit)	Comments
Drums (HDPE & steel) and IBC	65	0 – 250	Packaging for waste solvent
	20	0 – 85	Packaging for recycled solvent

Table 4-3 Energy data (All LCA data from [2, 3])

Type of energy	Amount -average- (kWh/functional unit)	Amount -ranges- (kWh/functional unit)	Energy source
Electricity	145	72 - 261	National grid
Steam	440	160 - 861	Natural gas and waste solvent

Table 4-4 Process waste and emissions data (all LCA data from [2])

Waste /emissions	Amount -average- (kg/functional unit)	Amount -ranges- (kg/functional unit)	Disposal method
Waste solvent	540	212 – 1,172	Heat recovery on-site and off-site
Wastewater	1,320	0 – 7,800	Off-site treatment
VOCs	1.2	0 – 3.6	Treated and fugitive emissions
Packaging waste	65	0 – 250	Recycling and reuse
Other waste (residues)	135	0 – 820	Incineration

Table 4-5 Transport data (all LCA data from [2])

Material	Distance -average- (km)	Distance -ranges- (km)	Transport mode
Waste solvent (mixed solvents) to recycling plant	270	200 - 370	Truck
Chemicals to recycling plant	50		Truck
Waste solvent to incineration (off-site)	100		Truck
Recycled solvent (mixed solvents) to user	270	200 - 370	Truck

4.2 Carbon footprint results

CCaLC V3.0 [2] has been used to model the system and to estimate the carbon footprint, following the CML 2001 impact assessment method [4]. The latest IPCC [5] global warming factors have been used for the estimation of the carbon footprint. As shown in Figure 4-1, the average carbon footprint of 1,000 kg of recycled mixed solvents has been estimated at 156 kg CO_2 eq. These values range from -2 to 281 kg CO_2 eq. thus reflecting different practices across the companies.

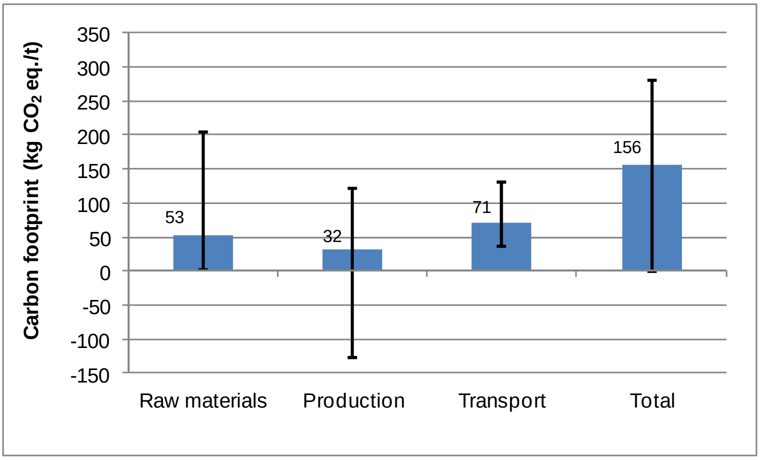

Figure 4-1 Total carbon footprint of 1,000 kg of recycled mixed solvents also showing the breakdown by life cycle stage

[Raw materials include packaging of waste solvent; production includes solvent recycling process, packaging of final product, VOCs emissions and waste management. The error bars indicate the minimum and maximum values while the height of each bar indicates the average value.]

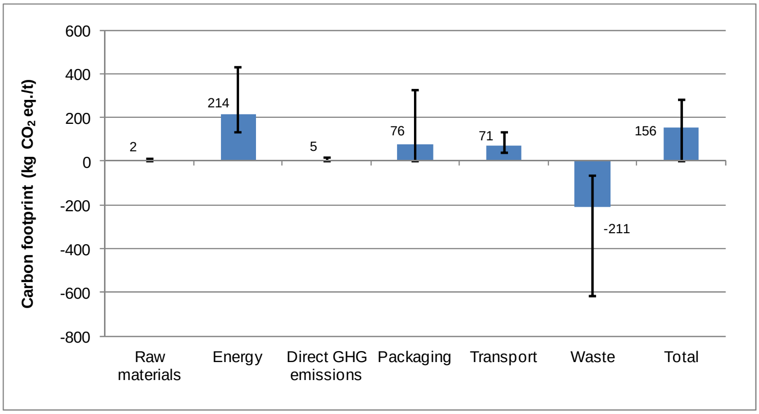

Figure 4-2 Carbon footprint of 1,000 kg of recycled mixed solvents by data category

[Packaging includes packaging of waste solvent and packaging of final product. The error bars indicate the minimum and maximum values while the height of each bar indicates the average value.]

4.2.1 Contribution of different life cycle stages to the carbon footprint

Raw materials and packaging: As shown in Figure 4-1, the average carbon footprint for the raw materials and packaging has been estimated at 53 kg CO_2 eq. The carbon footprint of raw materials and packaging varies hugely across the different companies as these values range from 1 to 200 kg CO_2 eq. This is mostly due to the use of packaging materials (see Figure 4-2).

Solvent recycling: The solvent recycling stage has an average carbon footprint of 32 kg CO_2 eq. as indicated in Figure 4-1. As can be observed from Figure 4-1, the recycling processes vary across different companies as these values range from -127 to 123 kg CO_2 eq. Within this stage, provisions of energy and waste management have the average carbon footprint of 214 and -211 kg CO_2 eq., respectively (see Figure 4-2); the latter has a negative value due to the credits for energy recovery from the waste solvent (see Section 4.2.2 for further detail). The average carbon footprint associated with the treatment and emissions of VOCs amounts to 5 kg CO_2 eq., while the average carbon footprint of packaging used for the product is estimated at 24 kg CO_2 eq.

Transport: The transport stage has the average carbon footprint of 71 kg CO_2 eq. as given in Figure 4-1. As shown, the carbon footprint results for transport range from 37 to 131 kg CO_2 eq. for different companies depending on the quantity of waste solvent transported (see Table 4-1) and the transport distances for waste solvent and recycled solvent (see Table 4-5).

4.2.2 Sensitivity analysis – credits for heat recovery

To examine if the results are sensitive to the assumptions for credits for heat recovery from incineration of waste solvent, different credit options are considered as part of scenario analysis as follows; these results are shown in Figure 4-3:

- ***Reference case (as above):*** Process waste is assumed to be incinerated in cement kilns for heat recovery replacing coal with all the credit for this allocated to the solvent recycling company. For this scenario, the average carbon footprint of recycled mixed solvents is estimated at 156 kg CO_2 eq./t.
- ***Scenario 1:*** The credits for heat recovery from waste incineration are allocated to the cement plant. In this case, the average carbon footprint is equal to 347 kg CO_2 eq./t of recycled solvent.
- ***Scenario 2:*** 50% of the energy credit from waste incineration allocated to the solvent recycling company and the remaining 50% to the cement plant. The average carbon footprint is now equal to 252 kg CO_2 eq./t of recycled solvent.
- ***Scenario 3:*** As the reference case but petroleum coke is assumed as the replaced fuel rather than coal. Under these assumptions, the average carbon footprint is equal to 272 kg CO_2 eq./t of recycled solvent.
- ***Scenario 4:*** As Scenario 2, but instead of coal, petroleum coke is assumed as the replaced fuel. For this scenario, the average carbon footprint is estimated at 309 kg CO_2 eq./t of recycled solvent.

  Therefore, the results are sensitive to the assumptions for heat recovery in the cement kiln and should be interpreted with this in mind.

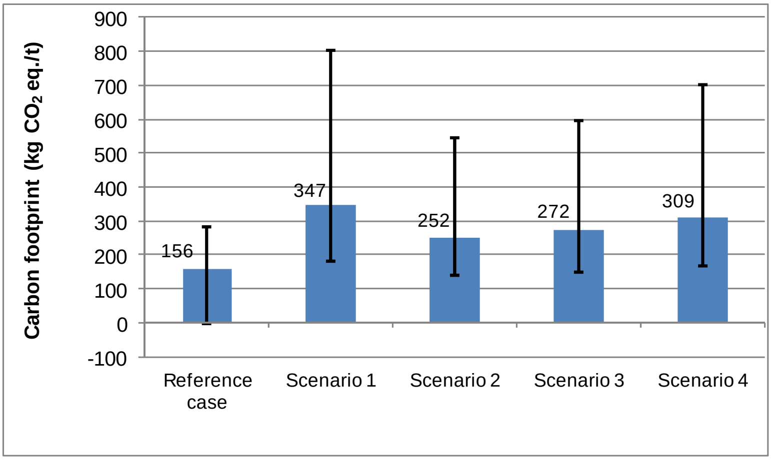

Figure 4-3 Carbon footprint of 1,000 kg of recycled mixed solvents for different credits for heat recovery

[The error bars indicate the minimum and maximum values while the height of each bar indicates the average value.]

4.2.3 Comparison with the virgin solvent

Figure 4-4 compares the average carbon footprint of recycled mixed solvents produced by ESRG members which were part of this study with the virgin solvent. The figure indicates that recycling of mixed solvents saves 92% of greenhouse gas emissions relative to the average emissions associated with the production of virgin solvent.

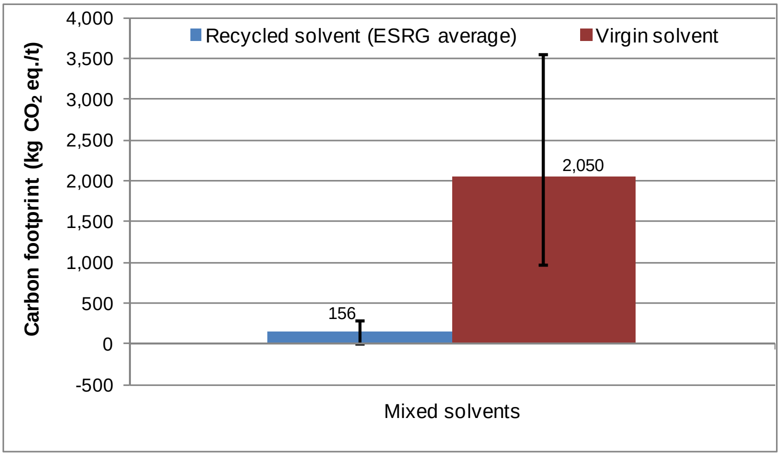

Figure 4-4 Comparison of recycled mixed solvents with the virgin solvent

[Data for the virgin solvent are from Ecoinvent [3]. The error bars indicate the minimum and maximum values while the height of each bar indicates the average value.]

5 Carbon footprint of recycled acetone

5.1 Inventory analysis

The inventory data for the recycling of acetone have been supplied by some of the ESRG members. The carbon footprint data have been obtained from the CCaLC V3.0 [2] and Ecoinvent V2.2 [3] databases. The following summarises the data used in the study and the assumptions made for filling the data gaps:

- ***Waste solvent, auxiliary raw materials and packaging:*** The data for the waste solvent and raw materials used in their recycling processes as specified by the participating companies are shown in Table 5-1. The waste solvent is transported to the recycling plants in bulk or in different types of packaging, such as drums and IBC (see Table 5-2).
- ***Energy:*** The average data for electricity and steam consumption provided by individual companies are presented in Table 5-3. Electricity is assumed as medium voltage from the corresponding national grid while steam is generated using natural gas, light fuel oil or waste solvent. Carbon footprint data for the production of electricity have been sourced from Ecoinvent V2.2 [3] and for the steam from CCaLC V3.0 [2].
- ***Process waste and emissions:*** The inventory for process waste and emissions represents the emissions of solvents from recycling processes, wastewater, packaging waste and other waste such as residues. The average data provided by different companies are summarised in Table 5-4.
- ***Transport:*** The transport modes and distances for delivery of the waste solvent to the recycling plant and recycled solvent to the user have been provided by individual companies. The average transport data are shown in Table 5-5. Other transport data such as transport of raw materials to the recycling plants and waste streams to the waste management facilities have been assumed. The carbon footprint data for transport have been obtained from CCaLC V3.0 [2].

Table 5-1 Data for waste solvent and raw materials (all LCA data from [2])

Raw material	Amount -average- (kg/functional unit)	Amount -ranges- (kg/functional unit)	Comments
Waste solvent (acetone)	1,340	1,200 – 1,700	
Water	2,440	165 – 8,900	Cooling water
Chemicals	13	0 – 50	H_2SO_4 and NaOH

Table 5-2 Data for packaging materials (all LCA data from [2])

Packaging material	Amount -average- (kg/functional unit)	Amount -ranges- (kg/functional unit)	Comments
Drums (HDPE) and IBC	4	0 – 22	Packaging for waste solvent
IBC	12	0 – 60	Packaging for recycled solvent

Table 5-3 Energy data (All LCA data from [2,3])

Type of energy	Amount -average- (kWh/functional unit)	Amount -ranges- (kWh/functional unit)	Energy source
Electricity	150	30 – 475	National grid
Steam	875	310 – 1,500	Natural gas, light fuel oil and waste solvent

Table 5-4 Process waste and emissions data (all LCA data from [2])

Waste /emissions	Amount -average- (kg/functional unit)	Amount -ranges- (kg/functional unit)	Disposal method
Waste solvent	220	0 – 700	Heat recovery on-site and off-site
Wastewater	1,190	10 – 4,800	Off-site treatment and incineration
VOCs	5	0 – 17	Treated and fugitive emissions
Packaging waste	4	0 – 22	Recycling and reuse
Other waste (residues)	24	0 – 120	Recovery plant

Table 5-5 Transport data (all LCA data from [2])

Material	Distance -average- (km)	Distance -ranges- (km)	Transport mode
Waste solvent (acetone) to recycling plant	240	100 – 500	Truck
Chemicals to recycling plant	50		Truck
Waste solvent to incineration (off-site)	100		Truck
Recycled solvent (acetone) to user	240	100 – 500	Truck

5.2 Carbon footprint results

CCaLC V3.0 [2] has been used to model the system and to estimate the carbon footprint, following the CML 2001 impact assessment method [4]. The latest IPCC [5] global warming factors have been used for the estimation of the carbon footprint.

As shown in Figure 5-1, the average carbon footprint of 1,000 kg of recycled Acetone has been estimated at 421 kg CO_2 eq. These values range from 165 to 753 kg CO_2 eq. thus reflecting different practices across the companies.

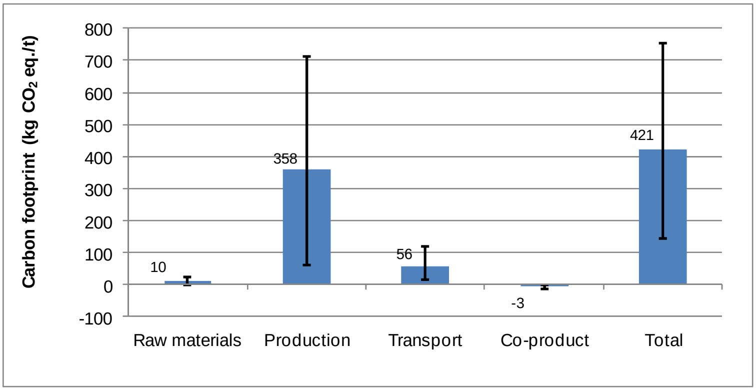

Figure 5-1 Total carbon footprint of 1,000 kg of recycled acetone also showing the breakdown by life cycle stage

[Raw materials include packaging of waste solvent; production includes solvent recycling process, packaging of final product, VOCs emissions and waste management. The error bars indicate the minimum and maximum values while the height of each bar indicates the average value.]

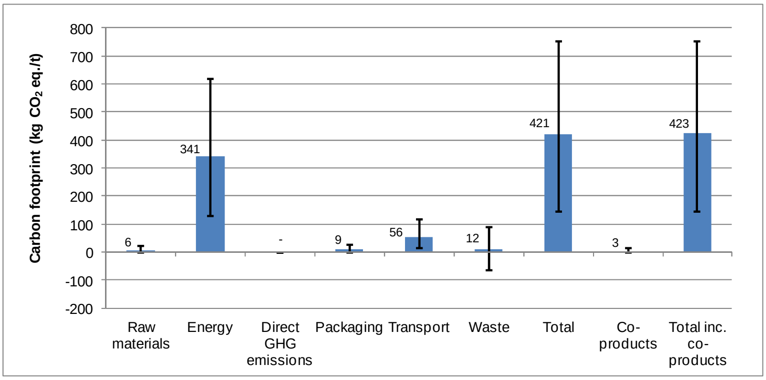

Figure 5-2 Carbon footprint of 1,000 kg of recycled acetone by data category

[Packaging includes packaging of waste solvent and packaging of final product. The error bars indicate the minimum and maximum values while the height of each bar indicates the average value.]

5.2.1 Contribution of different life cycle stages to the carbon footprint

Raw materials and packaging: As shown in Figure 5-1, the average carbon footprint for the raw materials has been estimated at 10 kg CO_2 eq. The carbon footprint contribution of raw materials varies across the different companies as these values range from 0 to 25 kg CO_2 eq. (Figure 5-1). This is mostly due to the use of chemicals and packaging (see Figure 5-2).

Solvent recycling: The solvent recycling stage has an average carbon footprint of 358 kg CO_2 eq. as indicated in Figure 5-1. As can be observed from Figure 5-1, the recycling processes vary across different companies as these values range from 62 to 710 kg CO_2 eq. Within this stage, provisions of energy and waste management have the average carbon footprint of 341 and 12 kg CO_2 eq., respectively (see

Figure 5-2). The carbon footprint of waste management includes credits for energy recovery from the waste solvent (see Section 5.2.2 for further detail).

Transport: The transport stage has the average carbon footprint of 56 kg CO_2 eq. as given in Figure 5-1. As shown, the carbon footprint results for transport range from 14 to 118 kg CO_2 eq. for different companies depending on the quantity of waste solvent transported (see Table 5-1) and the transport distances for waste solvent and recycled solvent (see Table 5-5).

5.2.2 Sensitivity analysis – credits for heat recovery

To examine if the results are sensitive to the assumptions for credits for heat recovery from incineration of waste solvent, different credit options are considered as part of scenario analysis as follows; these results are shown in Figure 5-3:

- ***Reference case (as above):*** Process waste is assumed to be incinerated in cement kilns for heat recovery replacing coal with all the credit for this allocated to the solvent recycling company. For this scenario, the average carbon footprint of recycled acetone is estimated at 421 kg CO_2 eq./t.
- ***Scenario 1:*** The credits for heat recovery from waste incineration are allocated to the cement plant. In this case, the average carbon footprint is equal to 441 kg CO_2 eq./t of recycled solvent.
- ***Scenario 2:*** 50% of the energy credit from waste incineration allocated to the solvent recycling company and the remaining 50% to the cement plant. The average carbon footprint is now equal to 431 kg CO_2 eq./t of recycled solvent.
- ***Scenario 3:*** As the reference case but petroleum coke is assumed as the replaced fuel rather than coal. Under these assumptions, the average carbon footprint is equal to 434 kg CO_2 eq./t of recycled solvent.
- ***Scenario 4:*** As Scenario 2, but instead of coal, petroleum coke is assumed as the replaced fuel. For this scenario, the average carbon footprint is estimated at 437 kg CO_2 eq./t of recycled solvent.

Therefore, the results are not sensitive to the assumptions for the credits for energy recovery.

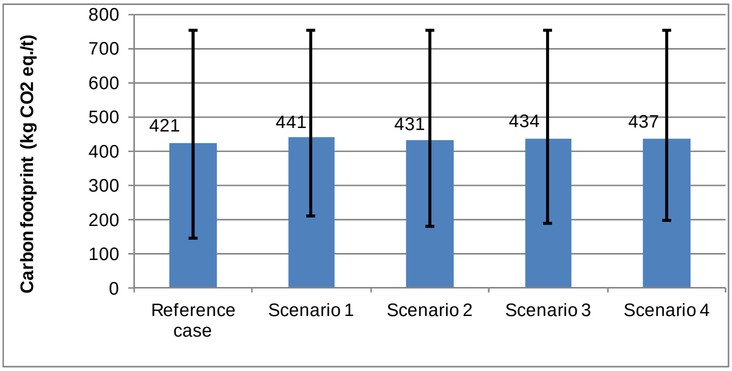

Figure 5-3 Carbon footprint of 1,000 kg of recycled acetone for different credits for heat recovery

5.2.3 Comparison with the virgin solvent

Figure 5-4 compares the average carbon footprint of recycled acetone produced by ESRG members which were part of this study with the virgin solvent. The figure indicates that recycling of acetone saves 79% of greenhouse gas emissions relative to the average emissions associated with the production of virgin solvent.

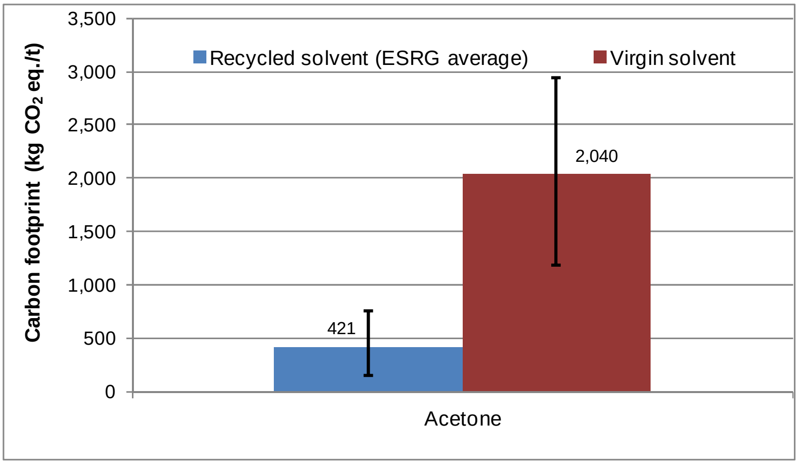

Figure 5-4 Comparison of recycled Acetone with the virgin solvent
[Data for the virgin solvent from Ecoinvent [3]. The error bars indicate the minimum and maximum values while the height of each bar indicates the average value.]

6 Carbon footprint of recycled tetrahydrofuran

6.1 Inventory analysis

The inventory data for the recycling of tetrahydrofuran (THF) have been supplied by some of the ESRG members. The carbon footprint data have been obtained from the CCaLC V3.0 [2] and Ecoinvent V2.2 [3] databases. The following summarises the data used in the study and the assumptions made for filling the data gaps:

- ***Waste solvent, auxiliary raw materials and packaging:*** The data for the waste solvent and raw materials used in their recycling processes as specified by the participating companies are shown in Table 6-1. The waste solvent is transported to the recycling plants in bulk or in different types of packaging, such as drums and IBC (see Table 6-2).
- ***Energy:*** The average data for electricity and steam consumption provided by individual companies are presented in Table 6-3. Electricity is assumed as medium voltage from the corresponding national grid while steam is generated using natural gas, light fuel oil or waste solvent. Carbon footprint data for the production of electricity have been sourced from Ecoinvent V2.2 [3] and for the steam from CCaLC V3.0 [2].
- ***Process waste and emissions:*** The inventory for process waste and emissions represents the emissions of solvents from recycling processes, wastewater,

packaging waste and other waste such as residues. The average data provided by different companies are summarised in Table 6-4.

Transport: **The transport modes and distances for delivery of the waste solvent to the recycling plant and recycled solvent to the user have been provided by individual companies. The average transport data are shown in**

- Table 6-5. Other transport data such as transport of raw materials to the recycling plants and waste streams to the waste management facilities have been assumed. The carbon footprint data for transport systems have been obtained from CCaLC V3.0 [2].

Table 6-1 Data for waste solvent and raw materials (all LCA data from [2])

Raw material	Amount -average- (kg/functional unit)	Amount -ranges- (kg/functional unit)	Comments
Waste solvent (THF)	1,870	1,150 – 3,500	
Water	40,250	500 – 170,000	Cooling water
Chemicals	44	0 – 150	NaOH, entrainers and stabilizers

Table 6-2 Data for packaging materials (all LCA data from [2])

Packaging material	Amount -average- (kg/functional unit)	Amount -ranges- (kg/functional unit)	Comments
Drums (steel) and IBC	8	0 – 37	Packaging for waste solvent

Table 6-3 Energy data (All LCA data from [2, 3])

Type of energy	Amount -average- (kWh/functional unit)	Amount -ranges- (kWh/functional unit)	Energy source
Electricity	126	66 – 193	National grid
Steam	1,450	400 – 3,000	Natural gas, light fuel oil and waste solvent

Table 6-4 Process waste and emissions data (all LCA data from [2])

Waste /emissions	Amount -average- (kg/functional unit)	Amount -ranges- (kg/functional unit)	Disposal method
Waste solvent	180	30 – 400	Heat recovery on-site and off-site
Wastewater	3,690	50 – 16,275	Off-site treatment and incineration
VOCs	7	0 – 33	Treated and fugitive emissions
Packaging waste	8	0 – 37	Recycling and reuse
Waste (residues)	54	0 – 270	Handled as co-products

Table 6-5 Transport data (all LCA data from [2])

Material	Distance -average- (km)	Distance -ranges- (km)	Transport mode
Waste solvent (THF) to recycling plant	770	20 – 2,400	Container ship, ferry and Truck
Chemicals to recycling plant	50		Truck
Waste solvent to incineration (off-site)	100		Truck
Recycled solvent (THF) to user	770	20 – 2,400	Container ship, ferry and Truck

6.2 Carbon footprint results

CCaLC V3.0 [2] has been used to model the system and to estimate the carbon footprint, following the CML 2001 impact assessment method [4]. The latest IPCC [5] global warming factors have been used for the estimation of the carbon footprint.

As shown in Figure 6-1, the average carbon footprint of 1,000 kg of recycled THF has been estimated at 650 kg CO_2 eq. These values range from 383 to 1,007 kg CO_2 eq. thus reflecting different practices across the companies.

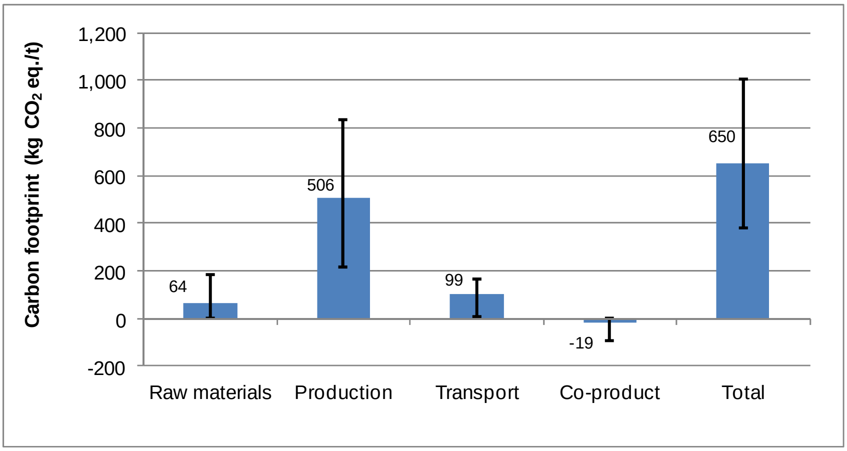

Figure 6-1 Total carbon footprint of 1,000 kg of recycled THF also showing the breakdown by life cycle stage

[Raw materials include packaging of waste solvent; production includes solvent recycling process, VOCs emissions and waste management. The error bars indicate the minimum and maximum values while the height of each bar indicates the average value.]

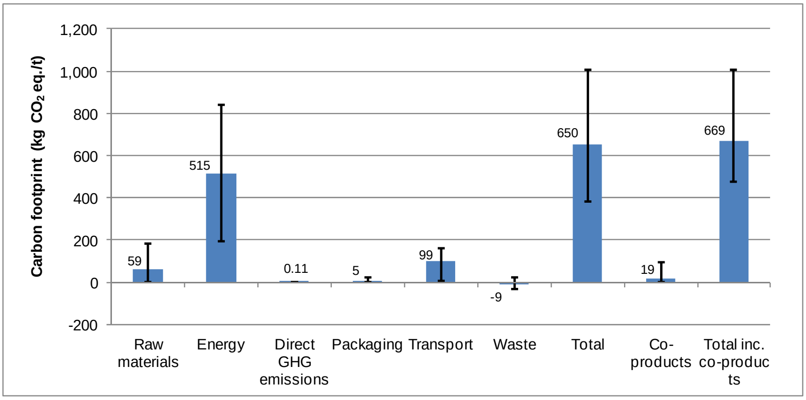

Figure 6-2 Carbon footprint of 1,000 kg of recycled THF by data category
[The error bars indicate the minimum and maximum values while the height of each bar indicates the average value.]

6.2.1 Contribution of different life cycle stages to the carbon footprint

Raw materials and packaging: As shown in Figure 6-1, the average carbon footprint for the raw materials has been estimated at 64 kg CO_2 eq. The carbon footprint of raw materials varies across the different companies as these values range from 2 to 182 kg CO_2 eq. This is mostly due to the use of chemicals (see Figure 6-2).

Solvent recycling: The solvent recycling stage has an average carbon footprint of 506 kg CO_2 eq. as indicated in Figure 6-1. As can be observed from Figure 6-1, the recycling processes vary across different companies as these values range from 215 to 836 kg CO_2 eq. Within this stage, provisions of energy and waste management have the average carbon footprint of 515 and -9 kg CO_2 eq., respectively (see Figure 6-2); the latter has a negative value due to the credits for energy recovery from the waste solvent (see Section 6.2.2 for further detail).

Transport: **The transport stage has the average carbon footprint of 99 kg CO_2 eq. as given in Figure 6-1. As shown, the carbon footprint results for transport range from 5 to 162 kg CO_2 eq. for different companies depending on the quantity of waste solvent recycled (see Table 6-1) and the transport distances for waste solvent and recycled solvent (see**

Table 6-5).

6.2.2 Sensitivity analysis – credits for heat recovery

To examine if the results are sensitive to the assumptions for credits for heat recovery from incineration of waste solvent, different credit options are considered as part of scenario analysis as follows; these results are shown in Figure 6-3:

- ***Reference case (as above):*** Process waste is assumed to be incinerated in cement kilns for heat recovery replacing coal with all the credit for this allocated to the solvent recycling company. For this scenario, the average carbon footprint of recycled THF is estimated at 650 kg CO_2 eq./t.
- ***Scenario 1:*** The credits for heat recovery from waste incineration are allocated to the cement plant. In this case, the average carbon footprint is equal to 685 kg CO_2 eq./t of recycled solvent.
- ***Scenario 2:*** 50% of the energy credit from waste incineration allocated to the solvent recycling company and the remaining 50% to the cement plant. The average carbon footprint is now equal to 668 kg CO_2 eq./t of recycled solvent.
- ***Scenario 3:*** As the reference case but petroleum coke is assumed as the replaced fuel rather than coal. Under these assumptions, the average carbon footprint is equal to 674 kg CO_2 eq./t of recycled solvent.
- ***Scenario 4:*** As Scenario 2, but instead of coal, petroleum coke is assumed as the replaced fuel. For this scenario, the average carbon footprint is estimated at 679 kg CO_2 eq./t of recycled solvent.

Therefore, the results are not sensitive to the assumptions for the credits for energy recovery.

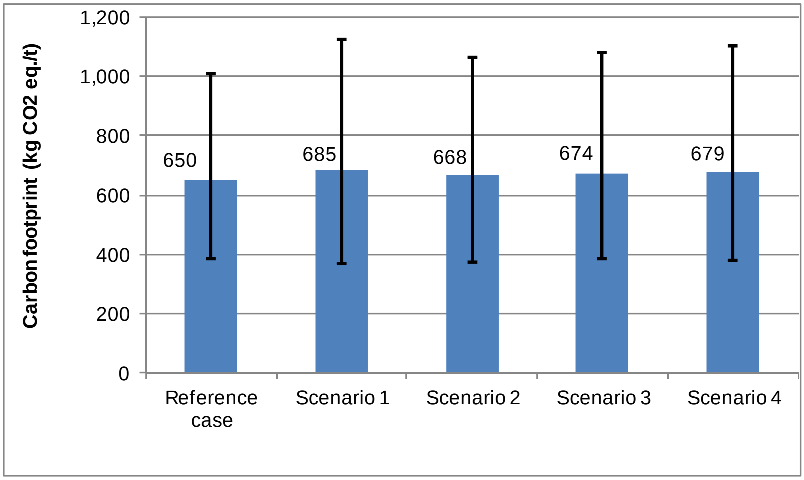

Figure 6-3 Carbon footprint of 1,000 kg of recycled THF for different credits for heat recovery

[The error bars indicate the minimum and maximum values while the height of each bar indicates the average value.]

6.2.3 Comparison with the virgin solvent

Figure 6-4 compares the average carbon footprint of recycled THF produced by ESRG members which were part of this study with the virgin solvent. The figure indicates that recycling of THF saves 89% of greenhouse gas emissions relative to the average emissions associated with the production of virgin solvent.

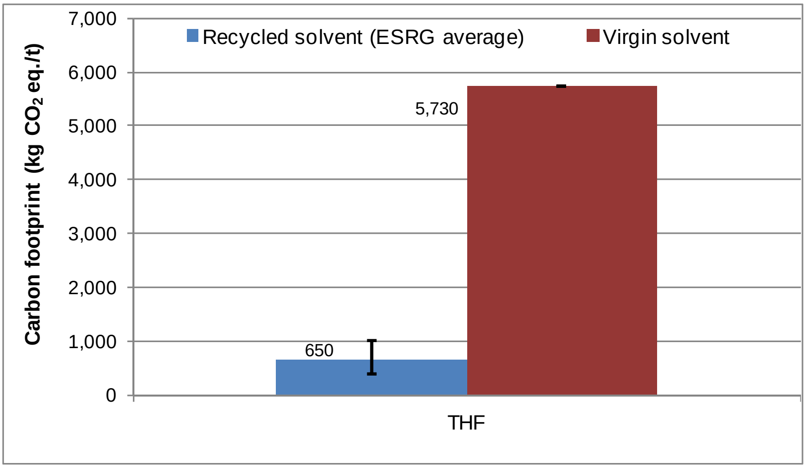

Figure 6-4 Comparison of recycled THF with the virgin solvent
[Data for the virgin solvent from Ecoinvent [3]. The error bars indicate the minimum and maximum values while the height of each bar indicates the average value.]

7 Carbon footprint of recycled methyl ethyl ketone

7.1 Inventory analysis

The inventory data for the recycling of methyl ethyl ketone (MEK) have been supplied by some of the ESRG members. The carbon footprint data have been obtained from the CCaLC V3.0 [2] and Ecoinvent V2.2 [3] databases. The following summarises the data used in the study and the assumptions made for filling the data gaps:

- ***Waste solvent and auxiliary raw materials:*** The data for the waste solvent and raw materials used in their recycling processes as specified by the participating companies are shown in Table 7-1. The waste solvent is transported in bulk to all recycling plants.
- ***Energy:*** The average data for electricity and steam consumption provided by individual companies are presented in Table 7-2. Electricity is assumed as medium voltage from the corresponding national grid while steam is generated using either natural gas or light fuel oil. Carbon footprint data for the production of electricity have been sourced from Ecoinvent V2.2 [3] and for the steam from CCaLC V3.0 [2].
- ***Process waste and emissions:*** The inventory for process waste and emissions represents the emissions of solvents from recycling processes, wastewater and other waste such as residues. The average data provided by different companies are summarised in
- Table 7-3.
- ***Transport:*** The transport modes and distances for delivery of the waste solvent to the recycling plant and recycled solvent to the user have been provided by individual companies. The average transport data are shown in Table 7-4. Other transport data such as transport of raw materials to the recycling plants and

waste streams to the waste management facilities have been assumed. The carbon footprint data for transport systems have been obtained from CCaLC V3.0 [2].

Table 7-1 Data for waste solvent and raw materials (all LCA data from [2])

Raw material	Amount -average- (kg/functional unit)	Amount -ranges- (kg/functional unit)	Comments
Waste solvent (MEK)	1,670	1,180 – 2,590	
Water	1,090	310 – 2,540	Cooling water
Chemicals	57	2 – 120	NaOH and entrainers

Table 7-2 Energy data (All LCA data from [2, 3])

Type of energy	Amount -average- (kWh/functional unit)	Amount -ranges- (kWh/functional unit)	Energy source
Electricity	270	60 – 670	National grid
Steam	1,620	320 – 2,280	Natural gas and light fuel oil

Table 7-3 Process waste and emissions data (all LCA data from [2])

Waste /emissions	Amount -average- (kg/functional unit)	Amount -ranges- (kg/functional unit)	Disposal method
Waste solvent	530	0 – 1,590	Heat recovery on-site and off-site
Wastewater	405	75 – 915	Off-site treatment and incineration
VOCs	8	0 – 22	Treated and fugitive emissions
Other waste (residues)	63	0 – 120	Incineration

Table 7-4 Transport data (all LCA data from [2])

Material	Distance -average- (km)	Distance -ranges- (km)	Transport mode
Waste solvent (MEK) to recycling plant	390	100 – 560	Truck
Chemicals to recycling plant	50		Truck
Waste solvent to incineration (off-site)	100		Truck
Recycled solvent (MEK) to user	390	100 – 560	Truck

7.2 Carbon footprint results

CCaLC V3.0 [2] has been used to model the system and to estimate the carbon footprint, following the CML 2001 impact assessment method [4]. The latest IPCC [5] global warming factors have been used for the estimation of the carbon footprint.

As shown in Figure 7-1, the average carbon footprint of 1,000 kg of recycled MEK has been estimated at 798 kg CO_2 eq. These values range from 281 to 1,309 kg CO_2 eq. thus reflecting different practices across the companies.

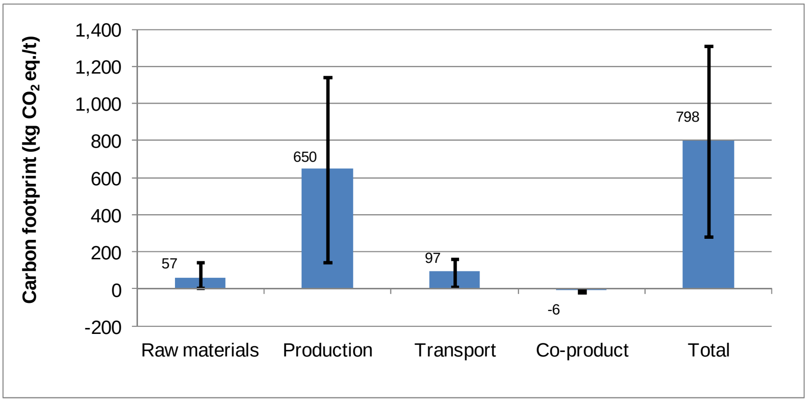

Figure 7-1 Total carbon footprint of 1,000 kg of recycled MEK also showing the breakdown by life cycle stage
[Production includes solvent recycling process, VOCs emissions and waste management. The error bars indicate the minimum and maximum values while the height of each bar indicates the average value.]

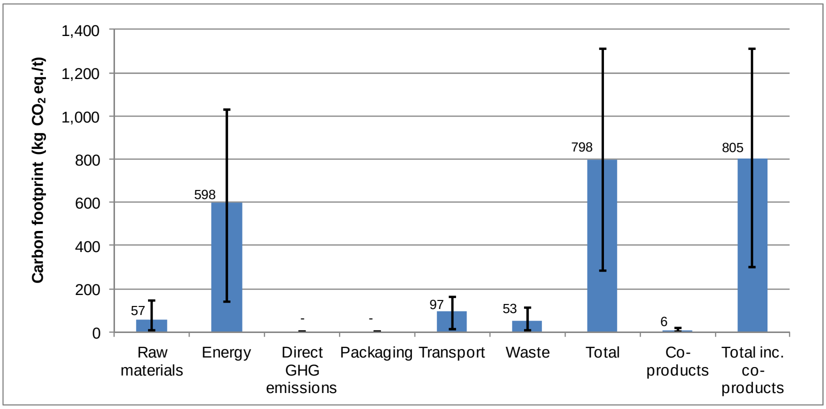

Figure 7-2 Carbon footprint of 1,000 kg of recycled MEK by data category
[The error bars indicate the minimum and maximum values while the height of each bar indicates the average value.]

7.2.1 Contribution of different life cycle stages to the carbon footprint

Raw materials and packaging: As shown in Figure 7-1, the average carbon footprint for the raw materials has been estimated at 57 kg CO_2 eq. because of the use of chemicals. The carbon footprint of raw materials varies across the different companies as these values range from 5 to 145 kg CO_2 eq.

Solvent recycling: The solvent recycling stage has an average carbon footprint of 650 kg CO_2 eq. as indicated in Figure 7-1. As can be observed from Figure 7-1, the recycling processes vary across different companies as these values range from 143 to 1,142 kg CO_2 eq. Within this stage, provisions of energy and waste management have the average carbon footprint of 598 and 53 kg CO_2 eq., respectively (see Figure 7-2Figure 6-2). The carbon footprint of waste management includes credits for energy recovery from the waste solvent (see Section 7.2.2 for further detail).
Transport: The transport stage has the average carbon footprint of 97 kg CO_2 eq. as given in Figure 7-1. As shown, the carbon footprint results for transport range from 13 to 118 kg CO_2 eq. for different companies depending on the quantity of waste solvent recycled (see Table 7-1) and the transport distances for waste solvent and recycled solvent (see Table 7-4).

7.2.2 Sensitivity analysis – credits for heat recovery

To examine if the results are sensitive to the assumptions for credits for heat recovery from incineration of waste solvent, different credit options are considered as part of scenario analysis as follows; these results are shown in Figure 7-3:

- ***Reference case (as above):*** Process waste is assumed to be incinerated in cement kilns for heat recovery replacing coal with all the credit for this allocated to the solvent recycling company. For this scenario, the average carbon footprint of recycled MEK is estimated at 798 kg CO_2 eq./t.
- ***Scenario 1:*** The credits for heat recovery from waste incineration are allocated to the cement plant. In this case, the average carbon footprint is equal to 802 kg CO_2 eq./t of recycled solvent.
- ***Scenario 2:*** 50% of the energy credit from waste incineration allocated to the solvent recycling company and the remaining 50% to the cement plant. The average carbon footprint is now equal to 800 kg CO_2 eq./t of recycled solvent.
- ***Scenario 3:*** As the reference case but petroleum coke is assumed as the replaced fuel rather than coal. Under these assumptions, the average carbon footprint is equal to 805 kg CO_2 eq./t of recycled solvent.
- ***Scenario 4:*** As Scenario 2, but instead of coal, petroleum coke is assumed as the replaced fuel. For this scenario, the average carbon footprint is estimated at 804 kg CO_2 eq./t of recycled solvent.

Therefore, the results are not sensitive to the assumptions for the credits for energy recovery.

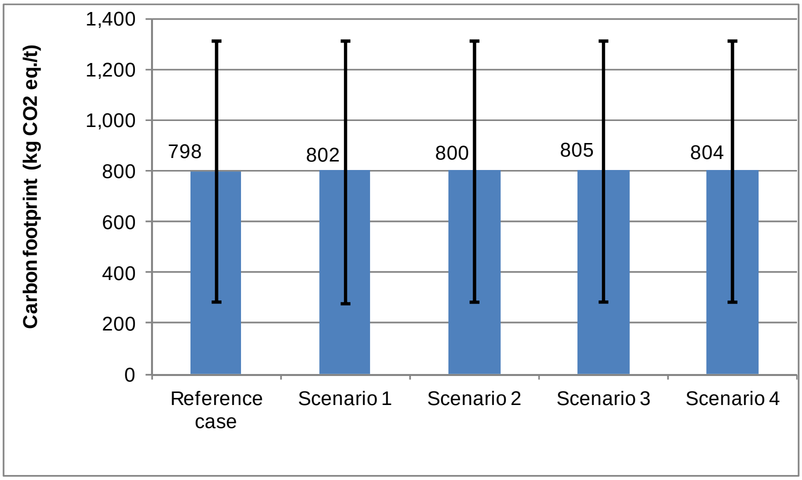

Figure 7-3 Carbon footprint of 1,000 kg of recycled MEK for different credits for heat recovery

[The error bars indicate the minimum and maximum values while the height of each bar indicates the average value.]

7.2.3 Comparison with the virgin solvent

Figure 7-4 compares the average carbon footprint of recycled MEK produced by ESRG members which were part of this study with the virgin solvent. The figure indicates that recycling of MEK saves 46% of greenhouse gas emissions relative to the average emissions associated with the production of virgin solvent.

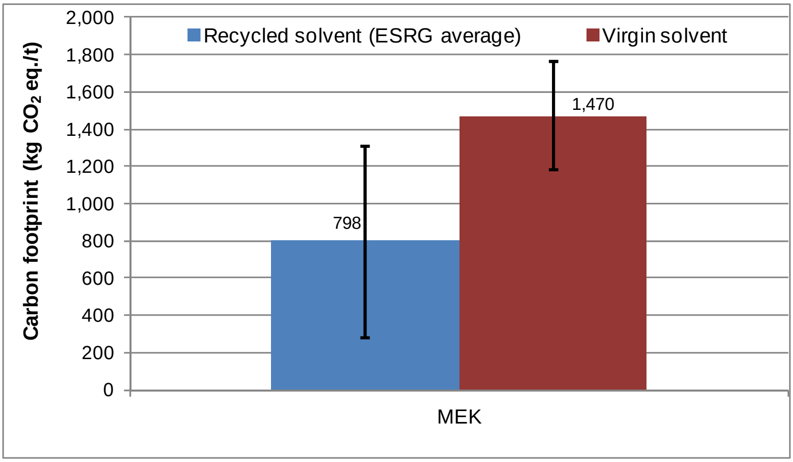

Figure 7-4 Comparison of recycled MEK with virgin MEK

[Data for the virgin solvent from Ecoinvent [3]. The error bars indicate the minimum and maximum values while the height of each bar indicates the average value.]

8 Carbon footprint of recycled triethylamine

8.1 Inventory analysis

The inventory data for the recycling of triethylamine (TEA) have been supplied by some of the ESRG members. The carbon footprint data have been obtained from the CCaLC V3.0 [2] and Ecoinvent V2.2 [3] databases. The following summarises the data used in the study and the assumptions made for filling the data gaps:

- ***Waste solvent and auxiliary raw materials:*** The data for the waste solvent and raw materials used in their recycling processes as specified by the participating companies are shown in Table 8-1. The waste solvent is transported in bulk to all recycling plants.
- ***Energy:*** The average data for electricity and steam consumption provided by individual companies are presented in Table 8-2. Electricity is assumed as medium voltage from the corresponding national grid while steam is generated using either natural gas or waste solvent. Carbon footprint data for the production of electricity have been sourced from Ecoinvent V2.2 [3] and for the steam from CCaLC V3.0 [2].
- ***Process waste and emissions:*** The inventory for process waste and emissions represents the emissions of solvents from recycling processes and wastewater. The average data provided by different companies are summarised in Table 8-3.
- ***Transport:*** The transport modes and distances for delivery of the waste solvent to the recycling plant and recycled solvent to the user have been provided by individual companies. The average transport data are shown in Table 8-4. Other transport data such as transport of raw materials to the recycling plants and waste streams to the waste management facilities have been assumed. The carbon footprint data for transport systems have been obtained from CCaLC V3.0 [2].

Table 8-1 Data for waste solvent and raw materials (all LCA data from [2])

Raw material	Amount -average- (kg/functional unit)	Amount -ranges- (kg/functional unit)	Comments
Waste solvent (TEA)	1,290	1,130 – 1,450	
Water	76,220	2,440 – 150,000	Cooling water

Table 8-2 Energy data (All LCA data from [2, 3])

Type of energy	Amount -average- (kWh/functional unit)	Amount -ranges- (kWh/functional unit)	Energy source
Electricity	76	60 – 90	National grid
Steam	2,000	1,750 – 2,250	Natural gas and waste solvent

Table 8-3 Process waste and emissions data (all LCA data from [2])

Waste /emissions	Amount -average- (kg/functional unit)	Amount -ranges- (kg/functional unit)	Disposal method
Waste solvent	173	45 – 300	Heat recovery on-site and off-site
Wastewater	473	85 – 860	Off-site treatment and incineration
VOCs	9	0 – 17	Treated and fugitive emissions

Table 8-4 Transport data (all LCA data from [2])

Material	Distance -average- (km)	Distance -ranges- (km)	Transport mode
Waste solvent (TEA) to recycling plant	250	0 – 500	Truck and pipeline
Chemicals to recycling plant	50		Truck
Waste solvent to incineration (off-site)	100		Truck
Recycled solvent (TEA) to user	250	0 – 500	Truck and pipeline

8.2 Carbon footprint results

CCaLC V3.0 [2] has been used to model the system and to estimate the carbon footprint, following the CML 2001 impact assessment method [4]. The latest IPCC [5] global warming factors have been used for the estimation of the carbon footprint. As shown in Figure 8-1, the average carbon footprint of 1,000 kg of recycled TEA has been estimated at 705 kg CO_2 eq. These values range from 697 to 713 kg CO_2 eq. thus reflecting similar practices across the companies.

8.2.1 Contribution of different life cycle stages to the carbon footprint

Raw materials: As shown in Figure 8-1, the average carbon footprint for the raw materials has been estimated at 13 kg CO_2 eq. because of the use of chemicals. The carbon footprint of raw materials varies across the different companies as these values range from 0 to 25 kg CO_2 eq.

Solvent recycling: The solvent recycling stage has an average carbon footprint of 628 kg CO_2 eq. as indicated in Figure 8-1. As can be observed from Figure 8-1, the recycling processes differs slightly across different companies as these values range from 584 to 672 kg CO_2 eq. Within this stage, provisions of energy and waste management have the average carbon footprint of 650 and -22 kg CO_2 eq., respectively (see Figure 8-2); the latter has a negative value due to the credits for energy recovery from the waste solvent (see Section 8.2.2 for further detail).

Transport: The transport stage has the average carbon footprint of 64 kg CO_2 eq. as given in Figure 8-1. As shown, the carbon footprint results for transport range from 0 to 129 kg CO_2 eq. for different companies depending on the quantity of waste solvent transported (see Table 8-1), the modes of transport and distances for waste solvent and recycled solvent (see Table 8-4).

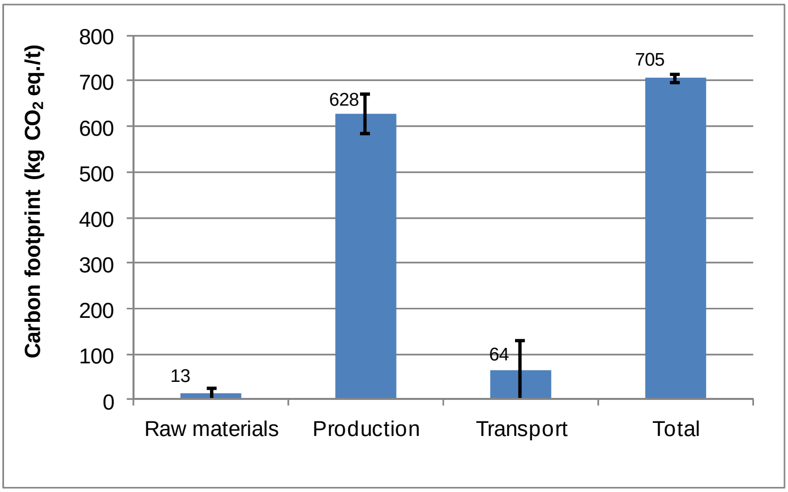

Figure 8-1 Total carbon footprint of 1,000 kg of recycled TEA also showing the breakdown by life cycle stage

[Production includes solvent recycling process, VOCs emissions and waste management. The error bars indicate the minimum and maximum values while the height of each bar indicates the average value.]

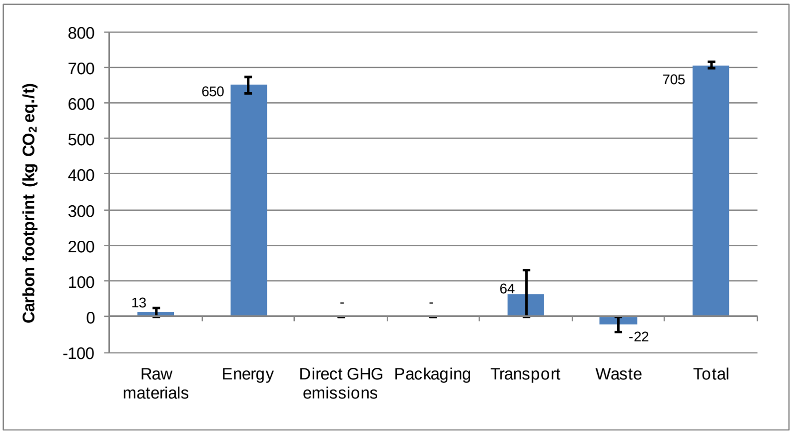

Figure 8-2 Carbon footprint of 1,000 kg of recycled TEA by data category

[The error bars indicate the minimum and maximum values while the height of each bar indicates the average value.]

8.2.2 Sensitivity analysis – credits for heat recovery

To examine if the results are sensitive to the assumptions for credits for heat recovery from incineration of waste solvent, different credit options are considered as part of scenario analysis as follows; these results are shown in Figure 8-3:

- ***Reference case (as above):*** Process waste is assumed to be incinerated in cement kilns for heat recovery replacing coal with all the credit for this allocated to the solvent recycling company. For this scenario, the average carbon footprint of recycled TEA is estimated at 705 kg CO_2 eq./t.
- ***Scenario 1:*** The credits for heat recovery from waste incineration are allocated to the cement plant. In this case, the average carbon footprint is equal to 750 kg CO_2 eq./t of recycled solvent.
- ***Scenario 2:*** 50% of the energy credit from waste incineration allocated to the solvent recycling company and the remaining 50% to the cement plant. The average carbon footprint is now equal to 728 kg CO_2 eq./t of recycled solvent.
- ***Scenario 3:*** As the reference case but petroleum coke is assumed as the replaced fuel rather than coal. Under these assumptions, the average carbon footprint is equal to 732 kg CO_2 eq./t of recycled solvent.
- ***Scenario 4:*** As Scenario 2, but instead of coal, petroleum coke is assumed as the replaced fuel. For this scenario, the average carbon footprint is estimated at 741 kg CO_2 eq./t of recycled solvent.

Therefore, the results are not sensitive to the assumptions for the credits for energy recovery.

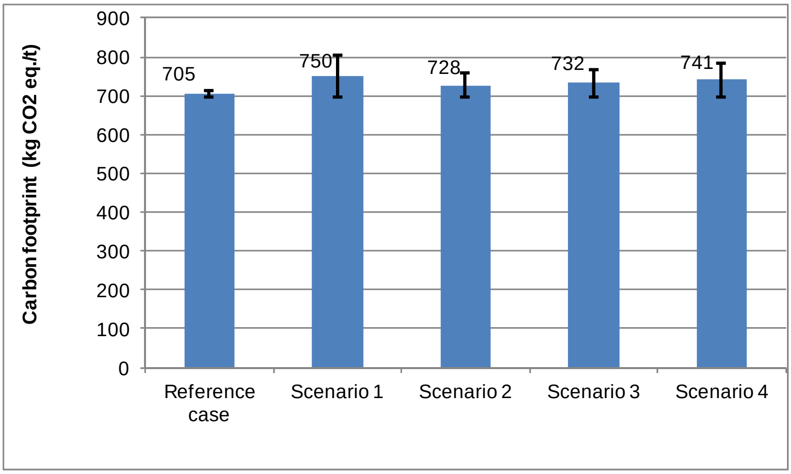

Figure 8-3 Carbon footprint of 1,000 kg of recycled TEA for different credits for heat recovery

[The error bars indicate the minimum and maximum values while the height of each bar indicates the average value.]

8.2.3 Comparison with the virgin solvent

Figure 8-4 compares the average carbon footprint of recycled TEA produced by ESRG members which were part of this study with the virgin solvent. The figure indicates that recycling of TEA saves 79% of greenhouse gas emissions relative to the average emissions associated with the production of virgin solvent.

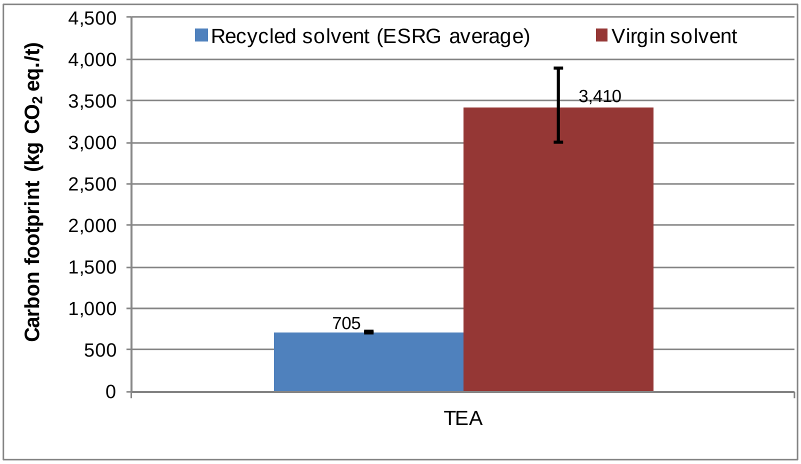

Figure 8-4 Comparison of recycled TEA with virgin TEA
[Data for the virgin solvent estimated from Ecoinvent [3] and Gabi [6]. The error bars indicate the minimum and maximum values while the height of each bar indicates the average value.]

9 Carbon footprint of recycled perchloroethylene

9.1 Inventory analysis

The inventory data for the recycling of perchloroethylene (PERC) been supplied by some of the ESRG members. The carbon footprint data have been obtained from the CCaLC V3.0 [2] and Ecoinvent V2.2 [3] databases. The following summarises the data used in the study and the assumptions made for filling the data gaps:

- ***Waste solvent, auxiliary raw materials and packaging:*** The average data for the waste solvent and raw materials used in their recycling processes as specified by the participating companies are shown in Table 9-1. The waste solvent is transported to the recycling plants in bulk or in different types of packaging, such as drums and pails (see Table 9-2).
- ***Energy:*** The average data for electricity and steam consumption provided by individual companies are presented in Table 9-3. Electricity is assumed as medium voltage from the corresponding national grid while steam is generated using heavy fuel oil. Carbon footprint data for the production of electricity have been sourced from Ecoinvent V2.2 [3] and for the steam from CCaLC V3.0 [2].
- ***Process waste and emissions:*** The inventory for process waste and emissions represents the emissions of solvents from recycling processes, wastewater,

packaging waste and other waste such as residues. The average data provided by different companies are summarised in Table 9-4.

- ***Transport:*** The transport modes and distances for delivery of the waste solvent to the recycling plant and recycled solvent to the user have been provided by individual companies. The average transport data are shown in Table 9-5. Other transport data such as transport of raw materials to the recycling plants and waste streams to the waste management facilities have been assumed. The carbon footprint data for transport systems have been obtained from CCaLC V3.0 [2].

Table 9-1 Data for waste solvent and raw materials (all LCA data from [2])

Raw material	Amount -average- (kg/functional unit)	Comments
Waste solvent (PERC)	2,220	
Water	1,500	Cooling and washing water
Chemicals	350	Solvents, washing agents, stabiliser, molecular sieve, antioxidants

Table 9-2 Data for packaging materials (all LCA data from [2])

Packaging material	Amount -average- (kg/functional unit)	Comments
Steel drums	600	Packaging for waste solvent
Drums (steel & HDPE)	110	Packaging for recycled solvent

Table 9-3 Energy data (All LCA data from [2, 3])

Type of energy	Amount -average- (kWh/functional unit)	Energy source
Electricity	150	National grid
Steam	720	Heavy fuel oil

Table 9-4 Process waste and emissions data (all LCA data from [2])

Waste /emissions	Amount -average- (kg/functional unit)	Disposal method
Waste solvent	20	Heat recovery on-site and off-site
Wastewater	160	Off-site treatment
VOCs	10	Treated and fugitive emissions
Packaging waste	600	Recycling & reuse
Other waste (residues)	1,130	Heat recovery off-site

Table 9-5 Transport data (all LCA data from [2])

Material	Distance -average- (km)	Transport mode
Waste solvent (PERC) to recycling plant	1,620	Truck, rail and ship
Chemicals to recycling plant	100	Truck
Waste solvent to incineration (off-site)	100	Truck
Recycled solvent (PERC) to user	1,620	Truck, rail and ship

9.2 Carbon footprint results

CCaLC V3.0 [2] has been used to model the system and to estimate the carbon footprint, following the CML 2001 impact assessment method [4]. The latest IPCC [5] global warming factors have been used for the estimation of the carbon footprint.

As shown in Figure 9-1, the average carbon footprint of 1,000 kg of recycled PERC has been estimated at 387 kg CO_2 eq.

9.2.1 Contribution of different life cycle stages to the carbon footprint

Raw materials and packaging: As shown in Figure 9-1, the average carbon footprint for the raw materials has been estimated at 384 kg CO_2 eq. mainly because of packaging.

Solvent recycling: The solvent recycling stage has an average carbon footprint of -175 kg CO_2 eq. as indicated in Figure 9-1. Within this stage, provisions of energy and waste management have the average carbon footprint of 302 and -630 kg CO_2 eq., respectively (see Figure 9-2); the latter has a negative value due to the credits for energy recovery from the waste solvent (see Section 9.2.2 for further detail). The average carbon footprint of packaging amounts to 153 kg CO_2 eq.

Transport: The transport stage has the average carbon footprint of 178 kg CO_2 eq. as given in Figure 9-1.

9.2.2 Sensitivity analysis – credits for heat recovery

To examine if the results are sensitive to the assumptions for credits for heat recovery from incineration of waste solvent, different credit options are considered as part of scenario analysis as follows; these results are shown in Figure 9-3:

- ***Reference case (as above):*** Process waste is assumed to be incinerated in cement kilns for heat recovery replacing coal with all the credit for this allocated to the solvent recycling company. For this scenario, the average carbon footprint of recycled PERC is estimated at 387 kg CO_2 eq./t.
- ***Scenario 1:*** The credits for heat recovery from waste incineration are allocated to the cement plant. In this case, the average carbon footprint is equal to 987 kg CO_2 eq./t of recycled solvent.

- ***Scenario 2:*** 50% of the energy credit from waste incineration allocated to the solvent recycling company and the remaining 50% to the cement plant. The average carbon footprint is now equal to 687 kg CO_2 eq./t of recycled solvent.
- ***Scenario 3:*** As the reference case but petroleum coke is assumed as the replaced fuel rather than coal. Under these assumptions, the average carbon footprint is equal to 644 kg CO_2 eq./t of recycled solvent.
- ***Scenario 4:*** As Scenario 2, but instead of coal, petroleum coke is assumed as the replaced fuel. For this scenario, the average carbon footprint is estimated at 815 kg CO_2 eq./t of recycled solvent.

Therefore, the results are sensitive to the assumptions for heat recovery in the cement kiln and should be interpreted with this in mind.

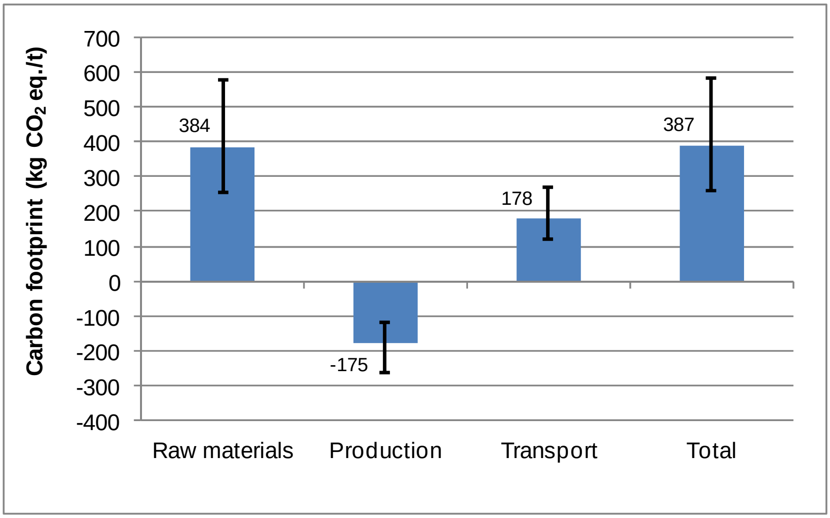

Figure 9-1 Total carbon footprint of 1,000 kg of recycled PERC also showing the breakdown by life cycle stage

[Raw materials include packaging of waste solvent; production includes solvent recycling process, packaging of final product and waste management. The error bars indicate the minimum and maximum values while the height of each bar indicates the average value.]

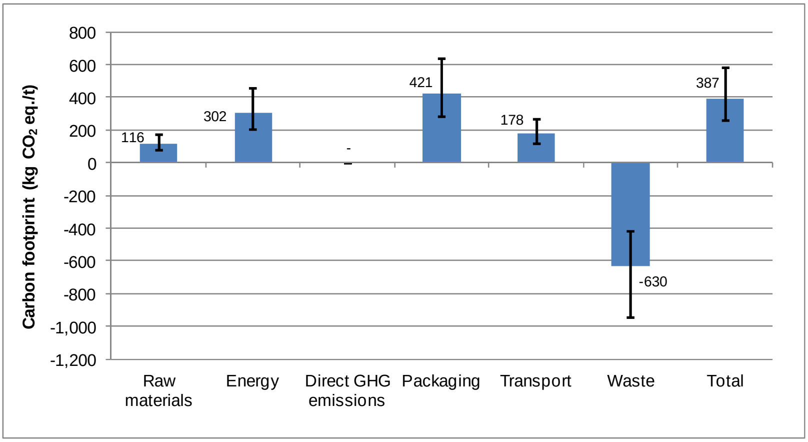

Figure 9-2 Carbon footprint of 1,000 kg of recycled PERC by data category

[Packaging includes packaging of waste solvent and packaging of final product. The error bars indicate the minimum and maximum values while the height of each bar indicates the average value.]

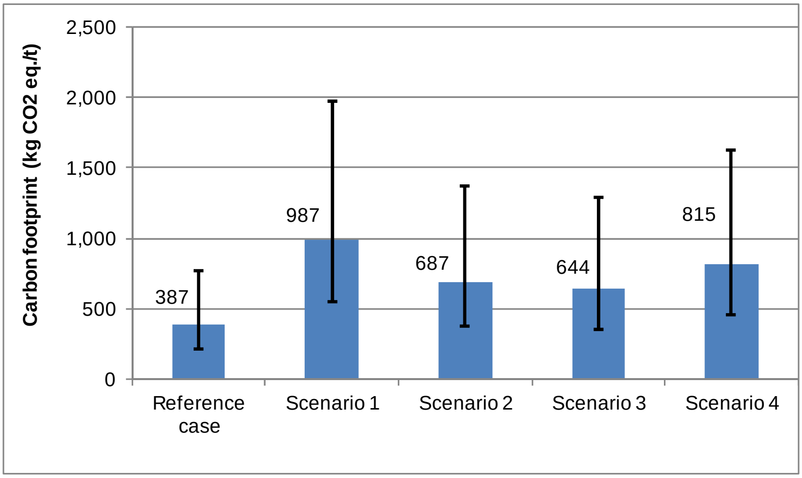

Figure 9-3 Carbon footprint of 1,000 kg of recycled PERC for different credits for heat recovery

[The error bars indicate the minimum and maximum values while the height of each bar indicates the average value.]

9.2.3 Comparison with the virgin solvent

Figure 9-4 compares the average carbon footprint of recycled PERC produced by ESRG members which were part of this study with the virgin solvent. The figure indicates that recycling of PERC saves 90% of greenhouse gas emissions relative to the average emissions associated with the production of virgin solvent.

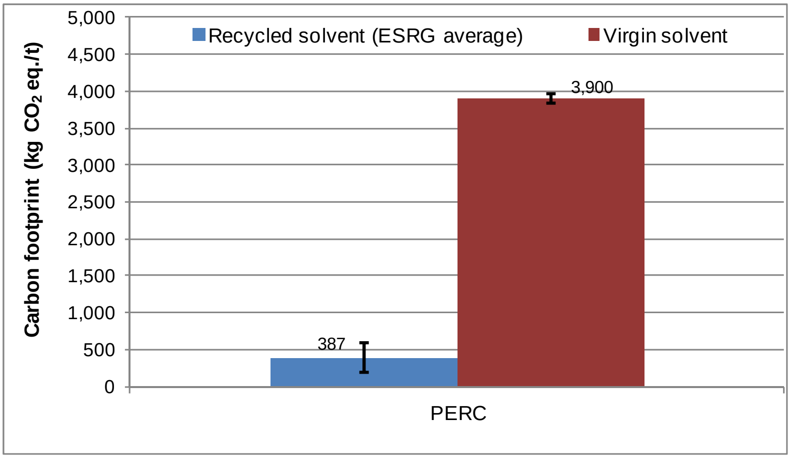

Figure 9-4 Comparison of recycled PERC with the virgin solvent
[Data for the virgin solvent from Ecoinvent [3]. The error bars indicate the minimum and maximum values while the height of each bar indicates the average value.]

10 Conclusions

The findings of this study indicate that the average carbon footprint of recycled solvents ranges from 156–798 kg CO_2 eq./t. The main contributor to the total carbon footprint for all six solvents varies. For example, the recycling process is the main contributor for acetone, THF, MEK and TEA, while transport and raw materials are the main contributors for mixed solvents and PERC.

For mixed solvents and PERC, the carbon footprint results are sensitive to system credits for energy recovery from waste incineration.

Recycling of mixed solvents, acetone, THF, MEK, TEA and PERC leads to significant savings of greenhouse gas emissions (ranging from 46-92%) compared to the virgin solvents. However, it should be noted that, although the data for the virgin solvents represent industry averages, they are secondary data taken from databases while the data for recycled solvents are primary data obtained directly from manufacturers. Therefore, the comparisons between the virgin and recycled solvents should be interpreted with this in mind. Nevertheless, as the differences in the carbon footprints are relatively large, the confidence intervals are high enough to render the comparisons robust.

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