



Technical Report accompanying the Study on the Energy Saving Potential of Increasing Resource Efficiency

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the Energy Saving Potential of
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Abbreviations

BAU	Business as usual (scenario)
BFR	Brominated flame retardants
C&D	Construction and demolition
CED	Cumulative energy demand
CN	Combined nomenclature, Council regulation (EEC) No 2658/87
CO ₂ e	Carbon dioxide equivalent
CRD	Cumulative raw-material demand (defined by VDI-Standard: VDI 4800 Blatt 1)
DE	Domestic extraction; domestically extracted
DfRR	Design for repair and refurbishment
DG.ENV	Directorate-General for the Environment of the European Commission
EEA	European Environment Agency
EED	Energy Efficiency Directive
ELV	End-of-life vehicles
EU	European Union
EW-MFA	Economy-wide material flow accounts
GHG	Greenhouse gas
GWh	Gigawatt-hour
GWP	Global warming potential
ICT	Information and communications technology
JRC	Joint Research Centre, Service of the EC
kt	Kilotonne; 1 000 tonnes or 10 ⁶ kg
kWe	Kilowatt electric
kWh	Kilowatt-hour
LCA	Life cycle assessment
LiPo	Lithium-polymer batteries
Mm ³	Million cubic meters (10 ⁶ m ³)
MS	Member States of the European Union
MSW	Municipal solid waste
Mt	Mega-tonne or million tonnes (10 ⁶ tonnes = 10 ⁹ kg)
OECD	Organisation for Economic Co-operation and Development
PCI	Pulverised coal injection
PWS	Public water system
RA	Reclaimed asphalt
RME	Raw material equivalent
RMI	Raw material input
ROW	Rest-of-the-world economy
SME	Small- and medium-sized enterprise
t	Metric tonne
TC/ TZ	Thin client/ zero client technology
WStatR	Waste Statistics Regulation
% _{wt}	percent of total weight
yr	Year

Energy expressed in:

MJ	Megajoule = 10 ⁶ joule
GJ	Gigajoule = 10 ⁹ Joule
TJ	Terajoule = 10 ¹² Joule
PJ	Petajoule = 10 ¹⁵ Joule
EJ	Exajoule = 10 ¹⁸ Joule
Mtoe	Mega-tonnes (or million tonnes) of oil equivalent. 41.868 PJ)

Abbreviations for Countries

AT	Austria
BA	Bosnia and Herzegovina
BE	Belgium
BG	Bulgaria
CH	Switzerland
CY	Cyprus
CZ	Czech Republic
DE	Germany (until 1990 former territory of the FRG)
DK	Denmark
EE	Estonia
EL	Greece
ES	Spain
FI	Finland
FR	France
HR	Croatia
HU	Hungary
IE	Ireland
IS	Iceland
IT	Italy
LT	Lithuania
LU	Luxembourg
LV	Latvia
ME	Montenegro
MK	The former Yugoslav Republic of Macedonia
MT	Malta
NL	Netherlands
NO	Norway
PL	Poland
PT	Portugal
RO	Romania
RS	Serbia
SE	Sweden
SI	Slovenia
SK	Slovakia
TR	Turkey
UK	United Kingdom
XK	Kosovo (under United Nations Security Council Resolution)

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1 Introduction

This *Technical Report* to the *Study on Energy Saving Potential of Increasing Resource Efficiency* provides data and background information for the quantification of the selected sectors. It provides details on the sources, calculations, case studies and scenarios considered for the *Final Report*.

The reasoning for the selection of the sectors and products in the chapters below is discussed in chapter 3 of the *Final Report*.

The selected sectors (and industrial symbiosis as a cross-sectoral approach) are addressed with the following case studies in this *Technical Report*:

Sector (by chapter number)	Case study
3. Waste management	- Potential <u>additional</u> recycling, excluding currently achieved recycling.
4. Water and wastewater management	- For the domestic sector, irrigation and industry sectors, <u>including</u> behavioural changes
	- For domestic sector, irrigation and industry sectors, <u>excluding</u> behavioural changes
5. Buildings and road construction	- Buildings
	- clinker optimisation in building concrete
	- increased wood construction
	- reduced new-building construction
	- increased building rehabilitation and lifetime
6. Modal shift in urban transport	- Road construction - reclaimed asphalt
	- Modal shift in urban transport, considering mobility data, climate zones, populations, vehicles and emissions
7. Information and communication technology (ICT)	- Thin / zero clients
	- Design for repair and refurbishment
	- Recycling plastics from WEEE
8. Food	- Food waste
	- Integrated aqua culture
9. Ferrous	- Meta-study on the ferrous sector
10. Industrial symbiosis	- By-products and reused components for computer manufacturing
	- Fermentation residues from biogas plants as raw material for the woodworking industry

2 Selection of sectors and goods

This project first sought to identify the sectors and goods that have the highest share of impact on mineral resources, metallic resources, biotic resources and the fossil fuel resources based on material flow accounts, before additional sectors are proposed for analysis below.

Detailed data on mass flows of 166 product groups and 52 material categories, published by Eurostat, offers insight into impact intensity. Eurostat combines national accounts and physical inputs in the economy-wide material flow accounts (EW-MFA¹). EW-MFA describe the domestic economy's interactions with the natural environment and the rest-of-the-world economy (ROW) in terms of material flows (excluding water and air) (see Figure 2.1). The economy is demarcated by the conventions of the national accounting system (resident units).

In Eurostat's EW-MFA for the EU27, material inputs to the economy cover material extractions from the natural environment and imports of materials from the ROW. These physical inputs are combined with flows in the economy, as represented in national accounts. The results show the cumulative use of the 52 materials for 166 product groups.

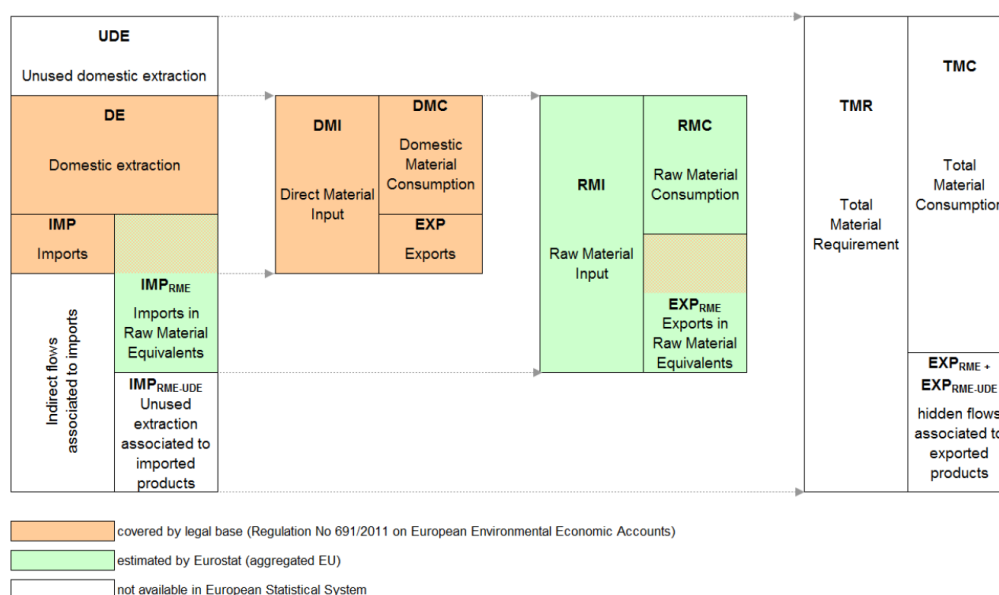
Figure 2.1 defines the resource system and illustrates boundaries and categories groupings. For the EU27, the input of domestically extracted (DE) resources is combined with imports. For a better comparison², the imports are adjusted with raw material equivalent (RME) coefficients to include pre-chain (upstream) impacts. The total of domestic extraction plus imports, expressed in the unit RME, is called raw material input (RMI).

$$\text{Equation (1): } \text{RMI} = \text{DE} + \text{IMP}_{\text{RME}}$$

To calculate raw material consumption (RMC), the export considering the RME coefficients is deducted from RMI, as expressed in the following equation.

$$\text{Equation (2): } \text{RMC} = \text{RMI} - \text{EXP}_{\text{RME}}$$

Figure 2.1: Scheme for economy-wide material flow accounts EW-MFA and derived indicators, Eurostat (2015)



Source: Eurostat.

¹ <http://ec.europa.eu/eurostat/documents/1798247/6191533/2013-EW-MFA-Guide-10Sep2013.pdf/54087dfb-1fb0-40f2-b1e4-64ed22ae3f4c>.

² E.g. if resource consuming processes are shifted to regions outside the EU.

Figure 2.2 and Figure 2.3 show what percentage of total resources for each of the four indicators (mineral resources, metallic resources, biotic resources and fossil fuels) is allocated to each specific product group based on EW-MFA. The product groups³ are defined according to the Statistical Classification of Products by Activity (CPA 2002)⁴. The allocation is derived from Eurostat Data⁵. Annex 7 gives further details.

Figure 2.2 and Figure 2.3 display a selection of the most relevant products only. The products not considered in these Figures represent a contribution of less than 10% of resources to each of the four indicators.

Referring to data on raw material input (RMI), Figure 2.3 represents the total material input to the economy, including material input for products exported after processing.

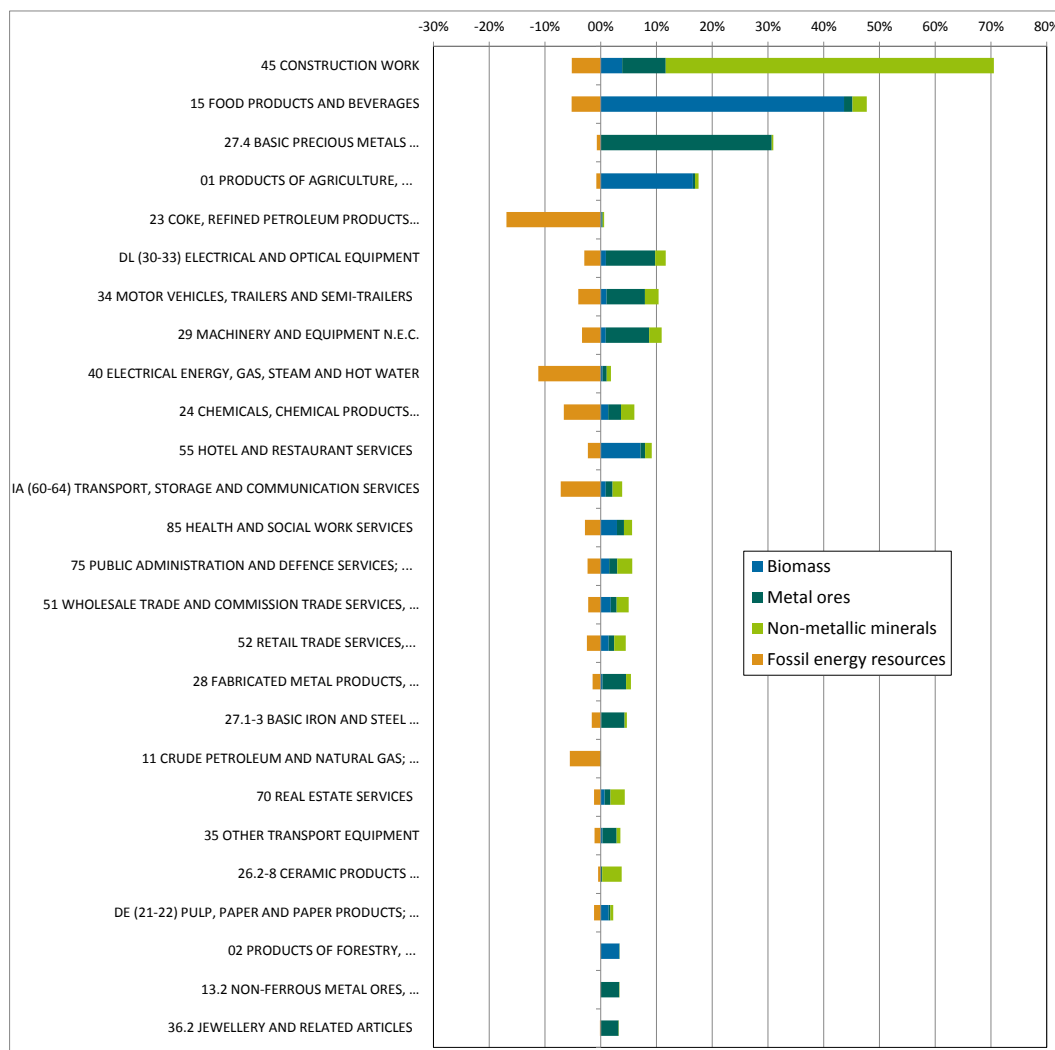
The product groups “construction work”, “food products and beverages” and “basic precious metals and other non-ferrous metals” represent high shares of the total raw material input where “construction works” represent more than 58% of the total input of mineral resources, the “food products and beverages” more than 43% of the total input of biomass and “basic precious metals and other non-ferrous metals” more than 30% of the total input of metal ores.

³ The numbering at the beginning of the product group refer to the below mentioned CPA 2002 code.

⁴ Please note that in the meantime the CPA 2008 is established; however the refer to the CPA 2002 and the full list of CPA 2002 codes is accessible via:
http://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=LST_NOM_DTL&StrNom=CPA&StrLanguageCode=EN&IntPcKey=&StrLayoutCode=HIERARCHIC.

⁵ <https://circabc.europa.eu/d/a/workspace/SpacesStore/ec24500b-c6c7-44e4-8391-3b6b2117e2cc/RME-coefficients%20by%20166%20product%20groups%20and%2052%20material%20categories.xlsx>.

Figure 2.2: Raw material input (RMI) of products: percentages of single criteria



Data-Source: Eurostat, reference year 2012 (see Annex 7 for a detailed calculation);

Code applied for Raw material input (RMI): total final use (FU);

Code applied for the classification of products by activity: CPA 2002

Unit: RME, transferred in % of the total for the single indicator

Concept for aggregation: Öko-Institut; Please disregard the indication of negative percent; it is only to distinguish the different indicator for fossil energy resources.

Figure 2.3 displays the “total final domestic use” which is considered as equivalent to the Raw material consumption (RMC), which is the RMI minus the resources for export. It displays consumption of resources for the inland consumption excluding the resources for the production of products exported.

Figure 2.3: Raw material consumption (RMC): percentages of single criteria



Data-Source: Eurostat, reference year 2012 (see Annex 7 for a detailed calculation);

Code applied for Raw Material Consumption (RMC): total final domestic uses (FU1);

Code applied for the classification of products by activity: CPA 2002

Unit: RME, transferred in % of the total for the single indicator

Concept for aggregation: Öko-Institut; Please disregard the indication of negative percent; it is only to distinguish the different indicator for fossil energy resources.

The RMC in Figure 2.3 is dominated the product groups "construction work" (45), "food products and beverages" (15) as the RMI before. The contribution of "basic precious metals and other non-ferrous metals" (27.4) is less significant, due to the high share of exports. Instead the "products of agriculture hunting and related services" (01) and "hotel and restaurant services" (55) both with a high share for biomass resources consumption, are ranked higher. In a similar manner this applies also for the product groups "machinery and equipment n.e.c." (29), "electrical and optical equipment" (30-33) and "motor vehicles, trailers and semi-trailers" (34) all of them with a relevant share of metal ore resources.

Since the study does not aim to directly assess measures addressing directly energy, the product groups "electrical energy, gas, steam and hot water" (40) and "coke, refined petroleum products and nuclear fuel" are excluded for the ranking of relevant product groups.

The RMI (including products for export) and RMC (displaying the consumption in EU-27 only) provide strong arguments to look into the product groups "construction work" and "food products and beverages" (the last together with "products of agriculture hunting and related services". In addition we propose also to look also into steel production, a key material input in several of the high-impact product groups.

RMI and RMC might not detect all sectors / products with relevant for natural resource impacts. Indeed, additional sectors and products might be relevant when addressing natural resources and it might be of interest to look into windfall win-wins for energy savings:

- **Waste management:** The potential of additional savings through increased recycling of metals, glass, paper, plastics and biomass is, not considered in the sector waste management but it would show up in the MFA of contribute to diverse product groups (like steel production, pulp & paper, glass, plastic) and would therefore be difficult to detect. As the contribution of improved recycling for resource efficiency is significant, this sector and should be addressed in detail:
- **Water and wastewater management:** Water is not addressed by raw materials, yet water is an important natural resource. Therefore, management of water and wastewater is selected as an issue for detailed assessment in this study;
- **Urban planning and the intelligent provision of infrastructure** is essential for, efficient use of space, energy and raw materials in urban areas. This covers the question how to facilitate brownfield rehabilitation and reuse, what is the appropriate density (capita per square kilometre) and how to avoid greenfield developments⁶. It also covers the quality of the public transport in relation to settlement and production / service sites. However it is extremely difficult to design scenarios for such developments and to upscale it for EU-28 as the situations for each urban area is so much different. Therefore we looked for this study into the modal split for public transportation across Europe and provided scenarios for modal shift in urban transport;
- **Information and communication technology (ICT)** is a dynamic and rising sector with short innovation cycles that consequently shorten life-spans of products. The recycling of technological metals represents a particular challenge. At the same time the energy demand for the ICT sector is continuously rising, making the sector a further interesting case for analysis. Insofar this sector is selected for detailed assessment as well;
- **Industrial Symbiosis** is a promising integrated concept for industrial cooperation, as recently concluded in a study on industrial symbiosis for DG GROW⁷. Examples of resource efficiency are not straightforward to upscale, as they tend to be driven by case-specific factors. In this study the potential for specific cases with high relevance for energy consumption shall be assessed in detail and other industrial symbiosis cases are discussed more qualitatively.

⁶ 'Brownfield' land is an urban planning term for often contaminated land previously used for industrial or commercial purposes. In contrast, 'Greenfield' land is generally understood as undeveloped land, often under consideration for urban development.

⁷ Analysis of certain waste streams and the potential of Industrial Symbiosis to promote waste as a resource for EU Industry.

3 Waste management sector

This chapter presents an estimate of the potential of energy savings from increasing the recycling rates of solid waste. The calculations cover a number of selected materials. As outlined below, due to data quality issues concerning recycling rates of total waste, an alternative hybrid method is used that assumes recycling potentials based on recycling rates achieved in the management of municipal solid waste (MSW) and packaging waste.

3.1 Recycling potential estimation

3.1.1 Total waste

Eurostat provides data on total waste generated and waste recycling for a list of materials based on the Waste Statistics Regulation (WStatR). Member States report their data biannually (2010, 2012 etc.), and for the purposes of this work, the latest available data from 2012 is used.

The selected materials are ferrous metals, non-ferrous metals, glass, paper and cardboard, plastics, wood wastes and bio-waste. The last material is extracted from the Eurostat code "Animal and mixed food waste; vegetal wastes (W091+W092)", which does not refer to organic waste totals, since wood and paper waste are not included. Recycling data is extracted as "Recovery other than energy recovery - Except backfilling" from the Eurostat database.

Table 3.1 shows the recycling rate (recycled quantity/ generated quantity) for each material based on data directly from Eurostat (i.e. not accounting for import/ exports or the influence of stockpiled or stored waste).

The red highlighted cells indicate recycled quantities higher than those generated in the same year (i.e. recycling rate >100%). The recycling data refer to waste quantities recycled within each country and do not take into account the influence of import and export flows of waste for recycling. Therefore, the recycling data used in this table refers to waste recycled in the country, but it could refer to waste also generated abroad. Moreover, recycling data do not necessarily refer to quantities of waste generated in the same year: some recycling might occur on waste generated the previous year due to delayed processing or storage, while some other recycled quantities might originate from stockpiled waste stored in the country. Another reason for these extensive discrepancies between generated and recycled data could be issues pertaining to the data collection systems applied in each EU MS. Overall, due to a combination of these factors, the recycling data for total waste in the EU MS are problematic and cannot be used for further analyses, especially in the cases where recycled quantities are higher than generated quantities.

The cells highlighted green indicate the highest recycling rate that is below 100%. The countries that correspond to the green cells for each material are, therefore, the best-performing countries in terms of recycling the specified material. The remaining countries are then benchmarked against the best-performing country per material in order to estimate the maximum possible recycling rate.

Table 3.1 Recycled waste in each EU Member State for selected materials in 2012, expressed as percentage of generation

Note: percentages estimated based on "generation" and "recovery other than energy recovery, except backfilling" data⁸

Country	Metal wastes, ferrous	Metal wastes, non-ferrous	Glass wastes	Paper and cardboard wastes	Plastic wastes	Wood wastes	Animal and ⁹ mixed food waste; vegetal wastes
Belgium	87%	68%	56%	34%	32%	16%	74%
Bulgaria	9%	99%	92%	68%	61%	25%	1%
Czech Republic	63%	75%	135%	48%	36%	4%	47%
Denmark	31%	31%	94%	69%	83%	61%	77%
Germany	96%	122%	106%	54%	65%	22%	86%
Estonia	0%	7%	54%	7%	13%	51%	64%
Ireland	4%	101%	3%	1%	58%	57%	20%
Greece	141%	194%	44%	43%	22%	21%	61%
Spain	199%	83%	101%	137%	93%	98%	44%
France	72%	42%	85%	64%	14%	66%	56%
Croatia	38%	39%	176%	91%	52%	53%	48%
Italy	132%	124%	82%	84%	51%	79%	57%
Cyprus	141%	23%	42%	39%	11%	8%	31%
Latvia	16%	92%	0%	25%	160%	14%	53%
Lithuania	0%	15%	90%	52%	51%	32%	30%
Luxembourg	1953%	3038%	22%	0%	45%	17%	102%
Hungary	26%	135%	34%	134%	49%	43%	46%
Malta	0%	0%	0%	0%	0%	0%	0%
Netherlands	103%	7%	136%	97%	68%	38%	96%
Austria	100%	148%	98%	108%	87%	57%	100%
Poland	116%	265%	92%	133%	58%	86%	50%
Portugal	41%	28%	76%	45%	33%	18%	39%
Romania	94%	90%	76%	102%	63%	97%	77%
Slovenia	276%	96%	86%	294%	67%	12%	56%
Slovakia	66%	63%	86%	41%	53%	66%	55%
Finland	26%	72%	113%	80%	9%	23%	108%
Sweden	69%	56%	42%	201%	55%	5%	72%
United Kingdom	58%	71%	63%	116%	63%	45%	57%
EU28	94%	90%	83%	82%	56%	42%	69%

Source: retrieved from Eurostat on 25 July 2015.

⁸ The data retrieved from Eurostat refer to treatment of waste in "recovery other than energy recovery, except backfilling" operations. The term recycling is used throughout this document for reasons of simplicity, although it might not represent adequately the treatment of animal, mixed food and vegetal wastes.

⁹ The "Animal and mixed food waste; vegetal wastes" fraction is used as a proxy for the organic waste, other than paper and wood, which is under this project's scope. The "Animal and mixed food waste; vegetal wastes" is used as a proxy because Eurostat does not collect data on organic waste as such.

By including import and export information, recycling can be estimated for each country as referring to recycling of waste exclusively generated in the same country. These recycling percentages can be estimated by including import/ export data from Eurostat's Comext database (database on trade statistics). This work has been already performed (and adopted here) by the Working Group Waste in Eurostat that is working towards the development of a new recycling indicator. Subtracting imported waste for recycling from the sum of the amount of recycled waste in the country and exported waste for recycling should result in the amount of waste recycled and originating from the same country (independent of where the recycling takes place):

$$\text{Own Waste Recycled } i = \text{Waste Recycled in the country } i + \text{Waste Exported from country } i \text{ for recycling} - \text{Waste Imported to country } i \text{ for recycling}$$

However, after accounting for import/ export quantities, there are even more cases compared to the previous table where recycling is higher than generation (>100%) or cases where a country imports more waste than generated (<0%). This is particularly relevant for highly tradable waste types, such as ferrous metal scrap. No trivial explanation for the discrepancies of data (detailed data in Annex 1) could be found. Possible explanations include considerations on the stock levels of waste or scrap in a country and potential double-counting, as the export and import data do not refer to the final destination of the waste (i.e. double counting may occur, for example, in cases when a country imports waste for processing and then exports them again for final treatment or recycling).

Recycling data from Eurostat's databases are problematic, both when considering or ignoring import/ export for recycling data.

3.1.2 *Municipal Solid Waste (MSW)*

MSW is also examined as a specific pool for estimating recycling potentials through a waste stream with much more reliable data. The European Reference Model on Municipal Waste Management (www.wastemodel.eu) from August 2015 is used as a data source. Data extracted from the Model include generation of each of the selected materials based on national generation compositions, recycled quantity for each material and the ranking of best-performing countries per material. Because the Model relies on Eurostat for data input, the data presented here always refer to 2013, which is the latest year with reported data on MSW management. Contrary to total waste data, for MSW no distinction is possible between ferrous and non-ferrous metals.

The recycling potential for the selected materials in each country and for the EU as a whole can be estimated by benchmarking the recycling rates against the best-performing country, defined as the country with the highest achieved recycling levels per material. These recycling rates, if applied in all other countries and to the EU as a whole, would indicate the maximum theoretical recycling that can be achieved according to the methodology chosen for this report. The resulting theoretical maximum recyclable quantities can be used to estimate the recycling quantities' potential if compared with existing recycling levels. The best-performing country (in terms of recycling rates achieved) for each material is benchmarked and the potential for recycling is estimated based on the scenario that all countries perform as well as the benchmarked country for each material. Also highlighted below in Table 3.2, these benchmark countries per material in the MSW stream are:

- Metals: Bulgaria (85%);
- Glass: Germany (93%);
- Paper & Cardboard: Germany (82%);
- Plastics: Germany (55%);
- Wood: Ireland (92%);
- Animal, mixed food, vegetal: Austria (85%).

Table 3.2 Recycled municipal waste in each EU Member State for selected materials in 2013, expressed as percentage of generation (%)

Note: percentages estimated based on "generation", "material recycling" or "composting and digestion" data

Country/%	Metals	Glass wastes	Paper and cardboard wastes	Plastic wastes	Wood wastes	Animal and mixed food waste; Vegetal wastes
Belgium	45%	50%	45%	38%	89%	63%
Bulgaria	85%	44%	68%	27%	7%	1%
Czech Republic	71%	58%	60%	43%	2%	9%
Denmark	80%	71%	50%	12%	77%	34%
Germany	62%	93%	82%	55%	1%	56%
Estonia	30%	52%	47%	9%	20%	13%
Ireland	65%	60%	66%	30%	92%	30%
Greece	32%	19%	29%	16%	12%	6%
Spain	43%	75%	27%	35%	65%	14%
France	52%	53%	14%	26%	0%	46%
Croatia	52%	31%	12%	3%	9%	5%
Italy	46%	65%	39%	21%	53%	33%
Cyprus	57%	40%	39%	6%	6%	12%
Latvia	37%	38%	28%	31%	16%	1%
Lithuania	69%	42%	52%	7%	6%	13%
Luxembourg	59%	70%	52%	15%	84%	53%
Hungary	69%	70%	37%	6%	15%	15%
Malta	16%	17%	20%	7%	0%	9%
Netherlands	37%	56%	55%	12%	24%	50%
Austria	60%	66%	72%	27%	55%	85%
Poland	26%	24%	24%	10%	2%	9%
Portugal	26%	59%	25%	9%	11%	3%
Romania	4%	8%	10%	4%	5%	2%
Slovenia	33%	49%	33%	19%	30%	19%
Slovakia	15%	36%	37%	20%	0%	13%
Finland	27%	80%	41%	7%	7%	32%
Sweden	85%	88%	56%	19%	3%	47%
United Kingdom	60%	65%	51%	19%	77%	46%
EU28	54%	62%	46%	29%	40%	36%

Source: Eurostat, retrieved on 25 July 2015.

Looking at the difference between the best performing country and the EU average, the potential to increase recycling is highest for wood (52% difference between EU average and best-performing country) and bio-waste (49% difference), followed by paper and cardboard (36%), ferrous metals (31%) and glass (31%). The high potentials particularly for wood and bio-waste demonstrate the large possibilities for improvement.

The potentially available quantities for recycling are estimated in Table 3.3 below. In terms of quantities, bio-waste and paper and cardboard show the largest potential for additional recycling. If the additional potential recycling from all MS across the EU is summed, around 47 million tonnes of bio-waste and 22 million tonnes of paper and cardboard could be recycled in addition to the existing recycling levels. Currently across the EU, 35 million tonnes and 27 million tonnes of biowaste and paper and cardboard are respectively recycled. It should be

highlighted that these potential amounts result after considering how much of the material is originally generated and also how high the existing recycling levels across the EU28 are.

Table 3.3 Theoretical maximum additional recycling potential in the EU28 Member states from MSW and for selected materials (1000 t)

Note: values estimated as the difference between current recycling levels and theoretical maximum (1000 t)

Country (values in 1000 t)	Metals	Glass wastes	Paper and cardboard wastes	Plastic wastes	Wood wastes	Animal and mixed food waste; vegetal wastes
Belgium	53	170	347	21	10	381
Bulgaria	0*	99	46	94	13	857
Czech Republic	24	153	226	93	248	1 194
Denmark	25	31	288	110	1	817
Germany	697	0*	0*	0*	1 424	4 259
Estonia	13	11	28	30	1	118
Ireland	22	96	117	86	0*	412
Greece	127	191	615	293	227	1 826
Spain	154	200	3 305	341	85	5 919
France	671	1 856	5 014	1 127	n/a	5 260
Croatia	20	37	290	183	13	444
Italy	583	727	3 362	1 319	516	6 482
Cyprus	4	7	49	43	21	170
Latvia	19	54	86	23	15	360
Lithuania	24	57	52	69	20	252
Luxembourg	2	7	21	10	1	42
Hungary	68	9	379	299	37	807
Malta	7	12	29	14	n/a	95
Netherlands	133	230	517	280	350	1 224
Austria	39	73	88	120	97	0*
Poland	321	842	1 281	708	180	2 418
Portugal	61	97	395	235	46	1 942
Romania	143	264	545	379	133	3 521
Slovenia	36	33	91	36	32	174
Slovakia	55	66	108	73	n/a	489
Finland	37	12	303	141	91	480
Sweden	2	10	357	123	353	553
United Kingdom	598	991	3 790	1 925	301	6 595
EU28	3 938	6 335	21 729	8 175	4 215	47 091

Note: France, Malta and Slovakia lack data for wood generation (marked n/a in the table) so the potential cannot be estimated.

* Country serves as benchmark, so no additional recycling assumed possible.

3.1.3 Estimation of recycling potential for total waste by using MSW figures

The existing data for total waste recycling, as extracted from Eurostat, is problematic, as it often shows unrealistically high recycling rates (sometimes higher than 100%), as demonstrated in chapter 3.1.1. Given that MSW data is more credible, the recycling potential for total waste could be calculated by applying existing and maximum recycling rates of MSW on total waste generation.

Extrapolating information from MSW to estimate waste amounts for total waste does not come without shortcomings, since different waste management systems use varying recycling routes and technologies which could impact the maximum achievable recycling potential. Moreover, the composition of the generated waste in MSW and the total waste stream is different, which affects recycling potential due to availability. For example, construction and demolition waste contain large quantities of metals that are easier to recycle compared to MSW metals, since they are generated in larger quantities and are normally cleaner from other fractions. On the other hand, the MSW stream is more regulated, with explicit recycling targets in place; a large amount of effort is invested in increasing the efficiency of MSW collection systems. These differences between total waste and the MSW stream undoubtedly create a bias in the data when extrapolating total waste quantities from MSW recycling rates. However, given the poor data-quality for total waste recycling, the results produced here for MSW can be seen as more realistic and the estimations for resource- and energy-savings will therefore be based on the MSW-based recycling benchmarks.

The extrapolation methodology begins by applying the existing MSW recycling rates per country for the selected materials on total waste so that the current recycled amounts per material are estimated for total waste. Table 3.4 shows the current recycled quantities of total waste if estimated by using MSW rates.

Table 3.4 Current estimation of recycling of total waste generated in the EU28 (1000 t)

Note: figures expressed as the product of total waste generated and the MSW current recycling rates¹⁰

Country (values in 1000 t)	Metal wastes, ferrous	Metal wastes, non- ferrous	Glass wastes	Paper and cardboard wastes	Plastic wastes	Wood wastes	Animal and mixed food waste; vegetal wastes
Belgium	971	229	446	1 754	231	3 739	3 009
Bulgaria	450	82	29	136	27	14	5
Czech Republic	2 033	135	181	424	141	4	42
Denmark	856	69	126	517	12	178	296
Germany	5 723	795	2 762	6 722	1 379	61	7 113
Estonia	137	8	26	45	2	163	5
Ireland	137	12	151	259	38	185	365
Greece	314	16	14	150	21	14	27
Spain	1 898	279	853	954	403	810	534
France	6 394	610	1 246	1 015	426	n/a	5 004
Croatia	174	11	14	25	1	9	4
Italy	4 228	468	1 629	2 010	582	2 053	3 207
Cyprus	5	9	9	53	5	1	10
Latvia	6	3	11	29	7	9	2

¹⁰ For MSW, no distinction is made between ferrous and non-ferrous metals. So, for total waste the MSW metals' recycling rate is used for both ferrous and non-ferrous metals.

Country (values in 1000 t)	Metal wastes, ferrous	Metal wastes, non- ferrous	Glass wastes	Paper and cardboard wastes	Plastic wastes	Wood wastes	Animal and mixed food waste; vegetal wastes
Lithuania	229	11	31	65	3	11	61
Luxembourg	75	4	43	57	4	73	45
Hungary	880	129	110	198	12	36	90
Malta	1	0	0	0	0	n/a	1
Netherlands	499	88	333	1 279	72	618	5 630
Austria	1 079	176	201	1 318	97	484	1 548
Poland	1 354	59	227	271	97	81	488
Portugal	267	46	364	249	19	88	7
Romania	53	2	19	93	28	112	324
Slovenia	84	24	22	43	9	101	36
Slovakia	116	5	23	81	22	n/a	49
Finland	84	9	114	269	6	888	305
Sweden	2 000	217	245	420	34	40	755
United Kingdom	8 046	1 181	2 527	2 901	744	2 894	4 778
EU28	38 093	4 677	11 758	21 338	4 423	12 667	33 740

Note: France, Malta and Slovakia lack data for wood generation (marked n/a in the table) so the recycling levels cannot be estimated.

Similarly, the maximum theoretical recycling potential for each Member State is calculated by multiplying the maximum recycling rates for MSW (see chapter 3) with the generated total waste for each selected material. The difference between existing (Table 3.4) and maximum theoretical recycling results (Table 3.5 below) is the theoretical maximum additional recycling potential, described in detail below.

Table 3.5 Theoretical maximum additional recycling potential in the EU28 Member states (1000 t) for selected materials

Note: figures estimated as the difference between current recycling levels and theoretical maximum, where recycling rates are extrapolated from MSW data

Country (values in 1000 t)	Metal wastes, ferrous	Metal wastes, non-ferrous	Glass wastes	Paper and cardboard wastes	Plastic wastes	Wood wastes	Animal and mixed food waste; vegetal wastes
Belgium	868	205	383	1 425	102	133	1 052
Bulgaria	0*	0*	32	29	27	172	522
Czech Republic	419	28	109	153	37	216	333
Denmark	62	5	39	326	46	36	447
Germany	2 163	301	0*	0*	0*	10 756	3 602
Estonia	248	14	20	33	10	591	26
Ireland	44	4	83	66	31	0*	673
Greece	515	27	55	279	52	97	383
Spain	1 910	281	201	2 002	220	342	2 799
France	4 009	383	939	5 021	472	n/a	4 292
Croatia	113	7	28	140	20	81	58
Italy	3 658	405	703	2 219	908	1 550	4 944
Cyprus	3	5	12	59	36	12	59
Latvia	7	4	16	58	5	42	114
Lithuania	56	3	37	37	24	157	335
Luxembourg	34	2	14	33	10	7	26
Hungary	202	30	35	244	89	187	429
Malta	3	2	2	7	2	n/a	12
Netherlands	662	117	222	621	260	1 758	3 968
Austria	447	73	83	195	98	335	0*
Poland	3 069	133	645	661	432	3 566	4 222
Portugal	611	104	211	562	98	673	153
Romania	1 124	40	198	670	326	1 789	11 876
Slovenia	136	39	19	63	17	212	123
Slovakia	533	23	35	101	37	n/a	268
Finland	176	20	18	264	44	10 140	512
Sweden	19	2	13	192	62	1 041	598
United Kingdom	3 500	514	1 078	1 765	1 429	561	3 974
EU28	24 592	2 769	5 231	17 224	4 893	34 454	45 800

Note: France, Malta and Slovakia lack data for wood so these MS are not taken into account in the calculation of the maximum additional recycling potential.

* Country serves as benchmark, so no additional recycling assumed possible.

3.1.4 Estimation of recycling potential for total waste by using packaging waste figures

Municipal solid waste (MSW) offers a good proxy for investigating total waste recycling, since its complete dataset covers all materials under investigation in this report. However, arguments can be found against the use of MSW data as a proxy for estimating maximum and current recycling levels for total waste: MSW is a very diverse mix of various waste materials and their separate collection or sorting, in order to recycle, is a complex procedure. Therefore, the potential for maximum recycling in MSW might be hindered by factors pertaining to the presence of foreign substances in collected waste, composite products in the MSW stream that are very difficult to separate and technical limitations of recycling.

For these reasons, packaging waste data could be used instead. Collection of packaging waste for recycling usually leads to a more homogenous material stream that is easier to recycle and offers higher recycling quality. Most of the waste streams (C&DW, industrial waste, agricultural waste) can be collected in a similarly homogenous manner as packaging. Therefore, using packaging waste data as a proxy could offer a more realistic approach towards filling the data gaps of total waste management.

For packaging waste we use a similar methodology, namely benchmarking the best performing countries in each of the investigated materials and using their level of recycling to calculate the maximum recycling in all other Member States. Table 3.6 below shows the current level of recycling in each of the materials. Note that because organic waste is not present in packaging waste, data from MSW is used for this material. The best performing countries for the rest of the materials are:

- Belgium: 97 % (metals);
- Belgium: 100 % (glass);
- Finland: 98 % (paper & cardboard);
- Slovenia: 82 % (plastics);
- Portugal: 98 % (wood).

Table 3.6 Recycled packaging waste in each EU Member State for selected materials in 2013, expressed as percentage of generation (%)

Country (values in % of generation)	Metallic packaging	Glass Packaging	Paper and cardboard Packaging	Plastic Packaging	Wood Packaging	Animal and mixed food waste; vegetal wastes
Belgium	97%	100%	89%	39%	59%	
Bulgaria	70%	61%	89%	41%	59%	
Czech Republic	59%	75%	88%	60%	36%	
Denmark	57%	78%	85%	36%	47%	
Germany	93%	89%	88%	49%	26%	
Estonia	58%	72%	76%	28%	66%	
Ireland	79%	80%	79%	40%	82%	
Greece	44%	62%	77%	44%	41%	
Spain	81%	67%	75%	41%	64%	
France	76%	74%	96%	26%	28%	
Croatia	12%	65%	88%	45%	2%	
Italy	74%	71%	85%	37%	56%	
Cyprus	71%	32%	97%	45%	12%	
Latvia	57%	55%	75%	25%	36%	
Lithuania	66%	55%	87%	43%	20%	
Luxembourg	84%	95%	74%	32%	51%	
Hungary	95%	32%	78%	31%	8%	
Malta	34%	49%	48%	23%	1%	
Netherlands	93%	79%	89%	46%	22%	

Country (values in % of generation)	Metallic packaging	Glass Packaging	Paper and cardboard Packaging	Plastic Packaging	Wood Packaging	Animal and mixed food waste; vegetal wastes
Austria	87%	85%	84%	34%	20%	
Poland	34%	44%	50%	20%	22%	
Portugal	76%	56%	73%	35%	98%	
Romania	44%	62%	77%	44%	41%	
Slovenia	58%	86%	79%	82%	15%	
Slovakia	69%	73%	80%	55%	36%	
Finland	82%	77%	98%	23%	15%	
Sweden	77%	89%	78%	46%	60%	
United Kingdom	57%	68%	89%	32%	42%	
EU28	74%	73%	85%	37%	36%	

Source: percentages estimated based on "generation" and "recycling" data retrieved from Eurostat on 17 February 2016.

Assuming that the best performing country represents the highest possible recycling for each material, the theoretical maximum additional recycling for each country can then be estimated based on the difference between the current levels of recycling and the theoretically highest recycling rate. In the EU28 as a whole, room for improvement can be found mainly in wood and plastic packaging (respectively 62% and 45% of difference).

Packaging waste data is used to estimate the current recycling levels of total waste; the results are shown in Table 3.7 below. Figures for organic waste are copied from the similar calculations done for MSW.

Table 3.7 Estimation of current recycling of total waste generated in the EU28 Member States (1000 t)

Note: values expressed as the product of total waste generated and packaging waste's current recycling rates¹¹

Country (values in 1000 t)	Metal wastes, ferrous	Metal wastes, non-ferrous	Glass wastes	Paper and cardboard wastes	Plastic wastes	Wood wastes	Animal and mixed food waste; vegetal wastes
Belgium	2 090	492	894	3 449	238	2 474	3 009
Bulgaria	368	67	40	179	41	118	5
Czech Republic	1 681	111	235	616	194	85	42
Denmark	612	49	138	876	39	108	296
Germany	8 609	1 197	2 640	7 215	1 249	2 989	7 113
Estonia	264	15	35	72	6	542	5
Ireland	168	15	202	313	51	164	365
Greece	430	22	46	402	59	50	27
Spain	3 610	531	766	2 699	465	802	534
France	9 235	881	1 741	7 037	421	1 719	5 004
Croatia	41	3	29	177	18	2	4
Italy	6 877	761	1 778	4 357	1 005	2 181	3 207
Cyprus	7	12	7	133	34	2	10
Latvia	9	4	16	79	5	20	2

¹¹ For packaging waste, no distinction is made between ferrous and non-ferrous metals. So, for total waste the packaging waste metals' recycling rate is used for both ferrous and non-ferrous metals. For animal and mixed food waste; vegetal wastes we continue to use the MSW rate.

Country (values in 1000 t)	Metal wastes, ferrous	Metal wastes, non- ferrous	Glass wastes	Paper and cardboard wastes	Plastic wastes	Wood wastes	Animal and mixed food waste; vegetal wastes
Lithuania	219	10	40	108	22	37	61
Luxembourg	107	5	58	81	8	45	45
Hungary	1 199	175	51	421	57	18	90
Malta	2	1	1	5	1	0	1
Netherlands	1 260	223	471	2 055	282	562	5 630
Austria	1 563	256	260	1 552	123	180	1 548
Poland	1 787	77	410	567	194	865	488
Portugal	779	133	345	725	75	811	7
Romania	612	22	145	715	286	849	324
Slovenia	150	44	38	102	39	51	36
Slovakia	524	23	45	177	60	146	49
Finland	249	28	110	633	21	1 793	305
Sweden	1 831	198	248	583	80	702	755
United Kingdom	7 758	1 139	2 654	5 080	1 260	1 584	4 778
EU28	52 038	6 494	13 443	40 410	6 332	18 898	33 740

Similarly, the maximum theoretical recycling potential for each Member State is calculated by multiplying the maximum recycling rates for packaging waste with the generated total waste for each selected material. The difference between existing and maximum theoretical recycling results is the theoretical maximum additional recycling potential.

Table 3.8 Theoretical maximum (1000 t) recycling potential in the EU 28 Member states for selected materials

Note: values estimated as the product of theoretical maximum packaging recycling levels and total waste generation

Country (values in 1000 t)	Metal wastes, ferrous	Metal wastes, non- ferrous	Glass wastes	Paper and cardboard wastes	Plastic wastes	Wood wastes	Animal and mixed food waste; vegetal wastes
Belgium	2 090	492	894	3 776	499	4 128	4 062
Bulgaria	511	93	65	197	82	198	528
Czech Republic	2 786	185	313	685	266	234	375
Denmark	1 043	84	178	1 001	88	228	743
Germany	8 960	1 245	2 976	7 985	2 068	11 532	10 715
Estonia	438	25	49	92	19	804	31
Ireland	206	19	253	386	103	197	1 037
Greece	941	49	75	509	109	119	410
Spain	4 328	636	1 136	3 511	934	1 228	3 333
France	11 820	1 128	2 355	7 170	1 346	5 958	9 296
Croatia	325	20	45	196	32	96	62
Italy	8 960	992	2 512	5 023	2 234	3 841	8 151
Cyprus	9	16	22	134	61	14	69
Latvia	15	7	29	104	18	55	116
Lithuania	324	15	74	121	41	179	396

Country (values in 1000 t)	Metal wastes, ferrous	Metal wastes, non-ferrous	Glass wastes	Paper and cardboard wastes	Plastic wastes	Wood wastes	Animal and mixed food waste; vegetal wastes
Luxembourg	124	6	61	107	22	86	71
Hungary	1 230	180	157	525	152	238	519
Malta	5	3	3	10	4	13	13
Netherlands	1 319	233	598	2 257	498	2 533	9 599
Austria	1 734	283	306	1 796	292	874	1 548
Poland	5 026	218	940	1 107	792	3 888	4 710
Portugal	998	171	620	963	175	811	160
Romania	1 338	48	234	906	531	2 026	12 200
Slovenia	250	72	44	127	39	333	159
Slovakia	738	32	62	217	88	395	317
Finland	295	33	143	633	75	11 756	817
Sweden	2 294	248	279	726	144	1 153	1 353
United Kingdom	13 119	1 926	3 885	5 542	3 258	3 684	8 751
EU28	71 225	8 460	18 306	45 806	13 967	56 599	79 541

Table 3.9 Theoretical maximum (1000 t) additional recycling potential in the EU 28 Member states for selected materials

Note: values estimated as the difference between current recycling levels and theoretical maximum, where recycling rates are extrapolated from packaging waste data

Country (values in 1000 t)	Metal wastes, ferrous	Metal wastes, non-ferrous	Glass wastes	Paper and cardboard wastes	Plastic wastes	Wood wastes	Animal and mixed food waste; vegetal wastes
Belgium	0*	0*	0*	327	261	1 654	1 052
Bulgaria	143	26	25	18	40	80	522
Czech Republic	1 106	73	78	70	72	149	333
Denmark	431	35	40	124	49	120	447
Germany	351	49	337	770	819	8 543	3 602
Estonia	174	10	14	21	12	262	26
Ireland	38	3	51	73	53	34	673
Greece	511	27	28	107	50	69	383
Spain	717	105	370	812	469	426	2 799
France	2 585	247	614	133	924	4 238	4 292
Croatia	285	18	15	19	14	94	58
Italy	2 084	231	734	665	1 229	1 660	4 944
Cyprus	2	4	15	0	27	12	59
Latvia	6	3	13	24	12	35	114
Lithuania	105	5	33	13	20	142	335
Luxembourg	17	1	3	25	13	41	26
Hungary	31	5	106	104	95	220	429
Malta	3	2	1	5	3	13	12
Netherlands	59	10	127	202	216	1 970	3 968
Austria	171	28	47	245	169	694	0*
Poland	3 239	140	530	540	599	3 023	4 222

Country (values in 1000 t)	Metal wastes, ferrous	Metal wastes, non-ferrous	Glass wastes	Paper and cardboard wastes	Plastic wastes	Wood wastes	Animal and mixed food waste; vegetal wastes
Portugal	220	38	274	238	99	0*	153
Romania	726	26	89	190	245	1 177	11 876
Slovenia	99	29	6	25	0*	282	123
Slovakia	214	9	17	40	29	248	268
Finland	46	5	33	0*	54	9 963	512
Sweden	463	50	31	143	64	451	598
United Kingdom	5 360	787	1 231	463	1 998	2 100	3 974
EU28	19 186	1 966	4 864	5 396	7 634	37 701	45 800

* Benchmarked country.

3.1.5 Estimation of recycling potential for total waste by using MSW or packaging waste figures

Packaging waste is able to reach higher theoretical maximum recycling levels than MSW, but packaging waste has already achieved higher current recycling levels in all materials. These two differences determine the variations in theoretical maximum recycling potentials for the two approaches.

Table 3.10 Difference (1000 t) in theoretical maximum additional recycling potential in the EU28 Member states for selected materials, estimated on the basis of MSW or packaging waste data.

Note: A minus sign in the table shows that the MSW-based potential is higher, meaning that the number in the table reflect the "packaging waste-based potential – MSW-based potential".

Country (values in 1000 t)	Metal wastes, ferrous	Metal wastes, non-ferrous	Glass wastes	Paper and cardboard wastes	Plastic wastes	Wood wastes	Animal and mixed food waste; vegetal wastes
Belgium	-868	-205	-383	-1 098	159	1 521	0
Bulgaria	143	26	-7	-12	13	-92	0
Czech Republic	686	46	-31	-83	35	-66	0
Denmark	369	30	0	-201	3	84	0
Germany	-1 812	-252	337	770	819	-2 213	0
Estonia	-74	-4	-6	-12	2	-329	0
Ireland	-6	-1	-33	7	21	34	0
Greece	-4	0	-26	-172	-2	-28	0
Spain	-1 193	-175	169	-1 190	249	84	0
France	-1 424	-136	-325	-4 888	453	4 238	0
Croatia	172	11	-12	-121	-6	13	0
Italy	-1 574	-174	32	-1 553	320	110	0
Cyprus	0	0	3	-59	-9	0	0
Latvia	-1	-1	-3	-34	7	-8	0
Lithuania	49	2	-4	-24	-5	-15	0
Luxembourg	-17	-1	-11	-8	3	34	0
Hungary	-172	-25	71	-140	5	33	0
Malta	0	0	-1	-1	0	13	0
Netherlands	-603	-107	-95	-419	-44	213	0

Country (values in 1000 t)	Metal wastes, ferrous	Metal wastes, non- ferrous	Glass wastes	Paper and cardboard wastes	Plastic wastes	Wood wastes	Animal and mixed food waste; vegetal wastes
Austria	-277	-45	-37	50	72	358	0
Poland	169	7	-115	-121	167	-543	0
Portugal	-391	-67	64	-323	1	-673	0
Romania	-398	-14	-109	-479	-81	-611	0
Slovenia	-37	-11	-13	-39	-17	70	0
Slovakia	-319	-14	-18	-62	-8	248	0
Finland	-130	-15	15	-264	10	-177	0
Sweden	444	48	18	-49	1	-590	0
United Kingdom	1 860	273	153	-1 303	569	1 538	0
EU28	-5 406	-803	-367	-11 828	2 741	3 247	0

The difference in organic waste is 0, as the potential is calculated on the basis of MSW data in both cases.

Table 3.10 shows that the potential for further increasing recycling appears higher when considering MSW data for metals, glass and paper and cardboard waste, while it appears lower for plastics and wood wastes.

3.2 Resource efficiency and energy savings estimation

In order to estimate the energy (and environmental) implications of increasing resource efficiency, which corresponds to maximising recycling in the solid waste sector, the additional recycling potential needs to be translated into energy and environmental savings. Life cycle data is used for this operation and the full savings are estimated by multiplying the additional recycling potential quantities with unitary savings (i.e. savings per tonne) for each material in question.

Life Cycle Assessment (LCA) data encompass the full consequences of increasing recycling by taking into account the implications to all economic sectors. In this way, LCA data represent the resource efficiency and environmental impacts associated with the recycling operations as such (e.g. re-melting of metals or de-inking of paper), but also the savings from avoiding production of primary materials (e.g. production of virgin metals from ores or paper from wood). However, since the focus remains on the recycling sector, further indirect implications, such as the reduction of emissions due to less landfilling or incineration because of the additional recycling are considered outside the scope of our calculations.

More specifically, while calculating the savings, two sets of processes are used for the selected waste materials: recycling processes that include all recycling operations and primary production processes that refer to production of the respective virgin materials (metals from ore, paper from virgin pulp, etc.). The net savings can be calculated by subtracting the impact of primary production from the impact of recycling, indicating that each kilogram produced in recycling plants could substitute 1 kg of virgin product (i.e. 1:1 assumed substitution ratio).

The Ecoinvent database V3, the state-of-the-art source for LCA data, provides the source data for all processes involved [Ecoinvent Database, 2015]. The exact processes selected and assumptions around the calculations can be found in Table A.1.5 in Annex 1.

Based on the Ecoinvent data, results are presented for energy savings and climate change. The method for estimating impacts for these two extra impact categories is compliant with the JRC's

International Reference Life Cycle Data System (ILCD)'s guidelines¹². Climate change is expressed in CO₂-eq, namely representing all emissions translated into CO₂ emissions.

Results of the energy savings calculations are estimated both based on MSW and packaging waste recycling rates. These are presented in Table 2.11 and 2.12

Below the results refer to the benefit from recycling in addition to the current level; benefits from current recycling are not included.

As shown in chapter 3.1, the margin for improvement (i.e. the difference between current and maximum recycling levels) for the EU is higher for MSW than packaging waste (for all materials examined, except for plastics). This fact is reflected on the resource savings results: the savings for total waste, based on MSW, are higher compared to the calculations based on packaging waste.

Table 3.11 Estimation of energy and resource savings from exploiting the additional potential recycling of total waste in the EU28. Calculations are based on MSW recycling rates.

Note: Savings from total annual recycling refer to the additional savings possible, corresponding to the difference between current recycling levels and maximum recycling.

Material	Average recycling and reuse in EU28 (%)	Maximum recycling and reuse at country level (%)	Potential for material recycling and reuse (1000 t)	Potential for energy savings (PJ)	Potential for CO ₂ savings (1000 t of CO ₂ e)
Metal waste, ferrous	54%	85% (BG)	24 592	361	52 925
Metal waste, non-ferrous	54%	85% (BG)	2 769	451	44 134
Glass wastes	62%	93% (DE)	5 231	46	3 813
Paper and cardboard wastes	46%	82% (DE)	17 224	542	8 511
Plastic wastes	29%	55% (DE)	4 893	209	7 312
Wood wastes	40%	92% (IE)	40 425	1 805	3 082
Animal and mixed food waste; vegetal wastes	36%	85% (AT)	45 800	99	100
Total				3 512	119 877

Note: average recycling in EU28 refers to weighted average, namely according to the level of waste generation in each country.

¹² <http://epica.jrc.ec.europa.eu/uploads/ILCD-Recommendation-of-methods-for-LCIA-def.pdf>.

Table 3.12 Estimation of energy and resource savings from exploiting the additional potential recycling of total waste in the EU28. Calculations are based on packaging waste recycling rates.

Note: Savings from total annual recycling refer to the additional savings possible, corresponding to the difference between current recycling levels and maximum recycling. Calculations for organic waste are based on MSW figures

Material	Average recycling and reuse in EU28 (%)	Maximum recycling and reuse at country level (%)	Potential for material recycling and reuse (t)	Potential for energy savings (PJ)	Potential for CO ₂ savings (1000 t of CO ₂ e)
Metal waste, ferrous	74%	97% (BE)	19 186	282	41 291
Metal waste, non-ferrous	74%	97% (BE)	1 966	320	31 336
Glass wastes	73%	100% (BE)	4 864	42	3 546
Paper and cardboard wastes	85%	98% (FI)	5 396	170	2 666
Plastic wastes	37%	82% (SI)	7 634	327	11 408
Wood wastes	36%	98% (PT)	37 701	1 683	2 874
Animal and mixed food waste; vegetal wastes	36%	85% (AT)	45 800	99	100
Total				2 923	93 220

3.3 References

- Ecoinvent Database 2015 Ecoinvent database, version 3. Accessed on December 2015. Available from <http://www.ecoinvent.org/database/database.html>.
- Eurostat Database 2015 Eurostat database. Accessed on September 2015. Available from <http://ec.europa.eu/eurostat/web/environment/waste/database>.

4 Water and wastewater management sector

As many studies highlight, water and energy consumption are closely linked. Energy is needed for water supply (pumping, treatment and distribution), water heating (e.g. for domestic use) and waste water treatment [EEA, 2012]. At the same time, water is needed to cool thermoelectric plants and to generate hydropower. This chapter investigates and assesses the potential for energy saving that would result from more efficient water use and from water savings¹³.

Many studies have investigated water-saving potential, applying different approaches relying on technical (efficiency of water-saving devices), economic (effectiveness of pricing policies), social (willingness to adopt new behaviour) and public policy (efficiency of various policies to reduce water demand) concepts and tools. Results on water-saving potential are available for the main water consuming sectors, i.e. irrigation for agriculture, water consumption by the domestic sector and industry. Options for reducing energy consumption in the same sectors have also been investigated. However, combining both approaches for assessing potential energy savings as a result of water savings, as this study offers, has received limited attention¹⁴.

4.1 Water saving and water-related energy consumption

Definition of 'water saving'

This section concentrates on water savings permitted through technological changes and with technologies that exist today. Since changes in behaviour or water savings induced by policy or economic drivers are more complicated to quantify, the assessments made and presented in the following sections focus on water savings that would be possible in the 28 European Union (EU) Member States (MS) with current technologies, population, cropping patterns and industrial production. The scope of this assessment is therefore similar to that of the 2007 EC study on water-saving potentials in Europe, which remains a key reference for the present study. Drivers and barriers to adopting the technological changes driving water savings, and thus energy savings, which are analysed here, are developed in section 5.

In all water-use sectors, water savings can take place at different levels: by reducing losses in the conveyance system/ network and increasing conveyance efficiency; or by applying adequate devices and processes that reduce the use of water by increasing water-use efficiency itself. For each sector, improvements in water-use efficiency or conveyance efficiency can be translated into potential water savings in terms of reducing the abstracted water volume and, when relevant, into potential reductions in wastewater volumes needing treatment in specialised plants.

Cooling processes, including those for electricity production, necessitate abstracting water that is subsequently returned to the water stream in (almost) the same quantity at a higher temperature. Since no water is consumed or diverted from the water cycle in this case, the potential decrease of the water volume abstracted by adopting a dry cooling process was not included in the scope of this study.

Energy saving directly generated by water savings

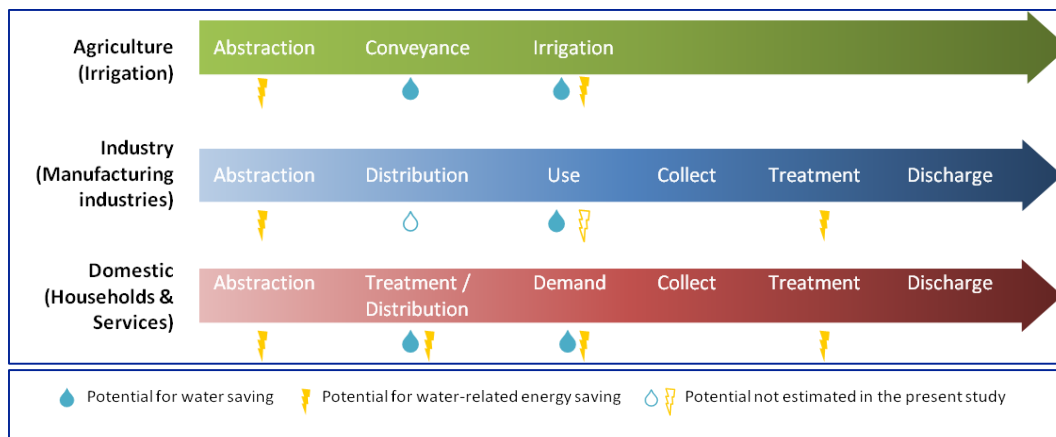
Depending on the sector considered, energy savings can occur in different steps of the water (service) system. The majority of energy savings, however, is mainly found in water abstraction and distribution and with waste water treatment. Treating water to ensure drinkability is also a step requiring energy. For the domestic sector, reducing water consumption can also be a source for energy savings, as it leads to reduced use of heated water.

¹³ The potential impact of reducing energy consumption on water consumption is not investigated here since it is out of the present study's scope.

¹⁴ Two studies requested by the European Commission estimated energy-savings potential by regulating taps and shower: Amended Ecodesign Working Plan under the Ecodesign Directive (VHK, January 2012) and Preparatory Study on Taps and Showers (JRC, February 2014). A comparison between the results of the present study and the ones of the two previously mentioned studies is proposed at the end of this section.

The components of the water system that have potential for water savings and for energy savings are summarized in Figure 4.1 for the main water-use sectors considered.

Figure 4.1 Potential water savings and energy savings in water systems



Other energy savings in the water and wastewater sectors

In addition to the direct water and energy savings listed in Figure 4.1, other energy savings could be achieved in water and wastewater systems. However, as not directly linked to water savings, these areas for savings are beyond the scope of the present effort for various reasons. For example, some are linked to the development of new technologies:

- The use of dry technologies for cooling processes allows decreasing water abstraction. Since this water is usually put back into water streams it nevertheless does not lead to any water saving. Moreover, as those technologies are less efficient, it offsets the gain of energy consumed for water abstraction;
- Innovative technologies to treat wastewater have been developed in recent years. Wastewater plants equipped with these technologies are more energy efficient than traditional ones and return the same results in discharged water quality.

Others areas for water savings can be found in mobilising alternative water sources leading to additional energy savings:

- Developing water reuse systems¹⁵, which reduce the volume of water abstracted and thus energy use for pumping fresh water¹⁶. But using reused water, might require obtaining high water quality after treatment¹⁷, and as a trade-off also implies higher energy demand;
- The use of water desalination and the additional (high) energy saving that can be expected from any water saving in countries that rely heavily on water desalination (e.g. Malta or Cyprus)¹⁸.

Furthermore, developing sludge recycling (to produce nutrient as phosphorus) and biogas production that generates energy can also improve the energy balance in the water sector¹⁹. It should be noted, however, that these activities are independent from reducing water abstraction and improving water savings *per se*, which are the central focus of the present investigation.

¹⁵ In the Eurostat statistics, 'reused water' refers to water that has undergone wastewater treatment and is delivered to a user as reclaimed wastewater (direct supply).

¹⁶ A recent report by BIO et al. (2015) provides a roughly estimated current volume of reused water in the EU: 1 100 Mm³ annually, accounting for about 2.4% of treated urban wastewater.

¹⁷ In most cases only, Indeed, tertiary treatment required for discharges to rivers would be enough for reuse in irrigation of numerous crops.

¹⁸ Anderson et al. (2008) investigated the potential impacts of desalination development on energy consumption in the EU. A chapter was dedicated to the impacts of water-saving measures on both avoided energy consumption for desalination and on energy savings within different water-use processes.

¹⁹ The Europe-funded research projects "European Nitrogen Assessment" (Sutton et al., 2011 - <http://www.nine-esf.org/ENA-Book>) and R3Water have assessed some specific aspects of materials extraction from wastewater.

Those indirect improvements in the energy balance of the water sector are more complicated to characterize and to quantify as they imply more complex changes in the overall management of the water service sector. Furthermore, reliable data are not available to indicate the importance of alternative water resources or for reporting on the development of sludge recycling and biogas production at the level of the EU and for the 28 MS. Thus, these indirect energy-saving issues are not investigated in this study. As a result, this chapter focuses on “direct” energy savings.

4.2 Data collection

The first step before assessing potential water savings is to collect data on current water consumption and to quantitatively assess different components of the water cycle (from abstraction to waste water discharge) for the different sectors. Energy consumption linked to current water use can then be calculated using average energy consumption to abstract and produce water, to heat water and/ or to treat waste water. Contextual data is also collected since it might help with assessing current energy consumption and potential energy savings.

(Waste) Water data

Eurostat collects data on water abstraction, water supply, water leakage, wastewater generation, wastewater treatment, water discharge after treatment and sludge disposal for the 28 EU MS. Even if all data come from the same source, heterogeneity, coherence, degree of completeness and recentness are highly variable between countries and variables. Whenever possible, mean values for the period 2009-2013 have been used to smooth out some of this variability. Most recent data were used when mean values for this period were not available. Missing values were recalculated, either by summing available information on other variables for the same country²⁰ or by applying available ratios from other countries²¹. Data mobilised in the present study include:

- Agriculture – only for irrigation; aquaculture and forestry are sectors with negligible total water volume abstraction for the vast majority of MS;
- Industry – manufacturing industries; mining and construction were excluded since these sectors have marginal water abstraction in terms of the total volumes of water abstracted;
- Domestic – households and services; when water abstraction data for households and services were not sufficient, these were recalculated using data from Public Water Systems (PWS) subtracting the industrial part;
- Public Water Systems (PWS) – water distribution to most households and services and to some industries; PWS is a key sector when dealing with conveyance efficiency and water leakages.

The list of data collected (or recalculated) from the Eurostat data base for each sector is provided in Annex 2: (Waste) Water Management: Figures and data.

Contextual data

For the agricultural sector, contextual data on irrigated land and on the share of irrigated land for different irrigation methods (surface, sprinkler and drop) have also been collected using Eurostat data. Whenever possible, mean values for the period 2009-2013 were used. When these were not available, most recent available data were used as already indicated above. As the number of holdings using only a specific irrigation method is available, the share between irrigation methods in terms of total land area has been recalculated using the average size of holdings in each country.

²⁰ For example, calculating the total volume of water abstraction by summing the water abstractions of individual water-use sectors.

²¹ For example by calculating the volume of waste water treated using the volume of waste water generated.

Eurostat data also provided MSs' total population figures, required for estimating the average domestic water consumption per capita. To estimate the energy consumption for the domestic sector, the volume of heated water is needed. According to literature [Action planète propre, 2015], heated-water volumes on average equal one third of domestic water use, corresponding to heated water for washing machines, dishwashers and showers.

Total electricity consumption per inhabitant and MS has also been collected on Eurostat.

Energy consumption

Aggregated energy consumption data for drinking water supply, various irrigation types (surface/ sprinkler/ drip), wastewater treatment and water heating have been obtained from literature. For water supply calculations, a mean value of 0.46 kWh/m³ is used to account for total electricity consumed in the process of freshwater abstraction, treatment and supply [EBC, 2013] – with values ranging from 0.08 kWh/m³ to 0.72 kWh/m³ [ACEEE, 2014]. As regards wastewater collection and treatment, a mean value of 0.53 kWh/m³ is used [EBC, 2013 and ACEEE, 2014], with values ranging from 0.27 kWh/m³ to 0.78 kWh/m³, and with the range for different levels of treatment (primary, secondary, tertiary) available. Since no value for self-supply and autonomous treatment could be found in the literature, the values of collective systems were used. For heating domestic water, a mean value of 42.4 kWh/m³ is used²², with values ranging from 34.8 kWh/m³ to 48.1 kWh/m³. Domestic water heating appears clearly as a highly energy-intensive activity. Finally, for irrigation the values summarized in Table 4.1 were used [Rasquilho, 1981].

Table 4.1 Energy consumption of main irrigation technologies

Energy consumption (kWh/m ³)	Mean	Minimum	Maximum
Surface irrigation	0.030	0	0.060
Sprinkler irrigation	0.340	0.256	0.509
Drip irrigation	0.192	0.131	0.256

Those ratios of energy consumption per activity and sector described above are called "elementary" energy consumptions in the following paragraphs.

As mentioned earlier, mean EU values for activities were applied to all MS. Clearly, the amount of energy consumed for water abstraction depends on the type of water resources mobilised (surface water or ground water) and the overall topography of a given MS or region. Some studies show that the amount of energy used in the abstraction of ground water is higher than for collecting and transporting surface waters (often transported by gravity).

4.3 Scenarios

4.3.1 Current water use in EU MS and assessment of energy consumption

Water use in EU MS

A total of 155 508 million cubic metres of water is abstracted each year in the 28 MS of EU28 for the three sectors analysed. Figure 4.2 displays the current water abstraction volumes per sector (domestic, industry and agriculture) and per MS in million cubic meters.

²² Value calculated to heat water from a temperature of 12°C to a temperature of 45°C (from 5°C for the maximum value, and 20°C for the minimum value).

Figure 4.2 Current water abstraction volumes per sector for EU28

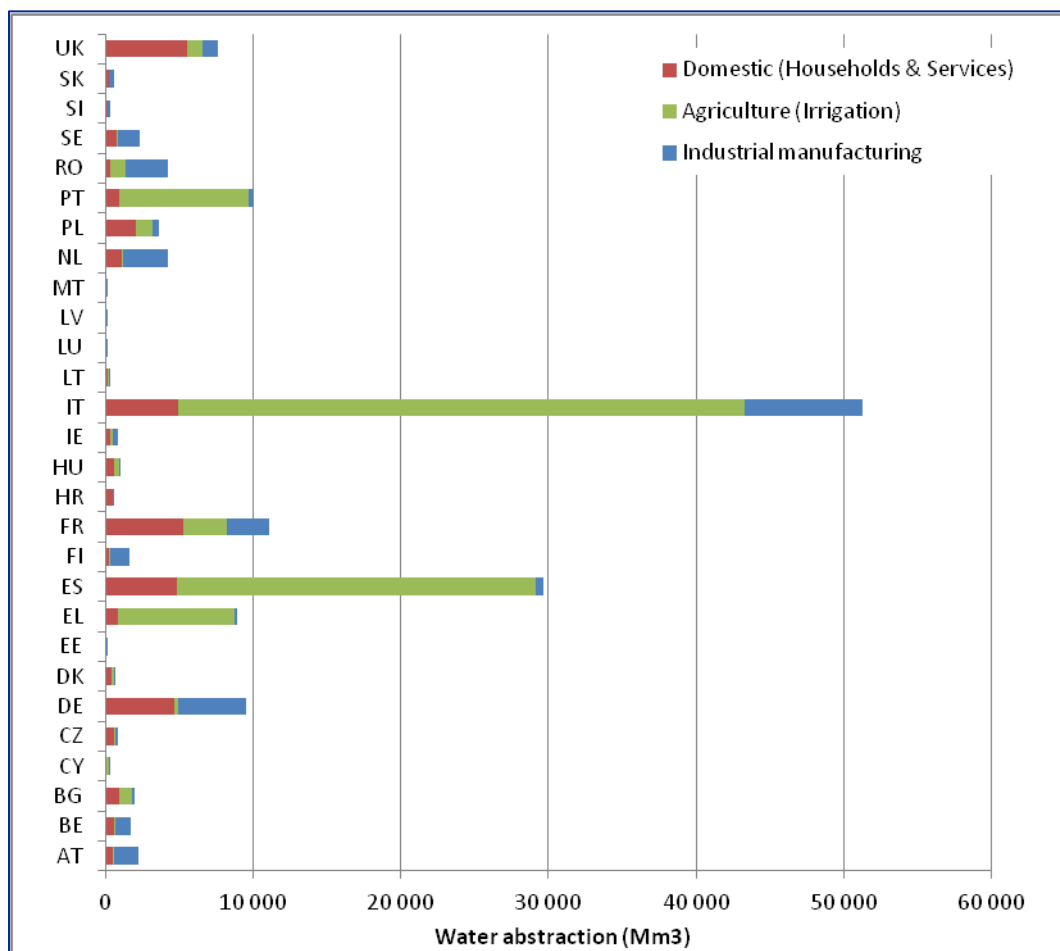


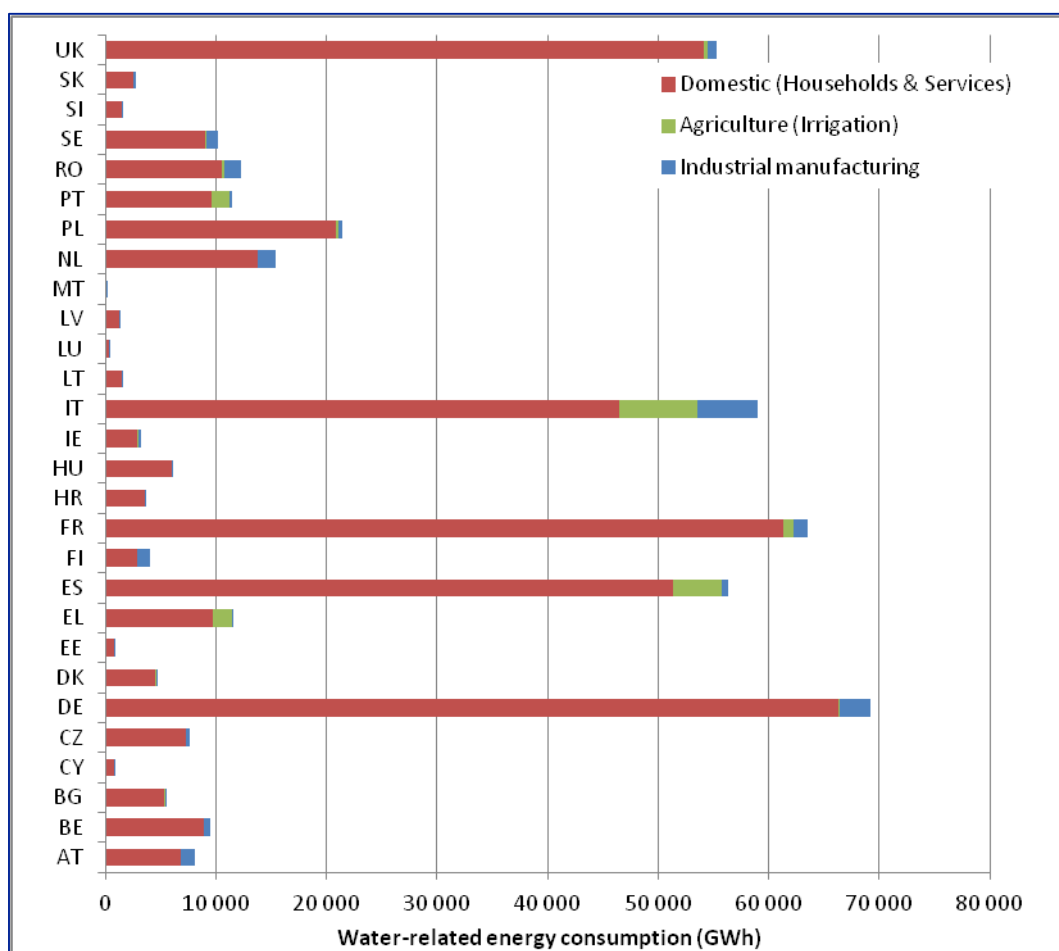
Figure 4.2 shows the large disparities in total water abstraction volumes per country for the selected sectors; Italy, Spain and France have the largest volumes of freshwater abstracted. Significant differences per country can also be found per activity type. In Italy, Spain, Greece, Malta, Cyprus and Portugal, more than half of the total abstraction volume comes from agricultural activities, while in many other countries more than half of the abstraction is intended for industrial purposes (Austria, Belgium, Germany, Finland, Netherlands, Romania, Sweden and Slovakia). Moreover, water for domestic supply rarely represents a large fraction of total water abstraction, with the exception of most of Central & Eastern Europe countries (Czech Republic, Estonia, Croatia, Hungary, Lithuania, Poland and Slovenia), Denmark, Luxembourg and the United Kingdom, where abstraction for domestic supplies represent the majority of total abstraction volumes. Clearly, energy savings will not depend uniquely on total water abstraction, but also on the types of activities that demand water. At the EU28 MS level, water abstraction for domestic, industrial and agricultural activities respectively represent 23%, 20% and 57% of total water abstraction volumes.

Displaying water abstractions per capita, as presented in Annex 2: (Waste) Water Management: Figures and data Figure A.2.1, is also interesting since it allows considering very different population sizes. Water abstraction over all sectors ranges from 57 m³ per capita (Luxembourg) to 988 m³ per capita (Italy). The mean total water abstraction volume is 257 m³ per person and per year over all sectors in the EU28. For the domestic sector, water abstraction represents 67 m³ per person and year on average and 42% of water abstractions per capita over all sectors.

Energy consumptions

Using the data mentioned above, water-related energy consumption was calculated per country and per sector, as can be seen in Figure 4.3

Figure 4.3 Total water-related energy consumption for the selected sectors in the EU28



In total, water-related energy consumption represents 447 324 GWh per year across sectors in the EU28, with a minimum and maximum estimated as 340 182 and 532 377 GWh per year (corresponding to the ratio between the minimum and maximum of each MS's energy consumption). In all countries, the domestic sector consumes the most energy for water use (on average 92%), ranging from 70% to 98% of total water-related energy use. The domestic sector's high demand for water-related energy consumption primarily stems from water heating. Energy demand for water can also reach beyond 10% for irrigation in some countries (e.g. Portugal, Italy, Greece), while industry consumes high amounts of energy for water in Finland and Austria (respectively 29% and 15% of total water-related energy consumption).

As indicated in Annex 2 (see Figure A.2.2) about water-related energy consumption, detailing the share between energy consumption linked to abstraction, waste water treatment and water heating), domestic water heating accounts for more than 64% of water-related energy consumption for all countries, whereas abstraction and wastewater treatment combined demand the remaining 36%.

4.3.2 EU28 water-saving potential

Water-saving estimation methodology

Potential water saving was estimated following the rules exposed in Annex 3, which follow the main assumptions developed in the EU water-saving potential, 2007 (Ecologic for the European Commission) for each sector. Those rules are summarized in Table 4.2.

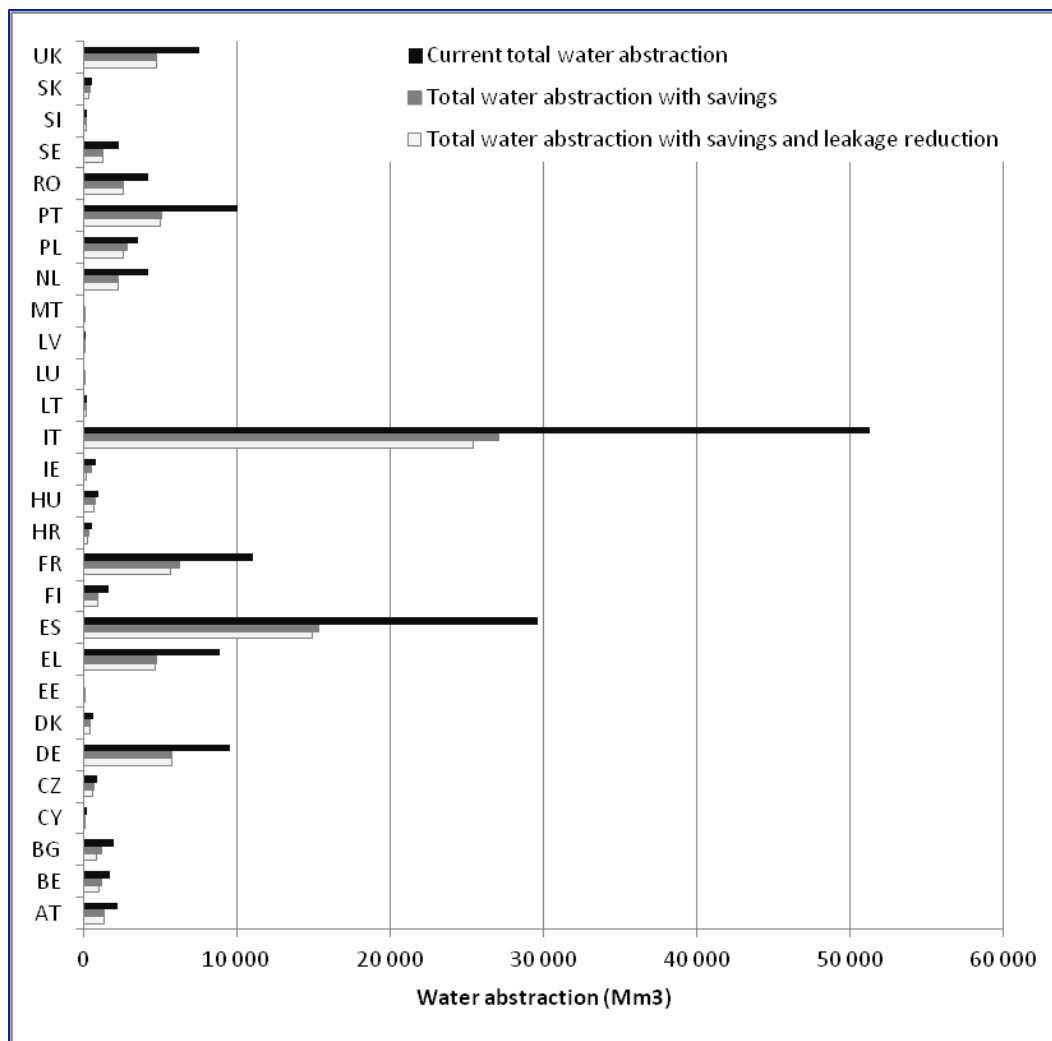
Table 4.2 Water-saving estimation methodology for each sector

Sector	Scope	Calculation method
Agriculture (irrigation)	Water savings achievable from technical measures that assume stable crop patterns, i.e. water savings resulting from improvements in either or both conveyance and application efficiency.	Water-saving potential calculated as the difference between the current water abstraction and an optimum water abstraction. Optimum water abstraction for each MS is calculated considering: <ul style="list-style-type: none"> the irrigated area (current = optimum); the water requirements of crops (current = optimum); a target conveyance efficiency (90% as in the 2007 study); a target share of irrigation methods (surface, sprinkler and drip) for each country, with assumptions based on the current share and on the 2007 study's assumptions; the application efficiency of each irrigation method.
Domestic	<p><u>Case 1:</u> Water savings relying on technical progress and changes in behaviour.</p> <p><u>Case 2:</u> Water savings relying only on technical progress.</p>	<p><u>Case 1:</u> Water-saving potentials are based on a target water demand per capita compared to current water demand per capita in each country. The total water demand was estimated based on the population of each country. The target domestic water demand of 100 l/p/d was used, as recommended in the Water-saving potential study of 2007.</p> <p><u>Case 2:</u> Water-saving potential through most efficient technologies only (with no behaviour changes) is considered equal to 10% in all MS, as recommended in the Study for the Amended Ecodesign Working Plan (2011). This saving potential would lead to an average water demand in the domestic sector equal to 133 litres per capita and per day instead of 148 l/p/d currently - but with a high variability among MS, as it is the case today.</p> <p><u>Cases 1 & 2:</u> Hot water-saving potential estimates were calculated equal to a third of domestic water demand. Water savings on demand were translated into changes in water abstraction for the domestic sector, proportionally to the ratio between current water supply and current water abstraction for the domestic sector - and similarly for the volumes of wastewater to be treated.</p>
Industrial manufacturing	Water savings that can be achieved through most efficient technologies.	Average saving potentials for various sub-sectors from the 2007 study were used (those were based on a literature review and several case studies). Those water saving potentials (identical for all MS) were applied to the share of water abstraction between sub-sectors (food products and beverages, textiles, paper, chemicals and manufacturing industries in general) available on Eurostat. Potential saving in the volume of waste water treated was calculated as the volume of water abstracted with savings multiplied by the current ratio of treated waste water on abstracted water for each country.
PWS	Additional water savings achieved with leakage reduction in public networks.	Additional water savings were estimated as the difference between the current volume of water losses during transport (from Eurostat) and the losses if a target leakage rate was attained in all MS (target leakage rate equal to 15% according to OECD environmental reports).

Water-saving potential

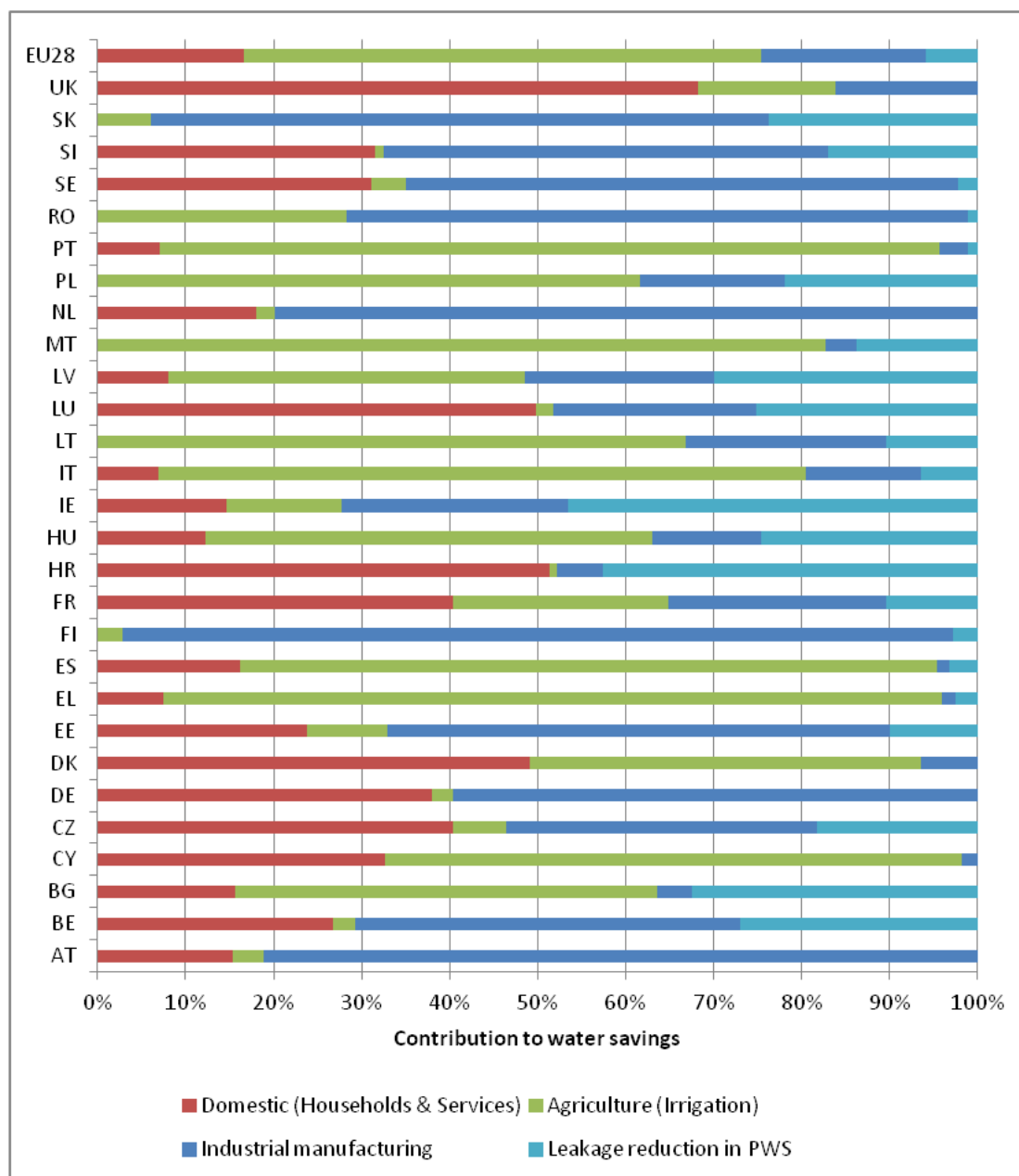
Applying the methodology described above, the total volume of water abstracted for the three main sectors (irrigation, domestic and manufacturing industries), after adopting water savings and leakage reduction in water networks, would be (case 1) 82 446 and 88 925 million cubic metres per year in the EU28 respectively for cases 1 and 2. Figure 4.4 shows total water-saving potentials per MS, including savings in the domestic (case1), industrial and agriculture sectors and in PWS (resulting from increased conveyance efficiency).

Figure 4.4 Water-abstraction and saving potential in the EU28 per MS



Water savings and leakage reduction would lead to a 47% reduced need for water abstraction volumes in case 1 (i.e. with some changes in behaviour for the domestic sector consumption) and 40% decreased need in case 2 (i.e. with technological progress only). This decreased need ranges from 17% reduction in Estonia up to 72% in Ireland in case 1 as compared to the current water abstraction amounts. The contribution of each sector to water-saving potential is shown in Figure 4.5 (considering case 1 for the domestic sector).

Figure 4.5 Sectors contribution to water savings as percent of total potential savings



In most countries, irrigation is the main sector that could deliver potential water saving, accounting for more than 60% in 8 countries (case 1). The domestic and industrial sectors contribute to the potential of water savings in correlation with the importance of each sector in total current water abstractions. Leakage reduction, calculated after estimating the reduced abstraction volume from savings in the other sectors, contributes up to 46% of water savings (46%). In 7 countries, leakage reduction accounts for more than 25% of the total water-saving potential (Belgium, Bulgaria, Croatia, Hungary, Ireland, Luxembourg and Latvia). On average at the EU28 level, domestic, agriculture and industry sectors contribute respectively to 17%, 59% and 19% of potential water savings, with the remaining 6% from savings through leakage reduction in water networks.

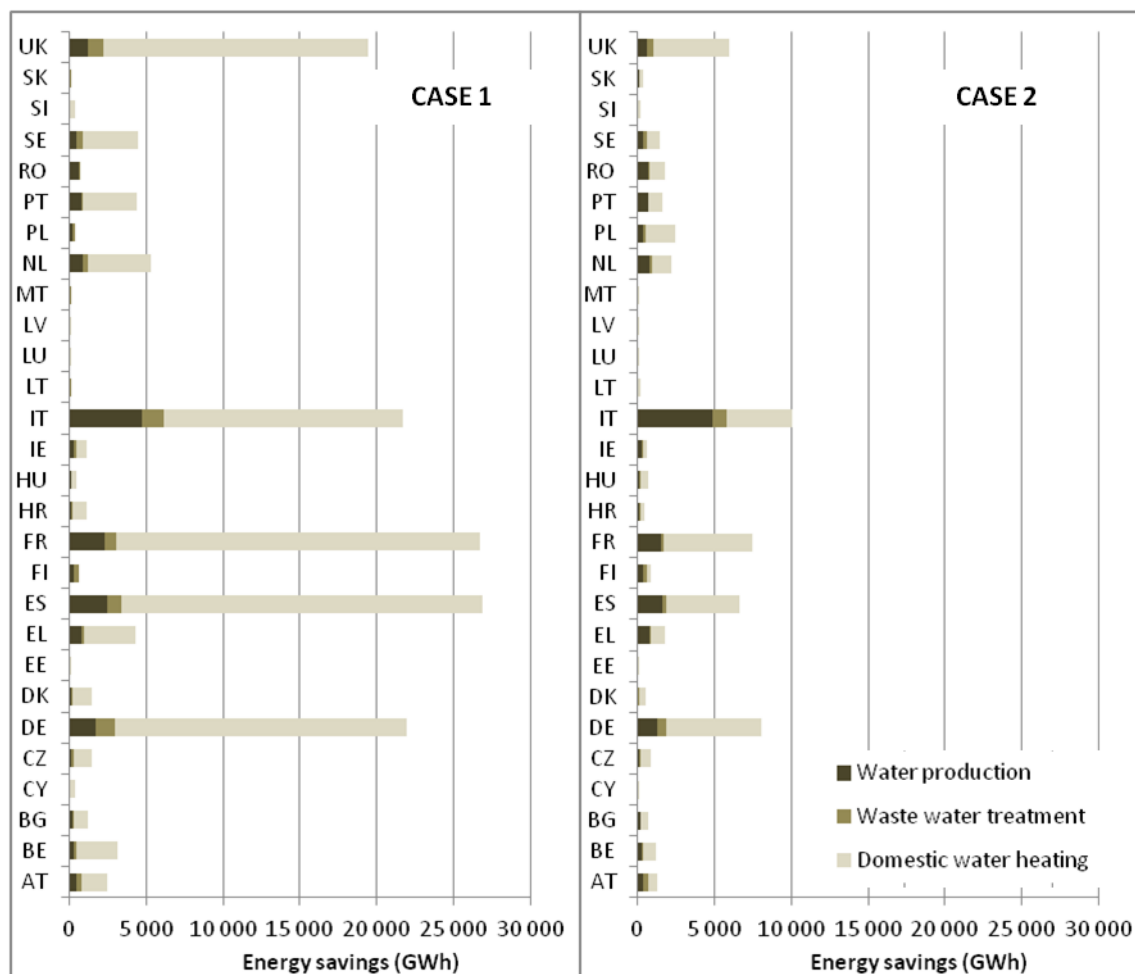
For water savings relying on technical progress only (case 2), contributions (in percent) for the agriculture and industry sectors as well as leakage reduction – respectively 67%, 21% and 7% of total potential water savings at the EU28 level – are approximately the same as in case 1. The main difference with case 1 is the importance of water savings in the domestic sector (17%), which in case 2 represents only 5% of potential water savings.

4.4 Energy-saving potential from increased water-use efficiency

4.4.1 Water-related energy-saving potential

Water-saving potential across different activities of the water (service) sector can be translated into energy-saving potential (Figure 4.6) for each MS, differentiating between energy savings from reduced water abstraction, reduced water heating and reduced wastewater volumes needing treatment. In total, water-related energy consumption could be reduced by 34% from current levels to 297 130 GWh per year (case 1); or by 13% to 389 819 GWh per year (case 2).

Figure 4.6 Potential energy savings per activity



Across the EU28 MS, potential energy savings from water savings are estimated at respectively 150 194 GWh and 57 505 GWh per year for cases 1 and 2. The United Kingdom, Italy, France, Spain and Germany, with individual saving potentials of approximately 20 000 to 25 000 GWh per year in case 1 (5 000 to 10 000 GWh per year in case 2), offer higher values for water-related energy-saving potentials than other MS. However, this logically follows from the fact that those countries are among the MSs abstracting the highest volumes of water across all sectors, and in particular, they are the ones with the highest volumes of water abstracted for the domestic sector (see previous Figure 4.2).

Water heating, the most energy-consuming activity for water use, has the potential to reduce water-related energy consumption by 82% if some changes in behaviour occur in the domestic sector (case 1). Such energy reductions are possible even though the domestic sector by far does not offer the largest water-savings potential in volumes of water saved. This study consequently recommends paying particular care to water-saving measures that target the domestic sector, since these can induce large energy savings in households by decreasing water heating.

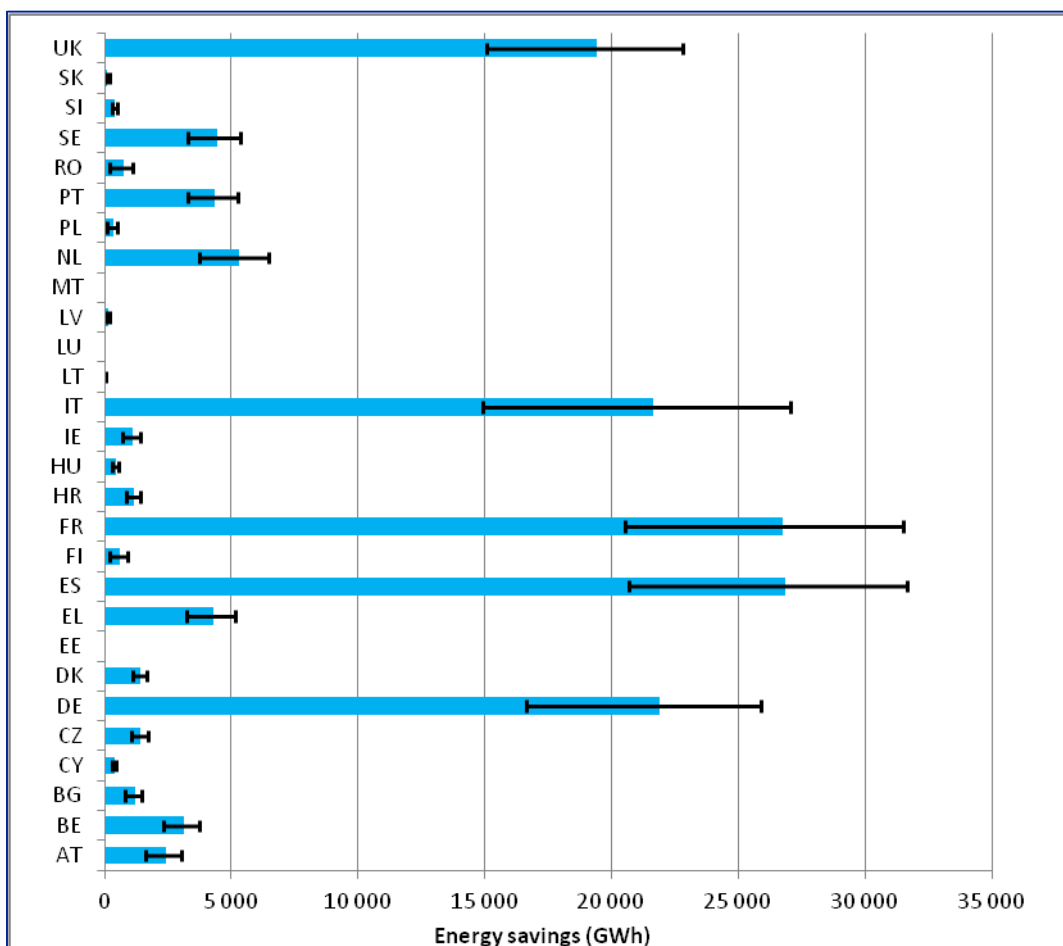
Water-related energy savings can also be analysed by sector contributions (Figure A.2.3 , Annex 2). As expected, the larger share of energy savings from water savings (90% in case 1 and 73% in case 2) is in the domestic sector at the EU28 level and for most MS. Although agriculture represents a high potential for water-saving potential, its potential for water-related energy saving is relatively low (3% of the total energy saving potential linked to water at the EU28 level in case 1; respectively 8% in case 2). While sprinklers and drip irrigation reduce the quantity of water used, they consume more energy per cubic meter compared to surface irrigation (which does not need any energy).

Water-related energy-saving results (Figure 4.6) must be considered with precaution, since the elementary energy consumption for each activity and sector varies considerably. At the EU28 level, water-related energy-saving potential ranges:

- (case 1) from 111 500 to 180 140 GWh per year, or from -26% to +20% compared to the mean estimation (150 194 GWh per year);
- (case 2) from 37 900 to 73 000 GWh per year, or from -34% to +27% compared to the mean estimation (57 500 GWh per year).

Figure 4.7 indicates these confidence intervals per MS for case 1.

Figure 4.7 Potential energy savings with confidence intervals per MS



Error bars represent the minimum and maximum of potential energy savings, calculated with respective minimum and maximum of elementary energy consumption ranges.

To better capture the importance of water-related energy consumption, Table 4.3 expresses in CED (primary energy) the estimated energy-saving values as the percentage of current water-related energy consumption.

Table 4.3 Water-related energy savings compared to total energy consumption

MS	Current water-related energy consumption (C) in PJ	Case 1			Case 2		
		Water-related energy consumption after savings (S) in PJ	Water-related energy savings in CED (C-S) in PJ	Water-related energy savings (C-S)/(C) in %	Water-related energy consumption after savings (S) in PJ	Water-related energy savings in CED (C-S) in PJ	Water-related energy savings (C-S)/(C) in %
AT	52	37	16	30%	44	8	15%
BE	113	75	37	33%	99	14	12%
BG	55	43	12	22%	48	7	12%
CY	10	5	5	49%	9	1	11%
CZ	82	67	16	19%	73	9	11%
DE	695	475	220	32%	614	80	12%
DK	48	33	15	31%	43	5	11%
EE	7	7	1	7%	7	1	11%
EL	101	63	37	37%	85	15	15%
ES	448	234	214	48%	395	53	12%
FI	40	34	6	15%	31	9	22%
FR	822	476	346	42%	725	96	12%
HR	35	24	11	32%	31	5	13%
HU	77	71	5	7%	68	9	11%
IE	23	15	8	34%	19	4	19%
IT	476	301	175	37%	395	81	17%
LT	11	10	0	1%	9	1	11%
LU	2	2	0	12%	2	0	11%
LV	7	6	1	12%	6	1	11%
MT	2	2	0	2%	1	0	12%
NL	136	89	47	34%	116	19	14%
PL	217	214	3	2%	193	24	11%
PT	85	53	32	38%	73	12	14%
RO	105	98	6	6%	90	15	14%
SE	85	48	37	44%	73	12	14%
SI	14	10	4	26%	12	2	12%
SK	28	27	1	4%	24	4	13%
UK	502	325	176	35%	448	54	11%
EU28	4 276	2 845	1 431	34%	3 734	542	13%
Range for EU28	3 260 - 5 080		1 060 - 1 700	33% - 34%		360 - 680	11% - 14%

In term of CED (primary energy), water-related energy savings represents 1 431 PJ for the whole EU28 (case 1); or 542 PJ if only technical progress is considered for domestic sector (case 2). Energy saving can also be compared to total energy consumption in each MS, as shown in Table 4.4.

Table 4.4 Water-related energy savings compared to total energy consumption (case 1)

MS	Total energy consumption in the MS (T) in GWh	Current vs. total energy consumption (C)/(T) in %	Consumption after savings vs. total (S)/(T) in %
AT	61 995	13%	9%
BE	80 810	12%	8%
BG	27 592	20%	16%
CY	4 494	18%	9%
CZ	56 441	13%	11%
DE	519 830	13%	9%
DK	31 521	15%	10%
EE	6 797	12%	11%
EL	52 087	22%	14%
ES	239 776	23%	12%
FI	80 178	5%	4%
FR	429 089	15%	9%
HR	15 506	24%	16%
HU	34 391	18%	17%
IE	24 725	13%	9%
IT	295 057	20%	13%
LT	8 632	17%	17%
LU	6 339	5%	5%
LV	6 387	20%	18%
MT	1 834	8%	8%
NL	106 186	15%	10%
PL	120 098	18%	18%
PT	47 521	24%	15%
RO	40 898	30%	28%
SE	126 305	8%	5%
SI	12 201	13%	10%
SK	24 213	11%	11%
UK	320 847	17%	11%
EU28	2 781 749	16%	11%

Water-related energy savings represent up to 49% of current water-related energy consumption, with the highest figures found in Cyprus, Spain, France and Sweden. In contrast, water-related potential energy savings are below 7% for Estonia, Hungary, Lithuania, Malta, Poland, Romania and Slovakia (mainly in Central & Eastern Europe).

In light of total energy consumption in each country, potential energy savings related to water consumption²³ account for approximately 10% of a country's total energy consumption in Cyprus, Greece, Spain and Portugal. On the other end of the spectrum, potential energy savings in Estonia, Finland, Hungary, Lithuania, Luxembourg, Malta, Poland and Slovakia account for less than 1% of total energy consumption in each country; however, even a low percentage can represent a high absolute value of energy-savings potential.

²³ This is the difference in percentage points between the last two columns of Table 4.4.

4.4.2 Comparison of water-related energy-saving potential with other studies' results

Two studies requested by the European Commission – Preparatory Study on Taps and Showers (JRC, February 2014) and Amended Ecodesign Working Plan under the Ecodesign Directive (VHK, January 2012) – estimated energy-savings potential by regulating taps and showers. According to these two studies energy consumption linked to taps and showerheads could potentially decrease by an estimated 336 PJ/year (JRC, 2014) or 885 PJ per year (VHK, 2012). Difference between these two results is high and no explanation was found so far, this difference may seem even more surprising knowing that JRC study includes energy savings from raw water abstraction to waste water treatment (as in the present study), which is not the case of VHK study. The present study estimated that water-related energy saving potential in the domestic sector when considering only technological progress (case 2) is 402 PJ/year, which is within a similar order of magnitude as the results from JRC (households and services being the main users of taps and showers) .,

4.4.3 Side-effects on energy consumption

The consequences of water savings on energy consumption, as calculated in earlier sections, could also lead to other, indirect consequences on water systems management and energy consumption. Indeed, water savings could decrease water demand to a level requiring additional maintenance to retain waterworks. For example, water companies may need to pump water through less often used pipes to clean them. At the same time, water-saving measures can imply similar pollution levels concentrated in a smaller quantity of wastewater, which is easier to treat. These opposing effects are not captured in the calculation approach chosen. Thus, results presented above have to be considered as rough estimates showing the potential of energy savings by increasing water-use efficiency but not as a consolidated forecast.

4.4.4 Global analysis

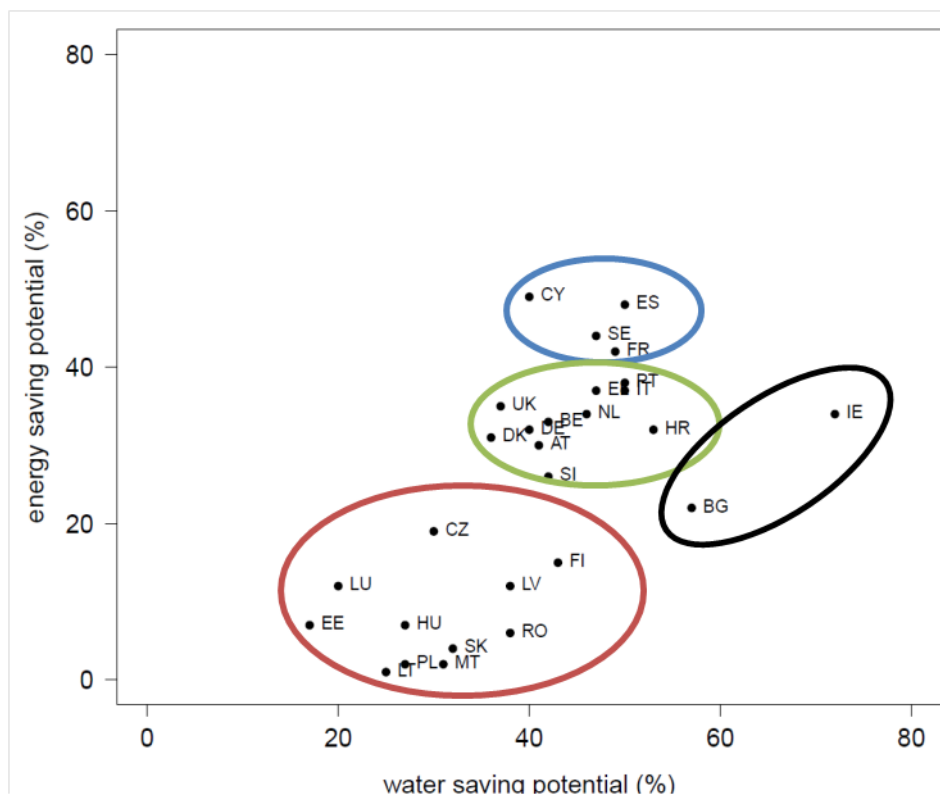
In a global analysis, results on estimated water-saving potential can be crossed and linked with energy-saving potential. The aim of this global analysis, conducted on case 1 results, is to help identify different groups of MS sharing similar profiles in terms of: (1) water-saving potential and water-related energy saving potential at the MS level (i.e. the saving potential in percentage of the current consumption); and (2) contribution to potential water savings and water-related energy savings at the EU28 level (i.e. the share of the EU28's potential savings that each MS contributes to).

Figure 4.8 displays water-saving potential (in percentage of the current water abstraction) as the x axis and energy saving potential as the y axis. The following groups of MS with similar profiles were identified:

- MS type 1 – mid water-savings potential and high energy savings potential (circled in blue);
- MS type 2 – mid water-savings potential and mid energy savings potential (circled in green);
- MS type 3 – high water-savings potential and mid energy savings potential (circled in black);
- MS type 4 – low water saving and low energy savings (circled in red).

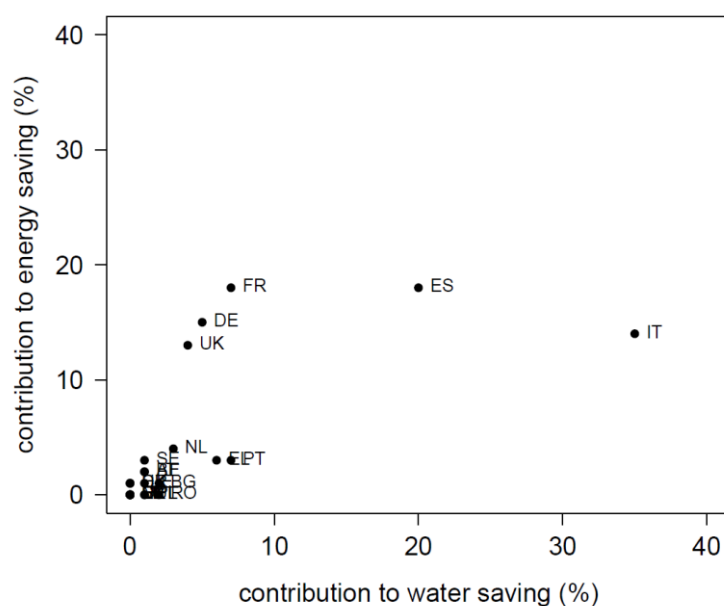
Type 4 countries might not set energy savings as a priority when implementing water-saving measures. Indeed, the impact on energy saving would be relatively low (less than 20% of energy saving compared to current water-related energy consumption for water savings comprised between 20 and 40% of current water abstractions). Type 3 and Type 1 countries respectively have high water-saving and energy-saving potentials. Consequently, implementing water-saving measures in those countries could initially lead to medium or high water savings and ultimately to medium or high energy savings. In conclusion, implementing water-saving measures could be rather beneficial for Type 1 and 3 countries. Type 2 countries have a middle profile with balanced water-saving and energy saving potentials.

Figure 4.8 Water-saving potential and water-related energy-saving potential for each MS compared to current water and water-related energy consumption



Countries can also be compared in terms of their contribution to the total potentials of water saving and energy saving at the EU28 level (Figure 4.9). This would help to specify priorities that might be proposed for implementing water-saving measures at the EU level.

Figure 4.9 Contribution of each MS to the total water-saving potential and water-related energy-saving potential for the EU28



To achieve simultaneously high water and water-related energy savings, the EU can rely on improvements in Germany, Spain, France, Italy and United Kingdom to reduce averages. Those 5 countries represent more than 72% of the water-saving potential and 78% of the water-

related energy saving potentials in Europe. They also abstract the largest water volumes for the agriculture, domestic and industry sectors analysed in EU28. Greece and Portugal currently have similar water abstraction levels to the UK and Germany, yet are surprisingly not included in this group because their water consumption profile is somewhat different; they have relatively low water-saving potential in the domestic sector (because of the currently low per-capita water demand) and/ or industrial sector (because of industry's currently low water-abstraction level).

4.5 References

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4.6 Interviews with stakeholders

ACTeon conducted interviews between December 2015 and January 2016 with the following experts:

- Peter Dane, European Benchmarking Co-operation;
- Laurent Bellet, EDF & leader of the EIP Water Action Group “Framework for evaluation and reporting of the energy impacts on water”;
- Adriano Battilani, senior researcher at Canale Emiliano Romagnolo and co-leader of the WIRE Action Group;
- Tom Vereijken, Director of European Water Stewardship.

5 Buildings and road construction sector

The construction sector is divided into surface constructions and underground engineering. The potentials for energy savings and resource efficiency in these sub-sectors are discussed below.

This study does not address energy-saving measures from insulation, which is recognised as able to drastically decrease energy demand in residential, office and public buildings²⁴ with a very low material intensity. As this study focuses on energy-saving windfalls from resource-efficiency measures, methods that specifically address energy-savings remain out of this study's scope.

Also possible resource-efficiency measures and effects from aluminium have not been considered in this study. A TU Delft found that recycling rates of aluminium in building deconstruction and demolition are consistently higher than 90%, reaching 98% in some instances [Boin 2004]. Thus, the recycling potential was considered to be marginal. Also, no parameters have been found in literature to estimate aluminium use in a bottom-up calculation. The study is not able to assess the potential of substituting aluminium with less energy-intensive materials in new construction.

5.1 Buildings

5.1.1 Introduction

Regarding surface construction, this study quantifies the savings potential for concrete and steel in the building shell, which accumulates to roughly 75% of total CO₂ emissions from building materials²⁵ in this sector. Commercial buildings generally use more steel and aluminium. Since the commercial building sector includes net-use areas, concrete and steel usage for these buildings is calculated using material-use assumptions for residential buildings. With this method, total material usage is underestimated for surface construction.

The building shell in residential buildings is the main driver for resource and energy consumption²⁶ regarding building materials in surface construction. The most important construction material is concrete, which is used in floors, tiles and walls. Clinker is the most energy-consuming constituent of concrete. In Europe, concrete is made with variable clinker content combined with other mineral binders like fly ash, blast furnace slag and other materials. The clinker process uses different process technologies with different energy demands and different fuels, including Refuse Derived Fuel (RDFS).

5.1.2 Methodology to upscale and calculate EU28 aggregates

Cembureau²⁷ estimates that 75% of construction activity in Europe is for buildings. This leads to the assumption that 75% of concrete production is also demanded by the building sector²⁸. As cement statistics offer the most reliable source for production data, the amount of concrete used is estimated by cement production. A top-down analysis for concrete estimates roughly 950 Mt of concrete used in the construction sector, with 191 Mt of cement produced in 2011²⁹ and an assumed share of 15% cement in concrete.

A bottom-up analysis uses the database for residential and office building stocks in the EU27 from iNSPIRe³⁰, a research project funded by the 7th Framework Programme to assess the current situation in stock. The future demand for concrete³¹ in building stock is estimated based on the further development of housing. It is assumed that the eastern Member States, which

²⁴ The German Federal Government speaks of easily reachable reduction potentials of 50% from only insulating outer walls. Room heating and warm-water preparation contribute to 40% of end energy consumption in Germany.

²⁵ Unpublished results from a research about climate friendly building materials commissioned by the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety.

²⁶ Resource efficiency in the building sector, ECORYS, Rotterdam, May 2014.

²⁷ CEMBUREAU 2011. "Activity Report 2011".

²⁸ Resource efficiency in the building sector, ECORYS, Rotterdam, May 2014.

²⁹ CEMBUREAU 2012 "The role of cement in the 2050 low carbon economy".

³⁰ Birchall, S.; Wallis, I.; Churcher, D.; Pezzutto, S.; Fedrizzi, R.; Causse, E.: "D2.1a Survey on the energy needs and architectural features of the EU building stock", funded by the European Community's Seventh Framework Programme, May 2014.

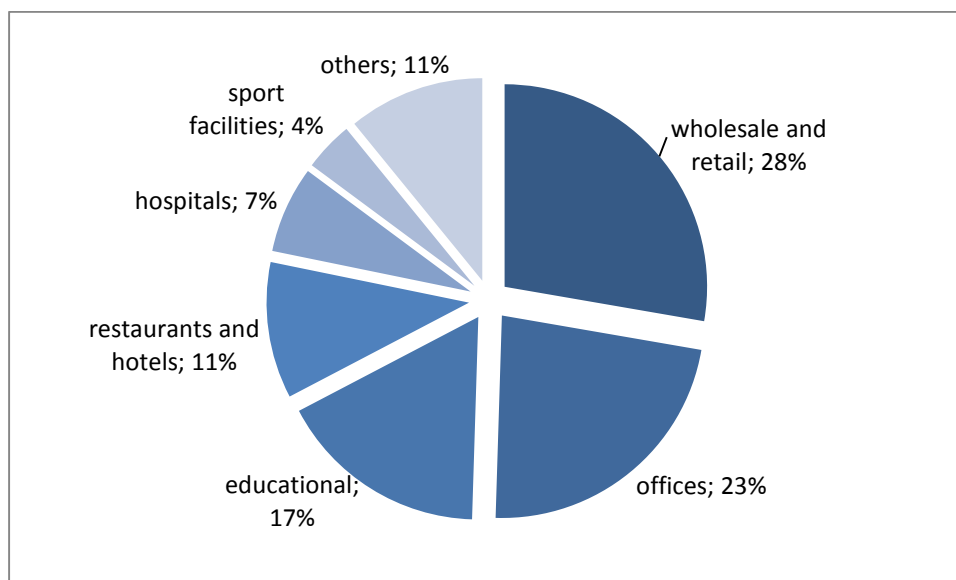
³¹ Resource efficiency in the building sector, ECORYS, Rotterdam, May 2014.

show a smaller living space per capita, will experience higher construction growth than western MS, consequently narrowing gaps in living space per capita currently found across Europe. All calculations are made for the EU27 and afterwards upscaled using population to include Croatia (because underlying data is not available for Croatia).

The iNSPiRe database includes Floor Area of the residential building stock by building type (single, multi-family house) and year of construction in 10 year steps from 1970 onwards for every country in EU27. To determine the material flow based on the existing building stock the following approach is used: In a first step, parameters for concrete and steel per floor area for the different buildings were needed. For single family houses built before 2001, 1.24 t of concrete per square meter and 0.08 t of steel per square meter were used. Multi-family houses have been found to be more efficient in material per square meter floor area, with 0.84 t/m² concrete and 0.08 t/m² steel³². For buildings constructed after 2001, a parameter of 2.1 t/ m² concrete is used for all residential buildings³³. Assuming the same degree of steel reinforcement leads to 0.2 and 0.14 Mt/m² for single and multi-family homes.

For non-residential buildings, the floor area for office buildings is available from the iNSPiRe database. The distribution of European non-residential building floor area is shown in the figure below³⁴. iNSPiRe information about office floor area was used to calculate the portions in other building sectors.

Figure 5.1 Distribution of non-residential floor area



Source: iNSPiRe.

Using the average lifetime estimate for all building types (residential, warehouses and office space) of 75 years, the yearly material flow in stock has been calculated.

Material demand from new construction is estimated with an assumed increase in floor area. A yearly increase of 1.52% is assumed until 2030³⁵. With the parameters of material use for residential and non-residential buildings after 2001 as outlined above, the material demand per year is 898 Mt of concrete, which sufficiently covers data from top-down analysis but leaves the calculated material demand somewhat underestimated. Steel demand is calculated to be 58 Mt.

³² Gruhler, K.; Böhm, R.; Deilmann, C.; Schiller, G.: „Material and energetic building characteristics – Building comparison and projection to building structures“, Institute for ecological spatial development (Institut für ökologische Raumentwicklung, Dresden, 2002.

³³ Müller, D. "Stock dynamics for forecasting material flows – Case study for housing in the Netherlands", in Ecological Economics V59 I1, August 2006.

³⁴ Economidou: "Energy performance of the existing building stock in Europe", BPIE, 2012.

³⁵ Uihlein, Eder "Policy options towards an energy efficient residential building stock in the EU 27", in Energy and Buildings, 2009.

All material estimates for stock and flow are expected to be lower than actual figures because all parameters for material intensity are related to the main useable floor area. In contrast, iNSPiRe measured gross internal floor area.

5.1.3 Results

Impact factors for all fields of action were taken from EcoInvent 3.1, with CRD factors supplemented by the ifeu institute (ifeu 2012). Four fields of action in surface construction were identified and quantified for reduction potential. The results are shown in Table 5.1. The results are described in more detail after the table.

Table 5.1 Comparison of material flow and indicator results for buildings in the EU28 with different fields of action

Material flows and indicator results		Mass (Mt)	CO2e (Mt)	CRD						Water demand (1 000 m ³)	CED				
Year, fields of action for buildings in the EU28	Parameter			Total CRD (Mt)	Energy resources (Mt)	Metal resourc e (Mt)	Stone and soil (Mt)	Other mineral resources (Mt)	Biotic resources (Mt)		Total CED (PJ)	Fossil (PJ)	Nuclear (PJ)	Renewable (PJ)	Others (PJ)
2011, Baseline	Concrete	898	97	932	12	0	919	0	0	1 375	476	354	97	25	0
	Cement, amount from concrete	117	89	173	10	0	162	0	0	251	367	286	66	15	0
	Steel	58	61	152	39	98	14	1	0	461	869	774	87	8	0
	Sum	956	158	1 084	51	99	932	1	0	1 835	1 345	1 128	184	33	0
2030, Buildings in EU28	Concrete	1 095	118	1 135	15	1	1 120	0	0	1 675	580	432	118	30	0
	Cement, amount from concrete	142	108	211	12	0	198	0	0	306	447	348	81	18	0
	Steel	67	76	195	48	128	17	1	0	596	1 073	965	98	10	0
	Sum	1 162	195	1 330	63	129	1 137	2	0	2 272	1 653	1 396	216	40	0
1) 2030, Buildings in EU28 with higher clinker substitution and energy efficient kilns	Concrete	1 095	93	1 125	12	1	1 112	0	0	1 604	476	351	99	26	0
	Cement, amount from concrete	142	83	200	10	0	190	0	0	235	343	267	62	14	0
	Steel	67	76	195	48	128	17	1	0	596	1 073	965	98	10	0
	Sum	1 162	170	1 320	60	129	1 129	2	0	2 201	1 549	1 315	198	36	0
2) 2030, Buildings in EU28 with less material-intensive construction and more timber use	Concrete	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Cement, amount from concrete	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Steel	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Sum	779	97	891	34	69	614	1	173	1 817	1 493	977	151	364	0
3) 2030, Buildings in EU28 with limited growth rate for new buildings	Concrete	701	76	726	10	0	716	0	0	1 072	371	276	76	19	0
	Cement, amount from concrete	91	69	135	8	0	127	0	0	196	286	223	52	12	0
	Steel	48	46	109	29	69	10	1	0	324	664	582	76	6	0
	Sum	749	121	835	38	69	727	1	0	1 396	1 035	858	151	26	0
4) 2030, Buildings in EU28 with shorter renovation cycles and longer building lifetimes	Concrete	1 052	114	1 091	14	1	1 076	0	0	1 610	557	415	113	29	0
	Cement, amount from concrete	137	104	203	12	0	190	0	0	294	430	334	78	18	0
	Steel	63	74	192	47	127	16	1	0	589	1 036	935	91	10	0
	Sum	1 115	188	1 283	61	127	1 093	1	0	2 119	1 593	1 350	204	39	0

1) Substitute more clinker and use more energy-efficient kilns

The first scenario addressing surface construction estimates energy-saving potentials from substituting clinker and increasing energy efficiency in kilns. As clinker, the main ingredient in concrete, is very energy-intensive, it accounts for more than 90% of GHG emissions in the concrete life cycle. Substituting clinker's 73.3% share in all EU cement [Cembureau 2011] with less energy intensive materials like fly ash and using more energy-efficient kilns has strong potential to increase overall energy efficiency for concrete. The potential to increase the share of clinker substitutes is estimated to be 4% (from 73% to 77%) in the former EU27 [CEMBUREAU 2012] and equally as high in the EU28. On average, 3 700 MJ are consumed per tonne of clinker, with the lowest documented energy demand around 2950 MJ/t³⁶.

This study has observed that substituting more clinker and using more energy-efficient kilns (scenario 1) affects all construction activity. Although the substitution potential for clinker is identified to be marginal, efficiency measures in kilns help to cut energy demand in concrete production by one fifth compared to the 2030 baseline.

2) Build sustainably using timber

This second scenario identifies potentials for more sustainable architecture in new buildings to decrease use of abiotic materials and increase the amount of wood. The resource-saving potentials through building with timber by using a low estimate on the potential decrease CRD by 33% overall, abiotic CED by 30% and GHG-emissions by 50% through reducing overall material demand and strongly increasing the use of timber³⁷. Results can be found in the second action field in Table 5.1.

Analysing the second scenario revealed that substituting steel and concrete with timber and applying lightweight architecture in new buildings reduces the examined total energy demand for building construction by 10% in comparison to the baseline in 2030. Fossil and nuclear energy demand are lowered by 30% overall, the CED for renewable energy (including inherent energy in timber) increases in return.

3) Lower new construction rates

The third scenario for surface construction calculates savings potentials when new construction is limited. In the base model, an increase in residential and non-residential building space of 1.52% has been assumed. With equal population in the EU28, this would lead to an increase of living space per capita from 35 m² in 2011 to 46 m² in 2030 on average. Further adding to this per-capita increase is the trend toward having secondary living spaces or summer residences. By stopping the trend of increased living space per capita and halving growth, less material and energy is used than in the baseline. An EU average of 40 m² per capita living space is assumed for this scenario for 2030 (instead of the 46 m² in the baseline).

Reducing the net amount of new buildings, as explored in the third scenario, offers the highest energy-savings potential. Total energy demand would be almost 40% lower with such changes than continuing construction at the current rates and with the current methods.

4) Increase renovation and rehabilitation

Calculations examine the effect of enhancing building lifetime by 50% by doubling rehabilitation rates to a 20-year cycle for residential and a 25-year cycle for non-residential buildings with an additional material input of 5.5% of original new construction per cycle [Deilmann et al. 2014].

Subjective impressions can affect perceptions of investments. Investors are dissuaded by high initial investment costs in deep rehabilitation that would be needed to extend building lifetimes. In some cases, the return on investment for such improvements is not acceptable, while for other owners living in their own housing, the investment's viability is not obvious. Such owners

³⁶ Ecofys 2009 : Ecofys, Fraunhofer Institute for Systems and Innovation Research, Öko-Institut : 'Methodology for the free allocation of emission allowances in the EU ETS post 2012 ; Sector report for the cement industry' ; By order of the European Commission, Study Contract: 07.0307/2008/515770/ETU/C2, November 2009.

³⁷ Kaufmann, Nerdinger "Building with Timber – Paths into the Future", ISBN 978-3-7913-5181-0, 2011.

are more easily attracted by new constructions that offer higher immediate rent incomes with less personal effort.³⁸

From the fourth scenario, to increase renovation cycles and thus enhance building lifetimes, this study found that total savings are marginal. A reduction of 4% or about 60 PJ CED in total energy demand is achieved. Although the material flows from building stocks are reduced by 15% to 20%, this only affects 30% of the total concrete demand and thus leads to a comparably small total reduction.

As new buildings dominate material demand, accounting for more than 70% of the demand for concrete and 55% for steel, measures affecting concrete production or alternating material demand from new buildings are very effective. This study recommends prioritising these measures in the near future.

5.2 Road construction

5.2.1 Introduction

This subsector focuses on road construction. As a recent study suggests, construction, renewal and replacement of roads totals 55% of THG-Emissions and 70% of the cumulative energy demand (CED) of underground engineering. Furthermore, data availability is considered very high in comparison to other subsectors. As 90% of the EU road network's bound layers consist of asphalt, the study focuses on asphalt roads only. Relative to the unbound materials, asphalt has high CED due to its energy-intensive binding agent bitumen.

Asphalt recycling is considered the main driver for resource- and energy-saving potential for underground engineering. Recycling quotas of asphalt show very high variety throughout the EU28, ranging from 0.5% to 46% reclaimed asphalt (RA) related to produced hot and warm mixed. Also, the use of reclaimed asphalt differs widely, ranging from landfill to *in situ* layer-appropriate substitution. Downgrading RA is still a common practice, with use in unbound layers up as high as 96%.

This chapter determines the potential for substituting primary asphalt with reclaimed asphalt and calculates savings potentials.

5.2.2 Methodology to upscale and calculate EU28 aggregates

A combined bottom-up and top-down approach is used to calculate yearly material flows. This approach uses top-down data about actual production and current recycling rates in every country. The bottom-up analysis provides the foundation to estimate the theoretically available recycling materials that cannot necessarily be deduced from production data. From these rates, the potential for maximized recycling is subtracted. A potential for cutting material flow by using lighter vertical road structures is not included, as it is assumed that the vertical structure is necessary to avoid premature wearout.

For the top-down analysis, information from the European Asphalt Pavement Association³⁹ was used. Information about production of hot and warm mixed asphalt is available for 25 countries of the EU28 as well as data for registered reclaimed asphalt (RA) for 19 of the EU28 countries, including data on usage of RA for 15 of these countries. Table A.4.1 in Annex 4 summarises the reported average production of EU countries combined with information about amounts of RA. For countries with no available data on reclaimed asphalt amounts of the average ratio from reclaimed asphalt to new asphalt production from available EU28 data was used (yellow cells in the table).

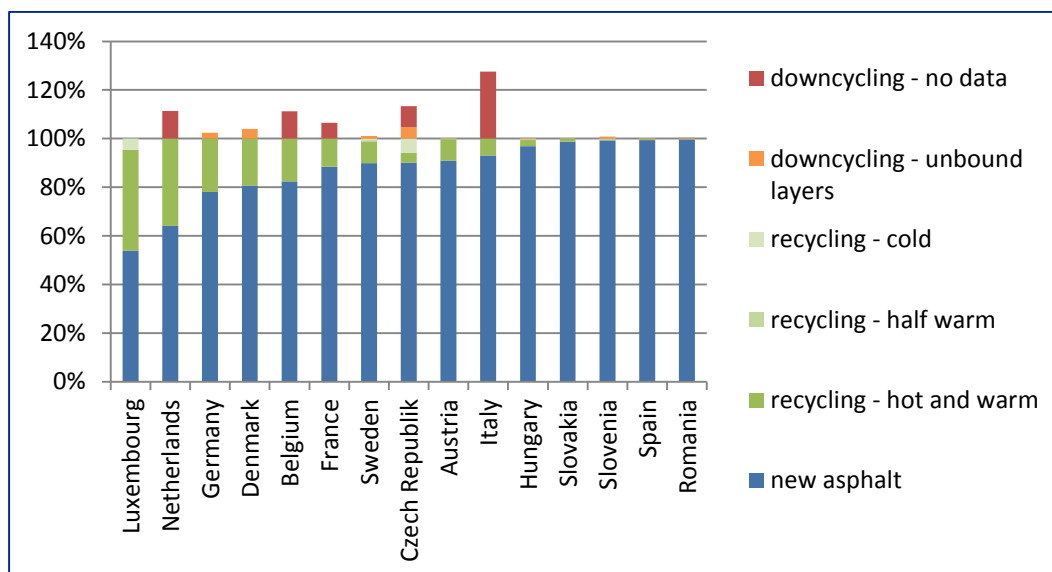
Reclaimed asphalt with no information about the specific usage compared to actual recycling is handled as down-cycling, such as use in unbound layers or subgrade. Figure 5.2 summarises the reported share of RA used in proportion to new asphalt production. The orange and red bars

³⁸ Boardman, B; Darby, S.; Killip, G.; Hinnells, M.; Jardine, C.; Palmer, J.; Sinden, Graham. 40% house. Environmental Change Institute, University of Oxford. Available from <http://www.eci.ox.ac.uk/research/energy/downloads/40house/40house.pdf>. February 2005.

³⁹ ASPHALT IN FIGURES 2013, European Asphalt Pavement Association, Brussels, 2014.

represent the potential for substituting primary asphalt with secondary asphalt from the top-down approach.

Figure 5.2 Share of new and reclaimed asphalt in asphalt production and asphalt in downcycling usage



The bottom-up approach follows a focussed material flow analysis by determining the length of different road classes for every country. Identifying an average estimated vertical thickness for the bound layers (wearing, binder and bearing course) and an average lifetime after renewal for each layer is required.

Eurostat data about road network length for motorways, highways, state roads and municipal roads for every country was used to determine the size of existing road networks. The data was complemented with further information about countries with little or no data in Eurostat (Germany, Greece and Portugal). Eurostat data on average newly built roads for the different road classes was derived from developments over the last 10 years for each country and road class. Assumptions on the percentage of roads made from asphalt pavement were determined for every road class (see Table 5.2).

Table 5.2 Share of roads under asphalt pavement for different road classes⁴⁰

Highway	Motorway	State road	Municipal road
90%	90%	90%	60%

These figures permit calculating the existing road network made from asphalt pavement, as presented in the material flow calculation. As Table A.4.2 in Annex 4 shows, the calculation considers a total of 3.4 million kilometres of road made from asphalt pavement, with France, Germany, Poland and the UK contributing to more than half the sum.

New road construction per road class and year was also calculated for the material flow calculation. According to average data, 14 000 km of new roads are built every year in EU28 countries. France, Poland, Italy and Romania account for roughly two thirds of the total (see Table A.4.3 in Annex 4).

The assumptions on road layer structure and layer lifetimes for calculating the material demand of renewal and new construction are shown in Table 5.3. This study assumes an average

⁴⁰ Knappe, F.; Bergmann, T.; Mottschall, M.: "Substitution of primary resources in the construction of roads and ways with mineral waste and road cut.", Commissioned by: German Federal Environment Agency [Umweltbundesamt], Dessau.

motorway width of 15 meters, the wearing course 4 cm thick and binder and bearing courses 8 cm and 22 cm respectively. The wearing course is estimated to have an average lifetime of 10 years, whereas the binder and bearing courses are assumed to have longer lifetimes up to 20 and 40 years. Highways are estimated to be 10 meters wide on average, with a generally thinner vertical structure and slightly longer lifetimes than motorways. For state and municipal roads, street width is assumed as 8 meters and 6 meters respectively, with thinner structure and longer lifetimes than motorways.

Table 5.3 Assumptions for structure of road classes and estimated layer structure lifetimes⁴¹

Roadway type	Street width [m]	Wearing course		Binder course		Bearing course	
		depth [m]	lifetime [yr]	depth [m]	lifetime [yr]	depth [m]	lifetime [yr]
Motorway	15	0.04	10	0.08	20	0.22	40
Highway	10	0.04	15	0.04	30	0.18	60
State road	8	0.04	30	0.04	60	0.12	100
Municipal road	6	0.04	50		100	0.08	100

When combining information from existing road networks and new built roads with the information about the structure of the roads and lifetimes of the layers an estimate about yearly material flows is obtained for the bottom-up calculation. The resulting material flows from road renewal are shown in Table A.4.4 in Annex 4, accumulating to 220 million tonnes of asphalt. For new built roads an estimate of 48million tonnes (Table A.4.5 , Annex 4) is calculated. This sums to a total of roughly 250 million tonnes of asphalt.

5.2.3 Results

The bottom-up approach, estimating 279 million tonnes of asphalt produced annually in the EU28, provides a slightly more reasonable estimate for calculating material flow than the top-down approach (261 Mt/yr). Because the bottom-up approach does not include walkways, bicycle ways or parking spaces, the calculation shows less material flow than the reported production. The calculations for every country from both approaches are shown in Table A.4.6 , Annex 4. Although major differences in both can be found for some countries, the total demand deviates only by 7%.

To calculate energy savings potential, the top-down data provides total material demand per country and the bottom-up approach offers shares and thus potentials for total demand. With this, the ratios between reclaimed asphalt and asphalt production and between reclaimed asphalt and asphalt demand can be calculated along with the amount of asphalt potentially reclaimable but not reclaimed in current practice. This ratio method ensures using the correct amount of base material in the calculation and in the ceiling for potentials. However, as expected the method avoids exactly displaying the current demands, as the degree of maintenance and renovation cycles differ per country. Denmark, Luxembourg and the Netherlands have the best ratios of reclaimed asphalt and reclaimable asphalt, unsurprisingly due to the lack of natural gravel deposits in these countries that leads to high transportation costs in proportion to the relatively low cost of the asphalt and thus making recycling more profitable.

Two potentials were calculated to estimate the energy saving potential from resource efficiency:

- The ratio of reclaimed and recycled asphalt to asphalt demand in road renewal from Denmark, the best practice country (53%);
- The best available technology: projects (e.g. in Germany) have renewed road sections with shares of reclaimed asphalt as high as 90%. The second potential analysis further examines the potential for reclaiming and equally recycling 95% of old asphalt. If this

⁴¹ Knappe, F.; Bergmann, T.; Mottschall, M.: "Substitution of primary resources in the construction of roads and ways with mineral waste and road cut.", Commissioned by: German Federal Environment Agency [Umweltbundesamt], Dessau.

amount surmounts 85% of all asphalt production in the country, the share is capped at 85% reclaimed asphalt.

As recycling potentials only apply for the flow of asphalt demand from road renewal, the split between asphalt demand from road renewal and new construction for every country has been considered. From the two ratios (best practice country and best available technology) and the share of demand from asphalt renewal, the potentials for every country were calculated, as shown in Table A.4.7 in Annex 4.

The identified material flows are then linked to the indicators Cumulative energy demand (CED) and cumulative raw-material demand (CRD) to describe the impact on raw material use and energy demand for the current state, potentials from best practice country and best available technology.

Base values for the CED for asphalt are taken from EcoInvent. CRD for the EcoInvent dataset was calculated by the ifeu-institute. Indicator values for reclaimed asphalt are taken from an Oeko-Institut study showing a 48% reduced potential for CED and 71% for CRD if new asphalt production is substituted by reclaimed asphalt use.

Table 5.4 Specific indicators for CRD and CED for new asphalt and reclaimed asphalt

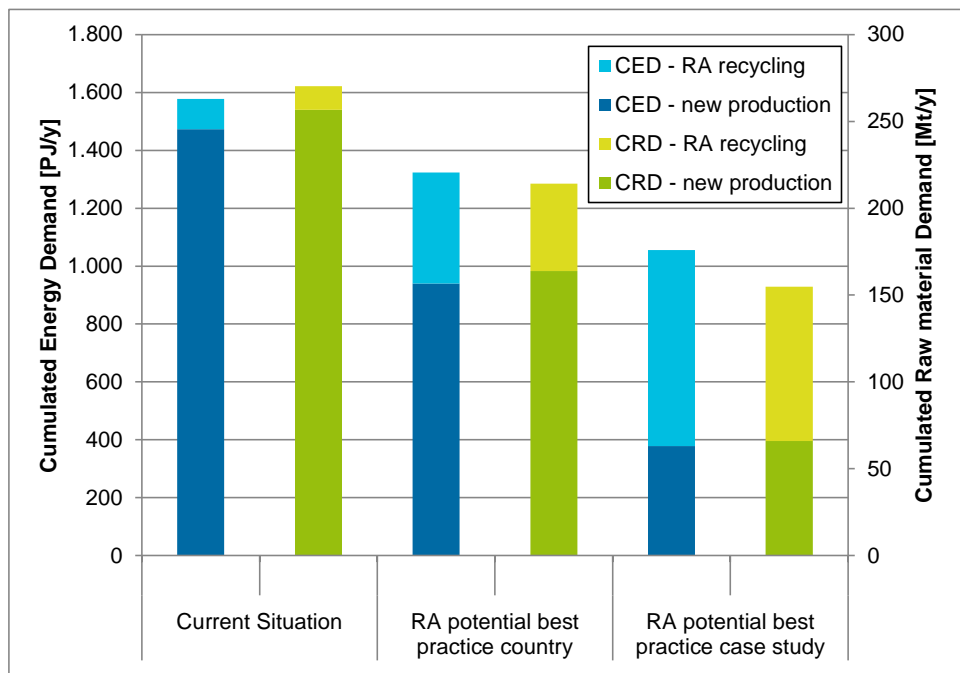
	CRD	CED
	<i>kg/t</i>	<i>MJ/t</i>
New asphalt	1094	6281
Reclaimed asphalt	432	3288

Sources: EcoInvent 3.1, Bergmann et al. 2015.

Results for the CRD for the current situation, best-practice country and best available technology for every country are shown in Table A.4.8 in Annex 4. By applying the current country-wide best-practice methods for all EU28 members, CRD can be reduced by 21% from 270 Mt/yr to 214 Mt/yr. If recycling-ratios can be increase to 85% in current best available technology projects, the CRD can be reduced by 43% to 155 Mt/yr, with the highest potential regarding pure amount for Germany, France and Spain. The highest relative potentials can be lifted in Greece, Finland and Austria.

Table A.4.9 in Annex 4 depicts results for the cumulative energy demand. Total reduction potentials for the EU28 regarding CED are 254 PJ/yr for the country-wide current best practice and 522 PJ/yr when implementing the best available technology. The highest absolute reduction potentials can be lifted in France, Germany and Spain, because of the extent of the existing road network. Highest relative potentials can be found in Greece, Austria, Finland and the Czech Republic. The potentials for CRD and CED for both reduction scenarios are visualized in Figure 5.3 . Results are split into CRD and CED from new asphalt production and asphalt recycling.

Figure 5.3 CED and CRD for current situation, best practice country and best available technique



6 Modal shift in urban transport

For the time frame from the present until 2020, promising strategies for resource efficiency in urban regions focus on developing and maintaining a sustainable transportation system and encouraging a modal shift from private motorized transport to public transportation, bicycles and walking. More attractive cities with mixed infrastructure and local centres are the foundation to reduce the travel distances for populations ('city of short distances'). By reducing car ownership and use, which among other aspects reduces the demand for parking areas, less air pollutants are emitted.

6.1 Scenarios

Within this section, a scenario analysis seeks to estimate the resource- and energy-efficiency potential of a modal shift from motorised private transport to bicycles and public transport in cities and urban areas. The modal shift can be a result of different measures in the field of urban planning, attractiveness of the public transport system, appropriate bicycle infrastructure or differentiation of mobility costs.

This shift to public or non-motorised means of transportation decreases the total energy consumption in the use phase, which is estimated in the following scenario analysis. Other measures can reduce the attractiveness of owning private cars and lead to lower car ownership rates. This is accompanied by reduced material consumption caused by less vehicle production. To provide an attractive public transport system, increasing the frequency of public transport may be necessary, which in turn creates more traffic and impetus for travellers to use public transport while causing additional resource requirements.

The estimation of the resource and energy efficiency potential in this section distinguishes between the vehicular use-phase and vehicle stock. To assess the use-phase's potential, the cumulative energy demand (CED) is calculated. The vehicle stock assessment additionally includes the cumulative raw-material demand (CRD) and water use. In addition, the results for both fields contain greenhouse gas emissions (GHG). Because fewer passenger cars would be used in cities, the demand for parking places decreases in parallel. As a result, a potential for land-use change can be shown.

In practice, there could be a modal shift to different forms of public transport, like buses, trams or undergrounds. The scenario analysis assumes that buses will cover the increased demand in public transport. This follows a conservative approach, to avoid an overestimation of resource and energy-efficiency potential. The specific energy consumption, as well as buses' specific material consumption exceeds other modes of public transport because buses have lower energy efficiency, a smaller vehicle size and shorter lifetimes compared to trams and subway trains.

The scope of the scenario described in this section is limited to a modal shift within cities or urban areas. Since the scenario assumes a reduced number of passenger cars, it is likely that a modal shift on long distance trips would occur as well. However, such a modal shift was not taken into account in this scenario.

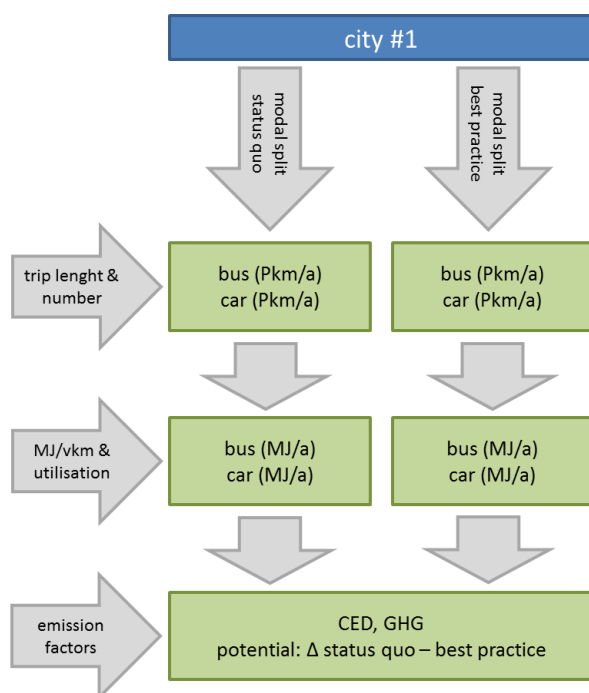
6.2 Methodology

Using a bottom-up approach to estimate the resource efficiency gains and energy savings caused by a modal shift in European cities and urban areas allows considering effects of different climate and city size on the maximum modal shift potential.

The 'status quo' and 'best practice' cases were analysed for 293 European cities and urban areas. The difference between these case statistics reveals each areas' resource and energy efficiency potentials.

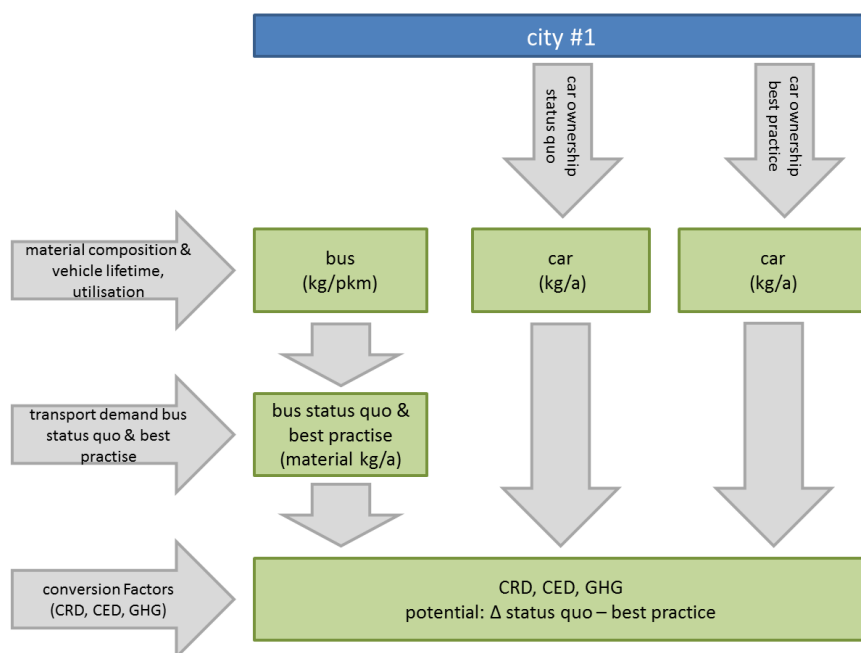
A schematic diagram of the methodology is shown in Figure 6.1 for the use phase and in Figure 6.2 for the vehicle stock. Details on data sources and assumptions are documented in chapter 6.3.

Figure 6.1 Calculation methodology for use-phase efficiency potential



Source: own figure.

Figure 6.2 Calculation methodology for vehicle-stock efficiency potential



Source: own figure.

Within the status quo case calculation, each city's original modal split data⁴² and regional car ownership rates (NUTS 2 level)⁴³ are used. The following steps were followed for each city or urban area:

⁴² EPOMM Modal Split Tool – TEMS.

⁴³ Eurostat: Stock of vehicles by category and NUTS 2 regions [tran_r_vehst] (06.11.15) and Population on 1 January by broad age group, sex and NUTS 3 region [demo_r_pjanaggr3] (02.11.15).

Transport demand in passenger kilometres (pkm) travelled for the transport modes *motorised private transport* and *public transport* for each year was calculated (pkm/yr). As the modal split data only provided information about the share of each mode in comparison with the number of trips, it was necessary to combine modal split data with assumptions of the number of trips and the distance travelled per mode:

1. Energy consumption was calculated for buses and private cars. The passenger kilometres travelled (pkm/yr) were multiplied by the specific energy consumption of buses and private cars (MJ/pkm). To gain the specific energy consumption, the total consumption (MJ/vkm) must be divided by the mode-specific utilisation factor;
2. The cumulative energy demand (PJ/yr) and greenhouse gas emissions (Mt CO₂e/yr) from the use phase were calculated by multiplying the energy consumption by conversion factors (CED) and emission factors (GHG);
3. The vehicle stock of passenger cars was then calculated based on the car ownership rate and the number of inhabitants. Each city's vehicle stock was multiplied by material consumption data (e.g. kg steel/vehicle) and divided by the vehicle lifetime in order to determine the total material consumption per year (e.g. t steel/yr);
4. Calculating the total material consumption of bus vehicle stock was based on transport demand (pkm/yr) and specific material consumption factors for buses (e.g. kg steel/pkm). The specific material consumption factors were obtained by dividing a bus's material consumption by the total passenger kilometres travelled in its lifetime. The result equalled the total annual material consumption (e.g. t steel/yr) of buses for each city;
5. Lastly, material consumption (e.g. t steel/yr) was multiplied by material specific conversion factors to obtain the cumulative raw-material demand (Mt/yr), the cumulative raw-material demand of energy carriers (Mt/yr), water use (million m³/yr), cumulative energy demand (MJ/yr) and greenhouse gas emissions (Mt CO₂e/yr) of the vehicle stock for each city.

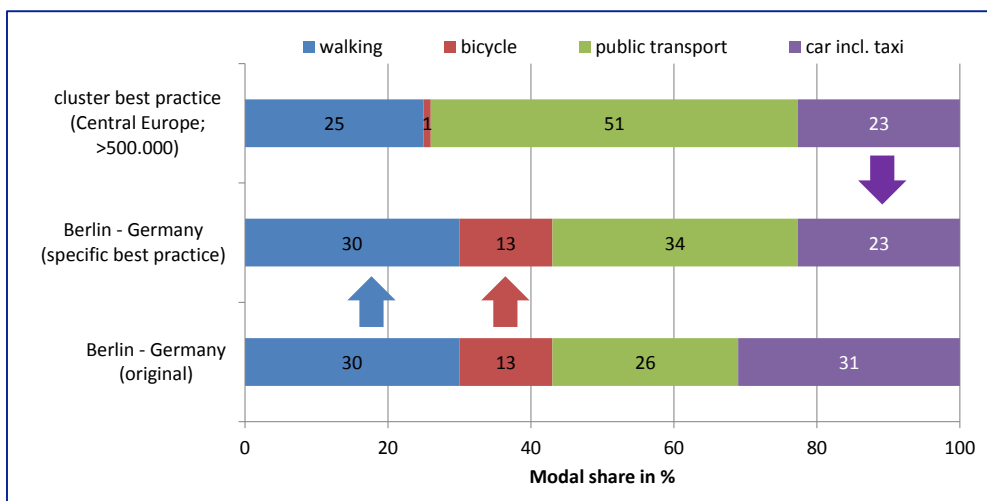
The approach for calculating the best practice case per city followed the same steps for determining the status quo case. However, instead of using the original modal split data and car ownership rate, best practice case modal split data and the car ownership rate were used:

- Twelve clusters of similar cities or urban areas were defined based on their urban sizes and climate zones. Three different urban size-classes (100,000 to <250,000, 250,000 to < 500,000 and >500,000 inhabitants) and four climate zones (Mediterranean, Atlantic, Central Europe and Continental) were used to accommodate differences in the maximum modal shift potential in the offered public transport service that could result from climate, such as hot temperatures in the summer or snow in the winter, and effects of the city size. Small cities only rarely offer underground or tram service compared to larger cities. Other factors which could have an effect on modal shift potential, including topography or cultural acceptance, could not be taken into account in the calculations;
- In a second step for each cluster, a general best-practice modal split and car ownership rate was derived. For this, the three cities with the lowest share of motorised private transport were identified and an arithmetic mean of the modal split and car ownership rate was calculated.

Then for each city or urban area, a specific best practice modal split was derived. The specific best-practice modal split was based on the general best-practice modal split within the same cluster of each city. In this specific best-practice modal split, the percentage of modal shift from the mode *car* was allocated to the modes *bicycle* and *public transport*. The share of the mode *bicycle* in the specific best practice modal split should not be lower than in the original modal split. Since a larger share could be shifted to the mode *bicycle*, the allocation method follows a conservative approach, likewise avoiding energy and resource efficiency potential

overestimation. An example can be seen in Figure 6.3 for the city of Berlin in the cluster *Central Europe*, with > 500,000 inhabitants. The best practice modal split is the average of data from the cities Budapest, Bucharest and Warsaw.

Figure 6.3 Example for derivation of a city-specific best practice modal split (cluster Central Europe, >500.000)



Source: own figure based on TEMS datasets.

The derivations used the following logic:

- Mode *walking*: original modal share;
- Mode *bicycle*: If the best-practice modal share is higher than that of the original, the best-practice modal share is used. Otherwise the original modal share is used;⁴⁴
- Mode *public transport*: original modal share of *public transport* plus the difference between original and best-practice modal share for the mode *car*, minus the difference of original and best practice modal share for the mode *bicycle*;
- Mode *car*: best practice share⁴⁵;
- The calculations follow the status-quo case methodology. The total transport demand in passenger kilometres (pkm) does not change in the best practice case. This means, that a greater trip distance travelled for new public transport users compared to average users was taken into account.

The estimation of resource-efficiency potential as well as energy-savings potential caused by modal shifts in the use phase and vehicle stocks is calculated by subtracting the results of the best practice case from the status quo case for each city. Additionally, the number of passenger cars in these cases is subtracted from and then multiplied by the area of a single parking space to obtain the land use change potential.

In a final step, the obtained results were **scaled up** based on the population within the analysed cities and the total population in EU cities and greater cities. The total population of the analysed cities and urban areas equals 131 million inhabitants. This represents 69% of the total population in cities and urban areas (190 million inhabitants) in the EU clusters. Upscaling is performed based on the city-size level and ignoring the climate regions due to a lack of data. The upscaling factors for each city size are documented in Table A.5.3 of the Annex 5.

⁴⁴ This ensures that the modal share of bicycle does not decrease.

⁴⁵ In some cases the original modal share for the mode car is used, if it is lower than the best practice modal share. This only occurs in cities which are part of the calculation of the best practice modal split.

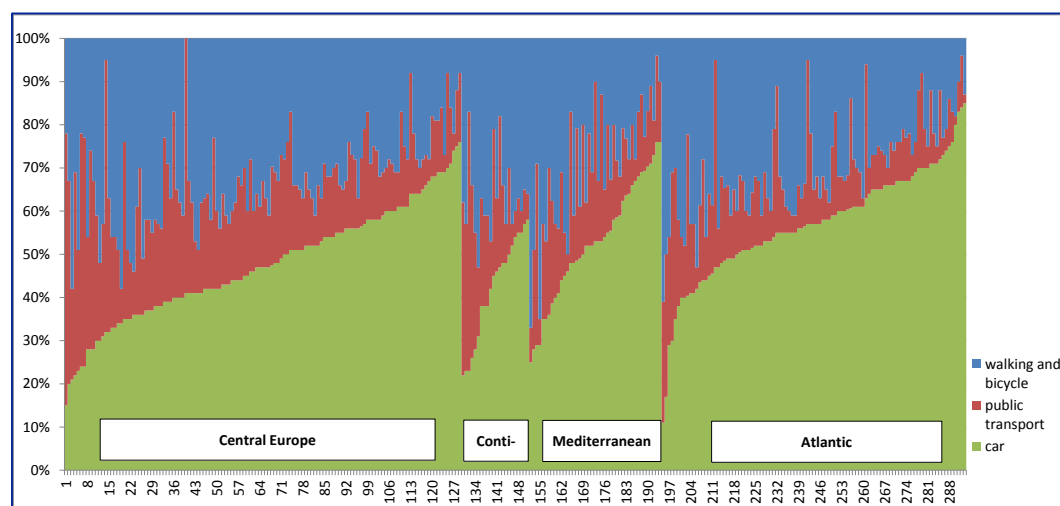
6.2.1 Data sources & Scenario assumptions

Modal split and mobility data

The most important data required for the scenario analysis is the modal split data of European cities and urban areas. Several European cities collect this data, but usually not on a regular basis. Within the EPOMM Modal Split Tool – TEMS⁴⁶, many datasets are listed to which cities may add. In consequence, the reference year as well as the applied methodology to collect this data varies between the datasets. Nevertheless, the TEMS-Tool offers the largest collection of urban modal split data for Europe and provides the data for the scenario analysis.

TEMS contains about 600 datasets, including duplicate data and data from non-EU cities. Of these datasets, 293 are included in the scenario analysis. Figure 6.4 illustrates the broad range in the proportion that the mode car (in green) takes up across various datasets. More detailed illustrations can be found in the Annex 5. To note, these 293 datasets cover a population of 131 million people (see Table A.5.2 in the Annex 5). This represents 69% of the total of 190 million inhabitants in these clusters within the EU⁴⁷. The TEMS Database includes city-specific data as well as urban area modal split data. Double-counting might occur when a city is included separately and within an urban area.

Figure 6.4 TEMS Modal split data of the examined cities



Within the scenario analysis, these modal split datasets are combined with information about trip length and number of trips per day. Unfortunately this information is not provided by the TEMS datasets. Therefore, assumptions had to be made, as follows.

Table 6.1 Scenario assumptions on trip length and numbers of trips per day

	Unit	Trip amount
Walk	km	3
Bicycle	km	5
Public transport	km	8
Car	km	10
number of trips	#	4

Source: own assumptions based on mobility data of London⁴⁸, Berlin⁴⁹ and (MID 2008).

⁴⁶ <http://www.epomm.eu/tems/index.phtml>.

⁴⁷ Own calculation based on Eurostat dataset: Population on 1 January by age groups and sex - cities and greater cities [urb_cpop1].

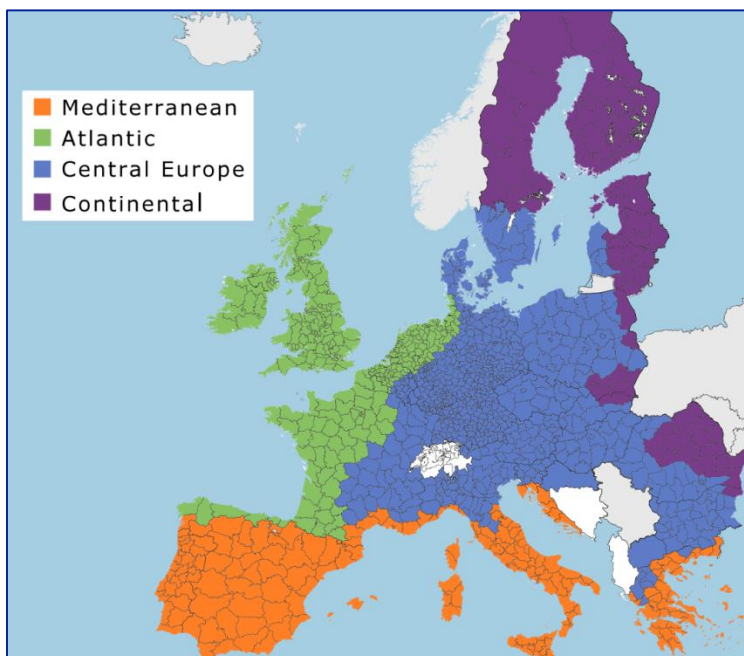
⁴⁸ <http://content.tfl.gov.uk/london-travel-demand-survey.pdf>.

⁴⁹ http://www.stadtentwicklung.berlin.de/verkehr/politik_planung/zahlen_fakten/download/Mobilitaet_dt_Kap-1-2.pdf.

Climate zones

To create the clusters, it is necessary to add the information about the climate zone to each city. This is done by matching the NUTS 3 code with the climatic zone information⁵⁰. This approach can be inaccurate if more than one climatic zone occurs within a NUTS 3 region; in this case, the predominant zone is taken. The climate zones are mapped in Figure 6.5.

Figure 6.5 Mapping of the climate zones to the NUTS 3 regions



Source: own figure.

Population and vehicle statistics

For the scenario analysis, different Eurostat data have been used to calculate the car ownership rate: population density by NUTS 3 region [demo_r_d3dens], population on 1 January by broad age group, sex and NUTS 3 region [demo_r_pjanagr3] and stock of vehicles by category and NUTS 2 regions [tran_r_vehst]. The population in cities and greater cities [urb_cpop1] was used to upscale the results to the EU28 level.

Vehicles

Within the scenario analysis, information about the composition of the vehicles, vehicle properties and typical use patterns of these vehicles are required.

The RENEWABILITY project provides material composition data for buses and different sizes and engine types of passenger cars (small, medium and large; diesel, gasoline) [Zimmer et al. 2009]. Within the scenario analysis, an average of the material composition of a medium-sized gasoline and diesel passenger car is used^{51 52}. For this, the weight of a passenger car is 1.35 t and for buses 11t. Both vehicle categories have an average lifespan assumed to be 12 years, while the average distance travelled for passenger cars is assumed to be far lower (12 000 km/yr) than for a bus (60 000 km/yr).

Figure A.5.4 and Figure A.5.5 in the Annex 5 illustrate the values used in the calculation.

The assumed fuel consumption of a medium-sized passenger car is 6.7 l/100 km for gasoline and 5.5 l/100 km for diesel [Hülsmann et al. 2014], with the average occupancy rate of 1.5

⁵⁰ The climatic zones are divided from Diercke Weltatlas.

⁵¹ An example for an medium sized passenger car is the VW Golf.

⁵² According to Mock & Campestrini (2011) 51% of the total sales / registrations in 2010 in the EU were diesel powered.

passengers per vehicle⁵³. Land-use change potential estimates are based on reducing the number of parking places as the number of passenger cars decreases. The size of a parking place is assumed to be 12 m².

Within the scenario analysis, fuel consumption for buses (43.3 l/100 km) was derived from the Handbook Emission Factors for Road Transport (HBEFA 3.2). This handbook provides emission factors and fuel consumption for all current vehicle categories, including urban buses, for a wide variety of traffic situations. How urban buses are used may vary between cities. In the scenario analysis, the typical German public transport utilisation rate (21%) is assumed for all cities. According to the TREMOVE v3.3.2 model (TML 2010), the German bus use is marginally above the European average, but the differences are negligible.

Emission and conversion factors

CED and the greenhouse gas emission calculations for the transport use phase are based on conversion and emission factors (Table 6.2) that are multiplied by the diesel and gasoline consumption.

Table 6.2 Conversion factors and GHG-emission factors for diesel and gasoline

		Diesel	Gasoline
CED	MJ/l	44	38.4
GHG	kg CO ₂ e/l	3.17	2.8

Source: DIN EN 16258.

Material-specific factors (CED, CRD, use of water and GHG) for calculations affecting the vehicle stock come from the ifeu-institute's databases. The (ifeu 2012) factors are published in the ifeu-institute's report 'Indicators for the use of raw materials in the context of sustainable development in Germany' (Indikatoren / Kennzahlen für den Rohstoffverbrauch im Rahmen der Nachhaltigkeitsdiskussion).

6.3 Results

As Table 5.3 shows, significant resources and energy savings can be obtained by modal shifts in European cities. In the calculation, the savings potentials for CRD (7.8 million tonnes per year (Mt/yr)) as well as the CRD for energy carriers was only considered for the vehicle stock. Energy carriers generate 1.3 Mt/yr (17%) of this CRD. The majority of this resource-saving potential can be found in cities with 100,000 to 250,000 inhabitants. On average, CRD savings potential per inhabitant is 41 kg/yr, whereas cities with 100,000 to 250,000 inhabitants have an average potential of 84 kg/yr. The average CRD per inhabitant in other city sizes is 23 kg/yr (250,000 to <500,000) and 24 kg/yr for ≥ 500,000. The difference of the average CRD per inhabitant occurs because of a higher average car ownership rate (TEMS data) and lower best-practice car ownership rates in smaller cities, especially in the cluster *central Europe* and *continental*. Other categories also see effects from ownership rate and best-practice differences.

The total energy-saving potential in Europe (510 PJ/yr) comes from a modal shift and lower private car ownership rates. This potential represents 16% of the total CED of 3 150 PJ/yr in the baseline. The vast majority of this potential (92%) comes from the use-phase.

The transport sector is the second biggest greenhouse gas-emitting sector and contributed about one quarter of the EU's total greenhouse gas emissions in 2012. According to EEA [2013] urban passenger travel causes 16% of the transport-related greenhouse gas emissions.

The results show, that for greenhouse gas emissions, the proportion of the use-phase for reducing potential is even larger than for the CED (94%). It represents a reduction potential of 16% of the greenhouse gas emissions of the use phase in the baseline. In total, the emission reduction potential amounts to 37 Mt CO₂e/yr.

⁵³ The assumption is based on the utilisation factor of the TREMOD emission model version 5.41 of the Federal Environment Agency in Germany. <https://www.umweltbundesamt.de/themen/verkehr-laerm/emissionsdaten>.

Table 6.3 Reduction potential by use-phase impact categories and changes in vehicle stock; total potential for EU28

Number of inhabitants in city/ urban area	Use phase		Vehicle stock				
	CED	GHG	CRD	thereof CRD Energy carriers	Water use	CED	GHG
	PJ/yr	Mt/yr	Mt/yr	Mt/yr	Mm ³ /yr	PJ/yr	Mt/yr
100,000 to <250,000	172.7	12.6	4.6	0.8	11.3	23.0	1.4
250,000 to <500,000	101.1	7.4	0.9	0.2	2.3	5.0	0.3
≥500,000	196.6	14.3	2.2	0.4	5.5	11.6	0.7
Sum	470.3	34.3	7.8	1.3	19.1	39.6	2.4

The total land use change potential, due to fewer private cars and a reduction in needed parking space, equals 14 750 ha, as can be seen in Table 6.4.

Table 6.4 Land use change potential

Number of inhabitants in city/ urban area	Former parking spaces
	(values in 1 000 ha)
100,000 to <250,000	7.9
250,000 to <500,000	2.2
≥500,000	4.7
Sum	14.8

The calculation results highlight the importance of the use-phase in calculating modal shift for European cities. Other positive effects, like reducing air pollution or noise, are not quantified, though they are nonetheless important for urban quality-of-living. The calculations apply a conservative approach; no modal shift to more resource- and energy-efficient modes of public transport, like trams or subway trains, was taken into account. Additionally, no modal shift on long distance trips were considered, which could be assumed as a consequence of reducing the private vehicle stock.

Scenario result interpretations are only estimations, since the quality of several input data would need improvement for more precise interpretation.

The most important aspect of these scenario calculations deals with the available mobility data (e.g. modal split, trip distance and purpose), for which a single methodology was applied. The data types and sources in the TEMS tool differ: in some datasets, all trips might be included, while in others only business trips are used. The datasets may also differ due to varying minimum ages within the surveys. Because young people more often use bicycles or walk, an effect on the result is likely. The number of passenger cars and therefore a reduced vehicle stock potential could be overestimated, since only data from the NUTS 2 level region was used. In further analyses, more specific city data should be collected and used.

In the scenario analysis, many assumptions were made. These assumptions can be modified slightly for a sensitivity analysis to estimate the effect to the total results. In Figure 6.6, five sensitivities were analysed:

Sensitivity 1: Fuel consumption of the passenger cars strongly depends on driving conditions. In the scenario analysis, these different driving conditions are not taken into count. Due to stop-and-go driving profiles, the consumption in some urban regions may be higher than assumed. To accommodate this factor, the fuel consumption was increased by 10% compared to the baseline in this sensitivity;

Sensitivity 2: In the scenario analysis, no change in the utilisation of the public transport is considered. The change in the modal split leads to a linear increase of the vehicle kilometres and therefore the number of new buses. A possible modal shift can be

achieved as well by increasing utilisation of the existing public transportation system. In this sensitivity analysis, the bus use is slightly higher than in the baseline (+10%). The average use rate (23%) in this sensitivity is slightly higher than the scenario analysis (21%);

Sensitivity 3: In practise, the average trip length may vary between the cities. In this sensitivity analysis, the assumptions on the trip length were modified. The trip length of all modes is reduced by 10% compared to the scenario analysis;

Sensitivity 4: The scenario uses an estimation of a maximum shift potential from motorised private cars to more efficient modes for the best practice modal split case. This potential is allocated on the use of public transportation (buses) and bicycles. This sensitivity represents the upper range of possible potentials due to the chosen allocation method (between public transportation and bicycles). In sensitivity 4 the total maximum shift potential is allocated completely to the mode *bicycles*, while the modal share of public transport does not change;

Sensitivity 5: In this sensitivity analysis, the method for allocation for the best practice modal split case was modified. A modal shift only in public transportation was assumed, while the modal share of bicycles does not change. This sensitivity shows the lower range of energy and efficiency potentials due to the chosen allocation method.

Figure 6.6 Resource efficiency potentials (CRD) and energy efficiency potentials (CED) for the baseline (scenario results) and 5 sensitivity cases

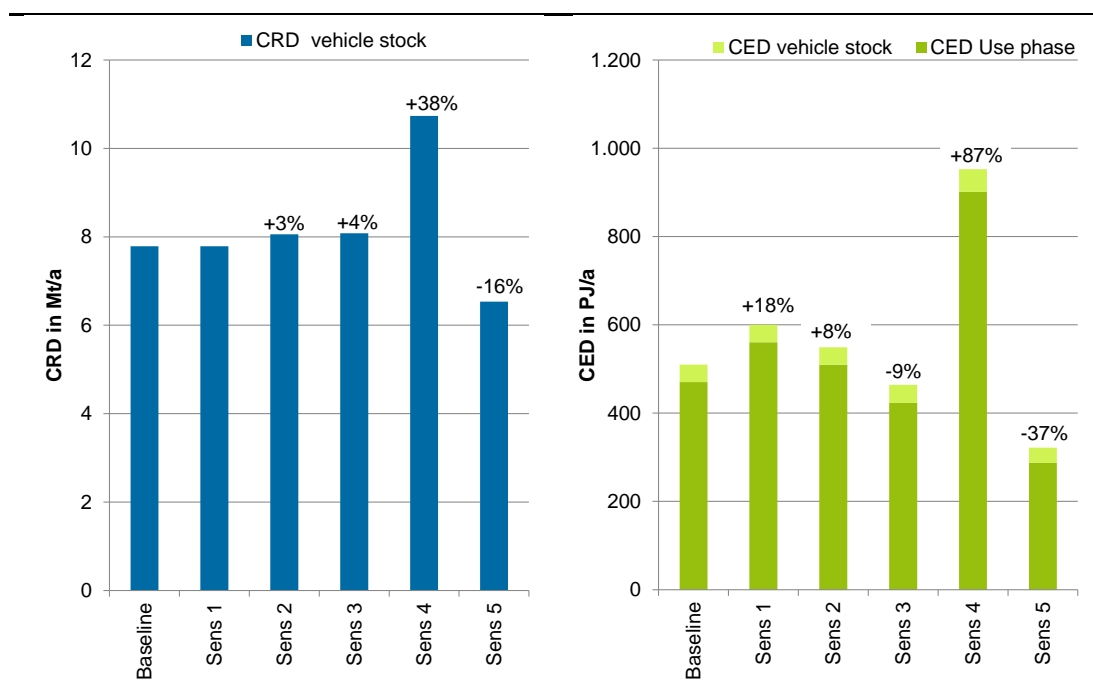


Figure 6.6 shows the sensitivity analysis results for the resource efficiency potentials of the vehicle stock (CRD) and the energy efficiency potentials (CED) of five sensitivities and the baseline.

The results of the sensitivity analysis highlight the importance of the applied best-practice modal split. For the CRD as well as for CED the variation of the allocation method has the largest effect on the total results (Sens 4 & 5). A variation in the assumptions for passenger car fuel consumption can be seen in the disproportionate increase in CED savings potential (Sens 1). In further studies, country-specific fuel consumption data should be used. The share of small and more energy efficient vehicles in cities might be larger than in rural areas. This could lead to an overestimation of the CED savings potential; city-specific data should be used in this case.

The result also shows that the assumption that no increase in bus use occurs and that increasing demand is achieved completely with new buses can lead to underestimating the CRD and CED savings potentials (Sens 2).

Sens 3 highlights the influence of the assumed mobility behaviour. A variation of the assumed trip length leads to a proportional change of the CED savings potential.

6.4 References

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7 Information and communication technology (ICT) sector

7.1 State of the art

The ICT (information and communication technology) sector is characterized by a substantial and increasing demand of critical raw materials (CRM), such as rare earth elements (e.g. neodymium, praseodymium in notebook computers), precious metals (gold, silver and palladium in the flat screen, notebook and smartphone devices), and commodities like steel and plastics. The recycling of obsolete ICT devices (WEEE) helps to recover a share of the commodity metals and precious metals at the end of the product life cycles. However, there are still serious shortcomings in the collection and pre-treatment of waste ICT equipment (Buchert et al. 2012). The recovery rates are generally insufficient for refining a range of metals in spite of the already highly-developed and established recycling processes from WEEE. This is particularly true for the CRM.

IT and telecommunication equipment is regarded to be most relevant, both in terms of reducing the demand for material resources as well as the demand for energy resources. Estimates of the mitigation potential, cited most frequently, anticipate that intelligent deployment of ICT solutions could yield reductions of greenhouse gas emissions totalling around the equivalent of 7.8 billion tonnes CO₂ worldwide in 2020. This amounts to around 15% of the global emissions expected in 2020 [The Climate Group, 2008].

This section addresses only such resource efficiency improvements that can be achieved at the level of the ICT hardware whereas second order effects, such as the energy savings from ICT application (e.g. better regulation of temperature / shadowing in buildings or smart demand regulation tools to smooth renewable energy production and demand) will not be addressed. To this end, technology-related levers are identified as the most relevant approaches for increasing resource efficiency in the ICT sector. These approaches encompass technical substitutions and design solutions that lead to energy-savings effects, for instance substituting thin or zero clients for desktop computers. Other relevant starting points refer to the recycling of plastics from WEEE and using recycled plastics for the production of new ICT (closed loop recycling). In addition, consumer-oriented levers are explored, like extending ICT products' useful service lives by making batteries (especially in mobile applications) more easily exchangeable [Möller et al. 2015]. As a rather simple solution, the product life-times for mobile applications can be easily extended if these devices are designed in such ways that the user can easily exchange depleted rechargeable batteries with new ones. Such a solution still needs to be analysed within the context of the eco-design of ICT products that should foster modular construction, reparability and upgradability. Other developments, like combining monitor use for TVs and computer applications could also be addressed.

Manhart et al (2010) report on the results of a life cycle assessment on thin clients. The study found that one thin client operated in a server-system causes the following environmental impacts:

Table 7.1 Environmental impacts of one thin client operated in a server-system

	CED (MJ)	GWP⁵⁴ (kg CO₂e)
Production	665.51	42.05
Use phase	4554.48	260.31
Disposal	-8.36	-0.25
Total	5211.63	302.11

⁵⁴ Calculated on the basis of the German power mix and data from EcoInvent (2009).

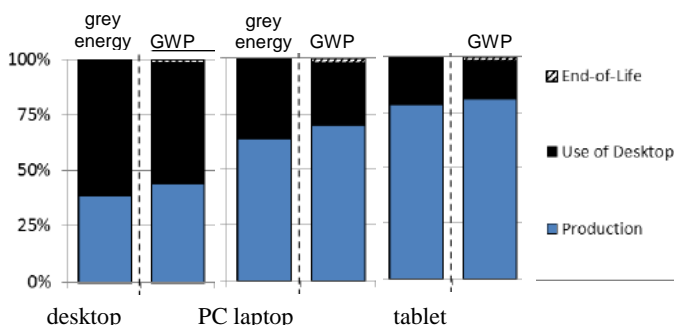
7.2 Methodology for the extrapolation of impacts on the Cumulative Energy Demand (CED) of ICT

7.2.1 CED saving potential of thin clients and zero clients

The substitution of zero clients (ZC) or thin clients (TC) for Personal Desktop Computers (PCs) is expected to bear enormous natural resource saving potential due to better utilisation of ICT hardware. Zero clients and (to a certain degree) thin clients constitute small ICT devices, which are equipped with limited hardware resources in comparison to PCs. By means of virtualisation, such devices provide approximately the same range of ICT functions (such as office computing, Internet access) as PCs. From the user's perspective, there is little functional difference between ZC/TC and PC in spite of the large difference in the hardware configuration that provides the functions. While the average PC, needed for the provision of a computer working place, weighs 10 to 15 kg in average, the ZC/TC device weighs not more than 2 to 3 kg and offers a potentially longer service life (up to 9 years). Moreover, the average power consumption of one ZC/TC device is much lower than that of a PC during the use phase. However, the ZC/TCs work only in combination with a system of ICT infrastructure in the background. Notably, data network infrastructure (local area network, LAN), server and file-server as well as auxiliary equipment (e.g. uninterruptable power supply, air-conditioned server rooms) are required to run virtual desktops on ZC/TCs⁵⁵ clients. A typical application case may encompass one hundred ZC/TCs clients that are connected to a LAN. Computers for office application show a large variability of possible hardware configurations. Moreover, the terminology used on the market to specify different types of computers is rather fuzzy; in particular the distinction between zero clients and thin clients is difficult.

For comparison, Hirschier et al. [2014] examined the "grey" (cumulative) energy consumption of different ICT devices during their entire life cycle by means of LCA. In the light of these findings, it is safe to assume that the focus of the analysis in this chapter can be limited to the production and use phases.

Figure 7.1 LCA results of three types of ICT hardware



Source: Hirschier et al. [2014]

Next to the locally operated end user devices (such as desktop computers and thin or zero clients), the global ICT infrastructure comprises various data network infrastructure and data centres, which are indispensable to access Internet-based cloud services. Coroama et al. (2014) categorise the Internet access equipment in four distinct classes:

- Customer premises equipment (CPE) (e.g. LAN/WLAN routers);
- Access network (e.g. multiplexing nodes and cables);
- Edge & core network (edge switches and the large backbone routers);
- Data centres (large server farms).

Therefore, for purpose of comparison, a simplified functional scenario is taken into account in order to cover the different types of hardware configuration: 100 solitary PCs are replaced with 100 ZC/TC devices including background ICT infrastructure. Table 7.2 summarises the assumed

⁵⁵ Most office PCs are connected to a LAN and server infrastructure as well. However, the function of these machines is not wholly dependent on this background system whereas ZC/TCs are.

hardware specifications of PCs and Zero clients and Thin Clients for the purpose of estimating the resource saving potential. Please refer to Annex 6 for details of the assumed hardware specifications used in the comparison of CED.

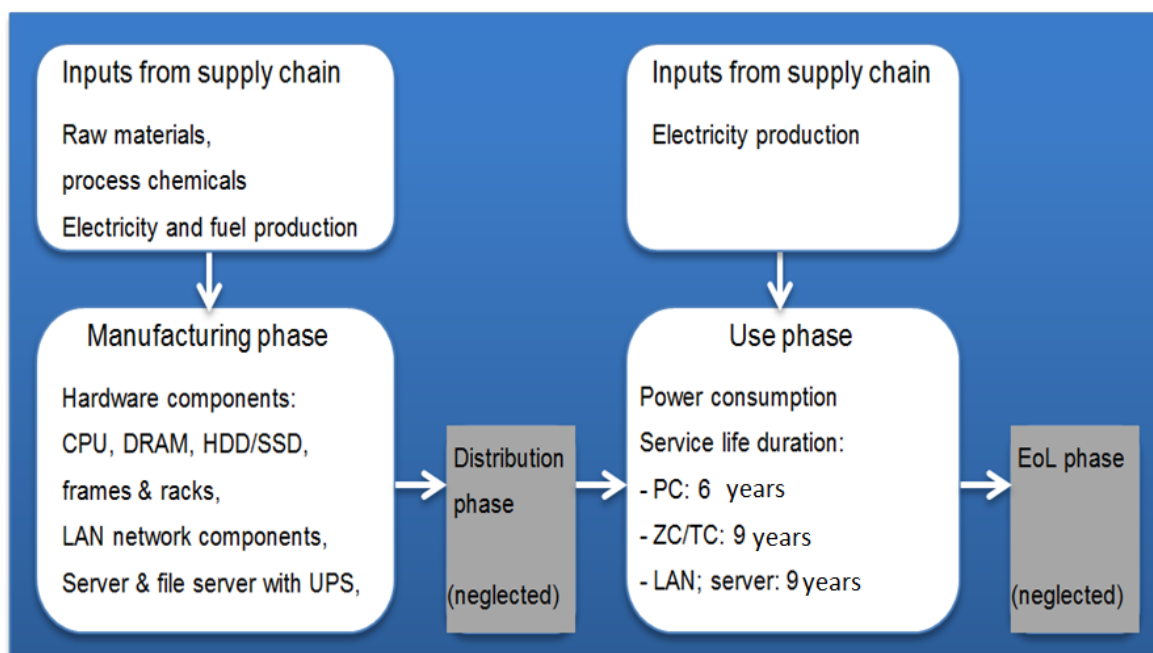
Table 7.2 Overview of hardware specifications of PCs and zero clients and thin clients

Personal Desktop Computers (PC)	Zero clients or thin clients (ZC/TC)
Function: one computer work place per PC	Function: one virtual desktop work place per client device
100 PCs (a 15kg) = 1500 kg hardware (+ LAN) (+ Server/Fileserver)	100 ZC/TC (a 2.5kg) = 250 kg hardware + LAN; Server/Fileserver + UPS, Air-condition
100 Desktop monitors	100 Desktop monitors
6 years lifetime per device	9 years lifetime per device
Annual power consumption of 100 standalone devices for office work. = 7180 kWh/yr	Annual power consumption of 100 devices, including servers and local area networks for office work. = 7331 kWh/yr

The calculation of the CED was undertaken by means of a simplified life cycle assessment (LCA) using the LCA software Umberto. The calculation is based on an abridged LCA model of both scenarios. The simplified LCA model features an abridged system boundary, which encompasses only the manufacturing phase of ICT hardware and the use phase. The distribution phase and the end-of-life phase are neglected in this simplified LCA model since these life-cycle phases usually yield only minor contributions to the overall CED in the life cycle assessment of computing devices. Figure 7.2 illustrates this proposition: the results of LCA studies on three types of ICT show that transports and end-of-life processes are nearly negligible in comparison to the total energy consumptions stemming from the production phase and the use phase.

The Figure 7.2 below provides an overview of the system boundary. The functional unit was defined as "Providing the means for typical office computer applications (Word/Excel) during working hours over a period of one year (typical working time)".

Figure 7.2 System boundary of the simplified LCA



Data sources on LC-inventory lists and background data:

- Öko APC Project (I/O data derived from German Probas datasets (UBA, 2014));
- EcoInvent 3.01;
- own assumptions based on in-house measurements on ICT infrastructure.

Data sources on power consumption:

- Koehn, M., Federal Environment Agency, (2016), personal communication;
- Knermann, C. et al. (2015);
- Fichter, K., Clausen, J. & Hintemann, R. (2011).

7.2.2 CED saving potential of Design for Repair and Refurbishment (DfRR)

Results of Life Cycle Assessment (LCA) studies show that the manufacturing phase of ICT hardware dominates the life-cycle-wide environmental impacts of computers. In particular the manufacturing of active semiconductor components is particularly energy and resource intensive. In other words: the embodied energy of ICT hardware exceeds the energy consumption of all other life-cycle phases, including the use phase.

In spite of this fact, the product lifespans of ICT equipment has been declining steadily during the past decade. Mobile phones, for instance were used for 4.8 years on average in 2000. In 2005, the average service life had declined by 3% to 4,6 years. Small ICT devices suffered a more tremendous decrease in service life of 20% (Bakker et al. 2014). As a consequence, there is an enormous loss of valuable material resources and embodied energy in WEEE. A larger number of short-lived devices need to be produced than long-lived ones to fulfil a similar range of functions over a given period of time. This trend to premature obsolescence is detrimental to resource efficiency.

The trend to earlier obsolescence has accelerated as a consequence of prevailing design trends in the ICT sector, specifically the market availability of small yet powerful rechargeable batteries. Most modern ICT devices are powered by embedded lithium Ion (LIO) batteries. This technology enables 300-1000 recharge cycles on average. Notably the trend towards small battery-powered gadgets has been made possible through the market introduction of embedded batteries. More and more devices are designed in such ways that the user cannot replace exhausted rechargeable batteries. Where the design doesn't support the replacement of exhausted battery after the average amount of load cycles, this usually means that the whole device is rendered obsolete. Hence, a large share of gadgets is disposed of due to battery exhaustions while otherwise functioning. Modern smart phones are used for less than 3 years on average and one of the most relevant failure modes is the exhaustion of recharge capacity of embedded LIO batteries. Thus, embedded batteries foster premature obsolescence of ICT devices.

Against this background, making batteries (especially in mobile applications) more easily exchangeable by design is a possibility to extend ICT products' useful service lives and reduce premature obsolescence.

The extrapolation of environmental saving potential in terms of CED builds upon the results of existing LCA studies on ICT devices. Results are interpreted in the context of the service life duration applied in the respective study. Where applicable, a scenario for service life extension is assumed and the original CED value is recalculated to the extended service life. The resulting difference is extrapolated on basis of statistical data on market proliferation of small ICT gadgets in EU28.

7.2.3 CED saving potential of recycling plastics from WEEE

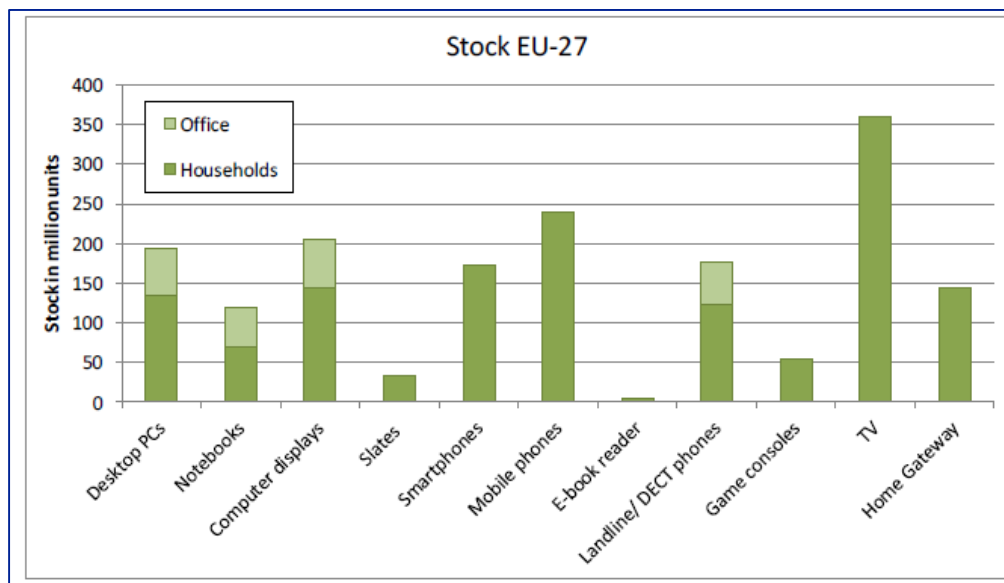
The extrapolation of the CED saving potential builds on best-in-class case studies described in a recent report by Oeko-Institut on best environmental management practice [Möller et al. 2015]. The raw data sources encompass information provided by large ICT producing companies as well as expert interviews. The TU-Delft's Idemat 2015 database of eco-costs was used as a source of secondary data for CED factors of different plastic types. The extrapolation of the CED saving potential implements a calculation on basis of statistical data on market proliferation of ink cartridges and TV sets in EU28.

7.2.4 Methodology to upscale and calculate EU 28 aggregates

Resource efficiency gains as well as energy savings that could be identified at the ICT product or component level will be up-scaled using a stock model that Öko-Institut developed in a project for DG Communications Networks [Prakash et al. 2014]. This model refers to 2011 and EU-27, but it has been updated for this study to the current situation and EU-28. The following Figure

7.3 shows the stock of the most relevant ICT product groups with a differentiation for household and offices.

Figure 7.3 Stock of ICT products in EU-27 in 2011



Source: Prakash et al. 2014.

In order to derive energy savings and other environmental impacts of the resource saving measures, LCA data from different studies will be combined with the stock model. The Bill-of-Materials (BOM) for various ICT products will be estimated based on recent Öko-Institut studies (e.g. Buchert et al. 2012) and interviews with recyclers and refiners (e.g. Umicore).

7.3 Results

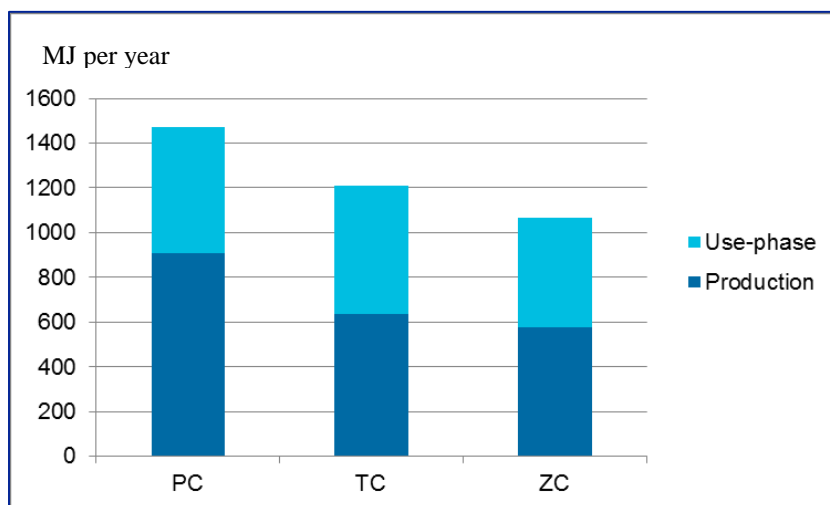
7.3.1 CED saving potential of thin clients and zero clients

This section presents the results of the simplified LCA for the three variants of workplace computers (desktop-PC; Thin client (TC) and zero-client (ZC)). The LCA-based comparison of the three types of computer workstations demonstrates the high environmental relevance of ICT. The production and use of computer hardware consumes a substantial amount of fossil energy and this causes significant greenhouse gas emissions. The environmental impacts result primarily from processes that are indirectly linked to the life cycle of the computer workstations. The largest shares of the CED stem from the generation of electricity used in the production of microelectronic hardware components. In particular, the manufacturing of DRAM (memory)-chips is the largest contributor to the total CED during the production phase. Another important contributor to the overall CED is the generation of electricity that is consumed during the computers during use phase. Figure 7.4 compares the total CED of the three respective models of computer workstation over the observation period of one year⁵⁶. According to the model assumptions⁵⁷, the figures encompass the CED of server and network components, which are necessary to operate the thin client and zero client.

⁵⁶ Note that the observation period of 1 year was chosen for the purpose of comparison because the respective types of computers differ in terms of service life duration as well as annual energy consumption.

⁵⁷ As explained in section 7.2 the simplified LCA neglects the transportation processes and the end-of-life phase because these processes are usually of marginal relevance to the total CED of ICT.

Figure 7.4 Comparison of the annual share of CED for the three types of computer workstations

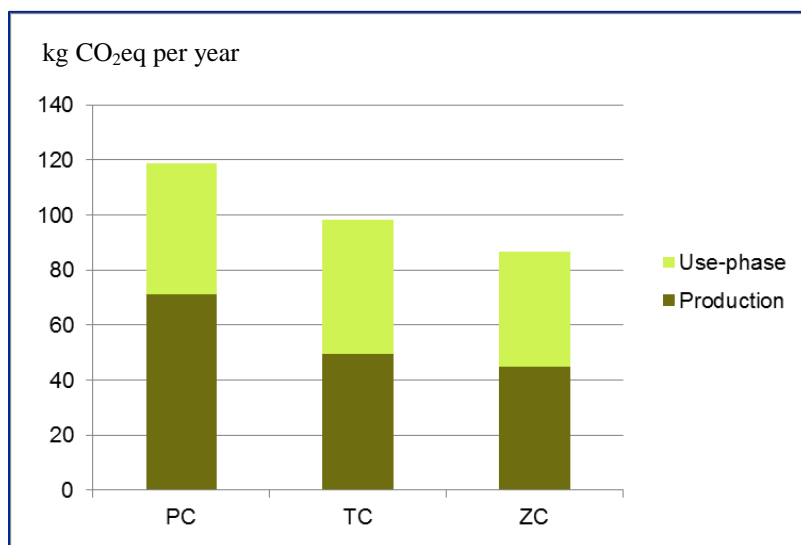


The results show that the highest cumulative energy demand is associated to the desktop-PC whereas the TC and ZC have a lower CED over their respective life cycles. The replacement of one desktop PC workstation with one thin client workstation saves 18% of CED per year and 27% in case of the zero client workstation. This holds true in spite of higher annual power consumption of the TC/ZC configuration because the improved hardware utilisation (longer lifetime) reduces the CED allocated to the production phase. Additionally, Figure 7.4 illustrates the importance of the ICT hardware in relation to the energy consumption during the use phase: slightly more than 50% of the CED is associated to the production phase in case of the TC and ZC. The production of PC hardware accounts for even higher share of CED: 62%. These results suggest that the extension of service life of hardware exerts substantial influence on the energy efficiency of ICT, measured as CED.

The analysis of the global warming potential (GWP) is expressed by the indicator greenhouse gas (GHG) emissions. The analysis presented in Figure 7.5 shows almost the same pattern of impacts as seen from the analysis of CED. The annual greenhouse gas emissions of a PC-based working place⁵⁸ amounts to 119 kg CO₂ equivalents. In comparison, the thin client working place accounts for 98 kg CO₂e and the zero client working place accounts for 87 kg CO₂e per year. The resulting GWP saving potential of TC is 21 kg CO₂e and 32 kg CO₂e for the ZC.

⁵⁸ The result encompasses the GWP of power consumption during 1 year office use and the sixth part of the GWP related to hardware production (assuming a lifetime of six years per PC).

Figure 7.5 Comparison of the annual share of GHG emissions (GWP=100) for the three types of computer workstations



It is noteworthy that the replacement of a single stand-alone PC with a thin or zero client would not yield advantages in terms of CED or GWP as the operation of a ZC/TC still requires a server. Benefits in resource efficiency materialize only when a larger number of PCs is substituted. The break-even point in terms of CED and GWP is approximately 2.3 ZC-devices (+LAN server) for the substitution of the same number of PCs. In case of thin clients, the break-even point is approximately 3,5 TC-devices + LAN server⁵⁹. The larger the serve-client networks (i.e. number of ZC/TC working places connected via LAN) the bigger the potential of hardware virtualisation. Hence, the potential increase of resource efficiency materializes predominantly in larger network settings such as medium sized enterprises or industry scale applications.

The upscaling of resource efficiency potential on EU28 level is influenced by the aforementioned uncertainties regarding size and configuration of ZC/TC networks in the real world. Concrete and statistically robust data on these aspects could not be acquired in the framework of this study.

The annual EU28-wide CED saving potential is calculated as the difference of CED attributed to the total number of PCs minus the CED attributed to the total number of ZCs and TCs respectively.

In 2015, the total number of PCs in the EU28 is estimated to sum up to 60 million devices approximately. The production⁶⁰ and operation of this amount of PC computers results in a total CED of 8.82×10^{10} MJ per annum (GWP: 7 130 247 t CO₂e). In comparison, the total number of thin clients in the EU28 in 2015 has been estimated to be 14 million devices approximately. Estimates of the market segment for TC or ZC foresee a shrinking market development over time [Digital Europe, 2016]. Therefore, the year 2015 is used as a baseline scenario and compared with a moderate growth scenario following possible policy interventions. Assuming a 50% substitution rate of TC/ZC for PCs in future, the production⁶¹ and operation of this amount of TC computers results in a total CED of 1.7×10^{10} MJ per annum (GWP: 1 377 523 t CO₂e). As for zero-clients, the total number of devices in the EU28 in 2015 has been estimated to be 7 million devices approximately. The production and operation of this amount of ZC computers results in a total CED of 7.5 billion MJ per annum (GWP: 606 095 t CO₂e).

⁵⁹ Note that the size and configuration of LAN servers for micro networks may not differ much from these of normal PCs. In this case one would need to consider the substitution of (3,5 TC-clients + 1 PC-like server) for (3,5 stand-alone PCs).

⁶⁰ The LCA calculation considers a 1/6 share of the CED attributed to the production phase of PCs in order to account for an annual share of a six-year lifetime of PC hardware.

⁶¹ The LCA calculation considers a replacement-cycle of 8 years for thin clients and zero clients (Digital Europe, 2016). Thus, a 1/8 share of the CED attributed to the production phase of TC / ZC in order to account for an annual share of an eight-year lifetime of TC/ ZC hardware, including LAN-server infrastructure.

These numbers are considered rough estimates and can thus be used to infer an approximate CED saving potential. Assuming that the number of newly installed ZC/TC working place computers does indeed substitute for PCs (which would otherwise have been installed), the substitution potential calculates as the difference of CED as follows:

- The replacement of 14 million PCs by 14 million thin clients results in a CED saving potential of 3.6 billion MJ per annum (as for 2015);
- The replacement of 7 million PCs by 7 million zero clients results in a CED saving potential of 2.8 billion MJ per annum (as for 2015).

Based on the same extrapolation approach, the future CED saving potential is shown in Table 7.3. The variation over time shown in the following tables is driven by changes in market diffusion of the respective computing technologies.

Table 7.3 Extrapolation of CED saving potentials of thin clients and zero clients

Year	PC		Thin clients		Zero clients	
	Extrapolated number in EU28, in millions	Approx. market share	Extrapolated number in EU28, in millions	CED saving potential (MJ/yr), in billions	Extrapolated number in EU28, in millions	CED saving potential (MJ/yr), in billions
2015	60	74%	14	3.6	5	2.8
2020	73	64%	18	4.5	9	3.5
2025	63	48%	22	5.7	11	4.4
2030	51	19%	27	7.1	14	5.5

Table 7.4 Extrapolation of GWP saving potentials of thin clients and zero clients

	PC		Thin clients		Zero clients	
	Extrapolated number in EU28, in millions	Approx. market share	Extrapolated number in EU28, in millions	GWP saving potential, Mt CO ₂ e	Extrapolated number in EU28, in millions	GWP saving potential, in Mt CO ₂ e
2015	60	74%	14	0.3	5	0.2
2020	73	64%	18	0.4	9	0.3
2025	63	48%	22	0.4	11	0.3
2030	51	19%	27	0.6	14	0.4

Discussion of the results

The system boundary of the LCA calculation, presented above, encompass only the impacts of data transmission via local area networks but not the Internet. The reason for this limitation is that the main function (office work) of computer working places in all three scenarios (PC, TC, ZC) does not necessarily depend on the Internet. Content-related data transmission over the Internet (such as email) remains the same in each of the scenarios and results in a similar energy consumption. Thus, the scenarios for thin / zero clients take only the energy consumption of the customer premises equipment into account but not the access network nor external data centres.

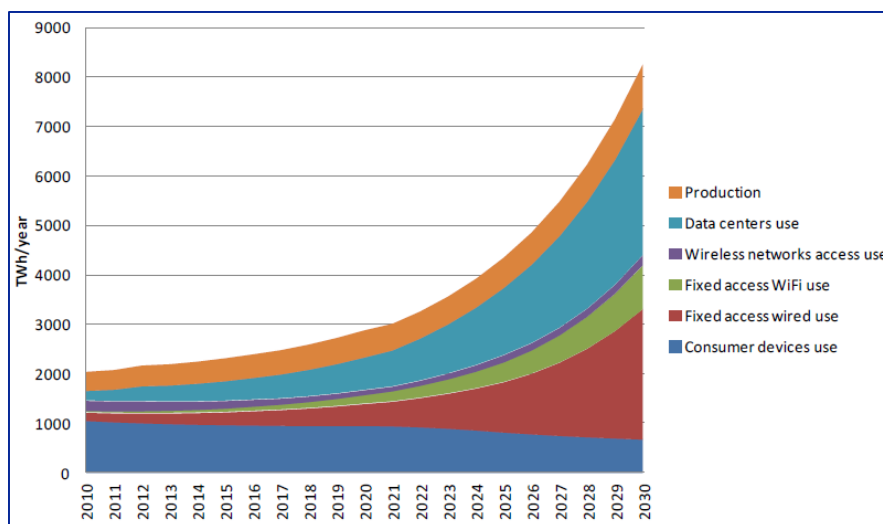
Nevertheless, the vast majority of office working places in the EU use Internet services to some extent and this aspect of computing functions is becoming more and more relevant. Internet based services, commonly considered as "cloud" services, represent a growing trend in the ICT sector. This applies equally for TC/ZC as well as for PC equipped working places⁶². Cloud

⁶² To some extent, TC/ZCs may take advantage of Internet based cloud services but their function relies nevertheless on a LAN-Server system rather than cloud services alone. In contrast, the functions of certain mobile devices (e.g. smartphones, tablets) may rely solely on cloud services but their functionality differs from office working places. Hence, a direct comparison is not possible in the framework of this study.

services provide “virtualised” functions and can partly substitute customer premises equipment, such as hard disk space and computer memory (RAM). Currently, cloud services are above all relevant for mobile devices (tablets and smart phones) whereas such delocalised services have not yet proliferated into the market segment of computer working places for office functions. While the latter may use cloud-based data storage the major part of the computing power is still deepened on the locally installed hardware. In future, taking into account the trend towards proliferation of teleworking and mobile ICT devices, cloud computing may partly replace for desktop computers.

It is therefore relevant to consider the global energy consumption trends in the ICT sector. Digital Europe [2016] points out that “the opportunity for thin-clients would appear to be in decline” because the primary driver for the difference in net energy consumption comes from the server and network infrastructure needed to support thin-clients. Andrae and Edler [2015] calculated scenarios of the global electricity usage of communication technologies and extrapolated the trends between 2010 and 2030. Their main conclusion is that the electricity consumption during the use phase of customer premises equipment will decrease and shift towards the data networks and data centres (see Figure 7.6). The authors expect significant increases in the electricity consumption⁶³ of access networks & core network infrastructures as well as data centres until 2030. In contrast, the direct power consumption of local consumer devices is expected to decrease slightly.

Figure 7.6 Global trends of electricity usage of communication technologies 2010–2030



Source: Andrae and Edler, 2015.

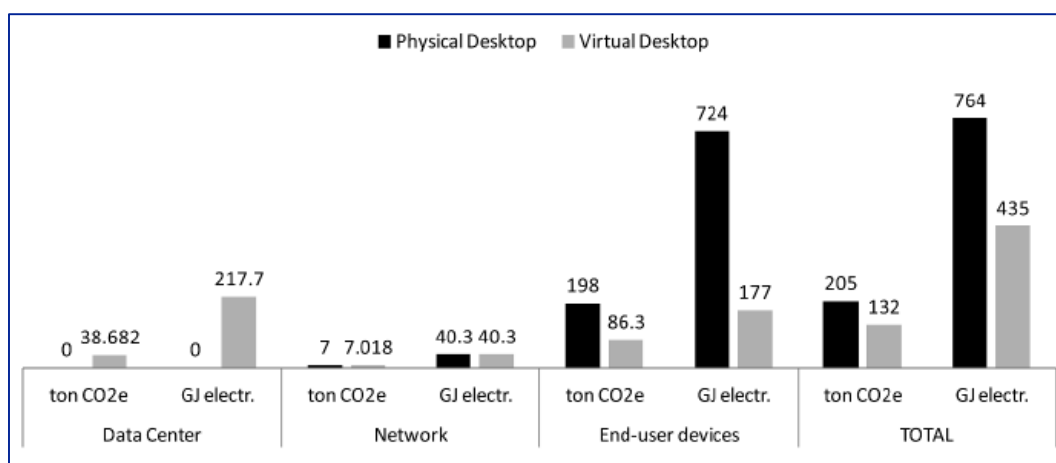
In spite of gains in energy efficiency due to virtualisation of computing functions, the total electricity consumption of ICT is set to increase due to the expected growth of fixed access networks and data centres. The use of cloud services as a means of virtualisation of hardware for office working places requires additional ICT infrastructure, which needs to be produced and operated in the background.

The calculation of impacts of Internet-based cloud services on the resource efficiency of ICT systems necessitates the inclusion of the four equipment classes in the scope of the study. However, this entails not only difficulties in allocating the share of cloud services among the impacts of all other Internet services. It also entails uncertainty regarding the geographical boundaries (it is hard to determine the actual location of ICT infrastructure that performs a given cloud service at a given time). Moreover, next to the actual data payload, a dynamically changing overhead of Internet capacity must be allocated to each given online service. For reasons explained above, it was not feasible in the context of this study to conduct an LCA based analysis of the CED associated to cloud services.

⁶³ Noteworthy, Andrae’s and Edler’s [2015] study refers to the direct electricity consumption rather than cumulative energy demand (CED). Moreover, the scope of this study includes TVs and home entertainment devices including the resulting data traffic induced by these CE categories.

Other authors have calculated the impacts of cloud computing as follows. Andrae (2013) estimated the electricity savings potential and greenhouse gas emissions of physical desktops PCs and virtual desktops (VD) for office usage in a theoretical cloud network (Figure 7.7). The results of this study suggest that the energy consumption of physical end-user devices (desktops PC) exceeds the energy consumption of their virtual counterparts. In total, the additional operation of data networks and data centres, necessary to provide cloud services, does not overcompensate the achievable gain in energy efficiency.

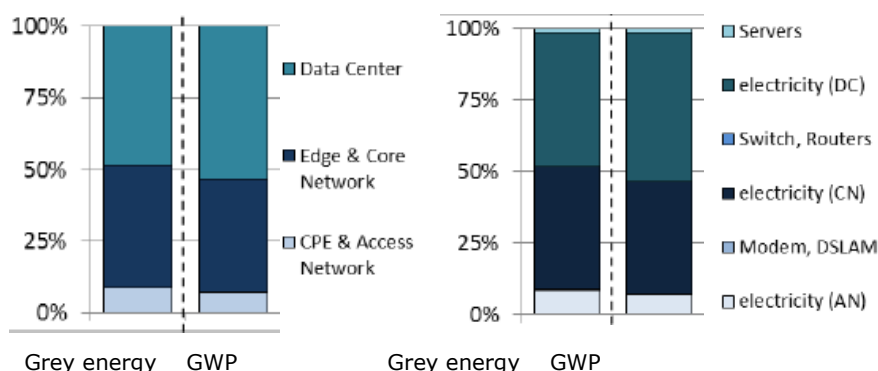
Figure 7.7 Annual electricity consumption and greenhouse gas emissions for 488 office working places equipped with physical desktop computers (PD) and virtual desktops (VD)



Source: Andrae, 2013.

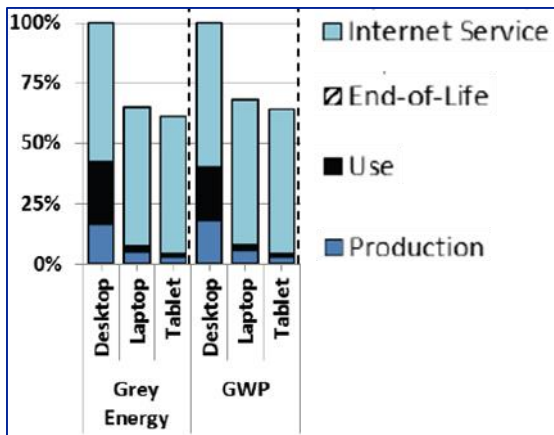
Hischier et al. [2014] estimated that 15 million Internet servers were in use worldwide as of 2012. The data traffic conducted through volume servers and core network components results in environmental impacts that were allocated to the impacts per Mega Byte (MB) of downloaded data. Figure 7.8 shows the relative shares of environmental impacts associated to the data traffic caused by Internet use. Figure 7.9 shows the same results associated to one hour of accessing Internet services by means of different computing devices. The findings of that study suggest that the major share of CED and GWP impacts of cloud services stem from data transmissions via the Edge&core networks and in data centres. This leads to the conclusion that the Internet-based cloud services are very sensitive to the energy efficiency measures implemented by the service operators.

Figure 7.8 Grey energy and Global warming potential (GWP) per MB of data downloaded from the Internet



Source: Hischier et al., 2014

Figure 7.9 Relative grey energy and global warming potential (GWP) per 1 hour of use of laptop computers and tablets compared to the impacts of desktop computers (set to 100%)



Source: Hirschier et al., 2014.

7.3.2 GHG saving potential of Design for Repair and Refurbishment (DfRR)

This chapter takes the Greenhouse Gas (GHG) emissions or respectively the Global Warming Potential (GWP) as a proxy indicator for the embodied energy because information on the CED of mobile ICT devices are hardly available in published literature.

Many electrical and electronic products are being replaced by new ones because users purchase new devices although the old ones are still functioning as good as they were designed for. ICT products are typically replaced by newer models after a relatively short service life and turn to waste (WEEE) even though they have not reached their technical end-of-life. The reason for this increasing trend is that older generations of ICT are rendered unfashionable by the subsequent ones (so called psychological obsolescence). Another reason for the retirement of physically functioning devices is that they become more and more incompatible with the fast evolving network infrastructure (so-called progressive obsolescence) [Slade, 2006]. Hilty et al. [2004] warned that ever-shorter innovation cycles and the accelerated ageing of software leads to a "virtual wear out" of ICT products (e.g. due to phased out security updates for software, incompatibility to contemporary network protocols).

A consequence of the high replacement frequency of high-tech devices is the squandering of scarce raw materials in the form of difficult-to-recycle WEEE. In addition, the product-embodied energy, i.e. the energy that has been used to produce the ICT hardware, is depreciated as soon as the ICT devices get retired. As for many contemporary ICT products, the embodied energy constitutes a major share of the GWP throughout the whole life cycle of such products [Hirschier and Wäger, 2015]. Figure 7.9 shows that the production stage of modern ICT devices (desktop PC, laptop, tablet) attains an increasing relative importance in terms of cumulative ("grey") energy demand and global warming potential. The production stage of 3G mobile phones accounts for a primary energy use of 42 kWh whereas the use stage consumes only 28 kWh (while transports and end-of-life processes are unneglectable) [Andrae and Andersen, 2010]. This means, the production of two short-lived devices consumes twice as much primary energy as the production of one long-lived device that is used doubled as long as the short-lived ones. In other words, much energy and raw materials can be saved if the service life of ICT products is prolonged.

The environmental benefits of Refurbishment result from the savings by reduced production: The production of electronic equipment is associated with significant environmental impacts, mostly caused by the energy-intensive production of mounted circuit boards and microchips. O'Connell & Stutz [2010] calculated that 47% of the greenhouse gas emissions of the life cycle of a notebook used in the EU is emitted during production. Other calculations showed that this value might even be above 50% depending on various assumptions for the use-phase [Prakash et al. 2012]. Based on scenario calculations, Prakash et al. [2012] demonstrated that an extension of life-time provides the biggest leverage in terms of reducing the overall environmental impacts of notebook PCs. Thus, it is clearly recommended to use notebook PCs longer than the average five years.

Bakker et al. [2014] suggest that not only laptops should be used longer than usual. Also refrigerators, which are assumed to be in use for 14 years on average in the EU, should be used for around 20 years to reduce overall environmental impacts. This is particularly noteworthy, as in 2007 it was still common sense that old and inefficient refrigerators should be replaced by new and high efficient devices to reduce electricity consumption and the net environmental impacts [Rüdenauer & Gensch, 2007]. Thus, the general approach has changed in the last years: Most electrical and electronic devices are significantly more energy-efficient than older models. With a time lag of several years, this development is also reflected in the devices that are taken out of active use.

Furthermore, future efficiency gains for consumer products will most likely be below the achieved improvements of the last decade. Thus it can be concluded that for consumer EEE products – apart from very old cooling and freezing devices and washing machines (age $\sim > 10$ years) – lifetime extension has environmental net benefits. This finding is also reflected in the European waste hierarchy, which is laid out in the EU Waste Framework Directive [2008/98/EC] which rates reuse and preparing for reuse clearly above recycling. This principle is also taken up by the WEEE-Directive [Directive 2012/19/EU].

Various strategies are available to extend the lifetime of products. Möller et al. [2015] specify the refurbishment of used ICT devices as follows:

- Repair activities that achieve product quality levels identical with those of the device when it was first placed on the market;
- It generates second-hand equipment that complies with all applicable standards related to safety and reliability that were in place at the time of manufacture;
- Refurbishing is one specific segment out of a range of activities that support the reuse of used and waste electrical and electronic equipment;
- High quality refurbishment typically focuses on devices of one specific manufacturer and is very often carried out by (or in close co-operation with) the Original Equipment Manufacturers (OEM). This is because the OEM is the only entity that has all information on product development, design and applied in-house quality tests. In addition, OEMs have established access to the suppliers of original parts and components that might be required for refurbishing activities. Generally, high quality refurbishment involves a series of activities ranging from the selection of used devices to service and maintenance activities.

Repair-friendly product design is a crucial precondition for the lifetime-extension of ICT. First, the design of ICT devices should ensure that devices are less much affected by psychological and progressive obsolescence. This is the most powerful strategy for the development of future generations of ICT. Second, Design for Repair and Refurbishment (DfRR) aims at the optimisation of products for repair, refurbishment and reuse. This could be achieved by designing ICT products in such ways that they can be easily updated (firmware, software) and upgraded (easy exchange of components that are particularly prone to “virtual wear out”). Moreover, DfRR principles encourage a physical design of devices that allows end-users for an easy and economically viable replacement of faulty electronic components without damaging the whole product. Refurbished old devices can enter the market for a second use phase [Möller et al. 2015]. Third, design for upcycling of ICT devices takes specifically into account that ICT products can be repurposed after they retire from their primary function. For instance, used smart phones could be repurposed for reuse as embedded control devices for smart buildings or decentral renewable energy plants. In summary, DfRR aims at extending a product’s lifetime in order to prevent electronic waste and to preserve valuable resources. Further research and development on new product design and re-/de-manufacturing approaches for smart mobile devices is currently under way⁶⁴ [Schischke, 2016].

However, there is a strong counteracting trend among Original Equipment Manufacturers (OEM) in the electronics industry to design products in ways, which hinder the replacement of components that are affected by internal ageing (e.g. integrated batteries) or external wear and tear (e.g. touch screen displays). Moreover, the fast speed of innovation cycles and fashion trend in the consumer electronic sector discourage end-users to decide for the use of

⁶⁴ H2020-EU Project “Sustainable Smart Mobile Devices Lifecycles through Advanced Re-design, Reliability, and Reuse and Remanufacturing Technologies” Project reference: 680604.

refurbished devices even if they still provide their main function [Cooper, 2004]. This effectively inhibits repair and refurbishment to emerge as a profitable business at larger scale. In consequence, the obsolescence of electronic products accelerates and the e-waste problems and squandering of resources aggravates.

Case study on smart phones refurbishment

The majority of modern smartphones are small slate computing devices consisting of the following main components:

- Touchscreen display;
- Rechargeable battery;
- Printed wiring board (including main processor, graphic processor, and memory ICs, modem and NFC chips, connectors, switches, antennas and various sensors);
- Camera assembly;
- Plastic enclosure (including front and rear bezel, if any);
- Small parts.

Figure 7.10 shows an example of a modular smartphone that has been designed for easy repair and refurbishment, i.e. it can be easily disassembled and components replaced.

Figure 7.10 Teardown picture of a Fairphone smartphone

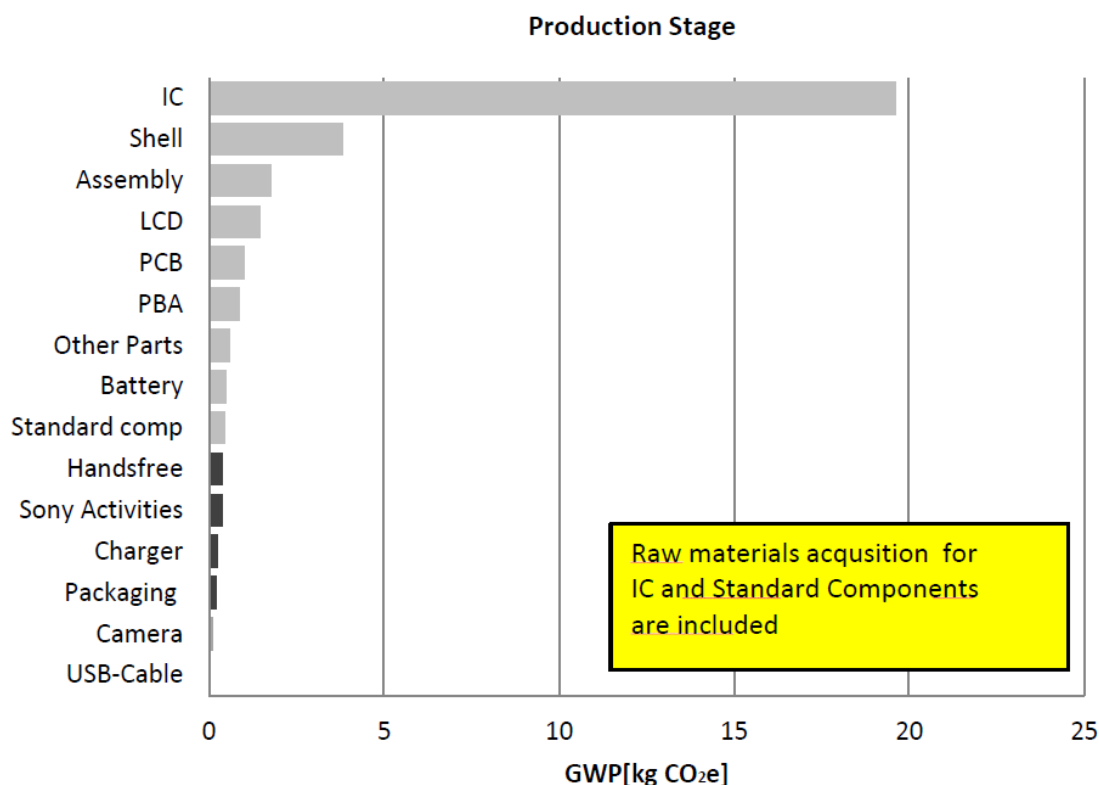


Source: Fairphone.

The integrated circuits, residing on the printed wiring board, are typically associated with the highest environmental impacts among all components of a smartphone.

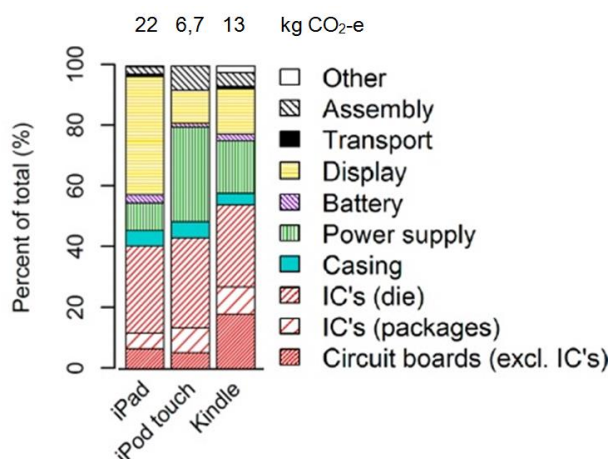
Among all components contained in a smartphone, the ICs and the touchscreen display form the hot-spots regarding embodied CED and GWP. This indicates that the repair of display and battery would help to extend the useful service life of the environmental hot-spot components (ICs), which are less affected by wear and tear. The consequent adoption of design for repair and refurbishment principles would thus contribute to higher resource efficiency of the mobile ICT sector.

Figure 7.11 Contribution of components and activities of a smartphone GWP with a 3-year lifetime to the GWP



Source: (Ercan, 2013).

Figure 7.12 Embodied GHG emissions of mobile devices

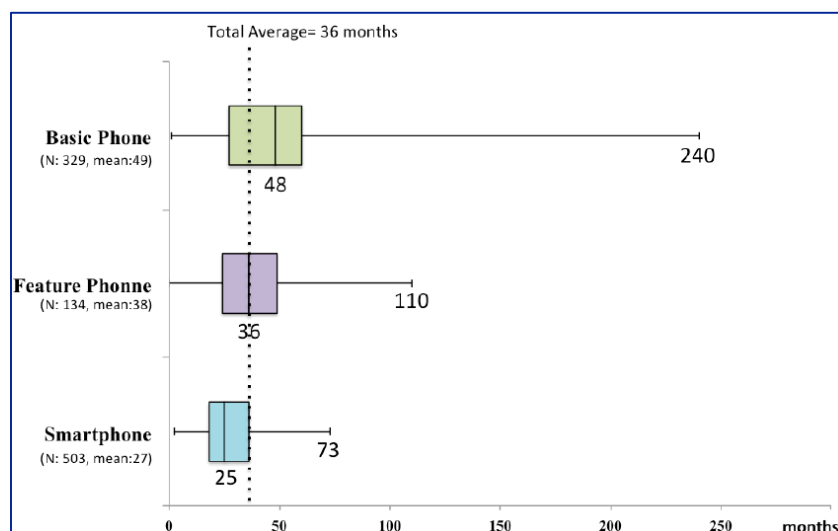


Source: Teehan and Kandlikar, 2013.

Usually, the physical life span of ICs mounted on a printed wiring board PWB exceeds the physical life span of other components that are more prone to wear and tear. One of the most frequent causes for premature obsolescence of smartphones is the internal ageing of lithium-polymer (LiPo) batteries. Bloated LiPo batteries are a frequent reason for users to retire the whole device if the product design does not allow their easy replacement. The typical life span of a prismatic lithium-polymer (LiPO) battery seldom exceeds 200 to 300 load cycles. Under normal operation conditions this translates to a physical life span of a LiPO battery of approximately two years. Another cause for obsolescence is breakage of touchscreen displays or

other mechanical components⁶⁵. The touchscreen display is the component of a smartphone that is most vulnerable against mechanical impacts and often cracks before other components break. Also the camera module is likely to become faulty due to dust or scratches on the lens surfaces. As a consequence, the physical life span of smartphone hardware can reach up to 4.5 years on average. However, the actual duration of a smartphone's service life is often much shorter due to consumer choices and premature failure of certain components. The lack of economically viable repair is the typical reason for consumers to replace their two years old smartphones although the devices could be repaired and be used for up to 4.5 years. Güvendik [2015], based on a broad survey among customers, reports that many smartphone users tend to retire (but not necessarily discard) their smartphones within less than 2 years after purchase.

Figure 7.13 Smartphone owners' estimate on the previously owned devices' life time



Source: Güvendik, 2015.

The "LCA to go" project has calculated the refurbishment and reuse scenario of a Google Nexus 5 smartphone [LCA to go, 2014]. According to this scenario, the smartphones' service life is extended from 3 years (the assumed "normal" lifetime) to 6 years after it has undergone a refurbishment process where parts (battery) have been upgraded for the second service life. The LCA based calculation shows that the GWP saving potential is 21 kg CO₂e per refurbished device in comparison to the baseline scenario (3 years lifetime).

The following scenario extrapolates the total GWP saving potential in the western European market. The scenario is based on the assumption that the average lifetime of smartphones could be doubled to 4.5 years through repair or refurbishment of used devices. Shipments of smartphones on the western European market totalled 174,1 million in 2014 [IDC, 2015]. Under the assumption that one or more components (display or battery) fail after 2.2 years in average, the consequent repair and refurbishment of all those devices could double their average lifetime to 4.5 years. Taking into account the extra energy- and resource consumption for refurbishment processes, this would avoid the energy and resource consumption for the production an equivalent of roughly 87 million new devices as of 2016. Table 7.5 shows the large variation in the greenhouse gas potential among various smartphone models and brands. The GHG value depends much on the technical specifications and the geographic location of the production sites for the electronic components. The scenario calculation takes the medium level GHG potential of 50 kg CO₂e, embodied per device, into account. This assumption represents an unspecified mid-range smartphone produced around 2014.

⁶⁵ <http://www.squaretrade.com/press/new-study-shows-damaged-iphones-cost-americans-10.7billion-4.8b-in-the-last-two-years-alone>.

Table 7.5 Comparison of the life-cycle-wide GHG potential of different smartphone models

Product	GHG in kg CO ₂ e	Source
Fairphone 2	8	[Güvendik, 2014]
Nokia Lumia 920	10.7	[Andrae and Vaija, 2014]
Huawei U8652	30	[Andrae and Vaija, 2014]
Nokia Lumia 1520	27.7	[Güvendik, 2014]
Orange OGE U8350	28.2	[Andrae and Vaija, 2014]
Huawei U8350	38.3	[Andrae and Vaija, 2014]
Sony Xperia T	40.8	[Güvendik, 2014]
iPhone 4s	55	[Apple Inc., 2016]
iPhone 5s	55.3	[Apple Inc., 2016]
iPhone 5C	60	[Apple Inc., 2016]
iPhone 6	83.6	[Apple Inc., 2016]
iPhone 6 Plus	93.5	[Apple Inc., 2016]

The extrapolation results in a hypothetical GWP saving potential of 4.350 kt CO₂e per year in the western European market. Considering the GHG impacts of spare parts production (assumed exchange of display and battery for each refurbished device) as well as domestic transports of broken devices to regional repair centres (assumed 500 km by truck⁶⁶), the amount of roughly 226 kt CO₂e needs to be deducted from the hypothetical GWP saving potential. Hence, the gross GWP saving potential of smartphone refurbishment is approximately 4.124 kt CO₂e per year.

Discussion of the results

The gross GHG saving potential calculated above is likely an overestimation for the following reasons:

1. The biggest share of GHG impacts occur during the raw material acquisition and primary production of smartphone components, particularly the semiconductors. The largest part of the value chain exists outside the EU28. Therefore, refurbishing smartphones mainly contributes to reducing GHG emissions occurring abroad;
2. The assumed refurbishment potential is already partly exploited. There is a large market for second-hand smartphones, in particular high-priced ones. The second life span of such devices is likely to be much longer than the assumed 2 years of the primary life span. This implies that used devices undergo some sort of repair and upgrade. This is often done by informal businesses of repair initiatives. Digital Europe [2016] remarks that "the technical lifetime of mobile phones is much longer than the first commercial lifetime" allowing for an extension of the total service life of smart phones to up to eleven years;
3. The fate of used smartphones is generally uncertain. Evidence from user surveys suggests that many users keep their smartphones at home for years after having retired them. Such devices still undergo virtual wear and tear until they become so old that nobody can reuse them anymore. Another uncertainty exists regarding transboundary exports of used smartphones via legal or illegal pathways. A large number of exported smartphone may actually be refurbished and used abroad. While the foreign markets for second-hand bear the same GHG saving potential it cannot be accounted for within the boundary of the EU28.

7.3.3 CED saving potential of recycling plastics from WEEE

The recycling of plastics from WEEE is one major challenge in the European action plan for a circular economy [European Commission, 2015]. Europe-wide, 566 thousand tonnes of ICT-

⁶⁶ Source: lorry 16 - 32 t Euro 5 (Idemat, 2015).

WEEE (category 3 “IT and telecommunications equipment”) were collected in 2013 (Eurostat, 2016). The content of different sorts of plastics contained in various types of ICT-WEEE is 20% of total weight in average [Baxter et al. 2014]. This share varies largely between 7% wt (e.g. PCs) and 35% wt (e.g. LCD monitors), depending on the WEEE category [Wäger et al. 2009]. The absolute plastic content in ICT-WEEE is approximately 113 000 t per year in the EU28. Table 7.6 shows the total availability of plastics in collected ICT-WEEE in the EU28. The theoretical plastic recycling potential from ICT-WEEE is doubled as high when taking into account the total amount of ICT products put on the market rather than the collected WEEE. In 2013, for instance, approximately one million tonnes of ICT products were put on the market in the EU28. Assuming an average product life time of 5 years for ICT products⁶⁷, the arrival of ICT-WEEE originating from 2013 products may be expected to peak in 2018. This e-waste flow contains 210 000 t of plastics that are theoretically available for recycling.

ICT contains over 300 different types of polymers as blends and composites. The most common plastic sorts used for ICT products are polystyrene (PS), high impact polystyrene (HIPS), and acrylonitrile butadiene styrene (ABS). These plastics are usually applied to make plastic housing parts for TVs and computers. The average composition of polymers in ICT-WEEE (product group 3 according to the EU WEEE directive) is 15%_{wt} ABS, 40%_{wt} PS, 10%_{wt} PC and 35%_{wt} other plastics [Dimitrakakis et al. 2008]. The latter fraction contains blends with 65-75%_{wt} polycarbonate (PC) and 15-25%_{wt} ABS, polyamides (PA), polybutylene terephthalate (PBT), silicone rubbers and other types of polymers.

Table 7.6 Potential annual availability of recyclable plastics in ICT-WEEE in the EU28

Country (WEEE recycling rate for 2013)	ICT- WEEE collected in 2013 in t	Total plastic content in ICT WEEE in t	Annual recycling potential per polymer material in t		
			ABS	PS	PC
Austria (37.6%)	17 503	3 501	525	1 400	350
Belgium (31.7)	18 482	3 696	554	1 479	370
Bulgaria (60.2)	2 851	570	86	228	57
Cyprus (12.2)	477	95	14	38	10
Czech Republic (28.5)	8 753	1 751	263	700	175
Germany (35.6%)	157 357	31 471	4 721	12 589	3 147
Denmark (37.6%)	12 797	2 559	384	1 024	256
Estonia (27.8%)	1 138	228	34	91	23
Greece (18.6%)	n.a.	n.a.	n.a.	n.a.	n.a.
Spain (26.1%)	23 510	4 702	705	1 881	470
Finland (36.3%)	8 230	1 646	247	658	165
France (23.6%)	64 151	12 830	1 925	5 132	1 283
Croatia (n.a.)	2 650	530	80	212	53
Hungary (40.0%)	9 606	1 921	288	768	192
Ireland (38.6%)	7197	1 439	216	576	144
Italy (n.a.)	n.a.	n.a.	n.a.	n.a.	n.a.
Lithuania (43.8%)	3 317	663	100	265	66
Luxembourg (29.3%)	754	151	23	60	15

⁶⁷ Disregarding possible delays between end-of-use and WEEE collection.

Country (WEEE recycling rate for 2013)	ICT- WEEE collected in 2013 in t	Total plastic content in ICT WEEE in t	Annual recycling potential per polymer material in t		
			ABS	PS	PC
Latvia (27.8%)	466	93	14	37	9
Malta (11.0%)	419	84	13	34	8
Netherlands (31.3%)	14 437	2 887	433	1 155	289
Poland (28.1%)	30 781	6 156	923	2 462	616
Portugal (32.3%)	7 151	1 430	215	572	143
Romania (14.5%)	n.a.	n.a.	n.a.	n.a.	n.a.
Sweden (64.9%)	30 895	6179	927	2 472	618
Slovenia (16.7%)	1 497	299	45	120	30
Slovakia (41.7%)	3 629	726	109	290	73
United Kingdom (22.8%)	137 595	27 519	4 128	11 008	2 752
Total	565 643	113 129	16 969	45 251	11 313

Source: Eurostat, 2016.

In practice, the amount of plastics available for recycling in collected ICT-WEEE feedstocks is much lower than the figures in Table 7.6 suggest⁶⁸. Plastic recycling is challenged by the large diversity of polymers, blended polymers, and plastic composites used for the production of ICT. The performance requirements of ICT products necessitate the use of engineered plastic materials, which are more heterogeneous than plastic components applied in other EEE categories. Thus, recycling of WEEE is hampered by the difficulty to separate homogeneous fractions of different sorts of plastic from a mixed WEEE feedstock. Contaminants such as brominated flame retardants (BFR) and heavy metals, which are considered substances of concern, pose a serious problem for recovering secondary plastics from WEEE [Wäger et al. 2010]. Other plastic parts consist of blends with 65–75%_{wt} poly-carbonate and 15–25 %_{wt} ABS (PC/ABS) and up to 14%_{wt} phosphor-based flame retardants. These compounds can transform into more toxic compounds when the plastic undergoes mechanical and thermal recycling processes. Baxter et al. [2014] assert that up to 75%_{wt} of all plastic components within ICT-WEEE can potentially contain BFR and heavy metals. Plastic blends that contain flame retardants and additives pose problems in recycling processes and lower the quality of recycled plastics. Most plastic parts in electronics contain also a variety of antistatic fillers, softeners and colour pigments, which are to the detriment of the quality of recycled plastics. In the recycling industry it is therefore common practice to pick out only such plastic parts from the WEEE stream, which are known to be free of contaminants. All other plastic is not recycled and disposed of by either incineration or landfilling. Digital Europe [2016] does not believe “that engineering plastics from WEEE will soon be recycled in high volumes” except of certain business-to-business recycling scenarios.

In spite of these drawbacks in the purity of recyclable plastics, there is a large potential for the recovery of plastics contained in ICT-WEEE. Plastics recycling helps lowering the GHG emissions by 0.42 kg CO₂-eq/kg of polymer material [Menikpura, 2014]. Wäger and Hischer [2015] calculate that recycling of plastics-rich residues from WEEE treatment has only 26% of the GWP impact as compared to the disposal by means of incineration [MSWI]. They conclude that plastics from post-consumer recycling have less than 20% of the GWP potential that virgin plastics from the primary production. As regards to the CED, the Idemat [2015] Database shows the following figures for selected plastics (Table 7.7).

⁶⁸ A certain amount of WEEE is exported to countries outside the jurisdiction of the EU28 and thus not available for recycling.

Table 7.7 CED and GWP key figures of selected types of polymers found in ICT-WEEE

Polymer type	Virgin plastics		Recycled plastics	
	CED in MJ/kg	GWP	CED in MJ/kg	GWP
ABS (Acrylonitrile butadiene styrene)	100.4	4.5	63.4	3
PS (Polystyrene)	89.2	3.6	65.7	3.2
PC (Polycarbonate)	108.8	7.9	58.3	2.7

Data source: Idemat, 2015.

Table 7.8 shows the absolute theoretical saving potentials in the EU28, calculated as the differences in CED and GWP between virgin plastics and recycled plastics and scaled up according to the total annual availability of recyclable plastics (c.f. Table 7.6).

Table 7.8 Theoretical annual CED and GWP saving potential in the EU28 from plastic recycling from ICT-WEEE

Polymer type	CED in TJ	GWP in t CO ₂ -eq
ABS (Acrylonitrile butadiene styrene)	628	25 454
PS (Polystyrene)	1 063	18 100
PC (Polycarbonate)	571	58 820
Total (all plastics)	3 525	161 209

Data source: Idemat, 2015.

Achieving CED and GWP savings potentials as outlined above depends on organising WEEE takeback and recycling systems in EU Member States. The total collection rate of WEEE from households and other sources in the EU is 37% by weight of amount of EEE put on the market in 2010 [EEA, 2013]. The current recycling rates of the collected WEEE (see Table 7.6) in most EU Member States leave a substantial recycling potential unexploited. Nordic countries, for instance, report recycling rates of WEEE-plastics at 30% [Nordic Council, 2015]. The following CED and GWP savings can be realised when taking the legislative targets for WEEE recycling as a yardstick for the amounts of plastic recycling achievable in the medium term. Directive 2012/19/EU (Annex V) stipulates that 80 % of ICT-WEEE (category 3 of Annex III WEEE directive) shall be recovered. From this background, Hestin et al. [2015] estimate the following recycling potential⁶⁹ of collected WEEE plastics in the EU28: 45% (by 2020); 55% (by 2025). The extrapolated additional CED and GWP saving potentials, shown in Table 7.9, are calculated on the basis of Table 7.6 and Table 7.7.

Table 7.9 Extrapolated additional CED and GWP saving potential in the EU28

Total (all plastics)	CED in TJ/a	GWP in t CO ₂ -eq/yr
Saving potential currently utilised (at 30% recovery rate)	1 058	48 363
Additional saving potential achievable by 2020 (at 45% recovery rate)	528	24 181
Additional saving potential achievable by 2025 (at 55% recovery rate)	881	40 302

The implementation of design for recycling in the manufacturing process of new ICT can help increase the amount of plastic recycling from ICT-WEEE beyond the extrapolation described above. The following DfR options are, inter alia, promising approaches:

- Maximised use of recycled plastic in the manufacturing process;
- Reduction of flame retardants and other additives that are to the detriment of the quality of recycled plastics;
- Avoid use of polymer blends and composites that are incompatible in the recycling process;
- Labelling of recyclable plastic components in products.

⁶⁹ Directive 2012/19/EU target for 2020 share of plastics in WEEE weighted average of the different targets by WEEE categories. (2025 targets based on estimation).

7.4 References

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7.5 Interviews with stakeholders

Inquiry was conducted especially with experts in the fields relevant to the investigated technology approaches mentioned above (substitution of desktop computers with thin clients or zero clients, use of recycled plastics for housings, extension of life-time via removability of batteries). The following expert and stakeholders were interviewed:

- M. Koehn, Federal Environment Agency (UBA), Advisory Office on Sustainable Information and Communication Technology - Green IT, input on thin clients / zero clients;
- N. Zonneveld, European Electronics Recyclers Association (EERA), input especially on removability of batteries;
- C. Bakker, Associate professor Design for Sustainability / Circular Product Design, faculty of Industrial Design Engineering, Delft University of Technology (TU Delft);
- A.S.G. Andrae, Ph.D. Huawei Technologies;
- K. Schischke, Dipl.-Ing. Fraunhofer-Institut für Zuverlässigkeit und Mikrointegration IZM;
- S. Feindt, Director at Digital Europe, input on thin clients / zero clients and use of recycled plastics.

8 Food sector

8.1 Introduction

The food sector has been identified as providing enormous improvement potentials regarding resource efficiency and energy savings. This is especially true for such foodstuff production resulting as waste and food packaging. According to recent studies, a significant amount of food still suitable for human consumption is unnecessarily discarded with sufficient evidence that a significant part of this amount can be saved. Thus, for the year 2020, a 50% cut from 2010 levels of household, retailer and catering edible food waste is proposed [Tan 2013]. The Sustainable Development Goals (SDGs) set out the aim to halve per-capita food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses, by 2030, globally [UN 2015]. One way forward would be through packaging and distribution measures that would minimise barriers to food redistribution and donation, innovating packaging and offering flexible portion sizes in food services [Kranert 2012; Tan 2013].

Besides tackling the waste issue, technology-related measures in food manufacturing offer many other advantages. For example, the integrated production of fish (marine and freshwater fish) in land-based aquaculture plants and the simultaneous cultivation of fruits or vegetables allows agriculture waste products to be efficiently recycled in a single system, improving not only nutritional balance of the production system, but also decreasing the water effort and demand for wastewater treatment.

For this analysis of the food sector, two case studies have been examined to assess the potentials for resource efficiency and energy savings. The data used for calculation and underlying assumptions are described in the following two sections (8.2 and 8.3). Results for both case studies are reported in section 8.4.

8.2 Case study on food waste

This case study quantifies the energy and resource savings derived from the prevention of food waste after initially describing the underlying data and methodological assumptions used to calculate the energy saving potentials of food waste reduction.

To understand food waste, the question must be posed whether typical European nutrition habits can be defined and corresponding types of food can be specified and quantified. For both the overall European foodstuff production and the annually arising amount of food waste, EU-specific data is available.

Table 8.1 2013 consumption in the EU27 of food categories as defined in the Eurostat ProdCom database

Categories of food products	2013 consumption in EU-27
	[1 000 t]
Cereal products	44996
Dairy products	67068
Oils and fats	20668
Fruit and vegetables,	36834
Meat and fish	58899
Alcoholic drinks	50659
Non-alcoholic drinks	126902
Pre-prepared meals	5013
Sugar and confectionaries	25548
Other	17353
Total	453940

Source: Monforti-Ferrario 2015.

Accordingly, the calculation of the theoretical resource end energy savings potential is initially based on the total foodstuff consumption in the EU27 in 2013 (without beverages), which sums up to 276.4 million tonnes (Table 8.1), and is upscaled to EU28 afterwards. Based on the consumption per categories of food products Monforti-Ferrario et al. defined the so-called "JRC food basket" by selecting 17 basket products, representing each food product category [Monforti-Ferrario 2015]. The basket products are not representing the entire food consumption but a mass share of about 61% of the consumed food in 2013 in the EU27 (Table 8.2).

Table 8.2 Details of the consumption and economic value of products making up the "JRC food basket" for 2013

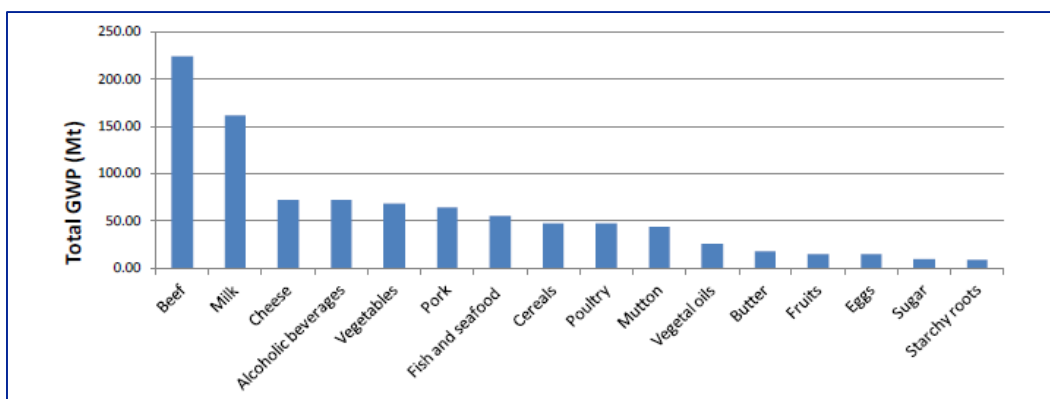
Basket product	Total consumption of basket product [1 000t/year]	Per-capita apparent consumption [kg/inhabitant year]	% of total per-capita apparent basket consumption	Economic value of the consumption of each basket product [million EUR/year]
Pig meat	22 449	44.7	8.1%	40 797
Beef	6 914	13.8	2.5%	30 818
Poultry	13 248	26.4	4.8%	28 444
Bread	19 136	38.1	6.9%	29 114
Milk and cream	39 326	78.2	14.2%	24 953
Cheese	9 347	18.6	3.4%	36 564
Butter	1 927	3.8	0.7%	7 193
Sugar	15 913	31.7	5.7%	11 383
Refined sunflower oil	2 661	5.3	1.0%	2 781
Olive oil	1 955	3.9	0.7%	4 490
Potatoes	36 475	72.6	13.1%	10 166
Oranges	7 012	14.0	2.5%	4 097
Apples	9 104	18.1	3.3%	5 340
Mineral water*	55 405 *	110.2 *	19.9%	11 358
Roasted coffee	1 793	3.6	0.6%	10 690
Beer*	33 553 *	66.8 *	12.1%	26 270
Prepared dishes and meals-meat based	1 502	3.0	0.5%	13 958
TOTAL	277 722	552.6	100.0%	298 415

* in litres

Source: Monforti-Ferrario 2015.

The production and provision of foodstuff causes a considerable amount of resource demand (i.e. including the demand for energy, agricultural land and water). To be able to quantify the different categories of resource depletion it needs to be considered that environmental burdens and the specific demand for energy varies for several product groups. The estimates of GWP emissions for food groups, derived from LCA data and FAO commodity supply in 2007, may serve as an example here (BIO Intelligence Service 2012, see Figure 8.1).

Figure 8.1 Total GWP (kg CO₂e) for supply of food to EU, by food group



In an initial step, the data on the JRC food basket composition and the data on resource requirements for the supply of the different foodstuff products therein have been calculated on a per capita and year consumption basis. In the second step, the per capita values have been

multiplied with the total population (506.9 million) in EU28 in the year 2013 in order to calculate the EU28 aggregates.

Since a considerable share of produced yet uneaten food is discarded, preventing as much food waste as possible is an essential factor in further increasing resource and energy efficiency in the European food sector. To quantify the environmental burden related to foodstuff production that is discarded as food waste, EU27 specific data is available. This data has been gathered on the basis of empirical surveys (including sorting analysis of domestic waste) and sums up to annually 176kg per capita⁷⁰ [Kranert 2012]. This value is confirmed by the results of another survey on household food and drink waste in the UK, giving an annually food waste production of 179kg per capita [Bio Intelligence Service 2012 citing WRAP 2009⁷¹].

However, it must be mentioned that not the full amount of food waste can be seen as avoidable. For example, unavoidable waste occurs during food preparation (i.e. preparation of fruits and vegetables). Accordingly, the calculation of saving potentials is based only on such food waste that is avoidable or at least partly avoidable. Based on literature data there is sufficient evidence that a part of 60% of the total food waste can be seen as unnecessarily discarded [Kranert 2012; WRAP 2009].

For the latest EU Member State Croatia (EU accession in July 2013), this study recognises that corresponding data on foodstuff consumption and food waste generation for the year 2013 is not available in official European statistics. It is consequently assumed that the average food waste generation in the EU27 countries may serve as a plausible approximation for the food waste generation also in Croatia. Furthermore, it is assumed that the loss in accuracy due to this lack of data is of only minor importance regarding the overall results on European level, since the population of 4.3 million Croatians account for less than 1% of the European overall population. For the calculation of the figures in section 8.3 the full theoretical saving potential of avoidable food waste has been taken into account. The results therefore have to be interpreted as upper estimate, overestimating today's practical saving potential.

Additional information on resource requirements for water and the occupation of agricultural land related to foodstuff production is only partly available in literature. Based on FAO statistics, BIO-IS reports an estimated demand of 172 million hectares of agricultural land for the entire foodstuff supply in Europe [Bio Intelligence Service 2012]. Even though the assumption of an arithmetic share on produced foodstuff resulting as food waste would be an oversimplification, it can be taken for granted that a food waste reduction also results in substantially reduced demand for freshwater and agricultural land.

8.3 Case study on integrated aquaculture production

Besides avoiding food waste as a consumer-oriented approach, technology-related measures in food manufacturing offer additional win-win potentials in terms of resource- and energy-savings. The integrated production of marine and freshwater fish in land-based aquaculture plants, with the simultaneous cultivation of fruits or vegetables has been chosen as an illustrative example. The rationale of this particular approach is that using waste heat and the fertilizing effect of nitrates and phosphates from aquaculture waste water effluent provides a potentially promising approach for improving resource and energy efficiency of the production process [IGB 2013; Möller 2015]. In addition to using the fish's mineral by-products, the plants also absorb the carbon dioxide that the fish exhale. Thus extra fertilization can be avoided, which saves both resources and energy⁷².

The corresponding energy savings for EU28 have been calculated based on a bottom-up approach. Within the course of calculations on a screening level, figures have been calculated in order to get a suitable approximation on the magnitude of possible savings. In particular, savings have been assessed that can be created when the conventional recirculating aquaculture (without any integrated production) can be substituted by integrated aquaculture

⁷⁰ EU 27 average, hides considerable variations across MS.

⁷¹ Within stakeholder and expert consultation we asked both institutions on whether they assume that the data from 2009 and 2012 may still serve as a suitable proxy for the situation in 2013/14.

⁷² The project team contacted leading R&D projects in the integrated aquaculture production field and thus accessed specific data and expert estimates on underlying assumptions of the calculation.

systems. According to FAO figures on fish and fishery products in 2010, on average 22 kg of fish is consumed per capita and year on EU28 level, forecasting a slight increase in upcoming years [FAO 2007] (Table 8.3).

Table 8.3 Fish consumption per capita for all EUR-28 countries from 2005 to 2030

(kg/caput/year)									
	Av. 94-98	2005	2010	2015	2020	2025	2030	% 98-30	# 98-30
Austria	11	11	11	12	12	12	13	17	2
Belgium-Luxembourg	22	22	22	23	23	23	24	9	2
Denmark	24	24	25	26	27	28	29	24	6
Finland	34	34	35	35	36	36	37	8	3
France	31	32	32	32	32	33	33	4	1
Germany	13	15	15	16	16	17	18	23	3
Greece	26	26	26	26	27	27	27	3	1
Ireland	21	21	21	21	21	21	20	-5	-1
Italy	23	24	25	26	27	28	29	24	6
Netherlands	16	15	15	15	15	16	16	6	1
Portugal	61	60	59	59	58	58	57	-7	-4
Spain	41	40	39	39	39	39	39	-5	-2
Sweden	27	28	28	27	27	27	27	-5	-2
United Kingdom	22	24	24	25	25	25	25	4	1
EU-15 Average	24	26	26	26	26	27	27	6	2
Cyprus	22	25	24	24	23	23	23	-10	-2
Czech Republic	9	10	10	11	11	12	13	42	4
Estonia	21	14	14	14	14	14	14	-5	-1
Hungary	4	5	5	5	5	6	6	42	2
Poland	12	12	13	13	14	15	16	41	5
Slovenia	7	7	7	8	8	8	9	34	2
EUR-6 Nc Average	10	10	11	12	12	13	14	41	4
Bulgaria	3	5	5	6	6	7	7	60	3
Latvia	41	37	37	38	38	38	39	4	2
Lithuania	18	17	19	21	23	25	27	81	12
Malta	27	30	31	32	33	34	36	24	7
Norway	46	46	45	45	45	45	45	-3	-1
Romania	3	3	4	4	4	5	5	58	2
Slovakia	7	6	6	7	7	8	8	55	3
EUR-7 NC Average	11	11	11	12	12	13	13	1	0
EUR-28 Average	21	22	22	23	23	24	24	9	2

Source: database

Source: FAO 2007.

In addition to the absolute per-capita consumption of fish and fishery products, the share of different groups of species also needs to be taken into account, as not all fish species are suitable for being produced in aquaculture and, in particular, in recirculating aquaculture systems (RAS), as Table 8.4 illustrates. Thus, not the total consumption of fish and fishery products were selected as reference value for the calculation. Instead, only the share of species that can be produced in RAS was considered.

Table 8.4 Food-use net supply by FAO groups of species from 1989 to 2030

(X 1000 tonnes live weight)

FAO Group of species	1989	1994	1998	2005	2010	2015	2020	2025	2030	% 98-30
Freshwater fish	39	98	150	152	152	154	156	157	159	6.0
Diadromous fish	474	592	723	736	747	760	773	788	804	11.2
Marine fish, pelagic, tunas	1418	1403	1617	1641	1659	1682	1706	1733	1762	9.0
Marine fish, pelagic, small	1527	1887	1512	1553	1589	1629	1675	1727	1784	18.0
Marine fish, demersal	2141	2352	2529	2584	2628	2676	2728	2785	2844	12.5
Marine fish, others	2182	2194	2235	2298	2348	2403	2463	2529	2602	16.4
Crustaceans	524	718	715	746	769	796	825	856	892	24.8
Molluscs	374	359	443	457	467	479	492	507	521	17.6
Cephalopods	649	539	710	735	753	771	791	812	833	17.3
Aquatic animals	15	14	21	22	24	25	27	29	31	46.9
Total EUR-28	9342	10158	10655	10923	11139	11376	11636	11920	12230	14.8

Source: database

Source: FAO 2007.

Based on information from the German "Fisch-Informationszentrum", 25% of the fish consumed in Europe can be assumed to be farmed successfully in aquaculture facilities [Fisch Wirtschaft 2013]. From this number, however, the aquaculture production in other so-called environmentally open aquaculture systems (16%, e.g. salmon production in marine net cages) must be subtracted. As a result, about 9% of fish consumed in Europe can be assumed as a good approximation of how many fish can be farmed successfully in land-based RAS.

The basic concept of integrated aquaculture production is the optimized use of nutrients the fish food contains. In conventional RAS these nutrients have to be removed from the system technically or through continuous dilution of the process water, leading to a higher demand for freshwater. In integrated aquaculture, however, these nutrients are reused as fertilizer for plant production. For the purpose of this calculation, it was assumed that this allows for savings in artificial fertilizer production, which is known to be an energy intensive process. Accordingly, the energy saving potential of fish production in integrated aquaculture was solely calculated on the basis of potential savings in artificial fertilizer production. Based on typical nitrate contents of diets for carnivorous fish and on expert estimations for the feed intake and feed utilization, the amount of nitrate nitrogen in typical fish feed diets was calculated.

Taking into account a typical feed composition for carnivorous fish and a realistic food conversion ratio (FCR) for fish production in RAS, the amount of nitrogen dissolved and therefore potentially accessible to plant uptake and utilization in the course of plant growth could be quantified. It is further assumed that the equivalent mass of artificial fertilizers can be replaced by the alternative nitrate nitrogen fertilizer from the integrated RAS production. Thus, energy savings due to avoided artificial fertilizer production have been calculated on the basis of process specific information on the synthesis of ammonia by the Haber-Bosch process. For this purpose, a generic dataset from the LCI-Database V3.1 [ecoinvent centre 2014] was evaluated comparing the primary energy demand and the global warming potential.

In addition to the saving potential through avoided artificial fertilizer production, further potential advantages are related to integrated aquaculture production discussed in section 8.5.

8.4 Results

8.4.1 Results for case study on food waste

Based on the data and assumptions documented in section 8.2, the total EU foodstuff consumption of 276.5 million tonnes was divided by the EU population count to get the average consumption of 545 kg per capita and year. According to [Monforti-Ferrario 2015], this results in a primary energy demand of 10 300 MJ -23 600 MJ per capita. Accordingly, foodstuff-consumption-related GWP of about 3 000 kg CO₂e per capita and year was calculated. The greenhouse gas (GHG) emissions of the share of avoidable food waste equals about 579 kg CO₂

equivalents (CO₂e) per capita and year. The overall results including EU28 aggregates are presented in Table 8.5.

Table 8.5 Overall results for the savings potentials through avoided food waste

Formula	Item	Cumulative energy demand (CED)
A	Average foodstuff production per capita and year	10 300 MJ - 23 600 MJ
B1...B2	Generation of avoidable food waste per capita and year	2 010-4 606 MJ
$C1...C2=(B1...B2)*TP^{73}$	Avoiding/saving potentials EU28	1.02-2.34 EJ
D	Total energy consumption EU28 (Eurostat 2013)	69 765 420 TJ
$E=C1/D$	Relative avoiding/saving potentials EU28 (lower estimate)	1.5%
$F=C2/D$	Relative avoiding/saving potentials EU28 (upper estimate)	3.4%

The EU28 aggregate therefore is approximately 1.0 to 2.3 EJ or 1.5% to 3.4% of the total EU28 demand for primary energy. Overall, the EU28 aggregate on food waste equals about 91.2 million tonnes of waste per year, of which 54.7 million tonnes are considered to be avoidable.

The GHG savings potential has been calculated accordingly. Based on the 3 t CO₂e per capita and year of GHG emissions related to food consumption, of which about 580 kg CO₂e results from discarded food waste, the EU28 aggregate generates a mitigation potential of about 300 million tonnes CO₂e per year. If a broader set of measures were addressed, including for example reduced meat consumption, even further savings are expected to be realised.

8.4.2 Results for case study on integrated aquaculture production

Based on the total amount of fish feed consumed in EU28 aquaculture (approximately 1 876 500 tonnes per year), and the share of nitrogen which is dissolved and therefore potentially accessible for plant uptake and utilization in the course of plant growth, 83 000 tonnes of nitric nitrogen from fish feed has been calculated to potentially serve as secondary fertilizer. As described in section 8.3, about 9% of the fish consumed in Europe can be successfully produced in RAS. The respective share has been taken into account to calculate the amount of nitric nitrogen and the potential for reduced artificial fertilizer production through synthesis of ammonia by the Haber-Bosch process (see Table 8.6).

Table 8.6 Overall results for the savings potentials through integrated aquaculture production

Formula	Item	Quantity	Unit
A	Energy savings due to avoided fertilizer production (EU28)	452	TJ
B	Total energy consumption EU28 (Eurostat 2013)	69 765 420	TJ
$C=A/B$	Relative avoiding/saving potentials EU28	0.06	%
D	GHG-mitigation potential due to avoided fertilizer production (EU28)	65 920	t CO ₂ e per year
E	Total GHG-emissions EU28	4 544	Mt CO ₂ e per year
$F=D/E$	relative avoiding/saving potentials EU28	0.15	%

⁷³ TP stands for the Total Population of EU-28 of 506 880 616 persons.

Even though the relative savings potentials of integrated production of fish and fruits in vegetables are comparatively small (i.e. when compared to the potential of food waste avoidance), there are still good reasons for proposing the further development of integrated foodstuff production. For a discussion of such relevant aspects, see also the following section.

8.5 Discussion

In this chapter, overall results of the two case studies are discussed in relation to the potential contribution to reach EU energy saving targets. Likewise, case-study-specific uncertainties, especially of parameters of relevance for the results, and the influence on the overall results are discussed.

8.5.1 Case study on food waste

As the calculation of energy saving and emission mitigation potentials found from avoiding food waste generation show, avoiding food waste makes significant contributions to reach EU energy saving targets. The calculation of energy and GHG emission savings through avoided food waste is based on the efforts related to food supply. As starting point the JRC Food basket composition has been taken into account. The calculated saving potential thus corresponds with the potential of avoided foodstuff production. However, it needs to be observed that the composition of food waste is not necessarily congruent with the composition of foodstuff production. For validating purposes, the composition of the JRC food basket and the respective composition of food waste were compared with each other in Table 8.7.

Table 8.7 Comparison of food production and generation of food waste per category of food products

Food waste category [Kranert 2012]	Basket product/ product group [Monforti-Ferrario 2015]	Percent of total per capita basket consumption	Percent of total avoidable and partly avoidable food waste
Meat and fish	Pig meat	8.1%	6.3%
	Beef	2.5%	
	Poultry	4.8%	
Bakery and pasta products	Bread	6.9%	20.2%
Dairy products	Milk and Cream	14.2%	7.9%
	Cheese	3.4%	
	Butter	0.7%	
---	Sugar	5.7%	---
---	Refined sunflower oil	1.0%	---
---	Olive oil	0.7%	---
Vegetables	Potatoes	13.1%	25.4%
Fruits	Oranges	2.5%	17.9%
	Apples	3.3%	
Beverages	Mineral water	19.9%	7.0%
	Roasted coffee	0.6%	
	Beer	12.1%	
---	Prepared dishes and meals-meat based	0.5%	---
	Total	100%	83.6%

Source: Monforti-Ferrario et al., 2015; and Kranert et al., 2012.

As shown in Table 8.7, the manufacturing of food products with high specific energy requirements and GHG emissions (i.e. meat, dairy products) are underrepresented in the composition of food waste, which means that the calculated potential of saving energy and avoiding GHG emissions by avoiding food waste is rather over-estimated. Hence, the lower estimate given in Table 8.5 seems a better approximation of reality.

8.5.2 Case study on integrated aquaculture production

Even though the relative saving potentials of integrated production of fish and fruits / vegetables calculated in this illustrative case study are comparatively small, the concept of integrated production by closing material and energy flows in the foodstuff production chain is applicable also for other food subsectors with potentially substantial relevance to the food sector in general. As well, there are additional positive effects of the integrated production that have not yet been considered in the calculation. An further aspect not considered in the calculation so far is the potential savings in the integrated aquaculture production since it does not need to cope with maintaining agricultural land and especially natural nutrient sources that are only available to a limited extent. Against this background, integrated aquaculture production has a relevant potential to prevent or limit food production related inputs of pollutants into water and other environmental media.

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9 Ferrous sector

The total production of crude steel for the EU28 in 2015 was 166 million tonnes, which implies a decrease of 1.8% compared to 2014 [Eurofer 2016]. Since 2012 the production of crude steel has never reached the levels of 2010-2011 which were on average 175.2 million tonnes. Comparing to the production levels before the start of the economic and financial crisis, the production of crude steel in terms of volumes marked a structural decrease of more than 35 million tonnes, which represents virtually 18% of its pre-crisis output⁷⁴.

9.1 State of the art

Resource and energy efficiency are an essential part of the ferrous (and non-ferrous) sectors' business models. Both energy and raw materials comprise an important portion of costs. Therefore, reusing scrap metal has become standard practice in these industries, elevating secondary metals to the level of ores as an input source. Urban mining is important for these sectors, with clear business gains in recovering iron and other metal production residuals. In addition, (post-consumer) scrap such as used vehicles (ELV), packaging material, recovered iron and steel from demolished buildings and large equipment and machinery, also production residuals of the ferrous and non-ferrous industries are exchanged between companies in these sectors to extract value from the remaining metal content. Each company has its own specialisation and techniques, and develops as such a market niche for recovering metals.

Besides resource efficiency, also the control of energy costs is an important part of the business model in the ferrous and steel industry. The Worldsteel Association [2012] points out that energy purchases count for 20% to 40% in basic steel production. JRC [2014, p34.] indicates that integrated steelworks are characterised by high levels of resource efficiency using a range of advanced techniques for the management of materials. However, the mix of energy sources differs substantially across the processes used. While for basic oxygen furnaces (BOF) the main energy input is coal or coke, electric arc furnaces (EAF) use electricity. Optimal material and energy management is therefore key for cost control and competitiveness of the companies and for the sector as a whole. Therefore, the potential of resource and energy efficiency win-wins is most likely to be situated in new technologies.

One might still expect differences in energy and resource efficiency parameters between plants in the Member States that joined after 2004 and those in the old Member States. This would imply a significant upscaling potential through catching-up. However, it might also be expected that through a combination of mergers and acquisitions on the one hand and competition on the other hand, as well as through the workings of the ETS system, less efficient plants may have been closed or upgraded. This leads to a lower variation in energy and material efficiency rates across Europe than before. This in turn would result in relatively less upscaling potential.

Recent developments are in recovering various metals from complex material combinations, which is a key characteristic of post-consumer scrap, also called old scrap [Muchová and Eder 2010]. Examples of the ferrous metals industry segment are the recovery of iron and steel from ELV, ships, aeroplanes, construction and demolition waste, electronics and electrical equipment (WEEE) and packaging material such as food cans, beverage cans and aerosols. By way of comparison, examples in the non-ferrous metals industries are the recovery of lithium from batteries and of precious metals from end-of-life mobile phones.

Industrial production residuals, also referred to as new scrap, are valorised as well, for instance the recovery of ferrous content in dusts collected in filters, and the reuse of solid residues. In the non-ferrous industry, examples are the recovery of precious metals from copper anode slimes, and zinc recovery from copper flue dusts. Based on historical settings, the high economic value of the residual metal contents in non-ferrous metal by-products allowed establishing strong inter-linked copper, zinc, precious metals, lead, production and recycling facilities in Europe.

⁷⁴ The average pre-crisis production of crude steel for the years 2004-2007 was 203.86 million tonnes; based on historical statistics of Eurofer [2016].

Research and demonstration activities exist to reduce the use of steel in end-user sectors, such as the ULSAB project in the automotive sectors or in the construction sector. The Steel Research Agenda to 2030 of the EU Steel Technology Platform aims to reduce the environmental footprint of steel production and steel solutions by reducing resource consumption, fostering the use of secondary raw materials and thus accelerating the move towards a more closed-loop economy.

The steel industry has several ideas and research agendas for transformation, including Cleaner Production (CP), Systems Innovation and the Steel Research Agenda to 2030 [Birat *et al* for ESTEP, 2013] and initiatives within SPIRE 2030 industry and ULCOS R&D⁷⁵. Indeed, the limits of the socio-technical system and the climate change challenge will induce changes in the production, distribution and consumption patterns of steel and other materials [Rynikiewicz, 2008].

9.2 Methodology to upscale and calculate the EU28 aggregates

Unlike the majority of other sectors covered in this report, we have not performed own bottom-up calculations based on LCA data. In order to assess the potential energy savings from resource efficiency methods, this section relied on a literature review and qualified the findings on the basis of information from interviews and own insights.

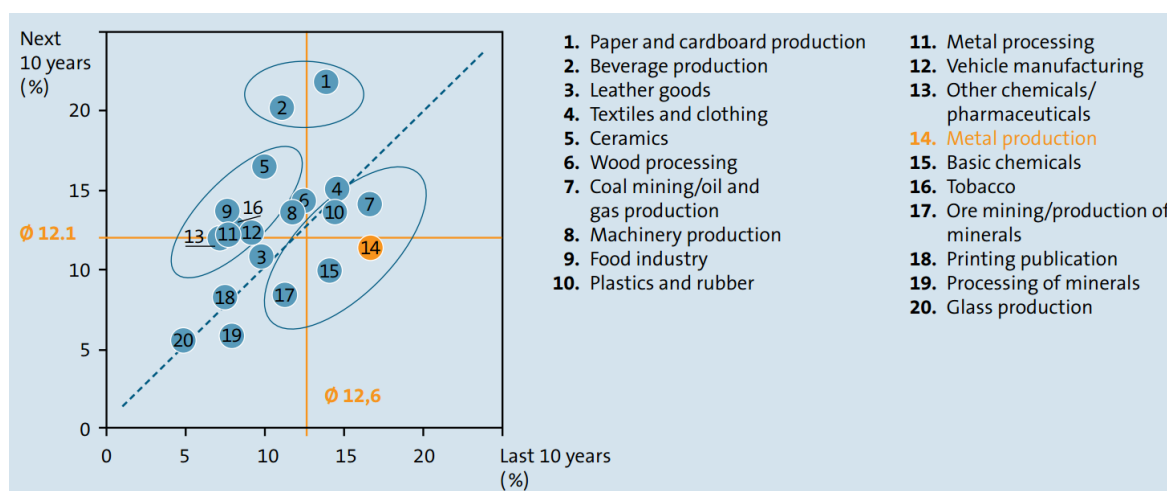
In a first step, the literature review of existing assessments identified both new resource efficiency technologies and energy saving technologies. The review resulted in a meta-analysis indicating various studies with their respective estimations for potential energy savings in the iron and steel industry. In a second step, those energy savings techniques were selected that involved resource efficiency measures. The selection was made on the basis of technology descriptions found in the literature and cross-checked with specialised engineers. As a third and last step, quantitative information on this select group of technologies was brought together in order to give a sector-wide estimate of energy savings resulting from improving resource efficiency in the ferrous industry.

9.3 Documented evidence of combined resource- and energy-savings in the ferrous sector

Based on a review of the relevant literature, one can infer that the potential for further efficiency gains for energy and resources might be more costly to realise in the sense that 1) the ones in applying individual techniques and processes have already been largely applied and that 2) the remaining potential is situated in the area of combining and streamlining individual processes across production units and companies. Yet various articles point to existing/remaining potential, especially in the area of value chain optimisation. Fröhling *et al.* [2012] analysing the energy and resource efficiency measures in the German steel and zinc industry indicate that “due to the large prior achievements, further improvements by single process innovations become more and more difficult as process efficiency comes closer to the technical optima. Nevertheless, additional potentials exist when the focus is shifted from single process views to inter-company considerations”. This is partly confirmed by the VDMA [2013] study. Figure 9.1 shows the energy efficiency improvements over the last ten years for manufacturing industries and projects these onto the expected energy efficiency gains in the coming 10 years until 2025. Metal production was characterised by a relatively high energy efficiency improvement, above the average for manufacturing industries, and so further improvements are expected to be harder to realise. Further down the value chain, metal processing has relatively more potential in the sense that higher energy efficiency gains are expected in the coming decade.

⁷⁵ ULCOS stands for Ultra-Low CO₂ Steelmaking, See <http://ulcos.org/en/index.php>.

Figure 9.1 Relative energy efficiency improvements by sectors of manufacturing industry in Germany



Source: VDMA 2013: 7.

At the level of individual processes in the manufacturing industry, relatively high efficiency gains might still be obtained, although it has to be indicated that many of potential efficiency improving techniques are already being applied and/or tested. The VDMA study [2013: 9] summarises selected measures for energy and resource efficiency in the metal production and processing industries, indicating the potential savings in kilograms CO₂ per tonne steel or iron output. Overall, the future potential for efficiency improvement is estimated at up to 37% over the period 2010-2050, depending on the particular process. About 17% would result from technology developments, while the remaining 20% would be the result of improvements in the use and roll-out of existing technologies. The study indicates that consistent use of high-efficiency technologies, process optimization and plant design, as well as valuing by-products through industrial symbiosis, are important elements for reaching resource and energy efficiency. Table 9.1 summarises measures which are already applied in the metal processing industry for different process routes.

Table 9.1 Selected potential measures for improving energy and resource efficiency in metallurgical plants and rolling mill technologies

Process stage	Solutions for CO ₂ avoidance	Potential kg CO ₂ per tonne
Sintering plant	Sintering plant with waste heat recovery Use of substitute fuels (e.g. lubricants) in sintering plant	Up to 57 Up to 20
Coking plant	Coke dry quenching	Up to 27
Blast furnace	Use of extremely pure ore Direct injection of reduction agents - Coal injection, coal dust injection - Gas injection, natural gas injection Improved blast furnace control Automation of cowper stoves	15 – 80 35 – 47 Up to 55 Up to 24 Up to 22
Direct reduction	Coal gasification (Syngas)	Depends on process
Basic oxygen furnace	Energy recovery from furnace gas Improved energy efficiency through automation	Up to 46 15 - 16
Electric arc furnace	Scrap preheating Use of hot DRI Improved process control Higher transformer efficiency Bottom stirring/gas purging	Up to 35 Energy saving similar to scrap preheating Up to 17 Up to 10 Up to 11

Process stage	Solutions for CO ₂ avoidance	Potential kg CO ₂ per tonne
Continuous casting	Compact strip casting Hot casting	Energy saving 50% compared with conventional continuous casting
Hot/cold rolling	Automated monitoring systems Recuperator burners Hot charge/direct rolling Waste heat recovery (annealing line) Process control for hot rolled wide strip	Up to 35 Up to 35 Up to 30 Up to 17 Up to 15
General	Combined generation of heat and power Preventive maintenance Energy monitoring/management systems	Up to 82 Up to 35 Up to 9

Adopted from: VDMA 2013: 8.

The Worldsteel Association [2012:18] points out that steel companies are at different points of maturity and development with regard to the application of resource and energy efficient technologies. The report indicates that there are still potential improvements to be made, mainly through two routes:

1. Technology transfer, especially the continued sharing and implementation of best practices; and
2. The optimisation of operations and controls, such as the optimisation of motor drive systems⁷⁶, which are estimated to use 19% of primary energy in making steel products, as well as optimisation with downstream clients' manufacturing processes.

The Association also explicitly lists the valorisation of slags as an important route to increase resource efficiency. It is indicated that the worldwide average recovery rate for slag varies from 80% for steelmaking slag to 100% for ironmaking slag, according to the Association.

Fraunhofer [no date] comes to similar conclusions and indicates that energy and material efficiency can be increased in various ways. For example:

- Control of start-up processes leading to a better process stability, as well as better process control and plant asset management;
- The report indicates that by shortening process chains and integrating processes an increase in resource efficiency of up to 30% can be attained, depending on the scope of application and interoperability;
- Optimisation of supply chain management. A systemic approach to integrated planning and optimisation of supply systems and structures is imperative for reaching energy efficiency targets.

With respect to the latter, Sievers et al. [2013] compared resource saving potentials of single companies versus that of entire manufacturing value chains. Using value chain simulations, the authors concluded that the resource saving potentials were by a factor 5 higher than those of single factory improvements. The authors indicate, however, that this potential of value chain optimisation is not well used by companies, from which the authors deduce that a significant saving potential is still being neglected.

Various papers point to the energy gains from using recycled metal, Fraunhofer [no date], UNEP [2013], Bilsen et al. [2015], JRC [2014], Sievers et al. [2013], Muchová and Eder [2010]. For instance the production of aluminium from scrap consumes only 5% of the energy needed to

⁷⁶ Motor drive systems are electric engines which in the iron and steel industry are used for pumps, fans, forming and machining, handling equipment, and compressors.

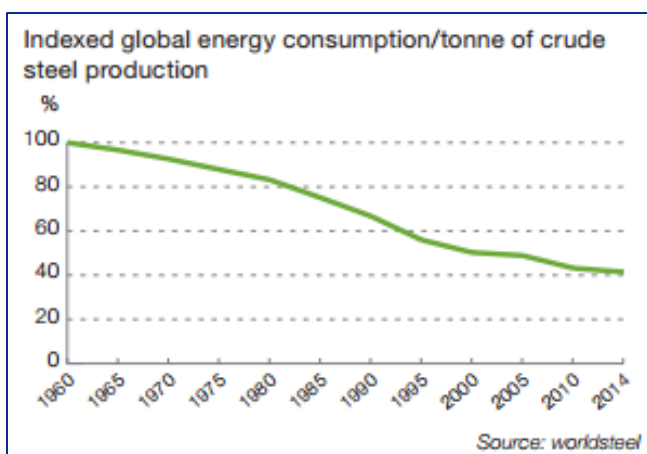
produce aluminium from virgin ores Muchová and Eder [2010] point to the environmental, resource and health benefits and indicate that using one tonne of scrap steel saves 1.86 tonnes of CO₂ and 1.89 tonnes of iron ore. Evidently this implies energy savings as well. Both Bilsen et al. [2015] and UNEP [2013] indicate however that resource efficiency targets that go beyond what is thermodynamically possible for recycling might lead to excessive energy consumption and therefore are likely to fail in further upscaling and application.

9.4 Estimated upscaling potential

9.4.1 Results from the meta-analysis

Much has been done in terms of energy savings in the iron and steel sector. Since 1960, improvements in energy efficiency have led to reductions of about 60% in energy required to produce a tonne of crude steel as displayed in Figure 9.2. This large reduction in energy consumption has been driven by process improvements, material efficiency and scrap recycling. Process improvements included introducing energy-saving equipment (including waste energy recovery equipment), improving the efficiency of energy conversion facilities such as power plants, and implementing total energy management systems. For primary steel production, the best plants are close to the thermodynamic and physical limits making the residual margin for energy savings limited [JRC 2013; ESTEP 2011].

Figure 9.2 Indexed global energy consumption/tonne of crude steel production



Source: Worldsteel 2015.

Estimations for the remaining potential for energy savings differ across sources, as displayed in Table 9.2. A common conclusion in all sources however is that most energy saving measures have already been taken, as it has been in the interest of the industry to do so, due to the high share of energy costs in the production process. The total remaining energy savings potential for the European iron and steel industry seems to be around 10% based on the (European) sources summarised in Table 9.2.

Table 9.2 Overview of various estimations for potential energy savings in the iron and steel industry

Source	Potential energy savings	Region	Time period
Moya, J.A., Pardo, N., Vatopoulos, K. [2012] <i>Prospective Scenarios on Energy Efficiency and CO₂ Emissions in the EU Iron & Steel Industry - JRC</i>	7-11%	EU27	2010-2030
European Steel Technology Platform [ESTEP] - Lamberterie, B. [2011] <i>Resource Efficiency for the European steel industry</i>	<10%	EU27	n/a
ESTEP/EUROFER WG Energy Efficiency [2014] <i>Steel production - energy efficiency working group</i>	10-12%	EU	n/a

Source	Potential energy savings	Region	Time period
ESTEP [2009] <i>Steel - a key partner in the European low-carbon economy of tomorrow</i>	10-15%	EU	n/a
VDMA/Roland Berger [2013] <i>The contribution of machinery and plant manufacturers to energy efficiency</i>	12%	Germany	2013-2023
Siemens VAI – Bettinger, D. [2012] <i>Energy Efficiency in Iron & Steelmaking</i>	±11%	EU-15	n/a
International Energy Agency [2009] <i>Energy Technology Transitions for Industry</i>	20%	Global	n/a
Worldsteel [2015] <i>Steel's contribution to a low carbon future and climate resilient societies</i>	15-20%	Global	n/a

Many of the measures that contribute to this energy savings potential would, however, not be classified as energy savings through resource efficiency measures, as defined in this study.

In order to identify the energy-saving effects caused by improved resource efficiency, it is necessary to have a clear understanding of what is meant by resource efficiency measures in the iron and steel sector and to distinguish the various types of measures.

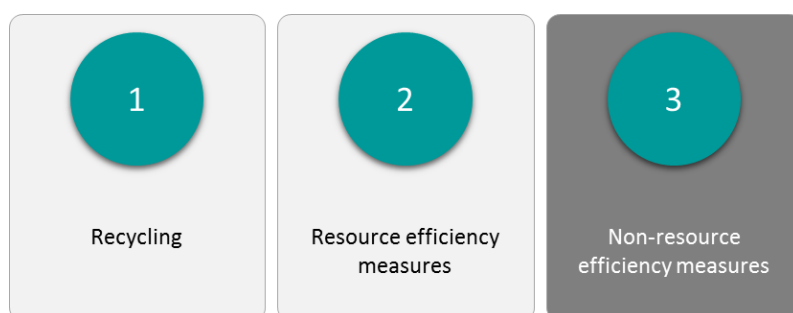
9.4.2 Defining energy savings through resource efficiency

According to the Worldsteel Association, resource efficiency – or material efficiency – in the iron and steel sector has three major components:

- Recycling;
- The reduction of material inputs and waste;
- The efficient use of co-products.

In this work the last two components are assessed together as general resource efficiency measures on a plant and installation level. Recycling is assessed separately in this work. Measures that lead to energy savings but do not relate to resource efficiency are left out of the scope of this study.

Figure 9.3 **Scope of this work**



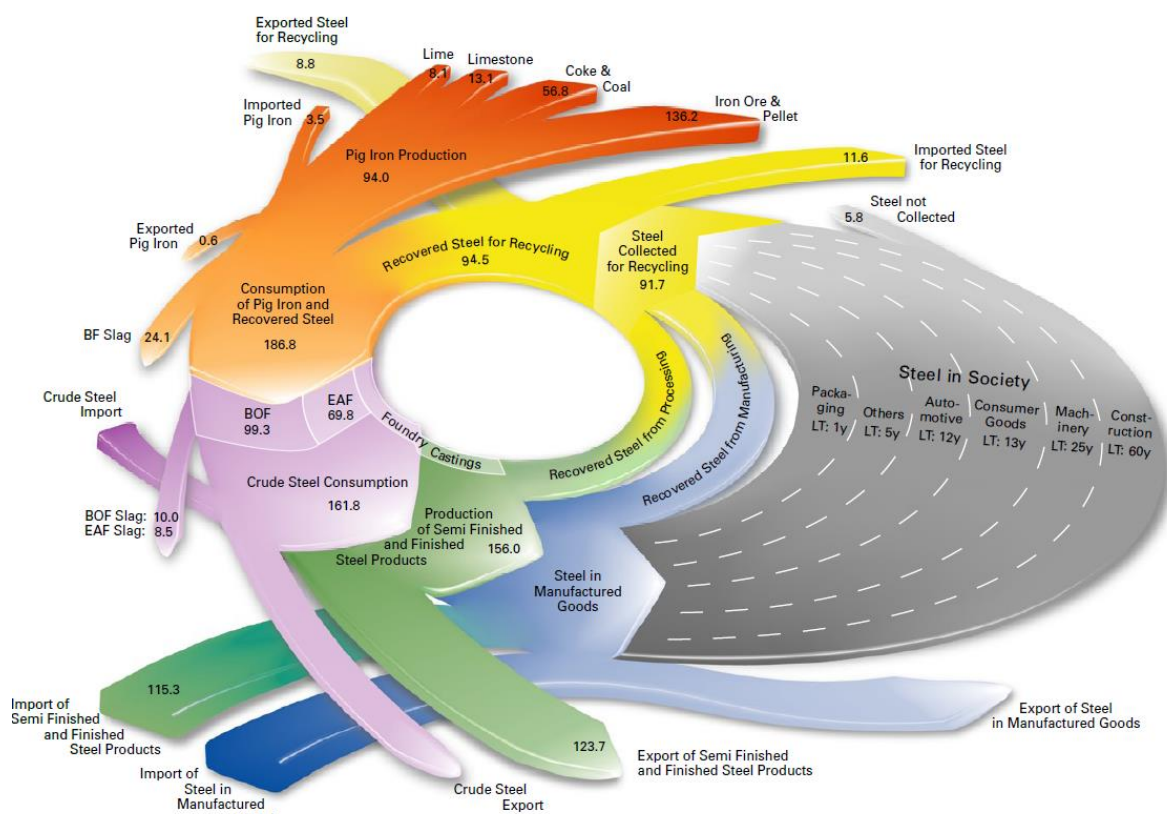
9.4.3 Assessing potential energy savings through resource efficiency

First, an assessment will be made of the potential energy savings as a result of increased or enhanced recycling. Second, the potential energy savings through resource efficiency measures will be explored. At the end of this section, the results will be synthesised into an overview of the overall energy savings potential through resource efficiency.

Recycling

According to the European Steel Technology Platform [2011], the European iron and steel industry currently recycles more than 90% of used steel products to produce new steel (because of the growth of steel consumption and thus steel production the actual share of scrap for steel production is only 45% of today's production levels [ESTEP, 2009]). As an indication, an illustration of steel flows in the EU15 in 2009 is displayed in Figure 9.4.

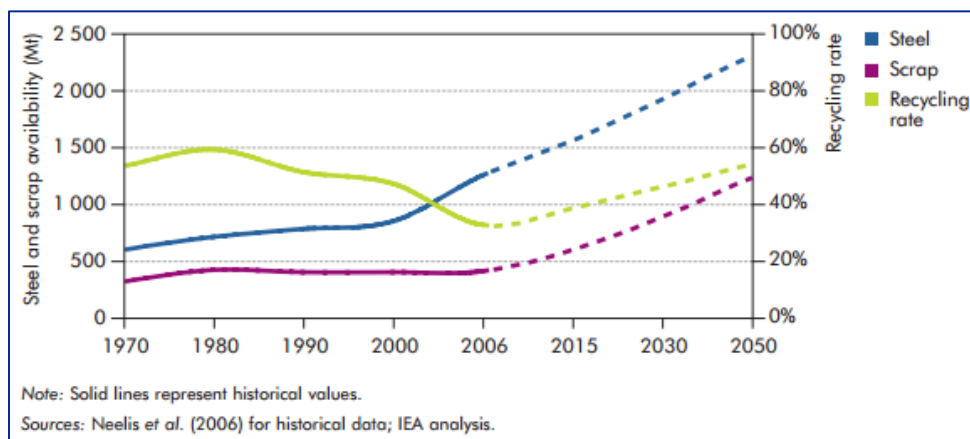
Figure 9.4 Steel flows in the EU15



Source: ESTEP 2009.

Recycling has been one of the main lever for energy savings in the iron and steel sector over the past decennia. Besides improving iron and steel facilities in Europe by the dissemination of best practices and BATS, the industry can still further increase its share of secondary steelmaking [JRC, 2013]. Using a capital stock turnover model of the world steel supply, the IEA identified scrap recovery levels and future estimates, shown in Figure 9.5 (dating from 2006). The steel production and scrap recovery are displayed on the left vertical axis, with the share of secondary steelmaking displayed on the right vertical axis. The volume of scrap is a function of past steel production subject, depending on a time lag per product category for the scrap to become available for recycling. The gap between scrap availability and steel demand is filled by primary steelmaking, expecting to rise up to 2050. However, it is also expected that the share of secondary steelmaking will increase up to 50% by 2050 [IEA 2009].

Figure 9.5 Steel scrap availability and estimates



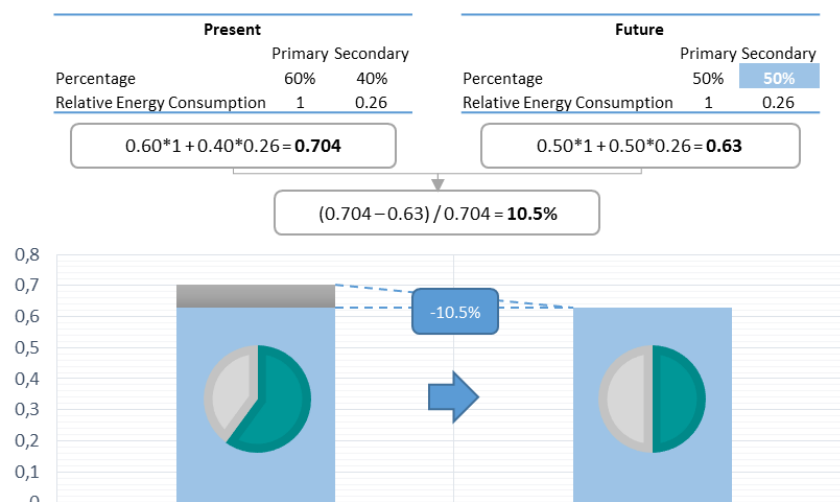
Source: IEA 2009.

Currently, over 650 Mt of steel is being recycled globally, making steel the most recycled material in the world in terms of volumes. The energy and resource efficiency of recycling is significant: according to Worldsteel [2014], over 1400 kg of iron ore, 740 kg of coal, and 120 kg of limestone are saved for every 1,000 kg of steel scrap made into new steel. Furthermore, the Environmental Protection Agency (2014) estimates that secondary steel production, which involves the use of recycling scrap, uses about 74% less energy than the production of steel from iron ore. Another source [ESTEP 2011] states that the energy net consumption is about factor 4.5 times higher for primary steel production than for secondary steel production, which seems to confirm the earlier mentioned estimation. Producing steel through the secondary route is less energy intensive than producing steel through the primary route, because it does not require the iron ore to first be reduced into reducing agents, removing several energy consuming processing steps such as ore preparation, coke-making and iron-making [IEA 2009].

Within the EU, 40% of the crude steel is produced by the secondary steel production route. However, there is still potential to increase this rate up to 50% in the next 20 years due to larger available quantities and better control of scrap qualities [ESTEP 2011]. Increases in the share of secondary steelmaking beyond 60% will be limited by the availability of scrap. Higher recycling values could increase impurities and reduce the overall quality of steel. Furthermore, high emissions of heavy metals and organic pollutants result from the recycling process due to the impurities of scrap. Research and development in this area might help to enhance the quality and rate of recycling in the iron and steel industry [JRC 2013].

Using these numbers, a rough assessment has been made of the theoretical potential energy savings due to an increase in the secondary steel production, displayed in Figure 9.6. If 74% less energy is consumed in the secondary route than in the primary steel making route, and the share of secondary steelmaking could be increased from 40% to 50%, it could result in total energy savings of 10.5%. Compared to the final energy consumption of the European iron and steel industry in 2009 of 2520PJ [European Environment Agency 2011] (the latest available information in the final energy consumption of the European iron and steel industry), 10.5% energy savings would constitute 265PJ of energy savings.

Figure 9.6 Energy savings due to increased secondary steel production



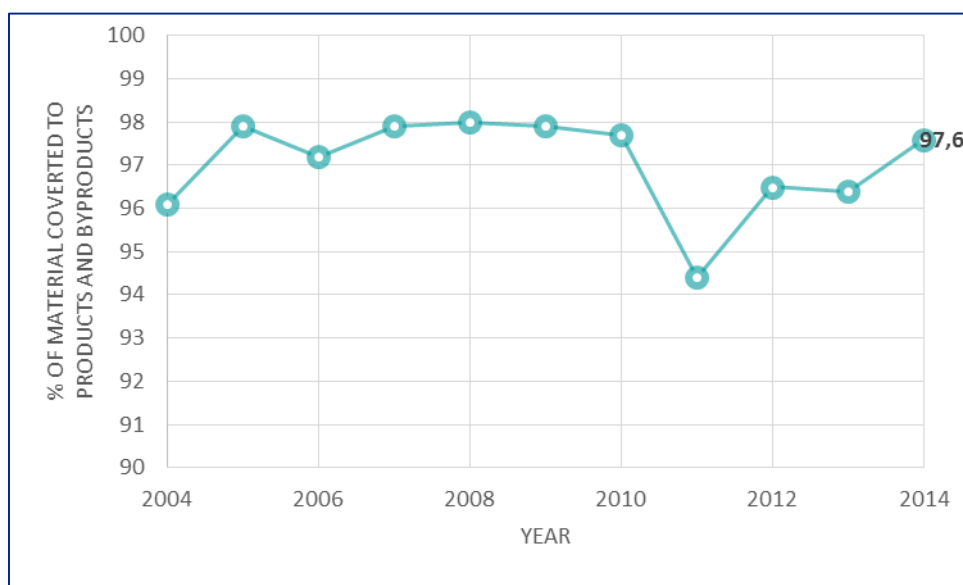
Source: IDEA Consult.

This back-of-the-envelope analysis is limited in the sense that it does not take into account that the energy consumption of the secondary route might increase due to the possibility of decreasing scrap quality coming along with an increase in scrap availability. The 10.5% potential energy savings should therefore be seen as a maximum estimation.

Resource efficiency measures

As displayed in Figure 9.7 on average 97.6% of the raw materials used on-site to make crude steel are converted to products and by-products, meaning that very little waste goes to landfill. This implies that the remaining potential for resource efficiency improvements is limited but present, as Worldsteel states that the goal of the industry is to achieve zero waste.

Figure 9.7 Material efficiency of Worldsteel members



Source: Worldsteel, modified by IDEA Consult.

The potential of energy savings through resource efficiency measures thus appears limited in relative terms. However, considering the major energy consumption of the iron and steel industry in absolute terms (over 60 million tonnes of oil equivalent in 2009 [EEA 2011]), it is still interesting to explore these measures.

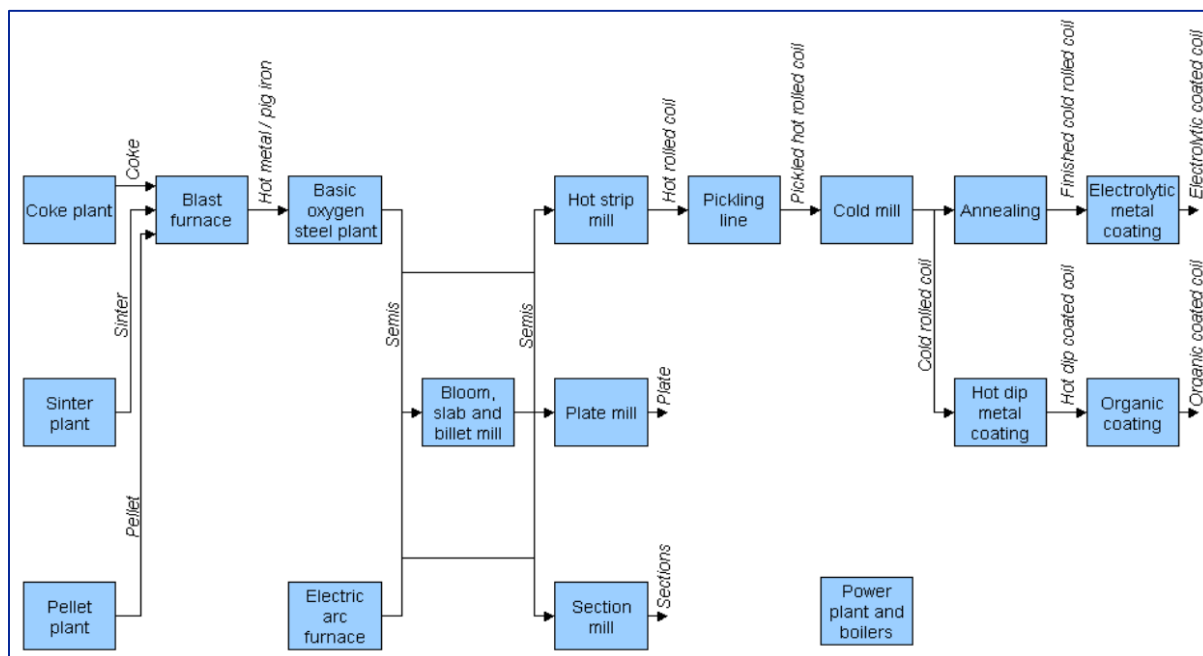
Moya, Pardo, Vatopoulos [2012] from the European Commission's Joint Research Centre (Institute for Energy and Transport) analysed prospective scenarios on energy efficiency and CO₂ emissions in the EU iron and steel industry. The study analyses the role of technology

innovation and its diffusion in the field of environmental and energy efficiency performance for the EU27 Iron & Steel sector. A bottom-up model at facility level of the European Iron & Steel industry has been used that models the cost-effectiveness of the market roll-out of the main technologies or processes within each facility. In order to develop scenarios on the potential evolution of the sector up to 2030, the study describes energy consumption, emissions of CO₂ in the processes, iron & steel production, scrap availability and economic cost, together with retrofitting options and potential innovation in each European iron & steel plant.

There are several reasons that make this study important for this work. First, the authors had access to data about the iron and steel industry on plant and installation level. Second, this data is used to calculate the installed base of Best Available Technologies (BATs) and other innovative technologies and their remaining potential in a bottom-up manner. The study is therefore the most detailed study that is currently publicly available and which is in line with our own study objectives of the literature that has been explored. An interview with one of the authors confirmed that this study is the most complete publicly available work on potential energy savings in the iron and steel sector in Europe. However, the drawback of the study is that it is based on slightly outdated information, as it extracted information on iron & steel plants in the EU27 from the VDeh Plantfacts database, based on an update of 17 December 2009.

The VDeh Plantfacts database contains information and data for each facility, such as the year of construction and modernization, manufacturer and operating status and details of the design, processes and dimensions, materials processed products, plant capacity and technologies implemented. The VDeh Plantfacts database contains no information, however, about resources, energy consumption and CO₂ emissions at facility level, because that information is considered confidential. This implies that the model has considered all iron & steel plants that have the same technologies to have the same specific energy consumption and CO₂ emissions. The different elements of the iron and steel production pathways in Europe are displayed in Figure 9.8, and the estimated specific energy consumption of each of these elements are displayed in Table 9.3.

Figure 9.8 Current pathways for iron and steel production in Europe



Source: Moya, Pardo, Vatopoulos, 2012.

Table 9.3 Estimated specific energy consumption per tonne of product of the current pathways for iron & steel production in Europe

	Primary energy (GJ/t)	Direct energy (GJ/t)
Coke plant	6.827	6.539
Sinter plant	1.730	1.549
Pellet plant	1.204	0.901
Blast furnace	12.989	12.309
BOS plant	-0.253	-0.853
Electric arc furnace	6.181	2.505
Bloom, slab and billet mill	2.501	1.783
Hot strip mill	2.411	1.700
Plate mill	2.642	1.905
Section mill	2.544	1.828
Pickling line	0.338	0.222
Cold mill	1.727	0.743
Annealing	1.356	1.086
Hot dip metal coating	2.108	1.491
Electrolytic metal coating	4.469	2.619
Organic coating	1.594	0.758
Power plant	12.173	12.173

Adopted from: Moya, Pardo, Vatopoulos (2012).

The VDEh Plantfacts database (version 2009) contains 1 590 processes present in the EU27, of which the frequencies by process types are presented in Table 9.4.

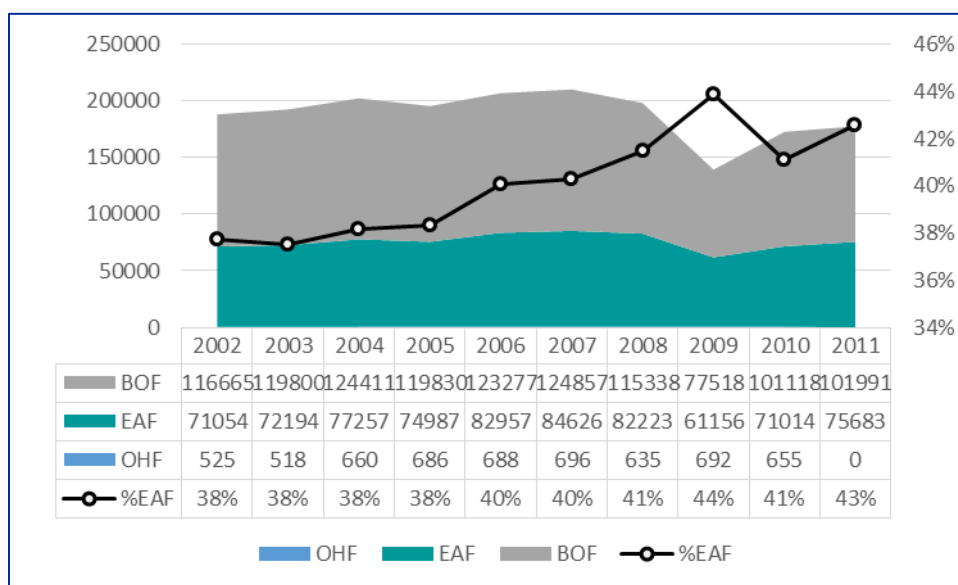
Table 9.4 Processes identified in the Iron & Steel industry in EU27

Count of processes			
Coke plants	62	Plate mills	41
Sinter plants	50	Section mills	206
Pellet plants	7	Pickling lines	145
Blast furnaces	88	Cold mills	222
Basic oxygen steel plants	41	Annealing plants	173
Electric arc furnaces	232	Hot dip metal coating lines	107
Bloom, slab and billet mills	52	Electrolytic metal coating lines	55
Hot strip mills	48	Organic coating lines	61

Adopted from: Moya, Pardo, Vatopoulos, 2012.

There are two main routes to produce steel: the blast furnace - basic oxygen furnace (BF-BOF) route and the electric arc furnace (EAF) route. In the BF-BOF route, steel is mainly produced using raw materials such as iron ore, coal, limestone and recycled steel. In this route, iron ores are first reduced to iron, also called hot metal or pig iron. Subsequently, the iron is converted to steel in the BOF. After casting, rolling and or coating, steel coil, plates, sections or bars are produced. In the EAF route, steel is made by melting scrap material using electricity. Depending on the quality of the used scrap material, other sources of metallic iron and additives are used to adjust the steel to the desired chemical composition. Further downstream processes are similar to those found in the BF-BOF route. Producing steel through the primary route, from iron ore into steel using the BF-BOF route, is more energy intensive than producing steel through the secondary route, due to the energy required to reduce iron ore into reducing agents. About 40% of the steel in Europe is produced through the secondary steel route [Worldsteel 2014], as displayed in Figure 9.9.

Figure 9.9 Production of crude steel by steel-making technology, 2002-2011 (thousand tonnes)



Adopted from Egenhofer et al. 2013.

The next step in the study identified the Best Available Technologies (BATs) and their energy saving potentials. BATs are different technologies which can be applied in the different processes which configure the current Iron & Steel pathways in order to improve their performance. The study by Moya, Pardo, Vatopoulos [2012] considered BATs to be deployed technologies that can be applied in multiple plants and enable significant reductions in the energy and CO₂ emissions to be achieved, summarised in Table 9.5.

Table 9.5 Overview of possible BATs in the Iron & Steel industry

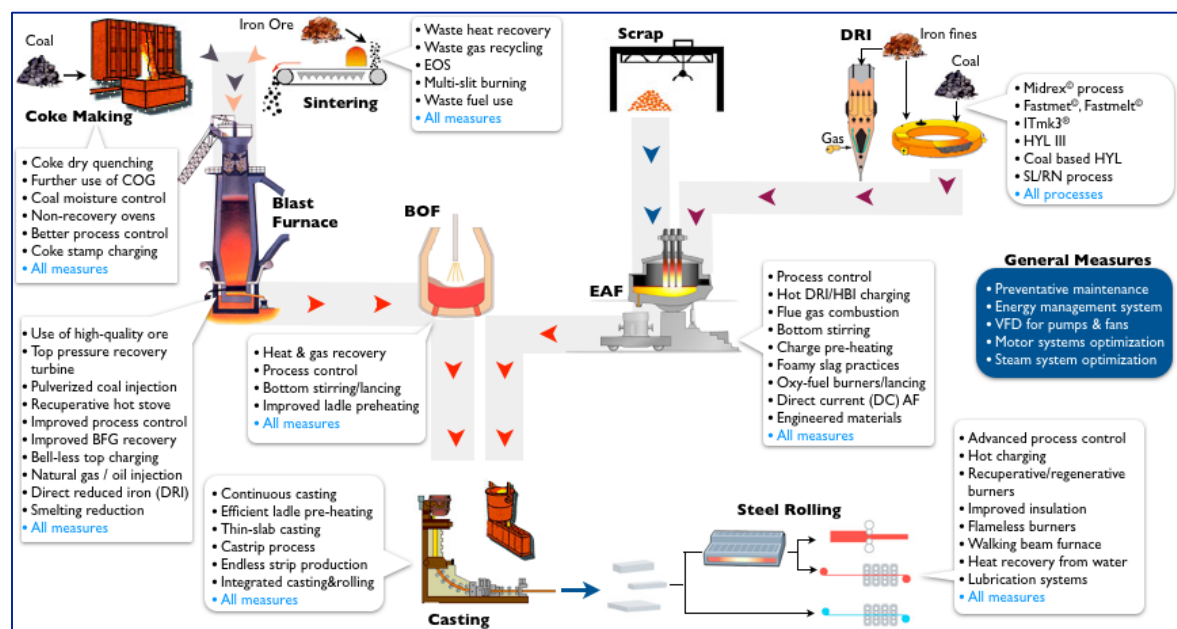
Area	Best Available Technologies for Iron and Steel Industry	Type
General	State-of-the-Art Power Plant	Add on
General	Energy monitoring and management system	Process Control
General	Variable speed drive: flue gas control, pumps, fans	Process Control
General	Preventative maintenance	Maintenance
Coke making	Coke Dry Quenching	Add on
Coke making	Programmed heating	Add on
Coke making	Coal moisture control	Add on
Coke making	Variable speed drive coke oven gas compressors	Process Control
Iron ore preparation	Sinter Plant Waste Heat Recovery	Add on
Iron ore preparation	Use of waste fuels in sinter plant	Process Intensification
Iron ore preparation	Reduction of air leakage	Process Control
Iron ore preparation	Increased bed depth	Process Control
Iron ore preparation	Improved process control	Process Control
Sinter Plant	Optimised sinter pellet ratio	Process Intensification
Iron Making	Top Gas Recovery Turbine	Add on
Iron Making	Stove Waste Gas Heat Recovery	Add on
Iron Making	BF Top Charging System	Add on
Iron Making	Recovery of Blast Furnace Gas	Add on
Iron Making	Optimised Sinter Pellet ratio	Process Intensification
Iron Making	Pulverised Coal Injection	Process Intensification
Iron Making	Natural Gas Injection	Process Intensification
Iron Making	Improved blast furnace control	Process Control
Steel making	BOF Waste Heat and Gas Recovery	Add on
Steel making EAF	Scrap Pre-heating	Add on
Steel making EAF	Oxy-fuel burners	Add on

Area	Best Available Technologies for Iron and Steel Industry	Type
Steel making EAF	Bottom stirring/gas injection	Add on
Steel making EAF	Foamy slag practices	Process Control
Steel making EAF	Improved process control	Process Control
Steel making EAF	Eccentric bottom tapping	New technology
Steel making EAF	Twin shell furnace	New technology
Steel making EAF	Direct Current (DC) arc furnace	New technology
Hot Rolling	Waste heat recovery from cooling water	Add on
Hot Rolling	Energy efficient drives in the hot strip mill	Add on
Hot Rolling	Insulation of furnaces	Add on
Hot Rolling	Process control in hot strip mill	Process Control
Hot Rolling	Recuperative burners in the reheating furnace	New technology
Hot Rolling	Hot charging	New technology
Cold Rolling	Reduced steam use in the pickling line	Add on
Cold Rolling	Waste Heat Recovery on the annealing line	Add on
Cold Rolling	Automatic monitoring and targeting system	Process Control
Integrated Casting	Efficient ladle pre-heating	Add on
Integrated Casting	Continuous Casting	Process Control
Integrated Casting	Direct Sheet Plant	New technology

Adopted from: Moya, Pardo, Vatopoulos 2012.

A clear visualisation of the application of these BATs in the iron and steel production process is displayed in Figure 9.10. Detailed information about the energy saving and CO₂ emission reduction measures can be found on the website⁷⁷ of the Industrial Efficiency Technology Database.

Figure 9.10 Schematic overview of technological developments within the different processes in the iron and steel sector



Source: Industrial Efficiency Technology Database⁷⁸.

In the study by Moya, Pardo, Vatopoulos [2012], the total energy savings potential of the specific BATs is calculated by multiplying the estimated reduction in specific energy consumption of the BAT technologies, displayed in Table 9.6, with the production in all the possible facilities

⁷⁷ <http://ietd.iipnetwork.org/content/iron-and-steel>.

⁷⁸ <http://ietd.iipnetwork.org/content/iron-and-steel>.

in the EU in which the BAT is not yet installed. For this purpose, Moya, Pardo, Vatopoulos used the VDeH plantfacts database for information about the presence of different technologies at plant level for iron and steel facilities in Europe. It should be noted that the calculations are irrespective of the state of the facility (e.g. whether the technology can practically be integrated in the facility) or the cost-effectiveness of the measure (e.g. whether it actually makes economic sense for the particular facility to implement the BAT).

	Primary energy (GJ/t)	Direct energy (GJ/t)
State-of-the-Art Power Plant	-2.830	-2.830
Coke Dry Quenching	-1.605	-1.463
BOF Waste Heat and Gas Recovery	-0.916	-0.908
Continuous Casting	-2.436	-1.727
Scrap Pre-heating	-0.900	-0.288
Sinter Plant Waste Heat Recovery	-0.402	-0.387
Optimised Sinter Pellet ratio – Iron Ore	-0.420	-0.359
Oxy-fuel burners	-0.215	0.013
Pulverised Coal Injection	0.203	0.126
Top Gas Recovery Turbine	-0.338	-0.108
Stove Waste Gas Heat Recovery	-0.160	-0.160
Optimized Sinter Pellet Ratio – Iron Making	0.000	0.000

Source: Moya, Pardo, Vatopoulos 2012.

Figure 9.11 shows the calculated potential energy savings in PJ in the EU for the BATs.

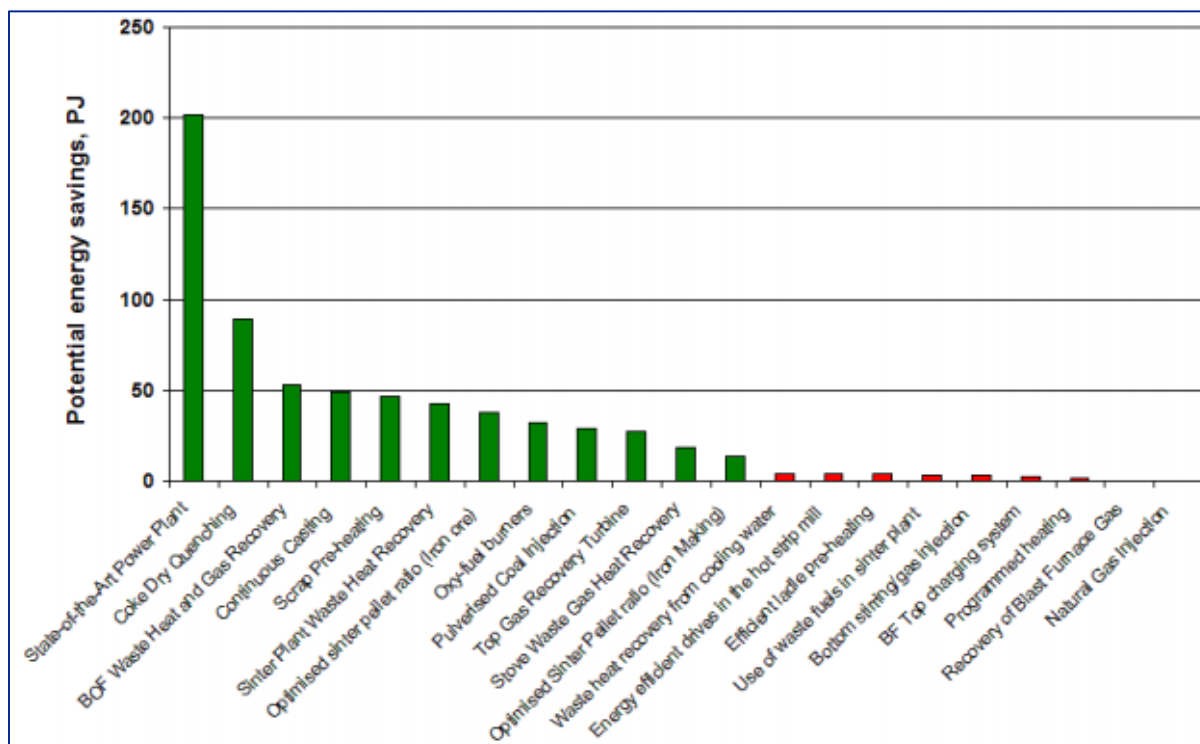
Table 9.6 Estimated reduction in specific energy consumption (per tonne of its corresponding product) of the BAT technologies

	Primary energy (GJ/t)	Direct energy (GJ/t)
State-of-the-Art Power Plant	-2.830	-2.830
Coke Dry Quenching	-1.605	-1.463
BOF Waste Heat and Gas Recovery	-0.916	-0.908
Continuous Casting	-2.436	-1.727
Scrap Pre-heating	-0.900	-0.288
Sinter Plant Waste Heat Recovery	-0.402	-0.387
Optimised Sinter Pellet ratio – Iron Ore	-0.420	-0.359
Oxy-fuel burners	-0.215	0.013
Pulverised Coal Injection	0.203	0.126
Top Gas Recovery Turbine	-0.338	-0.108
Stove Waste Gas Heat Recovery	-0.160	-0.160
Optimized Sinter Pellet Ratio – Iron Making	0.000	0.000

Source: Moya, Pardo, Vatopoulos 2012⁷⁹.

⁷⁹ It should be noted that the JRC study focussed on a selection of technologies, indicated with a * in Table 9.5. They clarify that the work is focussed on the BATs for processes up to the production of semis and on the 'add on' or 'process intensification' types. This implies that they have omitted all other BATs that have different implementation methods, such as 'new technologies', 'process control' and 'maintenance', due to the fact that this information is confidential at plant level. Second, they selected the BATs based on their energy savings potential, with a cut-off point at 5PJ of potential energy savings.

Figure 9.11 Potential energy savings of BATs in the Iron & Steel industry



Source: Moya, Pardo, Vatopoulos 2012.

Most BATs cannot be considered as resource efficiency measures, but rather as general energy saving measures. The BAT State-of-the-Art Power Plant, for example, refers to increasing the efficiency of energy conversion by replacing older installations with new state-of-the-art steam boiler and turbine technologies, since European integrated steel sites in Europe usually have a power plant on site or near the site where process related gases are used to produce power and steam. The BAT Coke Dry Quenching is an energy recovery process and the name of the BOF Waste Heat and Gas Recovery technique speaks for itself.

Three resource efficiency measures have been identified from the list in the study by Moya, Pardo, Vatopoulos [2012]. Most of the other measures are purely related to energy or heat recovery. A measure that could be selected as a resource efficiency measure, but is not described in detail in the study due to the limited energy savings potential, is the Blast Furnace Top Charging System. This technology reduces coke consumption and increases the attainable pulverised coal injection rate, by screening input materials before charging.

Continuous casting

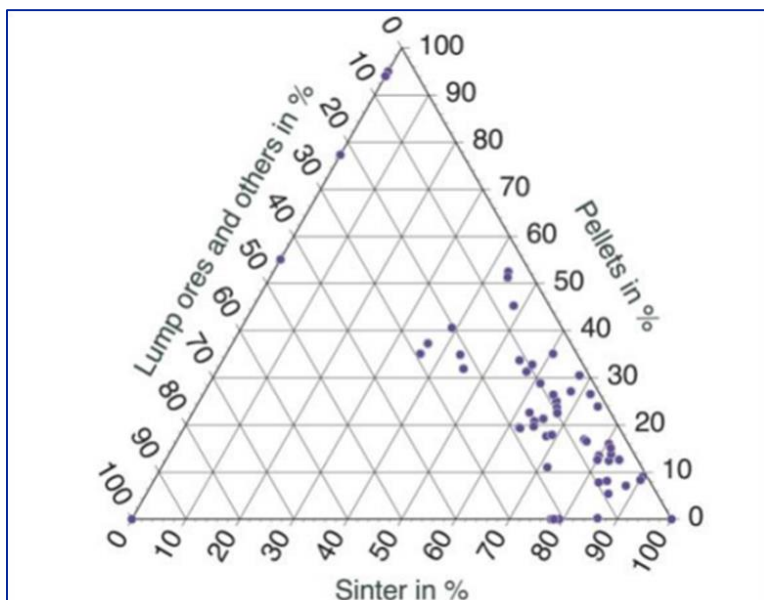
Continuous casting in the work of Moya, Pardo, Vatopoulos [2012] relates to the full deployment of the technology to bloom, slab and billet mills, in which continuous casting has not been implemented yet. Bloom, mill and billet mills are a relatively small portion of the steel capacity (with 21 Mt of steel produced annually), yet the potential energy savings are substantial. Some further information from desk research and literature is provided below:

Continuous casting, or *continuous near shape strip casting* or *thin slab/strip casting*, refers to steel making processes in which the metal is cast to a form and dimensions close to what is required for the finished product. This continuous casting method shortens the process from liquid steel to hot rolled sheet, therefore reducing the overall energy consumption and increasing resource efficiency, due to a reduction of material losses. This form of continuous casting is mentioned as one of the eight conclusions in the 2013 BAT Reference Document for Iron and Steel Production. Continuous casting is applicable both at new and existing and both BOF and EAF steel plants. The relatively small space needed (approximately 100 meters in length) offers the potential to integrate the BAT when retrofitting. The applicability however depends on the quality and product mix of the produced steel grades. Heavy plates for example cannot be produced with this continuous casting process. According to the Industrial Efficiency Technology Database, the technique has a commercial development status, and it casting is currently the preferred choice in new steelmaking plants, in place of ingot casting

Optimized Sinter Pellet Ratio

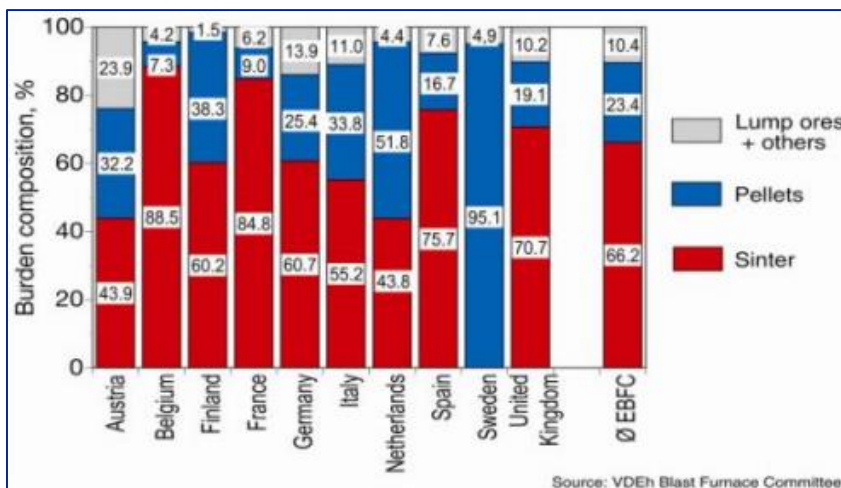
Iron ore is mainly fed into a Blast Furnace in the form of sinter and pellet. Figure 9.12 and Figure 9.13 show that there are plants operating with a pellet concentration of more than 50%, with several blast furnaces in Sweden operating with even 100% pellet concentration. In the 2012 JRC study, an optimised sinter pellet ratio refers to increasing the sinter pellet ratio of all facilities in Europe from an average ratio of 74:26 (assumed equal in all plants) to 50:50, resulting in an estimated reduction of specific energy consumption displayed in Table 9.7.

Figure 9.12 Ferrous burden composition in Western Europe 2008



Source: Luengen, et al. 2011.

Figure 9.13 Average ferrous burden composition of the blast furnaces in Western Europe



Source: Luengen, et al. 2011.

Pulverised Coal Injection (PCI)

PCI, a technology that injects fine coal particles into the blast furnace, is a widely applied technique in Europe and worldwide. The main advantage of the injection of coal in a blast furnace is the cost saving due to lower coke rates. A specific example is the Tata Steel Europe Ltd. blast furnace plant Ijmuiden in the Netherlands, where pulverised coal is injected on a

commercial scale [Paramanathan, B., Engel, E. 2012]. As stated on the website⁸⁰ of the Industrial Energy Efficiency Database, for every ton of coal injected, 0.85t to 0.95t of coke production can be avoided and energy savings are estimated to be 3.76GJ/t-injected coal. Another source states that, using PCI, about 30% of coal can be saved and that one tonne of PCI coal used for steel production displaces about 1.4 t of coking coal [Worldsteel 2014]. According to the Best Available Techniques (BAT) Reference Document for Iron and Steel Production, PCI is applicable both at new and existing blast furnaces. Particularly at plants which might face capital expenditure on rebuilding coke ovens or plants that have to purchase coke, PCI can achieve greater cost savings.

In the study by Moya, Pardo, Vatopoulos [2012], the potential energy savings do not refer to the mere deployment of PCI, as this is already a widely applied technique, but rather refer to the energy savings if the pulverised coal injection rate is raised from an average 130 kg/t-hot metal to 230 kg/t-hot metal, with the assumption made that all facilities are able to implement that increase.

Energy savings from resource efficiency measures

The potential energy savings from the three selected resource efficiency measures are displayed in Table 9.7. As can be seen in Table 9.7, the total energy savings potential in the 2012 JRC study is 670PJ. It can also be observed from this table that the final energy consumption of the European iron and steel industry in 2009 amounted to about 60 million tonnes of oil equivalent (Mtoe) [European Environment Agency 2011], which is 2520PJ (1 toe = 41.868 GJ). The total potential energy savings would therefore correspond to 27% of the energy consumption of the iron and steel industry in 2009 (670/2520). The potential energy savings of the identified resource efficiency measures are about 5% (117/2520) of the 2009 energy consumption of the EU iron and steel industry with a combined energy savings potential of 117 PJ.

Table 9.7 Potential energy savings of best available technologies in the iron and steel sector

Best Available Technologies	Potential energy savings (PJ/y)
State-of-the-Art Power Plant	201
Coke Dry Quenching	90
BOF Waste Heat and Gas Recovery	53
Continuous Casting	50
Scrap Pre-heating	48
Sinter Plant Waste Heat Recovery	43
Optimized Sinter Pellet ratio – Iron Ore	38
Oxy-fuel burners	32
Pulverised Coal Injection	29
Top Gas Recovery Turbine	28
Stove Waste Gas Heat Recovery	18
Optimized Sinter Pellet ratio – Iron Making	14
Waste heat recovery from cooling water	5
Energy efficient drives in the hot strip mill	5
Efficient ladle pre-heating	5
Use of waste fuels in sinter plant	4
Bottom stirring/gas injection	4
BF Top Charging System	2
Programmed heating	1
Recovery of Blast Furnace Gas	0

⁸⁰ <http://ietd.iipnetwork.org/content/iron-and-steel>.

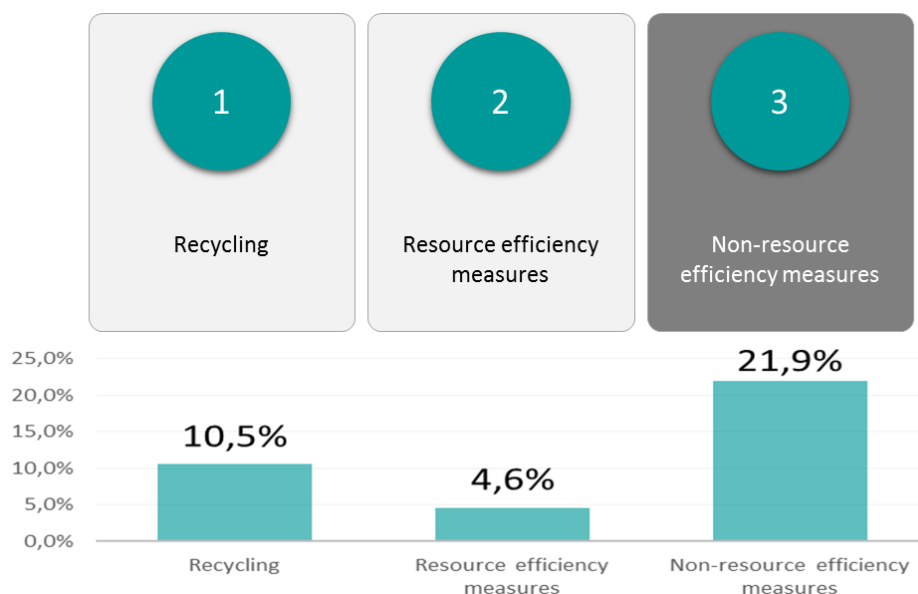
Best Available Technologies	Potential energy savings (PJ/y)
Natural Gas Injection	0
Total energy savings potential	670 PJ
Potential energy savings resource efficiency measures	117 PJ
Potential energy savings non-resource efficiency measures	553 PJ

Source: Moya, Pardo, Vatopoulos [2012], modified by IDEA Consult.

9.4.4 Calculating the energy savings potential

In the study two major sources of energy savings through resource efficiency measures have been identified, as displayed in Figure 9.14.

Figure 9.14 Potential energy savings as identified in this work



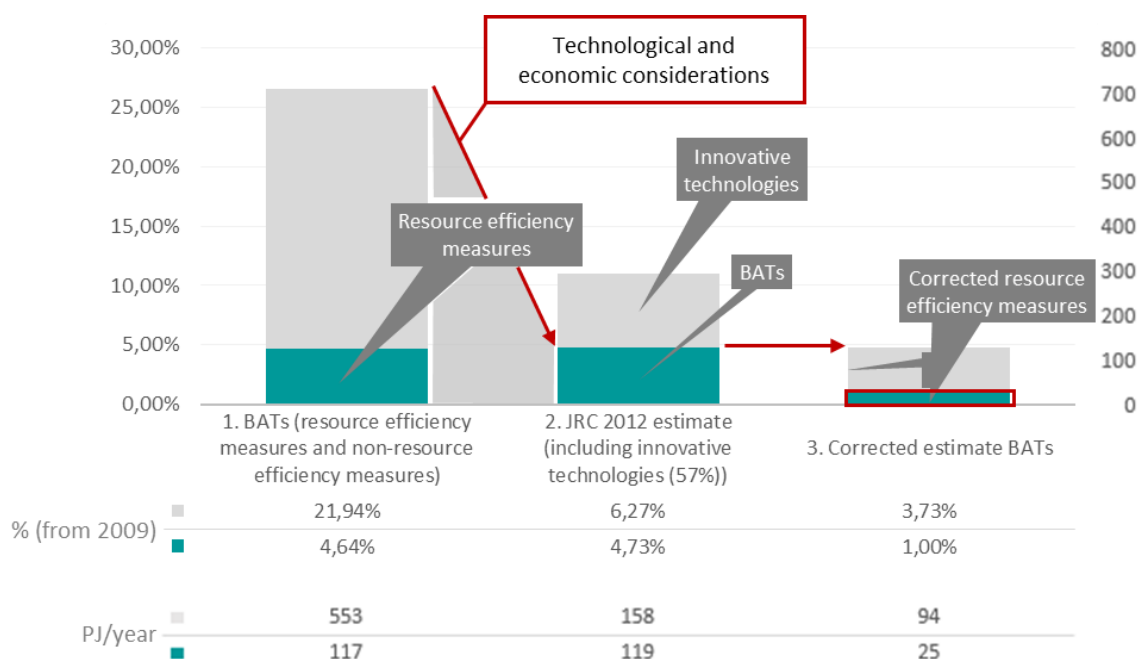
These results should be considered the theoretical potential, meaning that economic and technological practicalities have not been taken into account. When compared with the potential energy savings in Table 9.2, which varies around an energy savings potential of about 11%, a 38% total energy savings potential seems to be an overestimation. In order to derive a more realistic estimation for the potential energy savings, these findings must be corrected.

BATs calculations refer to the absolute theoretical potential, showing the potential energy savings if the BATs are implemented in all possible EU facilities where they are otherwise not yet installed. This does not take into account economic and technological considerations, such as whether the technology can be practically installed in the facility, or whether it makes economic sense to install the BAT in the facility.

To gauge the data to the potential energy savings estimations in Table 9.2, the calculations for the resource efficiency and non-resource efficiency measures can be compared with an estimation for total energy savings in the same JRC study (Moya, Pardo, Vatopoulos, 2012) that has been used to calculate the potential energy savings based on the BATs. In the model used to derive this estimation, the authors incorporated economic and technological considerations such as technological applicability at installation level, return on investment, etc. As a result, the JRC study estimates a maximum total potential energy savings of 11%. We therefore use this 11% as a reference for correcting the overestimated *theoretical* energy savings as displayed in Table 9.7.

The calculations on which the potential energy savings of 11% in the JRC study (Moya, Pardo, Vatopoulos, 2012) are based include besides the energy savings potential from BATs the energy savings from innovative technologies⁸¹, but they do not include the potential energy savings of an increase in secondary steelmaking. Since BATs account for a share of 43% in the total of 11% energy savings as estimated in the JRC study (the other 57% is achieved by the innovative technologies), a first step of correcting the estimate economic and technological considerations is to correct the 27% of energy savings from BATs (resource and non-resource efficiency measures) to around 4.7%. In Figure 9.15 this is displayed by correcting the left bar to the middle bar.. The second step is to apply the ratio between resource efficiency measures and non-resource efficiency measures (117:553) on this corrected 4.7% of energy savings from BATs to derive at a final estimate for energy savings from resource efficiency measures of 1% (compared to the final energy consumption of the European iron and steel industry in 2009 of 2520PJ) or 25 PJ per year instead of the previously estimated 117 PJ/y.

Figure 9.15: Illustrating the calculations for the corrected energy savings potential estimate for resource efficiency measures



From this study's assessments, it can therefore be concluded that the theoretical potential energy savings through resource efficiency measures would be approximately 290 PJ/yr. The largest share of potential energy savings would come from an increased use of secondary steelmaking, i.e. recycling (265 PJ/yr). The remaining 25 PJ/yr comes from the three selected resource efficiency measures.

9.4.5 Conclusion

The most important part of the energy savings potential for the EU iron and steel industry in Europe lies within an increased rate of recycling, which is also labelled as the secondary route of steelmaking. Producing steel through the secondary route is less energy intensive than producing steel through the primary route, because it does not require the iron ore to be first reduced into reducing agents, removing several energy consuming processing steps such as ore preparation, coke-making and iron-making. Currently, about 40% of the crude steel within the EU is already produced by the secondary route. However, there is still potential to increase this rate up to 50% over the next 20 years due to larger available quantities and better control of scrap qualities. Because secondary steel production uses about 74% less energy than the

⁸¹ "industrial innovative technologies which have already been demonstrated on an industrial scale, but have still not been implemented in Europe; and, second, the most promising technologies for the immediate future which are currently under development basically under the ULCOS programme" (Moya, Pardo 2013).

production of steel from iron ore, increasing the rate of secondary steelmaking from 40% to 50% would lead to a reduction of 10.5% in energy consumption. Compared to the 2520PJ energy consumption of the iron and steel industry in 2009 [European Environment Agency 2011], this would imply up to 265 PJ/yr energy savings. This calculation does not take into account that the reduced energy consumption in the secondary route might decrease due to the reduced availability of good quality scrap due to moving the frontier of using scrap as an input for secondary steelmaking ever further. The estimate should therefore be seen as a maximum potential.

Besides an increase in recycling, this work has identified several resource efficiency measures that contribute to energy savings: the deployment of continuous casting in bloom, slab and billet mills, an increase in the average sinter pellet ratio to 50:50, and an increased average rate of pulverised coal injection. If these technologies would be implemented in all the possible facilities in the EU in which the BAT is not yet installed, this would be 117 PJ/yr in potential energy savings. Compared to various potential energy savings estimations in the iron and steel sector, this number seems unrealistically high. One inflator could be economic and technological considerations, such as technological applicability at installation level and return on investments that are not taken into account. Using a model based estimate of the potential energy savings from the same study on which these resource efficiency measures are based, the potential energy savings have been corrected to 25 PJ/yr of energy savings.

The theoretical potential energy savings due to resource efficiency measures would thus be up to 290 PJ/yr (265 PJ/yr from an increase in secondary steelmaking and 25 PJ/yr from the application of BATs for increasing resource efficiency in iron and steelmaking facilities). It is notable that this can be compared with the annual energy consumption of Estonia [Eurostat, 2015].

Estimating the energy savings through resource efficiency in the iron and steel sector is not a straightforward exercise. The lack of available data and the fact that the many iron and steel installations in Europe are each very specific in terms of applied technologies and possible potentials make calculations uncertain. This is noted as well in an International Energy Agency study [2009], where it is stated that broad-based comparisons of total subsector energy consumption per tonne of crude steel are limited because of the large differences in production processes that vary both at the level of the country and especially at individual plant level. Because this data is not available, the International Energy Agency also works with bottom-up estimates, calculating potential energy savings if best available technologies become widely applied, similar the approach in this work and the works cited therein.

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10 Industrial symbiosis

An essential element of industrial symbiosis (IS) is the cooperation between companies to valorise input materials, infrastructure, production residuals, products and to improve energy efficiency. As such industrial symbiosis may involve companies of other sectors as well, and is not restricted to the ones of one particular sector. Therefore, industrial symbiosis ranges from between company production relations to inter-sectoral production relations.

In a broad sense industrial symbiosis is defined as the synergistic exchange of waste, by-products, water and energy between individual companies in a locality, region or even in a virtual community. Key to industrial symbiosis is collaboration between companies and the synergistic possibilities offered by geographical proximity. Industrial symbiosis engages traditionally separate industries in a collective approach to competitive advantage involving physical exchanges of materials, energy, water and/or by-products [Chertow, 2000].

10.1 Introduction

The symbiotic relations between companies valorise material resources as well as energy. Both inputs are an important cost factor; increasing energy and material efficiency contribute to profitability. Examples abound and can be roughly classified into two groups: 1) (self-)organised intercompany supply and demand of materials, water and energy; and 2) industrial symbiosis networks and parks developed through public support initiatives. Examples of the former are the company interrelationships in the ferrous and non-ferrous EU industry where companies specialise in particular technologies and market segments such as the recovery of precious metals from dross and sludge from metal processing. Other industries are food processing, construction and demolition, wood processing, paper and pulp, and chemistry. Examples of publicly supported initiatives include most notably Kalundborg, Denmark, SMILE in Ireland, the NISP initiative in the UK, Borsa de subproductes de Catalunya, Spain, as well as The By-Product Synergy Hub in the USA, Guitang Group in China, Kokubo eco-industrial park, Japan, and the Kwinana Industries Council in Australia.

Industrial symbiosis is basically a method for valorising materials, water and energy and may occur in principle in all sectors. It is therefore paramount to avoid double counting with the other sectors that are studied. Calculating the up-scaling potential is very difficult, as industrial symbiosis cases are very diverse and often driven by case-specific circumstances (e.g. the co-location of certain companies with matching waste output – input needs).

The aim of this chapter is threefold. First, it provides an overview of some of the major EU industrial symbiosis networks and the indirect energy savings that are realised in these networks thanks to resource efficiency. The issues associated with calculating the upscaling potential of indirect energy savings for industrial symbiosis networks and industrial symbiosis at large is discussed. Secondly, some individual examples of IS cases are addressed, for which a better assessment of the upscaling potential can be made thanks to the more disaggregated level of study. Thirdly, the chapter illustrates for the other sectors covered in this study how IS contributes to realising resource- and energy-savings.

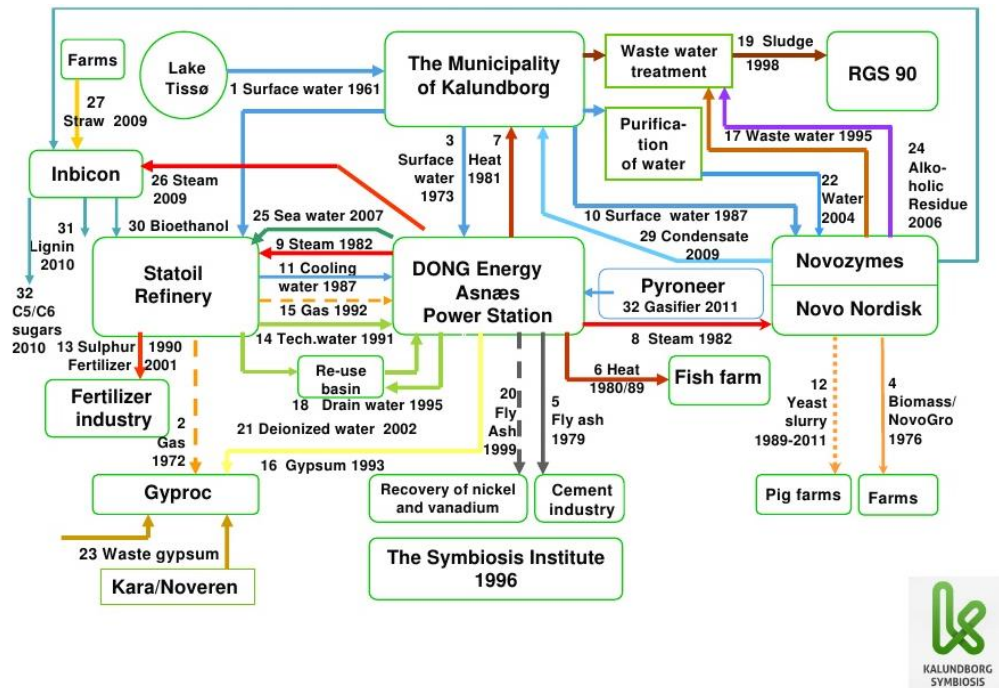
Industrial Symbiosis networks

The **Kalundborg (DK) network** is one of the most well-known examples of industrial symbiosis and was the first full realization of it. Kalundborg Symbiosis came into being as a result of private conversations between a few enterprise managers from the Kalundborg region in the 1960s and 70s. The primary partners in Kalundborg, an oil refinery, power station, gypsum board facility, pharmaceutical plant, and the City of Kalundborg exchange a variety of residues that become feedstock in other processes and share ground water, surface water and waste water, steam and electricity. Over the years more and more businesses were linked into the scheme, and in 1989 the term 'industrial symbiosis' was used to describe the collaboration for the first time.

Some of the material exchanges found in Kalundborg include sludge from the bioenergy plant used as fertilizer in nearby farms; a cement company uses the power plant's de-sulphured fly ash; the refinery's desulphurization operation produces sulphur, which is used as a raw material in the sulphuric acid production plant; and the surplus yeast from the biotechnological company

is used by farmers as pig feed. Figure 10.1 provides an overview of the resource exchanges in Kalundborg.

Figure 10.1 Industrial symbiosis relations in Kalundborg, Denmark



Source: Kalundborg Symbiosis, <http://www.symbiosis.dk/en/system>.

A study on the environmental impact of the Kalundborg network in 2012, demonstrates that the network activities enable saving 272 500 tonnes CO₂ emissions. The majority (66%) of this savings is the result of direct energy efficiency measures (steam exchanges and transfer of residual heat to other companies and households (district heating)). About 34%, or 91 100 tonnes CO₂, is the result of either material exchanges that avoid extra energy consumption for the production of virgin materials, or material exchanges that can be used for energy valorisation. Hence, the indirect energy savings realised in the network are significant.

The **National Industrial Symbiosis Programme (NISP)** in the UK started off by promoting industrial symbiosis in Scotland, the West Midlands and Yorkshire & Humber. In 2005, these pilot efforts were recognized by the national government and were followed by investments from the UK government through its Business Resource Efficiency and Waste Programme to fund the roll out of NISP as a national programme. The programme emphasises promoting collaboration between organizations, following the principles outlined by Chertow (2000), in “a collective approach to competitive advantage involving physical exchange of materials, energy, water and/or by-products together with the shared use of assets, logistics and expertise”. Through the network, NISP identifies mutually profitable transactions between companies so that underused or undervalued resources (including energy, waste, water and logistics) are brought into productive use. NISP members include micro, small and medium businesses (SMEs) and multinational/corporates from every industry.

Between 2005 and 2013, NISP was assessed to have reduced CO₂ emissions by 39 million tonnes, which is about 3.2 million tonnes annually. Similarly, NISP was assessed to have diverted 45 million tonnes of material away from landfill in this period.

The **SMILE Resource Exchange** is a free service in Ireland for businesses that encourages resource exchanges between its members in order to reduce waste going to landfill and to develop new business opportunities. The service is available to businesses in the Dublin, Cork, Limerick, Clare and Kerry regions. Potential exchanges are identified through networking events, an online exchange facility and a support team to assist throughout. At these exchange events and through the online platform businesses can identify resources they would like to exchange such as reusable items, by-products and surplus products. The exchanged materials include, among others, construction materials, wooden pallets, electronic equipment, paper, cardboard, plastic and furniture. The environmental impacts of this network are documented at

case level among others in the 'SMILE case studies 2014' publication. At the moment, no overall environmental impact figures are available; however, the network indicated to be working on calculations of such figures⁸².

Industrial symbiosis is a term which encompasses a variety of different cases. In order to comprehend this variety, it is informative to have a look for example at the aforementioned overview of synergies established and products exchanged under the SMILE network, which are as diverse as covering foams, rubber, glass, egg whites and even the valorisation of unusable hotel key cards. The variability of waste streams and sectors involved as well as the innovative type of solution established lie at the very heart of the concept industrial symbiosis, yet these factors at the same time impede calculating the upscaling potential of IS with regard to energy savings without making major assumptions. Indeed, for the calculation of the upscaling potential of IS networks as they stand today, one would need to know for each of the many established IS cases the occurrence of similar groupings of companies who have similar (and unresolved) input needs and waste output in other countries in the EU, information which is not possible to collect at such a large scale.

At a more disaggregated (i.e. case) level, there are fewer obstacles to assessing the upscaling potential. Therefore, a number of individual cases and their impact on energy savings are elaborated in the next section.

10.2 Case studies

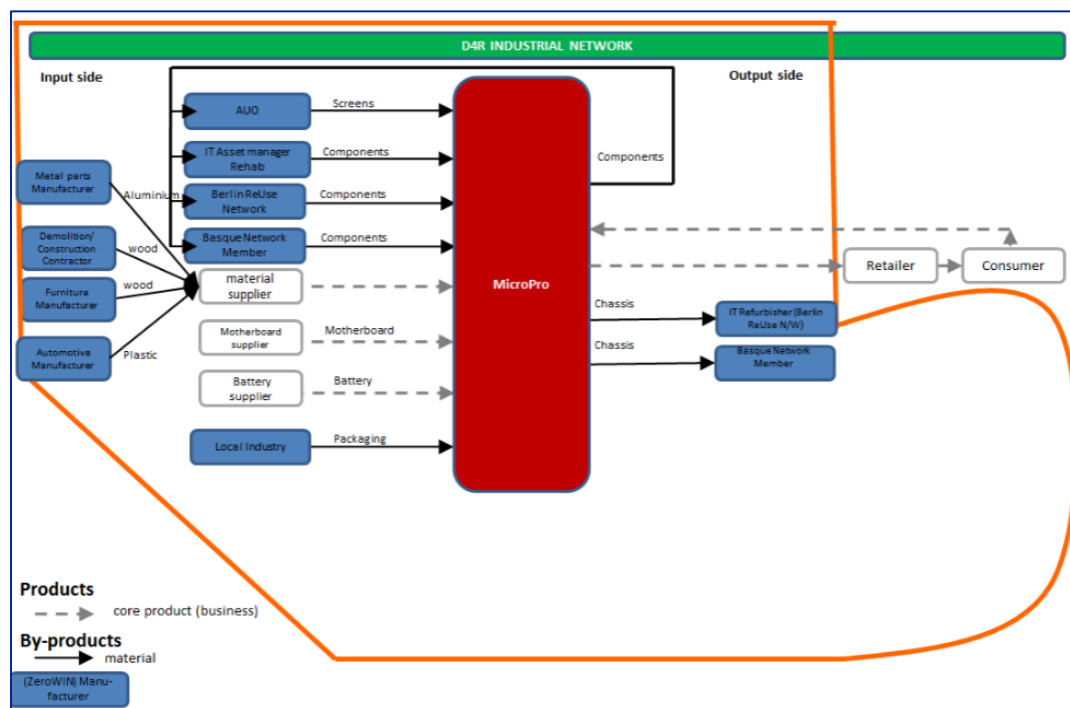
10.2.1 Case 1: using by-products and reused components for computer manufacturing

Over the past years, the Irish company MicroPro Computer Systems has developed a touchscreen computer and a laptop combining eco-design with an increased lifetime and reuse potential of the computer, in order to minimise waste throughout the lifecycle and across the supply chain. This business model was developed in order to counteract the high material and energy consumption of the ICT sector, which is characterized by relatively high disposal rates and short product lifetimes.

In the case of the 'D4R' laptop (based on the principles of design for Recycling, ReUse, Repair & Refurbishment) laptop, this new approach towards sustainability translates among others in making use of by-products from other companies along the supply chain, including reused components from existing computers recovered by social economy enterprises. The D4R laptop uses wood by-products from furniture companies and recycled industrial aluminium for the housing and facilitates the use of reused parts and components, including the LED screen, the hard drive, the memory, the power supply and so on. To permit the incorporation of a variety of reused components, MicroPro has developed a universal motherboard that can fit a wide range of recovered parts and components.

The aim is to develop synergies with network partners that can perform complimentary functions throughout the life of the product. Rather than returning products to the point of manufacture, regional "hubs" will be responsible for upgrading, repair and possibly remanufacture, using local personnel and resources, including spare parts and components sourced locally. In other words, many laptops will be remanufactured on a local, outsourced basis rather than centrally, thereby reducing transport costs significantly. Figure 10.2 illustrates the industrial network behind the laptop, including both the suppliers of input materials as well as the various European network partners involved that help to collect and repair/remanufacture laptops.

⁸² Communication with Michelle Green, project manager of the SMILE network.

Figure 10.2 Concept of industrial network behind D4R laptop


Source: ZEROWIN project website.

It should be noted that this case study has a different scope than the three case studies covered in the ICT sector (Section 4.6). The first case study in the ICT sector focuses on emerging concepts (thin/zero clients), while the current case focuses on several improvement in an existing 'classical' concept (laptop). The second case study in ICT focuses on mobile devices and specifically on the (currently difficult) recovery of batteries therefrom, while the IS case does not focus on mobile devices. The third ICT case focuses on recycling plastics from electronic waste (WEEE), while the IS case is about sourcing waste and by-products from other industries from computer manufacturing. As such, together the ICT and IS case studies illustrate the various potential avenues to reduce the resource and energy consumption of the ICT sector.

Environmental impact

In the context of the FP7 project ZEROWIN, in which the D4R laptop was further developed and the industrial network was elaborated, a comparison of the environmental impact of the D4R vis-à-vis a regular laptop was made. These results consider only the manufacturing phase, not the use phase. In terms of greenhouse gases, a reduction of 66% was realised. This high reduction reflects the substantial embedded energy contained in a number of computer parts, notably the LCD screen. Behind the high savings are the following strategies to improve the environmental performance:

Table 10.1 Overview of strategies followed to reduce environmental impact of D4R laptop

Strategy	Potential reuse / recycling rate
Sourcing wood for chassis from industrial network	67% / 90%
Use of by-product LCD panels from industrial network	43% / 83%
Sourcing packaging from industrial network	0% / 95%
Use of by-product motherboard (incl. CPU and RAM) from industrial network	50% / 85%
Use of other by-product from industrial network (e.g. DVD drive, hard disk drive, cabling)	50% / 85%
Total product including spare parts and packaging	58% / 87%

Source: ZEROWIN project website.

Upscaling potential

Interestingly, the use of various by-products has been realised after an active search of the company for available by-products in the region. This search was facilitated by the SMILE exchange network in Ireland (discussed above), which promotes industrial symbiosis in the region through an on-line platform and matchmaking. This model of using by-products of other companies does not hinge on the very close proximity of a few key by-product suppliers, and is assessed to be replicable in other EU countries. Hence, from the input side there would be therefore no structural obstacles to upscaling the production of such ecological computers. Given the very significant reduction in environmental impact (and relatedly, energy use) of these computers, as well as the major energy use of the ICT sector, the effects of the large-scale uptake of ecological computers could be important.

However, before this upscaling potential can be realised, there are some key barriers to overcome. As the D4R is based on a new design and new supply chain, which is necessary to reduce substantially the consumption of energy and materials, the manufacturing changes too. In a market which is characterised by competitors that produce on a very large scale and by consumers who are cost-conscious, this implies that to be competitive, efficient and large scale manufacturing is needed. Developing manufacturing lines that can work with the new supply chain and are sufficiently efficient compared to existing competitors is therefore the main challenge. This is discussed in more detail in the *Final Report*, where barriers to implementation of win-wins as well as possible policy options to overcome these are analysed.

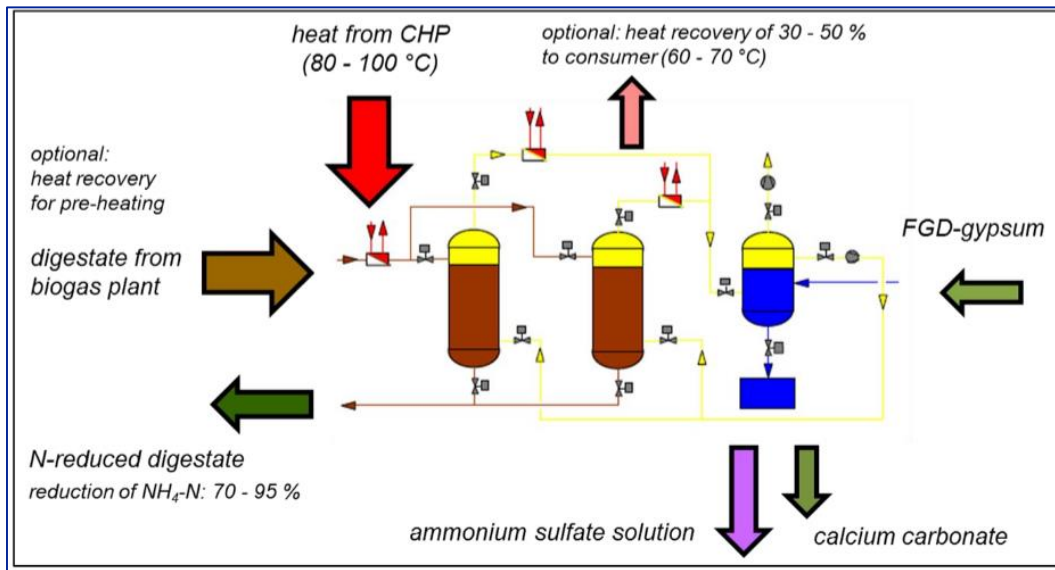
10.2.2 Case 2: use of fermentation residues from biogas plants as raw material for the woodworking industry

Introduction

Producing biogas is one method to give value to otherwise low value biomass stream, such as waste from the food or agricultural industries, by producing methane which can be used for the generation of heat and electricity. The production of methane is the result of anaerobic fermentation, a process in which anaerobic bacteria break down the biomass in the absence of oxygen. In addition to methane and a few other gases, this fermentation process results in a number of residues. During anaerobic digestion, nutrients contained in the organic matter are conserved and mineralized to more soluble and biologically available forms, and as a result the residues can be used well as inorganic fertiliser.

The idea behind the case is to separate the residues in several parts and valorise them according to their functionalities. More specifically, the ammonium nitrogen is removed from the digestates using the ANASTRIP process, leading to a concentrated ammonium sulphate solution and a solid calcium carbonate powder, which both can be used as fertiliser. The remaining fibre part can then be used for other purposes, for example as material for various flooring types, in particular chip boards and Medium Density Fibre (MDF) boards. Figure 10.3 illustrates the process resulting in several useful outputs of biogas production.

Figure 10.3 Flow diagram of the digestate treatment system



Source: GNS.

In the context of a multi-annual project funded by the German Federal Environmental Foundation (Deutsche Bundesstiftung Umwelt (DBU)), there has been a successful demonstration phase to produce 10 tons of nitrogen-reduced biogas residues (fibres) with the so-called ANAStrip-process. The use of these fibres in the woodworking industry to produce laminate and particle boards has been demonstrated on industrial scale.

Environmental impact

A study conducted by Nova Institute on the economic and ecological aspects of the case, shows that, compared to the baseline situation with no separation of residues applied, the biogas plant could reduce its emissions of greenhouse gases by about 16% per year, or about 386 t CO₂. This calculation incorporates the whole life cycle of operations, including the emissions related to build and apply the ANAStrip, the energy embedded in the inputs of the plant as well as the outputs.

The major drivers behind the positive environmental impact are the possibility to use more low value inputs (e.g. chicken dung) for biogas production, the higher quality of fertiliser output (leading to less energy use for the production of virgin fertiliser) and the higher output of biogas production (due to less ammonia inhibition in fermentation). The substitution of wood products by fibre residues does not contribute to the positive result as both categories are assigned a zero environmental impact in terms of GHG emissions.

What is not included in this assessment is the potential positive effect of increased by-product valorisation on the economics of biogas production, which may in the longer term promote the share of this renewable energy type in the overall energy mix.

Upscaling potential

Based on the total amount of biomass generated as fermentation residues, combined with efficiency rates for state of the art techniques for separating wet and dry biomass, it is estimated that in Germany there is a technical potential of about 1.5 million ton dry biomass per year. The economic potential refers to the part of the technical potential that could be valorised in a profitable manner. While this new valorisation type is still in its early stage of development and estimating the economic potential is therefore not straightforward, an important parameter would be the size of biogas plant, as scale effects are likely to be important to make the investment profitable. Whereas the stripping of ammonium nitrogen can be done at existing plants (retrofitting), there are still significant investments to be made in automating and integrating this new process. These and other barriers are discussed in more detail in the final report of which this *Technical Report* is an annex. The results of the upscaling calculation are presented in the next section.

10.3 Results

Case 1: using by-products and reused components for computer manufacturing

As outlined above, the D4R laptop case demonstrates that very significant resource- and energy-savings can be realised in the manufacturing phase of laptops by in making use of by-products from other companies along the supply chain, including reused and recycled components from existing computers. The calculation of the potential for energy savings induced in this manner is based on combining information on primary energy consumed in manufacturing of an average laptop, the improvement of the D4R laptop in terms of primary energy based on LCA study conducted in the context of ZEROWIN, annual laptop sales in 2014 as well as market estimates on the potential market shares for an eco-concept computer. Results indicate that the overall potential for energy savings amounts to about 21.1 PJ. This high saving potential is driven by the combination of both the size of the target market and the high energy saving potential per individual computer (66%), enabled by a different use of inputs and computer design.

While the above results apply to the laptops market, it should be noted that the concept is transferable to other product segments (notably desk tops, for which similar concepts have been produced, as well as tablets). The total potential could in this respect lie significantly higher than as calculated above.

The above calculation illustrates the high energy-saving potential possible in this case; however a number of uncertainties revolve around the upscaling. The foremost uncertainty relates to the estimation of the market potential. While in recent years the technical feasibility and environmental benefit of manufacturing this new concept has been proved and consumer response has been positive, market uptake is still limited and its future evolution is hard to anticipate. This will, among others, depend on the possibility to move toward large scale manufacturing in order to gain competitiveness vis-à-vis the classical computers. More insights on barriers to exploiting win-wins are provided in more detail in the Final Report.

A second source of uncertainty relates to the replacements effects. In the calculation an average primary energy use of 3675 MJ for a classical computer was employed, while in practice laptops typically fall within a range of 3010-4340 MJ, depending on laptop features. If in practice the eco-laptop would replace mostly laptops on the low end of the range, the results would be overestimated, and vice versa if mostly laptops on the high end would be replaced.

A third important remark is that these are overall figures based on LCA, which do not take into account the geographical dispersion of production activities. As the large majority of computer production is taking place outside of Europe (for illustration: none of the top-6 global computer manufacturers, accounting for about 73% of total sales end 2015, is EU-headquartered), the energy savings realised in Europe will be much lower than global energy savings. Interestingly there is a trade-off between environmental and economic effects, as the environmental gains to be realised in the EU are limited when production is mostly offshore, while potential net economic gains from new eco-friendly production in the EU are higher in these circumstances.

Case 2: use of fermentation residues from biogas plants as raw material for the woodworking industry

The idea behind the case 2 is to separate the residues of biogas production into several parts and valorise them according to their functionalities. In order to calculate the upscaling potential, information on the life cycle analysis of the new application conducted in the context of the demonstration project is used, providing information on the energy/GHG savings compared to existing practices, together with information on total biogas production in the EU [EurObserver 2014]. An important parameter to consider for the upscaling is the size of the biogas plant, as scale is important to make the investment in the new application economical. As due to the pre-commercial stage of development there is little guidance on the required scale, we apply a conservative threshold of 20% of biogas production, which would mean based on data for Germany that only plants with output > 500 KWe would be eligible.

Results indicate that the total saving potential related to EU biogas production amount to 991.7 TJ. The main drivers behind this energy saving are the improved production of fertilisers,

improved biogas yield and use of less energy intensive inputs (waste such as chicken dung) for biogas production.

The context of this upscaling potential needs to be outlined well. As with the ICT case, the main uncertainty regarding this upscaling relates to the relatively early development stage of the new technology. While demonstration activities were positively assessed and commercial investment is being investigated, the diffusion of this new practice (and the minimum scale which will be required for it) is uncertain. A second important remark is that using biogas digestate as flooring material offers only one possible valorisation for the solid part of biogas digestate, as it is a currently poorly valorised source of lignocellulose which could also be used for many other applications, e.g. the production of renewable chemicals and fuels. The outcome is likely to be a mixture of possible valorisation routes, with regional specialisation regarding lignocellulose valorisation in function of local expertise and type of industries present (e.g. flooring industries or chemical industries).

In summary, the two cases provides interesting illustration on how new intersectoral linkages can create energy savings by increasing resourcing efficiency. Given the size of the ICT market, even a relatively minor penetration of new solutions could lead to potentially high energy savings. However, if this potential were to be realised, the overall environmental effect at EU level would not be as high, since manufacturing today largely takes place outside Europe. In the second case, an intersectoral linkage is established as the woodworking sector would use raw materials from the biogas sector. While the energy savings in this case are an order of magnitude smaller compared to the ICT case, they would actually be realised within the EU.

10.4 The contribution of industrial symbiosis to resource- and energy-savings in other sectors

Industrial symbiosis (IS) is a recurring theme that cuts across sectors, creating symbiotic linkages within and between different sectors. Apart from the two above mentioned case studies in the ICT and biogas sector, examples can be found in several other industries. Below we illustrate for the other sectors treated in this report how IS can promote resource- and energy-savings. We start by discussing the relevance of IS for the food, buildings & construction and ferrous sectors. Subsequently, we discuss the special role of the waste (water) management sector, which is a key enabler for IS by making resources turned into waste available again as useful material⁸³⁸⁴.

Food sector

The food sector is important to consider from the point of view of waste generation, because of its size and the perishable nature of its trading product, which causes frequent disposal of food. Part of this disposal is avoidable, as is for example the case for waste generated at the consumer stage, as is analysed in detail above. In addition, also avoidable waste generation take place at other parts of the value chain, e.g. food that is thrown away due to imperfect organisation in the transportation and retail phases, or technical malfunctions in the food manufacturing phase. Other parts of food waste generation are unavoidable as not all crop parts are edible, e.g. carcasses from meat production of peels from fruit processing.

Industrial symbiosis can contribute to valorisation of food waste or by-products, especially when generated at the food manufacturing stage, as at this stage flows can still be relatively homogeneous and available in larger amounts, an important condition for economical valorisation. A number of new applications are emerging that take advantage of the valuable components contained in food waste. For example, food waste streams can be used for the extraction of nutraceuticals, cosmetics, pharmaceuticals, chemicals/materials (e.g. bioplastics), fuels, etc. Of course such efforts should never work against avoiding waste in the first place.

This requires new intersectoral symbiotic linkages to be developed in order to take full advantage of food waste by other industries, in which often an intermediate organisation

⁸³ The ICT sector is not covered as it is already subject of an IS case study in this chapter.

⁸⁴ The sector 'Urban planning including transport' is not discussed as it bears no relation with the industrial symbiosis concept, centred around the exchange of physical resources between different economic actors.

(technology supplier for treating the biomass) need to be involved. Typical areas where these new valorisation routes are being developed today is where agrofood clusters are collocated with other relevant industries (e.g. chemicals, cosmetics, energy).

The example of the integrated production of fish, in land-based aquaculture plants, with the simultaneous cultivation of fruits or vegetables provides another good illustration of industrial symbiosis. Here, the exchange of resources does not concern wasted biological material, but several minerals and CO₂, in addition to heat exchange. However, the characteristic combination of environmental and economic gains through direct resource exchange is also in this case present.

Ferrous sector

Over the last decade, the valorisation of production residuals in the iron and steel industry has gained significant importance. The motivations are not only the care for environment and increased resource efficiency, but creating economic value added as well. In the iron and steel industry one of the most important production residues is slag. According to Bilsen et al. [2015], 85% of the non-scrap metal waste flow in the iron and steel sector is slag, and the remaining 15% consists of dust and sludge. JRC [2014] defines slag as "A vitrified or partially vitrified residue of smelting, containing mostly silicates, the substances not sought to be produced as matte or metal, and having a lower specific gravity than the latter". Eurofer [2016] estimates that every year 45 million tonnes of ferrous slag are generated in the EU. Taking also the sludge and dusts into account and using EUROSILAG's survey data, Bilsen et al. [2015] estimated that in 2010, 54.56 million tonnes of ferrous non-scrap metal waste was generated in the EU28.

Ferrous slags are valorised in various applications. According to EUROSILAG, 87% of the ferrous slags are used for construction applications such as roads, bridges and waterways. Other applications include fertilizer due to silicate contents, and the production of cement. It is worth noting that iron and steel plants have a cost incentive to apply a whole range of techniques to minimise the generation of production residues from the metallurgical process since the valorisation of these residuals is less beneficial than the selling of the main product: iron and steel.

Given the sheer size of ferrous production residuals in the EU, it is worth facilitating and stimulating industrial symbiotic applications. Bilsen et al. [2015] indicated a number of policy options such as 1) fine-tuning relevant regulations, especially the Waste Framework Directive and REACH, 2) harmonising legal specifications, standards and interpretations across Member States, 3) endorse R&D and innovation for new production residual valorisation applications, and 4) use green public procurement as an instrument to create a lead market in new industrial symbiosis products that valorise ferrous non-scrap metal waste. It is evident that the valorisation of ferrous production residuals saves on the use of substitute products and increases resource efficiency. Additionally, due to its specific properties it can improve the features of existing products, e.g. heavy duty infrastructure, and cements. Due to the cost of CO₂ production, through the ETS, and the cost of energy, also in slag valorisation there is a continuous incentive to search for reducing the CO₂ exhaust and for increasing energy efficiency.

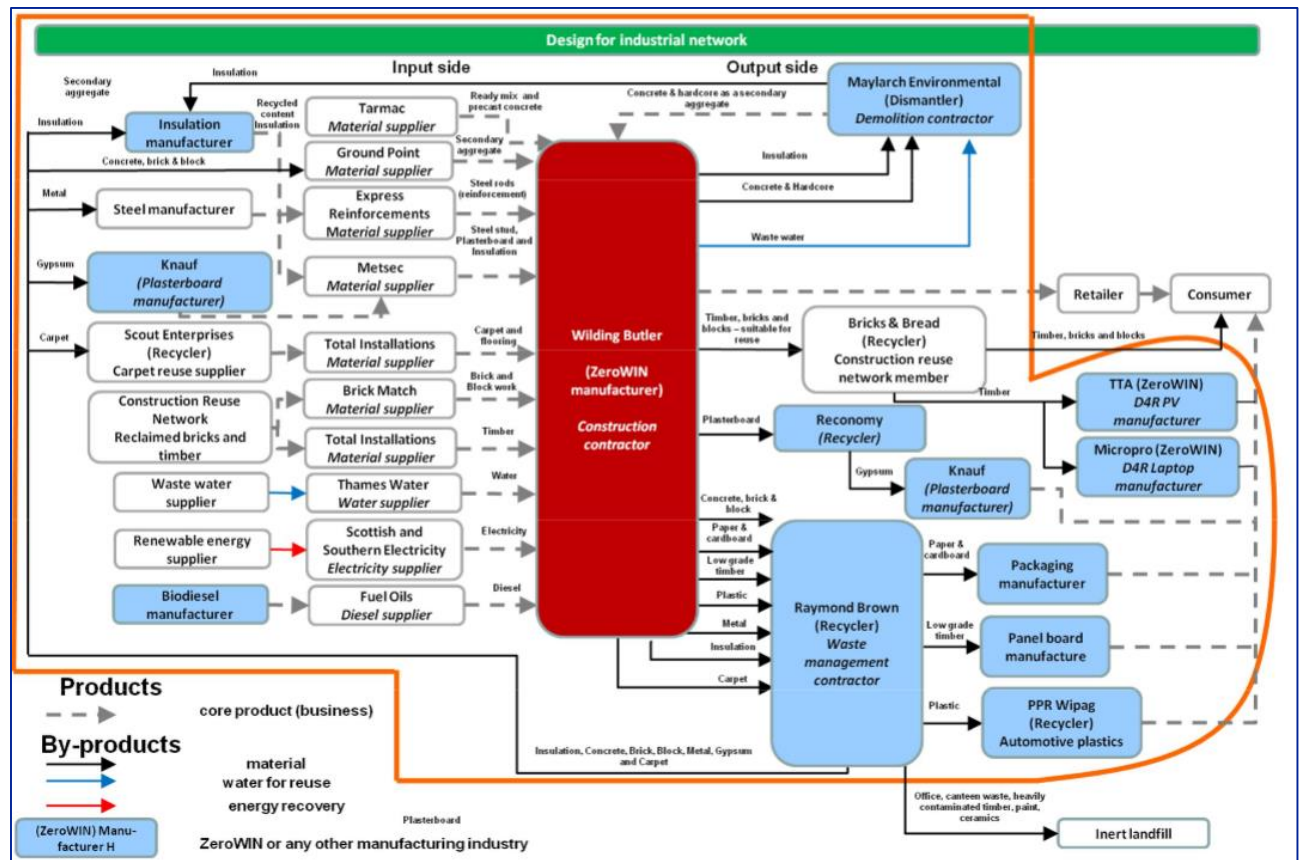
Buildings and construction sector

In chapter 4, the energy savings potential from substituting key inputs in construction and building sector (asphalt, concrete) by alternatives (recycled asphalt, fly ash, hydraulic binders, recycled concretes) is analysed. As with the other sectors, industrial symbiosis can be a key mechanism through which new and more sustainable resource flows and use can be implemented. This is well illustrated by a number of industrial symbioses that deal with construction- and demolition-related waste streams (including but not restricted to asphalt and concrete).

Probably the best documented network in this respect is the Wilding-Butler network in the UK. This industrial network, in which the construction contractor Wilding Butler operates at the centre, has arisen largely due to the ambition of this company to become more sustainable and to market its sustainable character especially towards public clients. In this network, 14 core industrial manufacturers are involved in exchanging resources, of which six core manufacturers were involved in the process of reusing construction and demolition wastes (see Figure 10.4).

The key mineral waste exchanges concerned are plasterboard, waste concrete, brick and block and other reclaimed materials [Bilsen et al. 2015].

Figure 10.4 Overview of the Wilding-Butler network



Source: ZEROWIN.

A defining factor in this market is the importance of transport costs, implying that industrial networks need to be closely integrated in a relatively small area. The economic case for IS initiatives is the strongest in local areas where the building stock is high (densely populated areas) and the supply of virgin materials is low. In these cases, transport costs for recycled materials are minimal and its price can compete with virgin material prices. Also important is that engaging in a network makes it easier to work in a standardised and controllable manner with sustainable materials, while the net economic benefit need not necessarily be high as working with sustainable material flows is also associated with substantial extra cost related to the time invested in managing the material flows [Bilsen et al., 2015].

Solid waste & waste water management sectors

Conceptually, it is possible to distinguish between different definitions of industrial symbiosis in the waste sector:

- The product residuals/waste are reutilised by another company, involving partnerships between companies at a local or regional level, either self-organised, organised by a public body or facilitated by a third party;
- The product residuals/waste sold on the market, involving specialised waste/by-product treatment and handling companies that further supply material content to other companies which use it as input in their production processes.

The first definition centres on the direct exchanges between companies (sometimes perceived as the 'purest' form of industrial symbiosis, and in line with early examples such as Kalundborg) while the latter allows intermediate organisation to play a role in the collection and treatment of waste into new resources. Both types were taken into account in the recently concluded study "Analysis of certain waste streams and the potential of industrial symbiosis to promote waste as a resource for EU industry" [Bilsen et al. 2015], which showed that the second type is prevailing,

while direct exchanges are relatively limited but can give rise to higher value added valorisations.

Given the importance of efficient waste management practices for the (more broadly defined) second type of industrial symbiosis in contrast to the other sectors, it is hence not IS that contributes to the waste management sector, but rather the opposite, the waste management sector being a key enabler for IS. A similar consideration applies to the water waste management sector, making water available again for use in industries.

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Annex 1: Solid Waste Management: Figures

Table A.1.1 Current (2013) recycling quantities (t) in EU28 Member States from MSW and for selected materials

Country	Metals (t)	Glass wastes (t)	Paper and cardboard wastes (t)	Plastic wastes (t)	Wood wastes (t)	Animal and mixed food waste; vegetal wastes (t)
Belgium	59 300	197 600	427 400	48 200	275 000	1 088 000
Bulgaria	37 400	88 600	216 800	95 400	1 000	9 000
Czech Republic	116 300	253 700	627 000	355 200	4 400	149 700
Denmark	349 800	98 100	457 600	29 700	3 000	541 600
Germany	1 844 300	3 012 200	8 556 400	4 119 600	8 100	8 409 400
Estonia	7 000	13 800	37 600	6 000	400	22 100
Ireland	67 600	173 900	462 500	104 500	65 200	223 400
Greece	77 300	50 300	329 700	117 200	33 600	130 600
Spain	153 500	849 100	1 575 200	625 800	202 000	1 130 300
France	1 070 700	2 462 300	1 013 800	1 018 700	n/a	6 132 300
Croatia	31 200	18 600	50 700	11 800	1 400	29 200
Italy	673 500	1 685 700	3 045 600	844 400	684 200	4 204 200
Cyprus	8 600	5 100	43 700	5 400	1 400	28 900
Latvia	14 500	36 900	43 400	30 700	3 200	5 700
Lithuania	97 000	47 200	91 600	9 600	1 400	45 800
Luxembourg	5 000	21 400	35 500	3 600	11 900	71 200
Hungary	295 200	28 500	308 000	40 200	7 100	169 600
Malta	1 600	2 600	9 000	1 900	n/a	10 800
Netherlands	100 200	345 300	1 065 700	77 700	122 900	1 737 000
Austria	94 700	175 800	597 200	119 700	139 900	1 559 600
Poland	141 600	296 800	524 900	158 800	4 100	279 400
Portugal	26 900	167 400	175 000	44 500	6 100	82 600
Romania	6 800	25 800	75 600	32 500	8 300	96 100
Slovenia	22 200	38 000	62 900	19 900	15 200	50 300
Slovakia	12 100	42 600	86 500	43 300	n/a	89 600
Finland	17 500	74 400	308 200	19 200	8 000	286 400
Sweden	195 900	189 600	781 800	66 700	13 700	699 400
United Kingdom	1 375 300	2 321 600	6 228 700	1 002 500	1 550 700	7 929 300
EU28	6903000	12722900	27238000	9052700	3172200	35211500

Note: France, Malta and Slovakia lack data for wood (marked n/a in the table).

Table A.1.2 Theoretical maximum recycling (t) in the EU28 Member states from MSW and for selected materials in 2013

Country (values in t)	Metals	Glass wastes	Paper and cardboard wastes	Plastic wastes	Wood wastes	Animal and mixed food waste; vegetal wastes
Belgium	52 985	169 796	347 408	21 244	9 811	380 516
Bulgaria	0*	98 949	46 480	94 345	12 576	856 551
Czech Republic	23 993	152 857	225 683	92 534	248 458	1 194 465
Denmark	25 225	30 521	288 374	110 115	602	817 294
Germany	697 021	0*	0*	0*	1 423 622	4 258 541
Estonia	12 639	10 606	27 542	30 194	1 447	117 743
Ireland	21 545	95 870	117 209	86 280	0*	412 240
Greece	126 778	191 352	614 987	293 032	226 738	1 826 180
Spain	154 495	199 820	3 304 642	340 911	85 305	5 919 051
France	671 303	1 855 598	5 013 550	1 127 360	n/a	5 259 704
Croatia	20 289	36 894	289 880	182 632	12 730	443 742
Italy	582 645	727 289	3 362 253	1 318 885	516 459	6 482 497
Cyprus	4 379	6 686	48 551	42 731	21 134	169 605
Latvia	19 058	54 323	85 735	22 882	14 993	360 159
Lithuania	23 739	57 015	52 403	68 783	20 118	251 577
Luxembourg	2 258	6 904	20 688	9 537	1 214	41 808
Hungary	67 870	9 084	379 321	298 898	36 859	806 843
Malta	6 853	11 598	28 787	13 744	n/a	95 352
Netherlands	132 824	229 783	517 267	279 713	349 661	1 224 327
Austria	39 274	72 812	88 150	120 193	96 889	0*
Poland	321 033	842 136	1 281 013	707 887	180 325	2 417 564
Portugal	61 477	96 709	394 687	234 748	46 448	1 941 562
Romania	143 056	264 479	544 854	379 204	132 628	3 521 014
Slovenia	36 120	33 363	91 454	35 971	32 084	173 854
Slovakia	55 442	66 069	108 106	72 585	n/a	489 324
Finland	36 892	11 904	302 725	141 164	91 370	479 856
Sweden	1 859	10 106	357 493	123 208	353 119	553 427
United Kingdom	598 276	990 530	3 790 158	1 924 505	300 851	6 594 687
EU28	3939328	6333054	21729400	8173286	4215440	47089483

Note: France, Malta and Slovakia lack data for wood generation (marked n/a in the table) so the potential cannot be estimated.

* Country serves as benchmark, so no additional recycling assumed possible.

Table A.1.3 Theoretical maximum recycling (t) in the EU28 Member states for total waste and for selected materials, estimated as the product of generated quantities and theoretical maximum recycling rates, extrapolated from MSW

Countries (values in t)	Metal wastes, ferrous	Metal wastes, non- ferrous	Glass wastes	Paper and cardboard wastes	Plastic wastes	Wood wastes	Animal and mixed food waste; vegetal wastes
Belgium	1 838 975	433 375	829 324	3 179 206	333 045	3 872 271	4 061 769
Bulgaria	449 791	81 631	60 428	165 558	54 466	185 891	527 568
Czech Republic	2 452 152	162 571	290 460	577 054	177 493	219 626	375 115
Denmark	917 722	73 678	164 966	842 407	58 431	214 210	742 809
Germany	7 885 834	1 096 123	2 761 965	6 722 489	1 379 340	10 816 900	10 715 470
Estonia	385 048	22 129	45 461	77 773	12 377	753 986	31 377
Ireland	181 084	16 330	234 879	325 230	68 817	185 191	1 037 304
Greece	828 499	43 238	69 189	428 570	72 623	111 721	410 106
Spain	3 808 670	559 777	1 054 227	2 956 141	622 991	1 151 566	3 333 284
France	10 402 836	992 637	2 185 104	6 036 139	897 645	5 588 416	9 295 688
Croatia	286 361	17 969	41 381	164 660	21 360	89 670	62 210
Italy	7 886 106	872 802	2 331 195	4 228 514	1 489 769	3 602 500	8 150 906
Cyprus	7 919	13 929	20 614	112 430	40 477	12 918	68 790
Latvia	13 081	6 397	27 195	87 250	11 761	51 418	116 270
Lithuania	284 772	13 445	68 527	101 814	27 602	167 740	396 146
Luxembourg	109 206	5 195	56 391	89 805	14 352	80 701	71 486
Hungary	1 082 213	158 408	145 573	442 196	101 270	223 032	519 170
Malta	4 064	2 526	2 635	8 698	2 379	12 291	12 803
Netherlands	1 160 778	205 192	555 194	1 900 436	332 309	2 375 617	9 598 703
Austria	1 526 501	249 462	284 115	1 512 376	194 920	819 763	1 547 582
Poland	4 423 051	191 610	872 273	932 219	528 545	3 647 229	4 709 584
Portugal	878 759	150 211	574 938	810 602	116 497	760 869	159 620
Romania	1 177 944	42 346	217 460	762 434	353 948	1 900 669	12 199 657
Slovenia	219 934	63 676	41 018	106 674	26 043	312 752	159 165
Slovakia	649 274	28 047	57 752	182 332	58 946	370 103	316 924
Finland	259 542	29 229	132 445	533 180	49 793	11 027 647	817 122
Sweden	2 019 022	218 625	258 472	611 502	95 846	1 081 283	1 352 931
United Kingdom	11 545 799	1 695 133	3 605 262	4 666 151	2 172 811	3 455 380	8 751 160
EU28	62684939	7445691	16988443	38563840	9315853	53091363	79540718

Table A.1.4 Recycled waste (%) in each EU Member State for selected materials, expressed as percentage of generation, including export – imports of waste for recycling (percentages estimated based on “generation” and “recovery other than energy recovery, except backfilling”)

Countries	Metal wastes, ferrous	Metal wastes, non-ferrous	Glass wastes	Paper and cardboard wastes	Plastic wastes	Wood wastes	Animal and mixed food waste; vegetal wastes
Belgium	56%	45%	78%	52%	59%	16%	74%
Bulgaria	127%	70%	48%	89%	68%	25%	7%
Czech Republic	117%	97%	100%	120%	39%	4%	47%
Denmark	135%	138%	116%	125%	105%	61%	63%
Germany	139%	149%	101%	42%	108%	22%	88%
Estonia	90%	77%	60%	71%	170%	51%	55%
Ireland	237%	444%	45%	90%	30%	57%	1%
Greece	104%	98%	73%	101%	45%	21%	60%
Spain	118%	76%	104%	118%	110%	98%	43%
France	101%	79%	84%	95%	38%	66%	56%
Croatia	191%	230%	103%	92%	58%	53%	40%
Italy	78%	93%	76%	114%	55%	79%	55%
Cyprus	1609%	106%	42%	70%	19%	8%	31%
Latvia	-2705%	82%	11%	54%	-421%	14%	45%
Lithuania	169%	73%	110%	16%	7%	32%	30%
Luxembourg	-32%	408%	4%	74%	34%	17%	88%
Hungary	115%	164%	53%	84%	58%	43%	52%
Malta	613%	101%	-1%	120%	20%	0%	0%
Netherlands	349%	126%	86%	122%	71%	38%	95%
Austria	102%	163%	100%	57%	74%	57%	102%
Poland	147%	276%	91%	146%	62%	86%	50%
Portugal	-52%	74%	-5%	85%	42%	18%	55%
Romania	229%	95%	79%	114%	65%	97%	77%
Slovenia	224%	114%	125%	167%	196%	12%	53%
Slovakia	78%	72%	37%	113%	-59%	66%	64%
Finland	128%	246%	159%	98%	42%	23%	104%
Sweden	117%	61%	62%	110%	-66%	5%	69%
United Kingdom	110%	111%	68%	192%	81%	45%	55%
EU28	115%	110%	80%	100%	70%	42%	68%

Source: retrieved from Eurostat on 25 July 2015.

Note: trade statistics for waste wood is missing and not included in the table.

Table A.1.5 Assumptions around the estimation of resource savings from recycling selected materials

Material	Primary Production	Recycling	Net emissions	Other assumptions
Metal waste, ferrous	steel production, converter, low-alloyed steel, low-alloyed APOS, U (RER)	steel production, electric, low-alloyed steel, low-alloyed APOS, U (RER).	Calculated as Recycling – Primary (substitution ratio assumed 1:1).	Steel from converter and from electric arc furnace have the geographical scope Europe.
Metal waste, non-ferrous	aluminium ingot, primary, to aluminium, cast alloy market aluminium, cast alloy APOS, U (GLO).	treatment of aluminium scrap, new, at refiner aluminium, cast alloy APOS, U (RER).	Calculated as Recycling – Primary (substitution ratio assumed 1:1).	Primary aluminium production has a global geographical scope. The aluminium recycling's geographical scope is Europe.
Glass wastes	packaging glass production, white, without cullet packaging glass, white APOS, U (GLO).	packaging glass production, white packaging glass, white APOS, U (RER w/o CH + DE).	Calculated as Recycling*0,6 (40 % virgin material in production) – Primary (substitution ratio assumed 1:1).	The primary glass process has a global geographical scope, while recycling is from Europe.

Material	Primary Production	Recycling	Net emissions	Other assumptions
Paper and cardboard wastes	Primary production assumed 55% information (graphic) and 45% packaging paper (JRC, 2011). The reference report includes 12% of total other types of papers but these are ignored due to lack of environmental data. Final data for primary production calculated as $0.55 \cdot (0.5 \cdot \text{paper production, newsprint, virgin} \mid \text{paper, newsprint} \mid \text{APOS, U (RER)}) + 0.5 \cdot \text{market for paper, woodcontaining, lightweight coated} \mid \text{paper, woodcontaining, lightweight coated} \mid \text{APOS, U (RER)} + 0.45 \cdot \text{linerboard production, kraftliner} \mid \text{linerboard} \mid \text{APOS, U (RER)})$.	$0.55 \cdot (0.5 \cdot \text{paper production, newsprint, recycled} \mid \text{paper, newsprint} \mid \text{APOS, U (RER w/o CH)} + 0.5 \cdot \text{graphic paper production, 100\% recycled} \mid \text{graphic paper, 100\% recycled} \mid \text{APOS, U (RER)}) + 0.45 \cdot \text{treatment of recovered paper to linerboard, testliner} \mid \text{linerboard} \mid \text{APOS, U (RER)}$	Calculated as Recycling – Primary (substitution ratio assumed 1:1).	All processes have an European geographical scope.
Plastic wastes	Production of primary plastics (global scope): PE-LD, PE-HD, PP, PET, PS, EPS, PVC, PUR. All as market processes. Mix from waste composition from Consultic, 2015.	Energy consumption for the recycling of plastics 0,7 kWh/kg from market group for electricity, high voltage electricity, high voltage APOS, U (RER w/o CH).	Calculated as Recycling – Primary*0,64 (substitution ratio assumed 1:1).	The primary processes have a global geographical scope. The electricity for recycling is an European mix without Switzerland.
Wood wastes	particle board production, for indoor use, from virgin wood particle board, for indoor use APOS, U (RoW).	particle board production, for indoor use particle board, for indoor use APOS, U (RER).	Calculated as Recycling – Primary (substitution ratio assumed 1:1).	Geographical scope for wood chips from market is Europe, while the recycling process is globally.

Material	Primary Production	Recycling	Net emissions	Other assumptions
Animal and mixed food waste; vegetal wastes	market for peat peat APOS, U (GLO).	market for compost compost APOS, U (GLO).	Calculated as Recycling – (Primary /0,52*0,1125) Peat has a carbon content of 52 %, compost of 11,25 %. The results for peat are scaled down to the carbon content of compost.	Peat production and biowaste treatment have a global geographical scope.

Source: Ecoinvent database, version 3.2 APOS, calculating software openLCA, used methods: CED (cumulative energy demand) for energy savings, land use in kg SOC (soil organic carbon) from ILCD 2011 midpoint for land savings, climate change from ReCiPe midpoint H for CO₂ savings.

Source for plastic waste composition [Consultic 2015]

http://events.bvse.de/sites/default/files/events/talks/2_LindnerVortrag_bvse_10062015%20%282%29.pdf.

Source for Animal and mixed food waste; vegetal waste: Carbon content peat: [Lindsay 2010] Lindsay, R.: Peatbogs and carbon: a critical synthesis to inform policy development in oceanic peat bog conservation and restoration in context of climate change. London 2010. Carbon content compost: [Bulach 2015] Bulach, W.: Stoffstrommanagement biogener Haushaltsabfälle – Ein Vergleich der Verwertungswege mittels Ökobilanz und Ökoeffizienzbewertung. Dissertation. Darmstadt 2015.

Note: Table cells for primary production and recycling indicate the name of the Ecoinvent process used for the calculations and the geographical location (RER=Europe, GLO=Global, CH=Switzerland, DE=Germany, RoW = Rest of World). Note on Animal and mixed food waste; vegetal wastes: The carbon emission that result from using peat (2 kg CO₂/kg peat) are not considered. Also the avoided emissions (methane) from not treating these wastes (like dumping in landfill) are also not considered. With these emissions, the potential for avoided CO₂-emissions would significantly rise by 1-2 orders of magnitude.

General Assumptions: Market-based processes preferred, as these also reflect import/export to the respective geographical area; the used processes' geographical scope, when assessing materials traded as global commodities, is global, unless there is no data available. In the latter case, European data is used.

Annex 2: (Waste) Water Management: Figures and data

The following data were collected from Eurostat:

- Agricultural sector: Water abstraction for agriculture;
- Industries: Water abstraction for manufacturing industry; Public water supply - Manufacturing and Self and other water supply - Manufacturing; Generation of wastewater - Manufacturing industries total;
- Public Water System: Water abstraction for public water supply; current losses during transport – total;
- Domestic sector: Public water supply - Households; Public water supply - Services; Self and other water supply - Households; Self and other water supply - Services; Generation of wastewater - Domestic sources - total; Percentage of population connected to an urban wastewater treatment plant / to a primary treatment plant / to a secondary treatment plant / to a tertiary treatment plant;
- Global level: Net water abstraction; Proportion of Fresh surface water in Fresh surface and groundwater abstraction; Total water available from desalinated water; Total water available from reused water.

For leakage in PWS, additional data were obtained from recent OECD reports available for some EU MS.

Figure A.2.1 Current water abstraction volumes per capita for various sectors, EU28

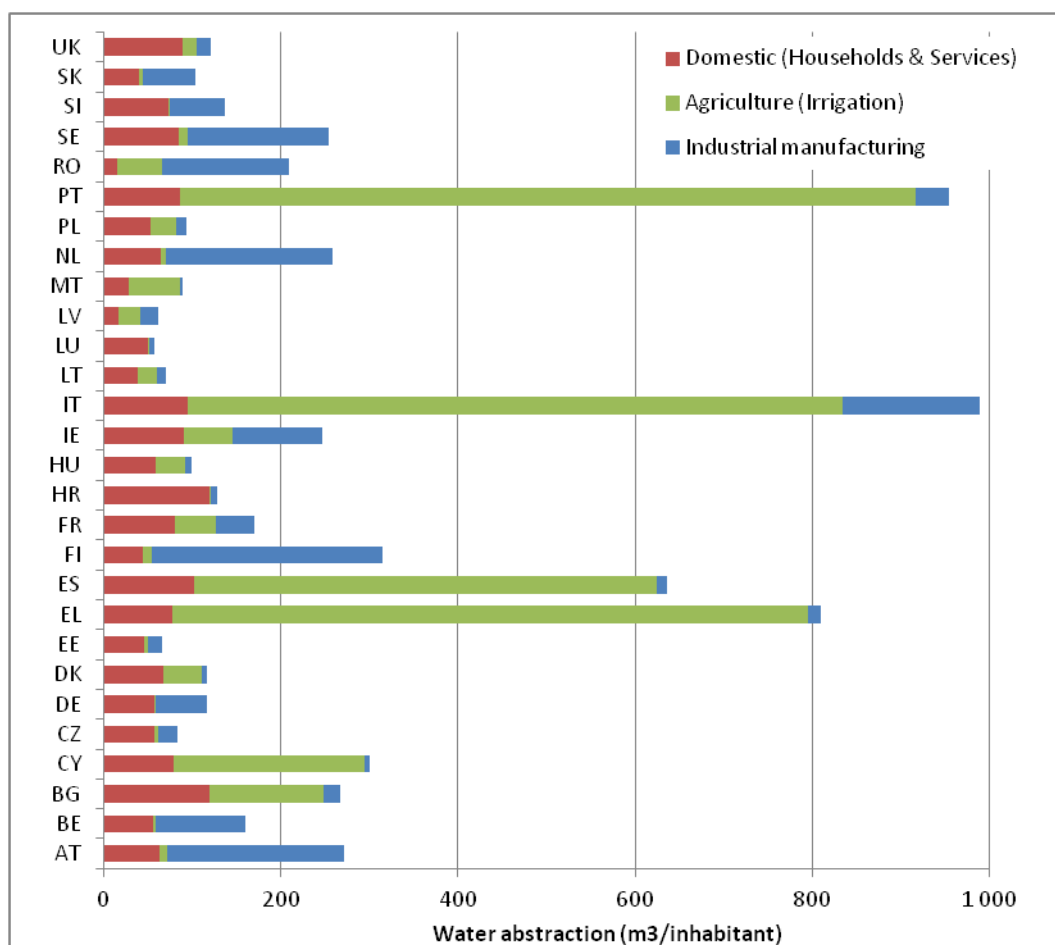


Figure A.2.2 Share of water-related energy consumption between activities over all sectors, EU28

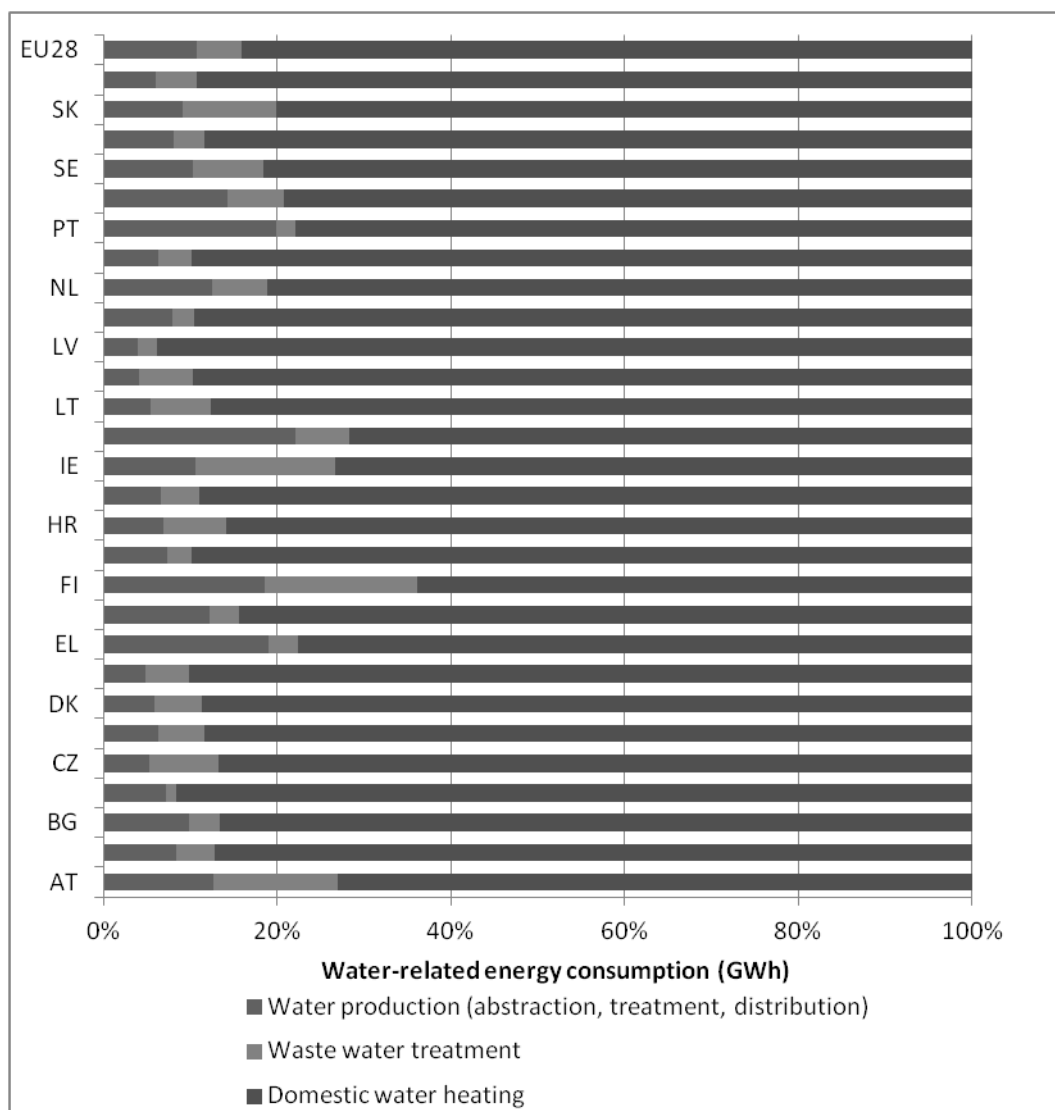
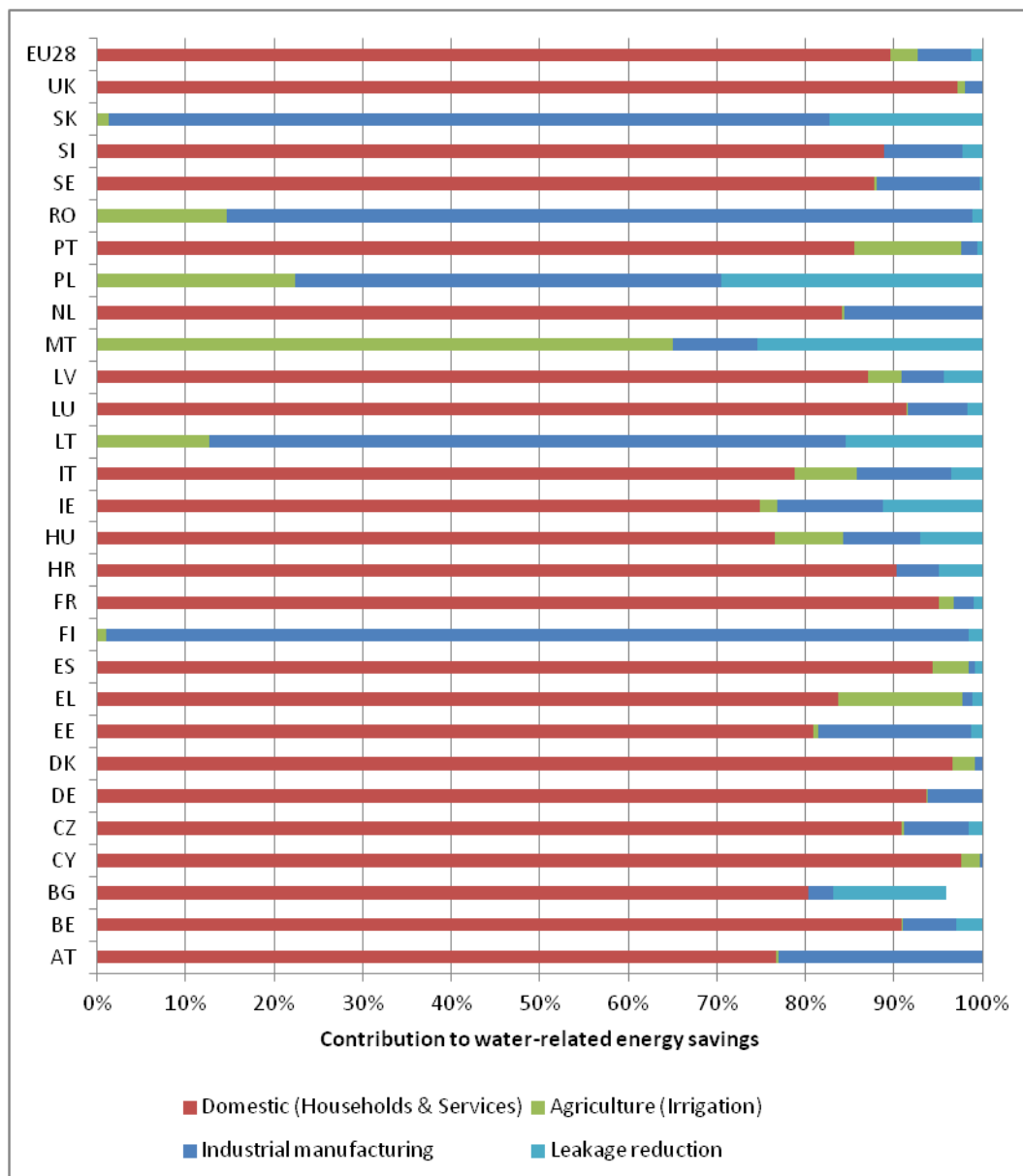


Figure A.2.3 Contribution of each sector to water-related energy savings, EU28



Annex 3: Water savings: Estimation methodology

Potential water saving was estimated following the main assumptions developed in the EU water-saving potential, 2007 (Ecologic for the European Commission) for each sector.

Agricultural sector

To address the water-savings potential in agriculture, water savings that can be achieved due to technical measures assuming that crop patterns remain stable must be distinguished from water saving that would originate from changing crop patterns.

Water consumption is the portion of water directly used by the plants that is poured onto a field (also named crop-water requirement). As cropping patterns are supposed to be constant, crop-water consumption is also constant. Water that needs to be conveyed to the plant depends on the irrigation method and its application efficiency. The global application efficiency for a country will depend on the relative importance of the different irrigation methods. The volumes of water that need to be abstracted will also depend on the conveyance efficiency of irrigation systems (i.e. the amount of water lost during transport). Thus, water saving in the agriculture sector can result from improvements in either or both conveyance and application efficiency.

For this study's calculations, current conveyance efficiency and optimum target conveyance efficiency for each country were considered equal to those estimated by Ecologic in 2007, i.e. values between 70% and 90% currently and a target for all countries of 90%. Application efficiency depends on the irrigation method⁸⁵. Using Ecologic 2007 data and data on irrigated area and shares between irrigation methods, an average plant requirement could be estimated for each country. It can be calculated with the following equation:

$$(1) A_{\text{current}} = \text{IrA} \times \text{IWR}_{\text{current}} / \text{Ec}_{\text{current}} \times (\% \text{ surf gravity}_{\text{current}} / \text{Ea gravity} + \% \text{ surf sprinkler}_{\text{current}} / \text{Ea sprinkler} + \% \text{ surf drop}_{\text{current}} / \text{Ea drop})$$

With

A_{current} the current water abstraction for irrigation based on Eurostat

$\text{IWR}_{\text{current}}$ the average Irrigation Water requirements of crops

IrA the current Irrigated area based on Eurostat

Ea : Current Application efficiency

Ec : Current conveyance efficiency

$\% \text{ surf } X_{\text{current}}$: Percentage of the total irrigated area irrigated with method X

Once the average plant requirement is estimated, the optimum water abstraction for irrigation can be calculated using the same equation, considering a target share of irrigation methods for each country. As drip irrigation cannot be applied to all crops and the current share between irrigation methods can be considered to define final conveyance efficiency targets, the following assumptions were made, similar to the ones proposed for the earlier 2007 study:

- For countries from Central & Eastern Europe and Western & Northern Europe, the relative shares of irrigation areas under gravity, sprinkler and drip irrigation were estimated as 0%, 95% and 5% respectively. If the current share of drip irrigation was higher than 5%, the target was adapted to the closest higher proportion (e.g. 7% as current share to 10% as target), and for Bulgaria and Lithuania surface irrigation target was fixed to 5% to take into account the large proportion of gravity irrigation today;

⁸⁵ Application efficiency values considered are the following: Surface irrigation 60%; Sprinkler irrigation 75%; Drip irrigation 90%.

- For countries from Southern Europe, the relative shares of irrigation areas under gravity, sprinkler and drip irrigation were estimated as 5%, 70% and 25%, respectively (to account for the larger share of vegetables and orchards for which drip irrigation is used). When the current share of drip irrigation is already higher than the 25% value, the target was adapted to the closest higher proportion. For France, the values of 5%, 85% and 10% were respectively chosen for gravity, sprinkler and drop irrigation, to account for the specific characteristics of the country⁸⁶.

Water-saving potential for the agricultural sector can therefore be calculated as the difference between current water abstraction and optimum water abstraction.

Industry

The current water saving potential in the industry section varies highly from one sub-sector to the other. Based on a literature review and several case studies, the 2007 study proposed average saving potential for the following sub-sectors: food products and beverages, textiles, paper, chemicals and manufacturing industries in general. Knowing the share of water abstraction between those sub-sectors plus metal, equipment and other manufacturing (available from Eurostat), the figures summarized in the table below were used. General manufacturing industry values were used for metals, equipment and other.

Table A.3.1 Estimated water-savings potential per industrial sub-sector

Industrial sub-sector	Water saving potential
Other manufacturing	45%
Food products and beverages	35%
Textiles	40%
Paper	45%
Chemicals	53%
Metals	45%
Equipment	45%

Source: Own compilation from Eurostat Database and Ecologic, 2007.

Although equipment level of water saving devices could be highly variable from one industry plant to another; a simplification is made considering that the water saving potential already take into account this variability.

Once the potential saving in water abstraction is estimated, the potential saving in the volume of waste water treated is estimated as the volume of water abstracted with savings multiplied by the current ratio of treated waste water on abstracted water for each country.

Domestic sector

Households and services use water for various activities (washing, cooking, drinking), among which some require hot water and thus water heating. As it would be too complicated to estimate total household water-saving potential considering water-saving potentials of each individual device or household activity, two methods of calculation were tested.

Case 1 (technical progress and changes in behaviour):

Water-saving potentials are based on a target water demand per capita compared to current water demand per capita in each country. The target domestic water demand of 100 l/p/d, as recommended in the Water-saving potential study of 2007, was also used for the present study. For all countries for which domestic water demand is already below this target value, the target was set to the current water demand. Based on these targets, an optimum domestic water demand was estimated based on the population of each country. Domestic water-saving

⁸⁶ France is a country with characteristics (in climate, cropping pattern, etc.) of Southern Europe and Northern Europe countries.

potential for water demand was then calculated as the difference between the current water demand and the optimum water demand.

Case 2 (only technical progress):

A unique water-saving potential in the domestic sector through most efficient technologies (and with no changes in behaviour) for all MS was considered, equal to 10% of current water demand, as recommended in the Study for the Amended Ecodesign Working Plan (2011).

Cases 1 & 2:

As mentioned previously, a third of the domestic water demand required to be heated, allowing the calculation of hot water-saving potential estimates.

Once the water-saving potential is estimated, water savings were translated into changes in water abstraction for the domestic sector, proportionally to the ratio between current water supply and current water abstraction for the domestic sector. Similarly, water-saving potential were translated into volumes of wastewater to be treated, i.e. by applying to estimated water demand the ratio between current urban waste water treated and current water demand for the domestic sector of each individual MS.

Public water systems

Water savings in consumption from PWS were already discussed with the industry and domestic sector investigations presented above. However, reductions in leakages and improvements in conveyance efficiency in PWS networks represent other means to conserve water and thus energy. According to OECD environmental reports, a target leakage rate for European countries could be of 15%. Knowing current abstraction for PWS and current leakage rate, the water lost during transport could be calculated. The comparison between the 15% target rate and current leakage rates helps to estimate the volume of water losses after savings (in consumption and in conveyance) as a means to estimate the supplementary water-saving potential in PWS.

Annex 4: Building and road construction: Figures

Table A.4.1 Average production of asphalt in Mt

Countries (in Mt)	Average production 2008-2013	Available reclaimed asphalt	Ratio RA/production
Austria	8	1	9%
Belgium	5	2	29%
Croatia	3	1	20%
Czech Republic	6	1	23%
Denmark	3	1	23%
Estonia	1	0	20%
Finland	5	1	17%
France	38	7	18%
Germany	47	12	24%
United Kingdom	21	5	21%
Greece	5	0	0%
Hungary	3	0	4%
Ireland	2	0	6%
Italy	29	10	35%
Latvia	1	0	20%
Lithuania	2	0	20%
Luxembourg	1	0	46%
Netherlands	10	5	47%
Poland	19	4	20%
Portugal	7	1	20%
Romania	4	0	1%
Slovakia	2	0	1%
Slovenia	2	0	2%
Spain	30	0	1%
Sweden	8	1	11%
Countries with RC-data	224	44	20%
EU28 minus Bulgaria, Cyprus, Malta	261	51	0%

Sources: EAPA 2014, own calculations.

Table A.4.2 Existing road network under asphalt pavement, in 1 000 km

Country (in 1000km)	Highway	Motorway	State road	Municipal road	Sum
Belgium	2	12	1	83	98
Bulgaria	0	17	0	0	18
Denmark	1	2	0	42	45
Germany	12	35	160	270	477
Estonia	0	15	22	11	48
Finland	1	70	0	18	88
France	10	9	340	400	759
Greece	1	0	0	24	25
Ireland	1	4	10	47	63
Italy	6	18	138	44	206
Croatia	1	6	9	5	21
Latvia	0	18	27	5	50
Lithuania	0	19	55	0	75
Luxembourg	0	1	2	0	3
Malta	0	0	0	0	0
Netherlands	2	1	6	73	82
Austria	2	9	21	0	32
Poland	1	17	138	145	302
Portugal	3	0	54	0	57
Romania	1	15	32	19	67
Sweden	2	14	75	28	118
Slovakia	0	3	3	21	28
Slovenia	1	5	0	19	25
Spain	13	14	62	40	129
Czech Republic	1	6	44	45	95
Hungary	1	27	153	0	182
United Kingdom	3	8	34	206	252
Cyprus	0	5	2	3	10
EU28 sum	65	350	1390	1550	3356

Table A.4.3 Yearly construction under asphalt pavement, in 1 000 km

Countries (in 1000km)	Highway	Motorway	State road	Municipal road	Sum
Belgium	0.0	0.1	0.0	0.3	0.3
Bulgaria	0.0	0.0	0.0	0.0	0.0
Denmark	0.0	0.2	0.0	0.6	0.8
Germany	0.1	0.0	0.0	0.0	0.1
Estonia	0.0	0.0	0.5	0.0	0.5
Finland	0.0	0.0	0.0	0.3	0.3
France	0.1	0.0	0.1	4.0	4.2
Greece	0.0	0.0	0.0	0.0	0.0
Ireland	0.1	0.0	0.0	0.0	0.1
Italy	0.0	0.3	0.2	1.1	1.5
Croatia	0.0	0.0	0.0	0.0	0.1
Latvia	0.0	0.0	0.0	0.0	0.0
Lithuania	0.0	0.0	0.4	0.0	0.4
Luxembourg	0.0	0.0	0.0	0.0	0.0
Malta	0.0	0.0	0.0	0.0	0.0
Netherlands	0.0	0.0	0.0	0.1	0.1
Austria	0.0	0.0	0.0	0.0	0.0
Poland	0.1	0.1	0.0	2.4	2.5
Portugal	0.0	0.0	0.0	0.0	0.0
Romania	0.0	0.7	0.0	0.2	1.1
Sweden	0.0	0.0	0.0	0.4	0.4
Slovakia	0.0	0.0	0.0	0.0	0.0
Slovenia	0.0	0.0	0.0	0.0	0.0
Spain	0.4	0.0	0.0	0.0	0.4
Czech Republic	0.0	0.0	0.0	0.0	0.0
Hungary	0.1	0.0	0.4	0.0	0.5
United Kingdom	0.0	0.0	0.0	0.5	0.5
Cyprus	0.0	0.0	0.0	0.1	0.1
EU28 sum	1.1	1.5	1.6	9.9	14.0

Table A.4.4 Calculated asphalt demand from road renewal, in Mt/yr

Countries (in Mt/yr)	Highway	Motorway	State road	Municipal road	Sum
Belgium	1	2	0	2	5
Bulgaria	0	3	0	0	3
Denmark	1	0	0	1	2
Germany	6	6	10	6	29
Estonia	0	3	1	0	4
Finland	0	12	0	0	13
France	5	2	22	10	38
Greece	0	0	0	1	1
Ireland	0	1	1	1	3
Italy	3	3	9	1	16
Croatia	1	1	1	0	2
Latvia	0	3	2	0	5
Lithuania	0	3	4	0	7
Luxembourg	0	0	0	0	0
Malta	0	0	0	0	0
Netherlands	1	0	0	2	3
Austria	1	2	1	0	4
Poland	1	3	9	3	16
Portugal	1	0	3	0	5
Romania	0	3	2	0	6
Sweden	1	2	5	1	9
Slovakia	0	1	0	1	1
Slovenia	0	1	0	0	2
Spain	7	2	4	1	14
Czech Republic	0	1	3	1	5
Hungary	1	5	10	0	15
United Kingdom	2	1	2	5	10
Cyprus	0	1	0	0	1
EU28 sum	33	61	89	37	220

Table A.4.5 Calculated asphalt demand for new roads, in Mt/yr

Countries (in Mt/yr)	Highway	Motorway	State road	Municipal road	Sum
Belgium	0.0	0.5	0.0	0.5	1
Bulgaria	0.3	0.1	0.0	0.0	0
Denmark	0.1	1.4	0.0	1.0	2
Germany	0.9	0.0	0.0	0.0	1
Estonia	0.1	0.0	2.0	0.0	2
Finland	0.2	0.0	0.0	0.5	1
France	1.2	0.0	0.3	7.2	9
Greece	0.0	0.0	0.0	0.0	0
Ireland	0.9	0.0	0.0	0.0	1
Italy	0.2	1.7	0.8	1.9	5
Croatia	0.5	0.1	0.0	0.0	1
Latvia	0.0	0.0	0.0	0.1	0
Lithuania	0.0	0.0	1.5	0.0	1
Luxembourg	0.0	0.0	0.0	0.0	0
Malta	0.0	0.0	0.0	0.0	0
Netherlands	0.1	0.0	0.0	0.1	0
Austria	0.1	0.0	0.0	0.0	0
Poland	1.2	0.6	0.0	4.2	6
Portugal	0.6	0.0	0.0	0.0	1
Romania	0.5	4.9	0.1	0.4	6
Sweden	0.3	0.0	0.1	0.7	1
Slovakia	0.1	0.1	0.0	0.0	0
Slovenia	0.4	0.1	0.0	0.0	0
Spain	5.0	0.0	0.0	0.0	5
Czech Republic	0.0	0.0	0.0	0.0	0
Hungary	1.2	0.0	1.6	0.0	3
United Kingdom	0.0	0.0	0.1	0.9	1
Cyprus	0.0	0.0	0.0	0.2	0
EU28 sum	14	9	7	18	48

Table A.4.6 Comparison of asphalt demand results top-down and bottom-up, in Mt/yr

Countries (in Mt/yr)	Top-Down	Bottom-Up all	Bottom-Up renewal	Bottom-Up new
Austria	8.2	3.8	3.7	0.1
Belgium	5.2	5.9	5.0	0.9
Croatia	3.0	2.9	2.3	0.6
Czech Republic	6.2	5.2	5.2	0.0
Denmark	3.4	4.4	1.9	2.5
Estonia	1.2	6.4	4.3	2.1
Finland	5.0	13.6	13.0	0.7
France	38.4	46.9	38.1	8.8
Germany	47.2	41.2	35.0	6.2
United Kingdom	21.2	11.2	10.2	1.0
Greece	4.8	1.1	1.1	0.0
Hungary	2.5	18.1	15.2	2.8
Malta	n.A.	0.0	0.0	0.0
Ireland	2.3	3.8	2.9	0.9
Italy	29.0	20.7	16.1	4.6
Latvia	0.6	5.0	5.0	0.0
Lithuania	1.6	8.5	7.0	1.5
Luxembourg	0.7	0.3	0.3	0.0
Netherlands	9.5	3.4	3.4	0.0
Bulgaria	n.A.	3.6	3.2	0.3
Poland	19.5	22.1	16.1	6.0
Portugal	7.3	5.4	4.8	0.6
Romania	3.5	11.5	5.5	6.0
Slovakia	2.0	1.7	1.5	0.3
Slovenia	1.7	2.2	1.8	0.4
Spain	29.6	19.0	14.0	5.0
Sweden	8.0	9.8	8.7	1.1
Cyprus	n.A.	1.2	1.2	0.0
EU28 sum	261	279	227	52

Table A.4.7 Current asphalt production and reclaimed asphalt as well as identified potentials for current best practice country and best available technology, in Mt/yr

Countries (in Mt/yr)	Present production	RA currently	portion down- cycled	RA potential best- practice country	RA potential best available technology
Austria	8.2	0.8	0.0	4.2	6.9
Belgium	5.2	1.5	0.6	2.3	4.1
Croatia	3.0	0.6	0.3	1.3	2.3
Czech Republic	6.2	1.5	0.8	3.3	5.3
Denmark	3.4	0.8	0.1	0.8	1.4
Estonia	1.2	0.2	0.1	0.4	0.8
Finland	5.0	0.9	0.4	2.5	4.3
France	38.4	6.9	2.5	16.5	29.7
Germany	47.2	11.5	1.2	21.2	38.1
United Kingdom	21.2	4.5	2.0	10.2	18.0
Greece	4.8	0.0	0.0	2.5	4.1
Hungary	2.5	0.1	0.0	1.1	2.0
Malta	0.0	0.0	0.0	0.0	0.0
Ireland	2.3	0.2	0.1	0.9	1.7
Italy	29.0	10.0	8.0	11.9	21.4
Latvia	0.6	0.1	0.1	0.3	0.5
Lithuania	1.6	0.3	0.1	0.7	1.2
Luxembourg	0.7	0.3	0.0	0.3	0.6
Netherlands	9.5	4.5	1.1	5.0	8.1
Bulgaria	3.6	0.7	0.3	1.7	3.1
Poland	19.5	3.9	1.7	7.5	13.4
Portugal	7.3	1.5	0.7	3.5	6.2
Romania	3.5	0.0	0.0	0.9	1.6
Slovakia	2.0	0.0	0.0	0.9	1.6
Slovenia	1.7	0.0	0.0	0.7	1.3
Spain	29.6	0.2	0.0	11.5	20.7
Sweden	8.0	0.9	0.1	3.8	6.8
Cyprus	1.2	0.2	0.1	0.6	1.0
EU28	266.3	52.0	20.3	116.6	206.0

Table A.4.8 Cumulative raw-material demand (CRD) for current situation, best practice country and best available technique, in Mt/y

Countries (in Mt/yr)	Current Situation			RA potential best practice country			RA potential best available technique		
	new	rec.	su m	new	rec.	sum	new	rec.	sum
Austria	8	0	8	4	2	6	1	3	4
Belgium	5	0	5	3	1	4	1	2	3
Croatia	3	0	3	2	1	2	1	1	2
Czech Republic	6	0	6	3	1	5	1	2	3
Denmark	3	0	3	3	0	3	2	1	3
Estonia	1	0	1	1	0	1	0	0	1
Finland	5	0	5	3	1	4	1	2	3
France	37	2	39	24	7	31	10	13	22
Germany	40	4	45	28	9	38	10	16	26
United Kingdom	20	1	22	12	4	16	3	8	11
Greece	5	0	5	2	1	4	1	2	3
Hungary	3	0	3	2	0	2	1	1	1
Malta	0	0	0	0	0	0	0	0	0
Ireland	2	0	2	2	0	2	1	1	1
Italy	30	1	30	19	5	24	8	9	18
Latvia	1	0	1	0	0	0	0	0	0
Lithuania	2	0	2	1	0	1	0	1	1
Luxembour g	0	0	1	0	0	0	0	0	0
Netherlands	7	1	8	5	2	7	2	3	5
Bulgaria	3	0	4	2	1	3	1	1	2
Poland	19	1	20	13	3	16	7	6	12
Portugal	7	0	7	4	1	6	1	3	4
Romania	4	0	4	3	0	3	2	1	3
Slovakia	2	0	2	1	0	2	0	1	1
Slovenia	2	0	2	1	0	1	0	1	1
Spain	32	0	32	20	5	25	10	9	19
Sweden	8	0	8	5	2	6	1	3	4
Cyprus	1	0	1	1	0	1	0	0	1
EU28	257	14	270	164	50	214	66	89	155

Table A.4.9 Cumulative energy demand (CED) for current situation, best practice country and best available technique, in PJ/yr

	Current Situation			RA potential best practice country			RA potential best available technique		
Countries (in PJ/yr)	new	rec.	sum	new	rec.	sum	new	rec.	sum
Austria	47	2	49	25	14	38	8	23	30
Belgium	27	3	30	18	8	26	7	14	20
Croatia	17	1	18	11	4	15	5	7	12
Czech Republic	35	2	37	18	11	29	6	17	23
Denmark	17	2	19	16	3	19	12	5	17
Estonia	7	0	7	5	1	6	3	3	5
Finland	29	2	30	16	8	24	5	14	19
France	214	15	228	138	54	192	55	98	153
Germany	231	34	265	163	70	233	57	125	182
United Kingdom	117	8	126	69	33	103	20	59	79
Greece	30	0	30	14	8	22	4	13	18
Hungary	15	0	15	9	4	12	3	7	10
Malta	0	0	0	0	0	0	0	0	0
Ireland	14	0	14	9	3	12	4	6	9
Italy	169	7	176	107	39	146	48	70	118
Latvia	3	0	4	2	1	3	1	2	2
Lithuania	9	1	9	6	2	8	2	4	6
Luxembourg	2	1	3	2	1	3	1	2	2
Netherlands	38	11	50	28	17	45	9	27	36
Bulgaria	20	1	21	12	6	17	3	10	13
Poland	109	7	116	75	25	100	38	44	82
Portugal	41	3	44	24	11	36	7	20	27
Romania	22	0	22	16	3	19	12	5	17
Slovakia	12	0	12	7	3	10	2	5	8
Slovenia	11	0	11	6	2	9	3	4	7
Spain	185	1	185	114	38	152	56	68	124
Sweden	45	3	48	27	12	39	8	22	30
Cyprus	7	0	7	3	2	6	1	3	4
EU28	1 473	104	1 577	940	383	1 323	378	677	1 056

Annex 5: Urban planning and modal shift: Figures

Table A.5.1 Number of modal split datasets for each cluster

Number of inhabitants in city/ urban area	Number of available modal-split datasets				
	Mediterranean	Atlantic	Central Europe	Continental	Sum
100,000 to <250,000	20	57	75	15	167
250,000 to <500,000	9	22	26	3	60
>=500,000	14	20	28	4	66
Sum	43	99	129	22	293

Table A.5.2 Sum of inhabitants per cluster, in millions

Number of inhabitants in city/ urban area	Sum of inhabitants (millions)				
	Mediterranean	Atlantic	Central Europe	Continental	Sum
100,000 to <250,000	3.6	9.0	11.9	2.2	26.7
250,000 to <500,000	3.1	7.7	8.8	1.0	20.6
>=500,000	22.7	29.2	28.3	3.8	83.9
Sum	29.4	45.9	48.9	7.0	131.2

Source: TEMS datasets.

Table A.5.3 Upscaling factors and population for different city sizes within the scenario analysis and in the EU

Number of inhabitants in city/ urban area	Analysed	Total	Upscaling factor
100,000 to <250,000	27	55	2.1
250,000 to <500,000	21	39	1.9
>=500,000	84	96	1.1
Sum	131	190	

Source: Eurostat: Population on 1 January by age groups and sex - cities and greater cities [urb_cpop1], most actual year, own calculations.

Figure A.5.1 TEMS modal split data of the examined cities with 100,000 to 250,000 inhabitants

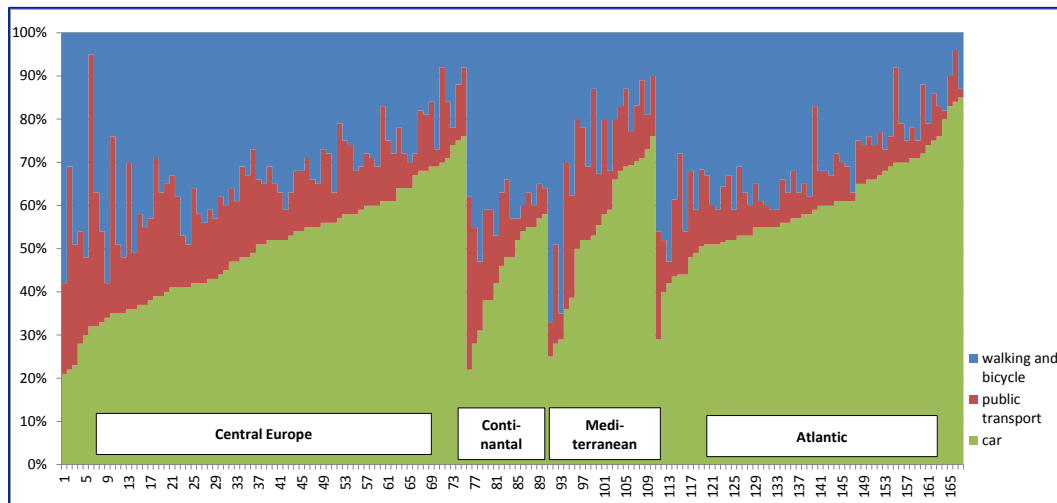


Figure A.5.2 TEMS modal split data of the examined cities with 250,000 to 500,000 inhabitants

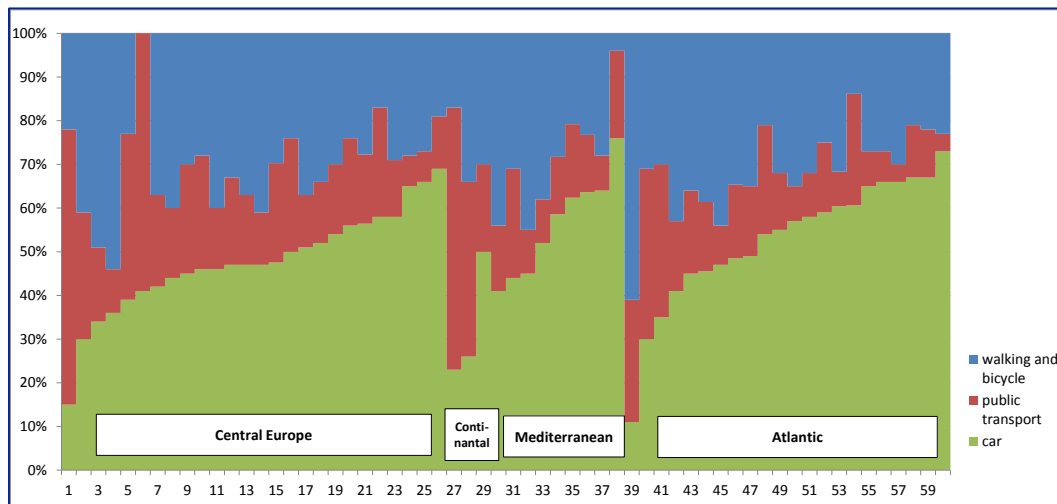


Figure A.5.3 TEMS modal split data of the examined cities with >500,000 inhabitants

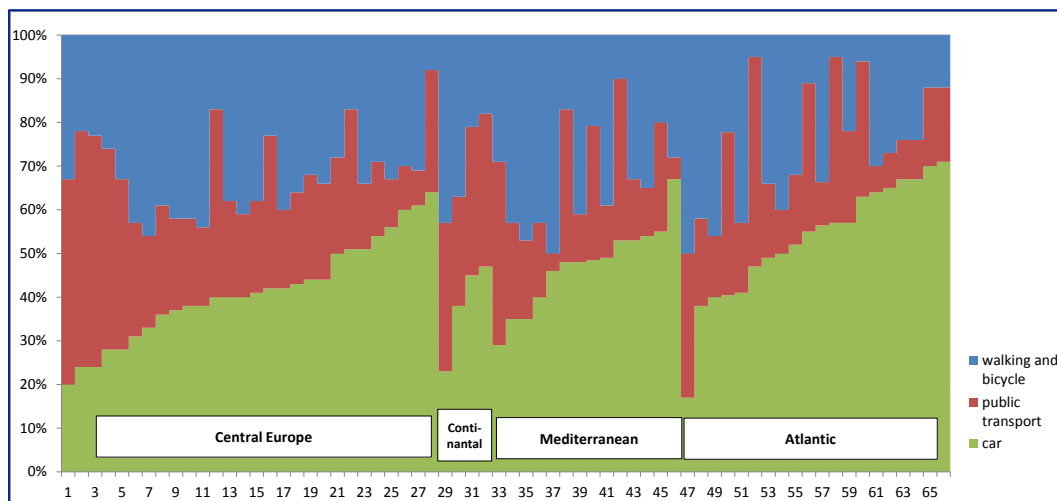


Figure A.5.4 Material consumption of a medium-size passenger car

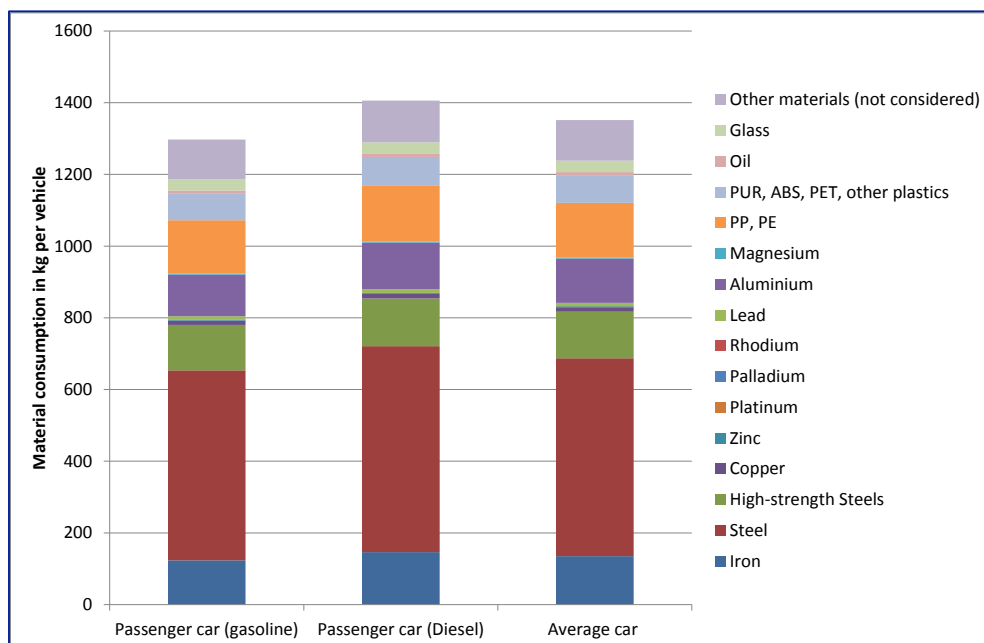


Figure A.5.5 Material consumption of an urban bus

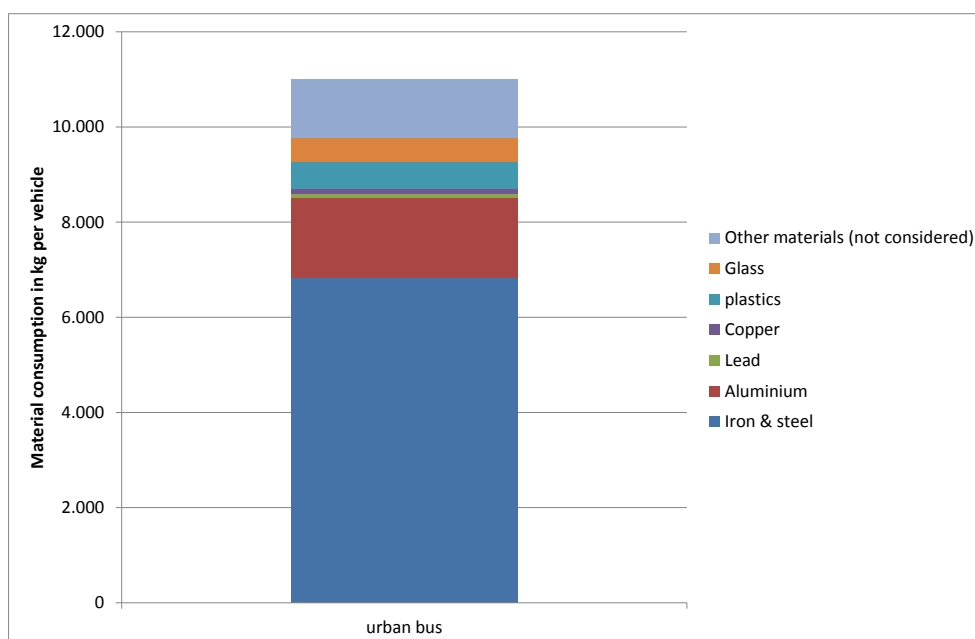


Table A.5.4 Reduction potential by impact category's of the use-phase and the change in the vehicle stock for the analysed cities/ urban area

Number of inhabitants in city/ urban area	Use phase		Vehicle stock				
	CED	GHG	CRD	<i>thereof CRD Energy carriers</i>	Water use	CED	GHG
	PJ/yr	Mt/yr	Mt/yr	Mt/yr	mill. m ³ /yr	PJ/yr	Mt/yr
100,000 to <250,000	83.4	6.1	2.2	0.4	5.4	11.1	0.7
250,000 to <500,000	53.9	3.9	0.5	0.1	1.3	2.7	0.2
>=500,000	171.2	12.5	1.9	0.3	4.8	10.1	0.6
Sum	308.4	22.5	4.7	0.8	11.5	23.9	1.4

Annex 6: Inventory list of hardware components for the LCA-based comparison of Desktop PCs and Zero/Thin clients

Functional unit: doing typical office work (Word/Excel) during a year (typical working time)

Table A.6.1 Simplified LCA model of the desktop PC

Production stage - Hardware components		
Component	Amount	Unit
DRAM (DIMM DDR2)	4	Gbyte
CPU	1	
Mainboard with generic chipset	6	dm ²
HDD (3,5")	100	Gbyte
Chassis (consists of 3 kg steel) + 0,3kg plastic)	1	
Power supply unit	1	
DVD drive	1	
Keyboard	1	
Mouse	1	
External 22" display	1	
Use phase (stand-alone w/o LAN)		
Electrical power	71	kWh per year
Service lifetime	6	years

Source: Öko APC Project (I/O data derived from German Probas datasets & EcoInvent 3.01).

Table A.6.2 Simplified LCA model of the thin client

Production stage - Hardware components		
Component	Amount	Unit
DRAM (DIMM DDR2)	2	GByte
CPU (abridged)	1	
Mainboard with generic chipset	2.89	dm ²
SSD (2,5") 10 GB	1	GByte
Chassis (consists of 0,2 kg steel) + 0,1kg plastic)	1	
Power supply unit (laptop type)	1	
Keyboard	1	
Mouse	1	
External 22" display	1	
Use phase		
Electrical power	40.48	kWh per year
Service lifetime	6	years

Source: modified from Öko APC Project (I/O data derived from German Probas datasets & EcoInvent 3.01).

Table A.6.3 Simplified LCA model of the zero client

Production stage - Hardware components		
Component	Amount	Unit
DRAM (DIMM DDR2)	0.512	GByte
CPU (abridged)	0	
Mainboard with generic chipset	2.89	dm ²
SSD (2,5")	4	GByte
Chassis (consists of 0,2 kg steel) + 0,1kg plastic)	1	
Power supply unit (laptop type)	1	
Keyboard	1	
Mouse	1	
External 22" display	1	
Use phase		
Electrical power	30	kWh per year
Service lifetime	6	years

Source: modified from Öko APC Project (I/O data derived from German Probas datasets & EcoInvent 3.01).

Table A.6.4 Simplified LCA model of the terminal server/ file server (combined)

Production stage - Hardware components		
Component	Amount	Unit
DRAM (DIMM DDR2)	108	GByte
CPU	2	
Mainboard with generic chipset	10	dm ²
SSD (2,5")	8	TByte
Chassis (consists of 8 kg steel) + 0,3kg plastic)	1	
Power supply unit incl UPS (2kg NiMH battery)	2	
DVD drive	1	
LAN router	1	
network cable	2000	m
LAN power supply unit	1	
Use phase		
Electrical power	3283	kWh per year
Service lifetime	6	years

Source: adopted from Öko APC Project (I/O data derived from German Probas datasets & EcoInvent 3.01).

Assumptions: 100 TC/ZC per terminal server used in a medium sizes Company for office work.

-> CED Server is divided by 100 and added to the TC/ZC.

Annex 7: RME calculation for determining scope

The attached electronic attachments detail:

- the RMI calculation in Figure 2.2 in Chapter 2 – Annex_7A.xlsx:
http://ec.europa.eu/environment/enveco/waste/pdf/Annex_7A.xlsx
- the RMC calculation in Figure 2.3 in Chapter 2 – Annex_7B.xlsx:
http://ec.europa.eu/environment/enveco/waste/pdf/Annex_7B.xlsx

Annex 8: Energy savings under the Energy Efficiency Directive 2012/27/EU

This study seeks to assess measures addressing resource efficiency and their effects on energy savings. In particular, it calculates the energy-saving potentials from resource efficiency measures and contextualises these within energy-efficiency targets set in the Energy Efficiency Directive (EED) 2012/27/EU. The energy efficiency targets refer to “primary energy consumption” and “final energy consumption,” both defined in Article 2 of the EED 2012/27/EU:

(2) “Primary energy consumption”⁸⁷ means gross inland consumption, excluding non-energy uses;

(3) “Final energy consumption” means all energy supplied to industry, transport, households, services and agriculture. It excludes deliveries to the energy transformation sector and the energy industries themselves;

Eurostat provides definitions of the elements by which “Primary energy consumption” is defined, as follows:

Gross inland energy consumption by fuel type⁸⁸

Gross inland consumption is calculated as follows: primary production + recovered products + total imports + variations of stocks - total exports - bunkers. It corresponds to the addition of final consumption, distribution losses, transformation losses and statistical differences.

Non-energy uses

Non-energy use of energy carriers means use for products and not for the generation of energy. It includes for instance natural gas used not for combustion but for producing chemicals⁸⁹.

The EU28’s (final) non-energy use remains around 6% of the gross inland energy consumption⁹⁰. Approximately 75% of (final) non-energy use is in the petrochemical sector⁹¹.

The legislative requirements in Directive 2012/27/EU refer to two aspects of EU energy data – the measured energy consumption and the consumption which would take place in the year 2020 in a business-as-usual (BAU) scenario. The difference between the two should total 20% for the objective to be reached. The target values for year 2020 are prescribed in Article 3 of Directive 2012/27/EU (amended by Council Directive 2013/12/EU): EU28 2020 energy consumption must be no more than 1 483 Mtoe (=62 090 PJ) of primary energy or no more than 1 086 Mtoe (=45 469 PJ) of final energy.

The current level of the primary energy consumption, in Figure A.8.1 below can be breakdown broken down by energy carrier. The BAU scenario and target mentioned in the EED are displayed in red (BAU scenario) and yellow (explicit target for the year 2020).

The current level of final energy consumption in Figure A.8.2 below can be breakdown broken down by the used energy. The BAU scenario and target mentioned in the EED are displayed in red (BAU scenario) and yellow (explicit target for the year 2020).

⁸⁷ Shortcut to Eurostat data on primary energy consumption: [tsdcc120](#).

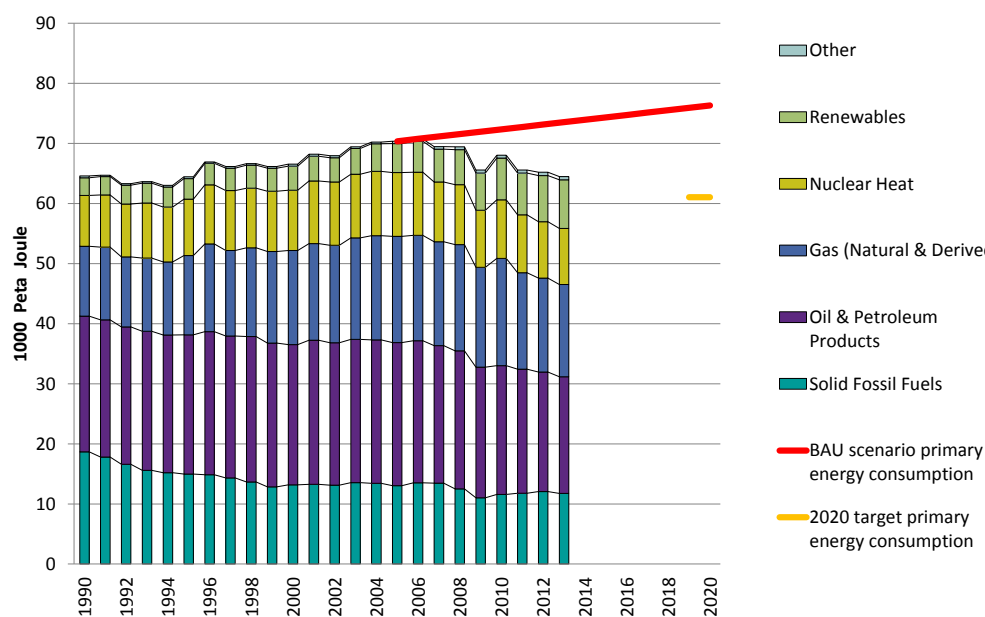
⁸⁸ Shortcut to Eurostat data on gross inland energy consumption by fuel type: [tsdcc320](#), download 25.11.2015.

⁸⁹ Source: Eurostat, short description to the data set [tsdcc120](#), download 25.11.2015.

⁹⁰ Source: Eurostat, Complete energy balance - annual data (data set: [nrg_110a](#)), download 1.12.2015; calculations by Oeko.

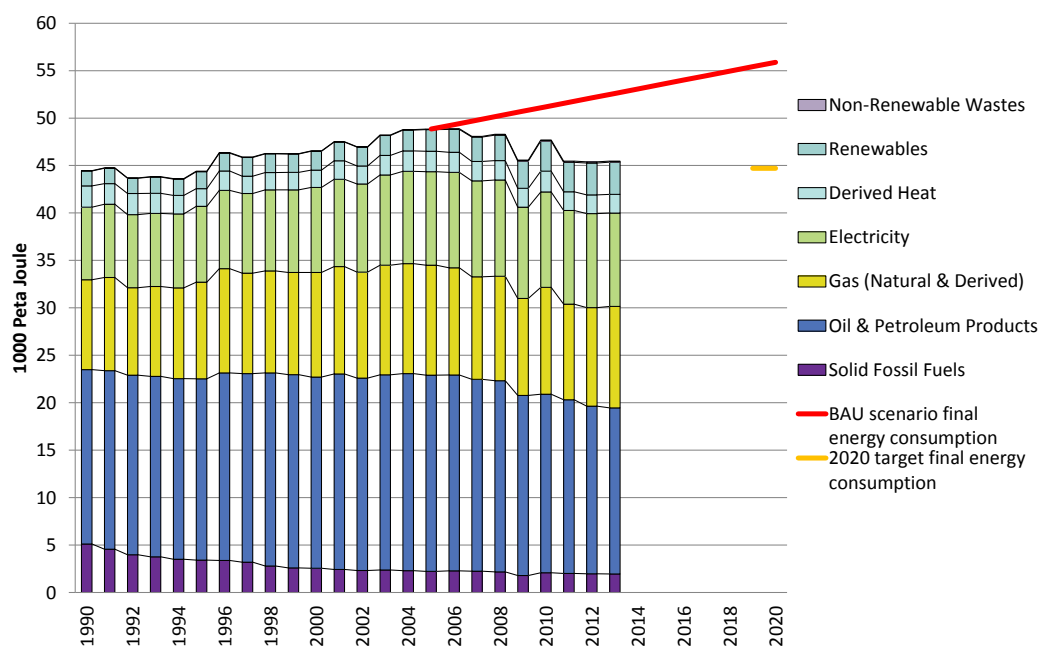
⁹¹ Source: Eurostat, Complete energy balance - annual data (data set: [nrg_110a](#)), download 1.12.2015; calculations by Oeko.

Figure A.8.1 EU28: Primary energy consumption for monitoring the targets in the Energy Efficiency Directive 2012/27/EU



Data Source: Eurostat [Statistics Explained: Energy Savings Statistics](http://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_saving_statistics).

Figure A.8.2 EU28: Final energy consumption for monitoring the targets in the Energy Efficiency Directive 2012/27/EU



Source: Eurostat Statistics Explained: Energy Savings Statistics – http://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_saving_statistics.

As an attempt to contextualise this study, it should be noted that energy efficiency can be influenced through many channels. In recent years, adverse economic conditions resulting from the financial crisis in 2008 / 2009 and the subsequent slow recovery have had a marked impact.

The increasing share of renewable energy have has had an impact on primary energy consumption⁹².

Discussion of scope for EU28 primary energy consumption and cumulative energy demand (CED) from LCAs

This study calculates energy savings in different sectors and case studies using Life Cycle Assessments (LCA) or similar methods. Consequently, the effects of energy consumption are expressed in Cumulative Energy Demand (CED). In principle, CED includes the complete upstream effort, including all material flows for a product or service from the primary resources extracted, the effort for this extraction and the effort for disposal (or recycling/ recovery). Ecoinvent provides CED data while GEMIS additionally offers the option to distinguish between CED (in German "kummulierter Energieaufwand KEA") and "kummulierter Energieaufwand, KEV"⁹³.

Both GEMIS and ecoinvent data distinguish between different carriers for primary energy for the CED:

- Renewable energy resources:
 - Biomass;
 - geothermal, converted;
 - solar, converted;
 - potential (in barrage water), converted;
 - kinetic (in wind), converted.
- Non-renewable energy resources:
 - Fossil;
 - Nuclear;
 - primary forest.

This distinction is relevant in case studies, for instance in the food sector where CED includes a relevant amount of energy from the food itself (not in compliance with the concept of primary energy consumption for the EED directive targets). This mismatch can be reduced by excluding biomass from the CED calculation.

The differences in scope between the EU28's primary energy consumption and cumulative energy demand (CED), which are calculated using LCA, have been summarised in Table A.8.1 below.

⁹² Tomescu, M.; Moorkens, I.; Wetzels, W.; Emele, L.; Förster, H.; Greiner, B. (2016), Renewable energy in Europe 2016 - Recent growth and knock-on effects, EEA Report No 4/2016.

⁹³ Unlike CED, KEV excludes non-energy use for aggregation. KEV is more in-line with the concept of primary energy consumption as applied for the EU Energy Efficiency targets. Because GEMIS' data on KEV are only available for basic industrial processes like power generation, ecoinvent data, with only CED, must be used for several case studies.

Table A.8.1 Comparison of scope for EU28's primary energy consumption and cumulative energy demand (CED)

Case study	National primary energy consumption	CED calculated in LCA
Geographical areas	<p>The primary energy required (e.g. electricity, fuels for heating, incorporated carbon as plastics) for producing goods imported to the EU28 is not included in the concept of (EU28 domestic) primary energy consumption.</p> <p>→Relevant for products where a major share of production occurs in foreign countries outside the EU28, such as ICT products that are commonly produced in Asia.</p>	<p>Incorporated energy in imports is included in the upstream LCA calculation and thus included in the CED.</p>
Non-energy use	<p>The 'primary energy consumption' concept for assessing EU energy efficiency targets excludes the energy consumed for purposes other than producing useful energy (non-energy use).</p> <p>→Relevant for products with high proportions of plastic components.</p>	<p>Energy consumed for purposes other than producing useful energy (non-energy use) is included in the CED. This calculation is relevant, for instance, for plastics. For the EU28, total non-energy use is approximately 6% of primary energy consumption.</p>
Higher / Lower Heating Value	<p>Primary energy consumption refers to the higher heating value (HHV) and includes energy not used in the steam.</p>	<p>Ecoinvent refers to the HHV; GEMIS provides data for LHV and alternatively for HHV.</p>

Consequently, each case study is assessed to determine if the differences in the scope for the CED and primary energy consumption are relevant for the results.

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