Quantified potential of industrial symbiosis in Europe

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SCALER

SCALING EUROPEAN RESOURCES WITH INDUSTRIAL SYMBIOSIS

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Executive summary

This study aims to assess the potential of industrial symbiosis (IS) for major heavy industries in Europe and support evidence-based policy-making, based on the in-depth assessment of a representative set of 100 synergies.

The industrial sectors covered in this study are: agro-industry, fertilisers, cement, lime, ceramics, combustion plants, glass, inorganic and organic chemicals, livestock farming, non-ferrous metals, paper, pharmaceuticals, refineries, slaughterhouses, steel, textiles, waste incineration, wastewater treatment plants. The EU counts 6 656 industrial facilities. The total number of combinations among these sites is around 43 million. The average and median distances between all couples of facilities are 1 000 and 1 050km.

The SCALER project vision is to successfully scale up the delivery of value embedded in European physical resources (materials, water and energy) through efficient and quick implementation of industrial symbiosis (IS) across the whole European territory. It will provide mechanisms to promote a wider implementation of IS in the European process industry by developing action plans and adapted solutions to industrial stakeholders and communities.

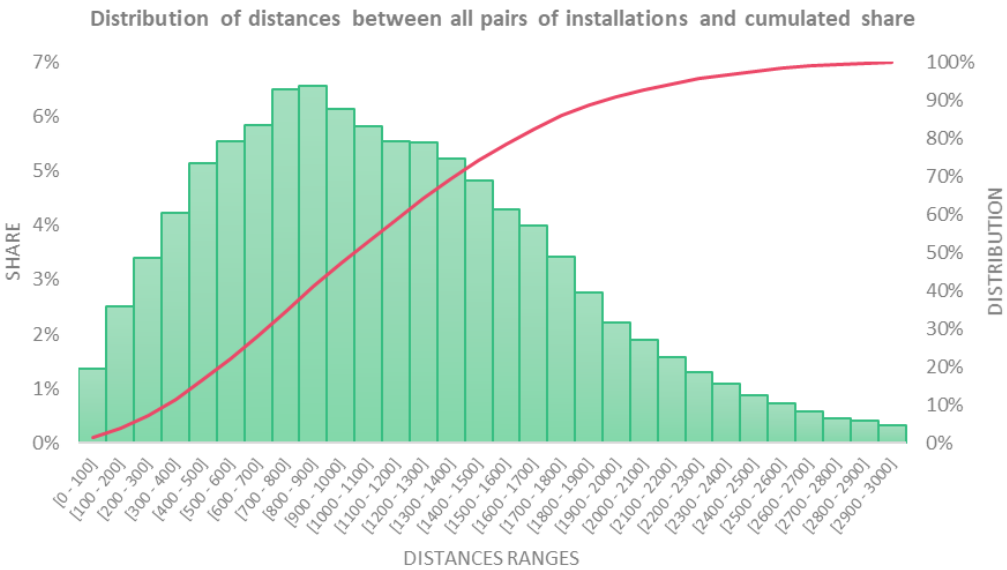


Figure 1: Distribution of distances between all pairs of installations and cumulated share (Source: Strane)

Europe counts 4 major, dense hotspots: Benelux, Western Germany and North of France; Northern Italy; Valencia region & the industrial district of Castellon; UK midlands. The main one is the Benelux, Western Germany and North of France hotspot with 210,000 km2 and 14% of EU installations with a very well-balanced distribution per type of sector. Northern Italy has 6.7% of all EU industrial sites particularly represented by tanning plants, cement plants and secondary steel. UK midlands, already identified as a medium hotspot in EOPS project mainly represented by glass, non-ferrous metals and other petrochemical activities. A 30km large hotspot is identified, Valencia region & the industrial district of Castellon, with a weak variety of industrial activities. Other medium industrial hotspots are located near Paris, Lyon, Eastern Germany & Prague, Barcelona, Krakow, Lisbon, Madrid.

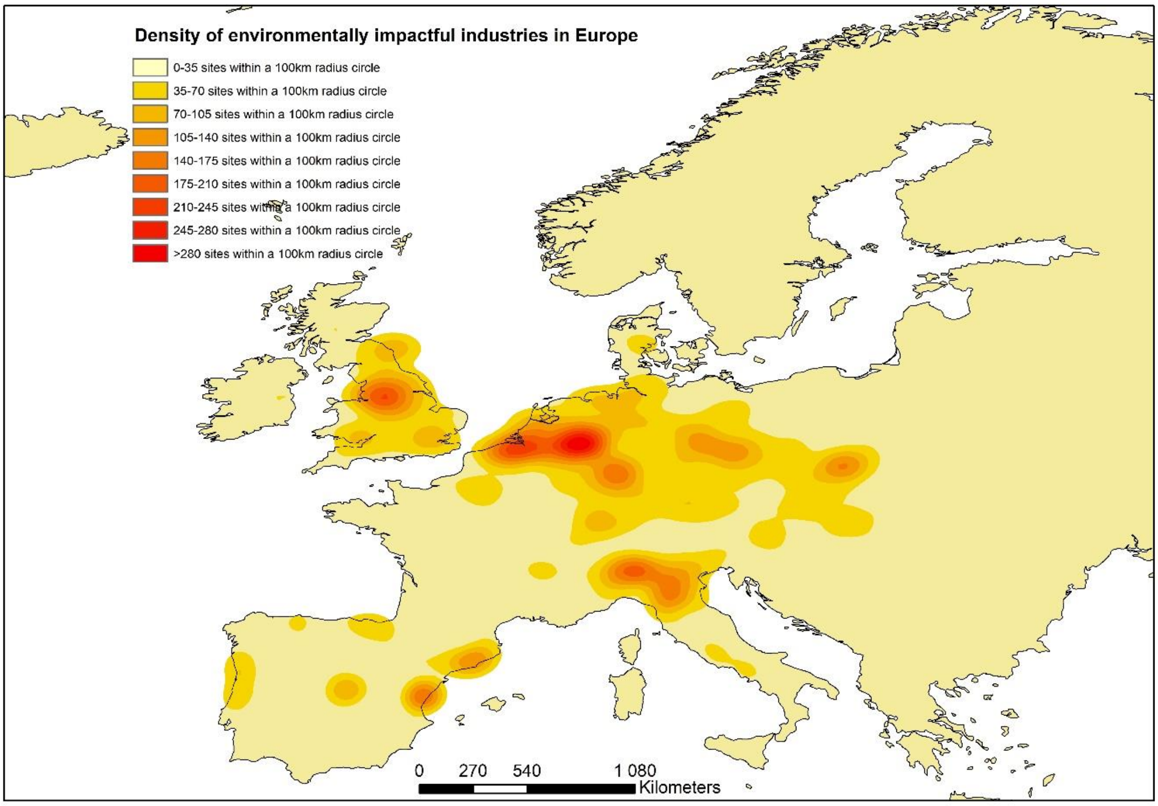


Figure 2 Density of environmentally impactful industries in Europe (source: Strane)

27% of all heat emitting installations are directly located within large cities, plus 19% (432 facilities) in Functional Urban Areas. 2 200 opportunities of district heating (distance between heat producer and the nearest city downtown) were assessed. 10% are below 2.8 km, a distance relevant for district heating. Most opportunities are in the range 5 – 10 km. The peak of opportunities is at 3 – 4 km (345).

SCALER project followed an ambitious methodology by modelling process industries, setting up databases, creating matching algorithms to identify a representative set of 100 credible cross-sectorial synergies. They were assessed technically, environmentally and socio-economically. A ranking led to focus on the 38 most impacting synergies, representing 90% of the total environmental and socio-economic impact of the 100 synergies. They concern about 327 million tonnes of material.

The total implementation of the 38 most impacting synergies in EU would save 91 Million tons of CO_2 (24% of the direct emissions from industrial processes), 98 835 DALY, 24 031

836 256 PDF.m2.y, 1 559 479 649 GJ and 2 564 Million m3 of water. The volume not yet implemented represents 13,5 Million tons of CO_2 savings (3.6% of direct emissions from industrial processes), 17 379 DALY, 5 408 511 897 PDF.m2.y, 296 809 Million MJ and 837 Million m3 of water.

These 38 synergies were found to be profitable and generating socio-economic benefits: 22 Billion € of added value (0.8% of the European industry added value), 5 Billion € of value added tax, 230 000 new direct industrial jobs and 115 000 new indirect jobs, 11,5 Billion € of waste management costs savings, 42 Billion € equivalent damages costs avoided, 2.5 Billion m3 of water savings. The remaining part not yet implemented is equivalent to 8 Billion € of value added (0.3% of the European industry added value), 1.7 Billion € of VAT, 85 000 new direct jobs and 42 000 new indirect jobs, 4.3 Billion € of waste treatment cost savings, and around 800 Million m3 of water savings.

Indirect synergies require a total investment about 800 Million € to deploy 371 technologies with 3.8 Million € of annual operating costs. The remaining part not yet implemented would require an investment of at least 350 Million € to deploy 193 technologies.

Heavy industries produce around 489 TWh waste heat, which could save 260Mt of CO2 emissions (5.2% of the EU annual emissions). However, this theoretical potential cannot be fully grasped since installing district heating requires infrastructures, favourable topology, adapted climatic conditions justifying such a capital-intensive investment, and social acceptance. 20TWh of waste steam could also be recovered, saving 10Mtonnes of CO2 (0.4% of EU annual emissions).

Recommendations include both recommendations to continue further this work, in particular by collecting more data and information and recommendations for policy-makers in order to fully grasp the untapped potential of the synergies.

Figures and tables

Abbreviations

IS: Industrial symbiosis
SPIRE: European association for Sustainable Process Industry through Resource and Energy Efficiency
IMA: International Mineralogical Association
ORC: Organic Ranking Cycle
ADT: Air Dry Tonne
EAF: Electrical Arc Furnaces
EAFD: Electrical Arc Furnace Dusts
COG: Coke Oven Gas
BOF: Basic Oxygen Furnace
BOFG: Basic Oxygen Furnace Gas
BF: Blast Furnace
BFG: Blast Furnace Gas
DPM: Deodorized and sanitized Poultry Manure
ATS: Ammonium Thiosulfate
S: Sector
P: Process
SS: Subsector
LHV: Lower Heating Value
BREF: Best Available Techniques Reference Document
LCP: Large Combustion Plant
LCA: Life cycle analysis
CAPEX: CAPital EXPenditure
OPEX: OPerational EXPenditure
LHV: Lower Heating Value
LCA: Life cycle assessment
TDB: Technology database
WWTP: Wastewater Treatment Plant
WW: Wastewater
NACE Rev 1: NACE 1
NACE Rev 2: NACE 2
SEA: Socio-Economic Assessment
SE: Socio-Economic
LCA: Life Cycle Analysis

1. Introduction

The SCALER project vision is to successfully scale up the delivery of value embedded in European physical resources (materials, water and energy) through efficient and quick implementation of industrial symbiosis (IS) across the whole European territory. It will provide mechanisms to promote a wider implementation of IS in the European process industry by developing action plans and adapted solutions to industrial stakeholders and communities.

1.1 Context, Scope & Objectives

1.1.1 Context and Objectives

Some studies were performed to assess the IS potential in Europe. As an example, the Economic Analysis of Resource Efficiency Policies [1], provide key elements to estimate the IS scaling-up potential at European level.

This assessment was performed assuming a homogeneous replication of the UK NISP program in the other 27 EU countries. By investing a total of €250 million, EU member countries could generate €3 billion, reduce landfill by 53.9 Mt of waste, avoid 45.5 Mt of CO2 emissions and the use of 73 Mt of raw materials and 72.1 Mt of water. This potential would be achievable in the medium term as the facilitation mechanisms would only need to be adapted to local contexts. However, this study builds on 9 case studies, that are not representative for the whole IS opportunities in EU, and presents trends of the potential and associated economic benefits. This assessment does not take into account local economic structures and contexts that are different from country to country. Moreover, NISP program does not seem to be relevant for process industries since these types of companies require process engineering skills to build collaboration and implement synergies.

This deliverable builds specifically upon a similar, confidential study carried out managed by STRANE in the EPOS project: D6.1 EPOS Market study. This study was restricted in scope to the EPOS sectors: refineries, petrochemicals, steel, minerals and cement. More than 1,000 ideas of synergies were generated from interviews with field actors, collaborative brainstorming sessions and a technical assessment. All European industrial facilities in these sectors were mapped to systematically assess the geographic dimension of industrial symbiosis. Five hotspots were identified in Europe (Northern France-Belgium-Netherlands-Luxembourg-Western Germany, Northern Italy, Krakow, Bilbao and the UK Midlands). A techno-economic assessment was carried out on a selection of 28 synergies using 12 resources. Only a minor share of the synergy ideas was found to be economically credible. Solid or liquid resources, with high intrinsic value, produced in sufficiently large amounts both on each site and at EU level, and used as feedstock instead of energy, had more chances to be economically viable. Economically credible synergies represent a truly sizeable impact. For instance, the valorisation of tar sludge from steel to cement represents 24% of the annual energy consumption of the cement sector in Europe. District heating is also promising. The EPOS sectors may produce 317 TWh/year of waste heat, to be compared with the current consumption of district heating of 225 TWh/year. 52 million inhabitants live at less than 8km from a site in the EPOS Sector, representing a theoretical heat demand of 346 TWh/year. Developing district heating could replace the consumption of fossil fuels, saving 200 $MtCO_2$ per year (4% of EU emissions).

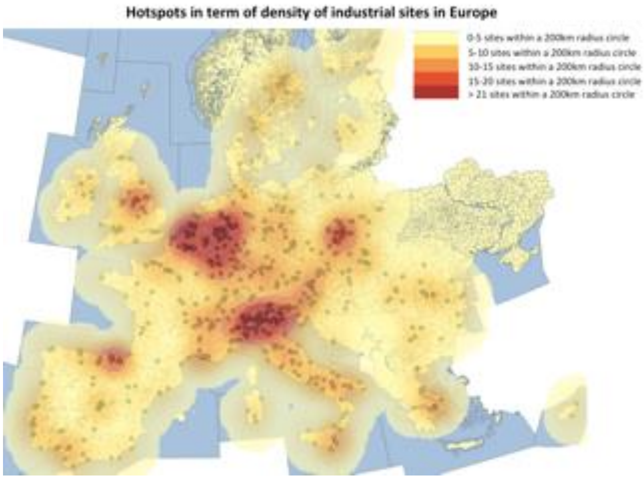


Figure 3: Hotspots in term of density of industrial sites in the sectors of steel, refining, petrochemicals, and cement in Europe (Source: STRANE)

WP3 in SCALER aimed to extend this assessment widely to other industrial sectors, in particular all SPIRE sectors, and to a larger set of representative synergies.

This report builds on the results of 5 earlier tasks:

- Mapping all industrial facilities from any industrial sector with a significant environmental impact in Europe (T3.1)
- Shortlisting 100 representative synergies for deeper analysis (T3.2, and deliverable D3.1"Short list of the 100 most promising synergies")
- Assessing them technically and identifying relevant technologies for the implementation (T3.3, and deliverable D3.2 "Technology database")
- Analysing the life cycle impact of each of the 100 synergies (T3.4, and D3.3 "Synergies environmental impact assessment")
- Assessing the socio-economic impacts and benefits of each of the 100 synergies (T3.5 and D3.4 "Synergies socio-economic impact assessment")

This deliverable synthesises all results in an integrated assessment of the potential of these 100 synergies. Statistical analysis was performed based on geolocated data to provide the number of couples of sites combinations and the distribution at European scale. The total number of synergies in Europe is detailed. This deliverable is one of the key outcomes of the SCALER project.

1.1.2 Scope

SCALER is a project funded under the SPIRE's public-private partnership. SPIRE is an alliance of 8 sectors of the European industry (cement, ceramics, chemicals, engineering, minerals and ore, non-ferrous metals, steel and water).

The SCALER project focuses on process industries with significant production volumes that involve large volumes of raw materials used and wastes generated. One synergy fully implemented thorough Europe could directly avoid significant environmental, social and economic benefits as found in [2] D3.3 and D3.4 [3].

Manufacturing activities are not included in the scope of SCALER mostly due to a lack of data about input and output flows since processes are not continuous and standardised as the heavy process industries.

The geographical scope spans all of the European continent.

1.2 Methodology

1.2.1 Collection of geolocated data

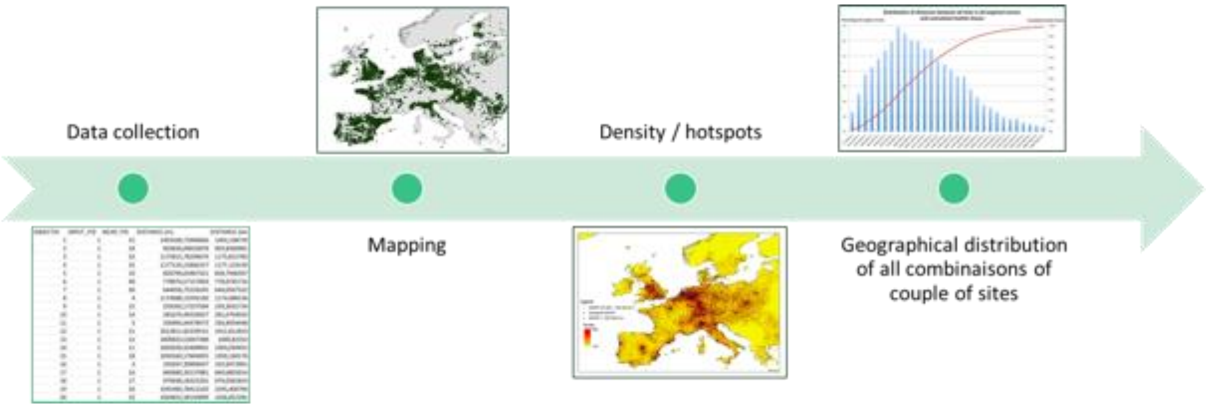
Distance is a key parameter to the economic viability of an industrial synergies. To quantify the European IS potential, the first crucial step was to gather geolocated data. Many sources were used to build a consistent and exhaustive geolocated database on industrial activities in Europe.

NACE classification of economic activities were used to identify the activity of industrial installations and for gathering geolocated data. Revisions 1 [4] (NACE 1) and 2 [5] (NACE 2) were used. E-PRTR database [6] and associated activity reports were used to identify specific activities not reflected by NACE classification. As an example, an industrial installation that is classified as a chemical producer (e.g. NACE 2: 20 - Manufacture of chemicals and chemical product) can declare several activities as combustion, mining, wastewater treatment, etc. Data provided by European industrial associations data were used when possible. Key European sector organisations are [7]: EUROPIA / CONCAWE, EUROMINES, EUROFER, EAA, EUROMETAUX, CEMBUREAU, EULA, CPIV, CERAME-UNIE, EURIMA, EUROGYPSUM, CEPI, CEFIC, EFMA, etc. In some cases, bibliographic resources like the Best available techniques Reference documents (BREFs) [8] from the European IPPC Bureau (EIPPCB) were used to cross-check information.

As depicted in the figure below, the geolocated data were treated as follows:

- All facilities were mapped to visualise the distribution of facilities across Europe
- Hotspots where the geographic density of facilities is high were identified using spatial data mining algorithms and visualised on a map

- Statistical analyses were systematically carried out on every combination of couples of partner sectors



1.2.2 Structure of the document

The deliverable is organised as follows:

- Section 2 presents the results of mapping activities and geographical analyses
- Section 3 provides an overall assessment of the IS potential in the SCALER sectors
- Section 4 focusses on the detailed potential of the 100 representative synergies
- Section 5 concludes and provides recommendations

2. EU Mapping of industrial facilities

There are 2 levels of mapping in this section.

- The ***General map*** includes all industrial facilities with a significant environmental footprint in order to provide an overall perspective. For technical issue (to many combinations possibilities with the number of installations involved in the general map), a map focusing only on large volume process industries and industries involved in the 100 synergies sample was build and analysed.

- The ***SCALER map*** focuses mainly on large volume process industries and includes all sectors and type of activities involved in the sample of 100 synergies. It includes the majority of sectors in the General map, excluding wastewater treatment plants with a capacity below 150 000 persons equivalent, medium and small volumes chemicals and fertilisers installations*, paper industries producing only paper and not pulp*, steel and non-ferrous metals processing industries, textiles with other activities than tanning, starch*, other combustion plants different from coal combustion and gasification/liquefaction plants, pharmaceutical products*.

**Not involved in the 100 synergies*

The livestock farming, mining and quarrying and small wastewater treatment plants were treated separately since the number of related facilities was very high compared to other sectors. A dedicated map is proposed in dedicated subsections below.

All industrial sectors studied, segmentations defined, sources and data collection methodology are detailed in Table 1.

Table 1: Industrial sectors and activity segmentations sources of geolocated data (Source: Strane)

Sector	Activity	Number of facilities	Scope
Agro-industries	Starch	54	General map
	Sugar	111	General map / SCALER map
Fertilisers	All fertilisers plants	185	General map
	AN & CAN	15	SCALER map
	NPK & CN	37	SCALER map
	UREA & UAN	20	SCALER map
Cement & Lime	Clinker plants	5	SCALER map
	Full Cement plants	168	SCALER map
	Grinding cement mills	72	SCALER map
	Lime manufacturing	108	SCALER map
Ceramic	Bricks and roof tiles	1276	General map / SCALER map
	Technical ceramics	26	General map / SCALER map
Combustion plants	Large combustion plants	2051	General map
	Coal combustion plants	383	SCALER map
	Coal plants new projects	75	SCALER map
	Coal gasification and liquefaction	20	SCALER map

	Installations for gasification and liquefaction	85	SCALER map
Glass	Container glass	289	General map / SCALER map
	Flat glass	121	General map
	Glass fibres	71	General map / SCALER map
Inorganic chemicals	All inorganic chemicals installations	660	General map
	Calcium carbide	11	SCALER map
	Carbon black	8	SCALER map
	Soda ash	17	SCALER map
	Sodium Chlorate	11	SCALER map
	Sodium silicate	8	SCALER map
	Synthetic amorphous silica	17	SCALER map
	Titanium dioxide	12	SCALER map
Livestock farming	All farming and raising installations	13673	Livestock farming map
	Farming and raising of poultry	5189	Livestock farming map
Mining & quarrying	Hard coal and lignite	240	Mining & quarrying map
	Gravel and sand pits, mining of clay and kaolin	350	Mining & quarrying map
	Quarrying of ornamental and building stones, limestones, gypsum, chalk and slate	336	Mining & quarrying map
Non-ferrous metals	Aluminium and alloys smelters	117	General map / SCALER map
	Copper and alloys smelting	46	General map / SCALER map
	Crude Aluminium	44	General map / SCALER map
	Crude Copper	17	General map / SCALER map
	Lead	2	General map / SCALER map
	Other aluminium processing installations	185	General map
	Other copper installations	53	General map
	Other crude lead and tin producers or smelters	51	General map / SCALER map
	Other installations processing zinc, lead and tin	82	General map
	Others potential nickel and cobalt processing installations	82	General map
	Potential crude nickel and cobalt producers	18	General map / SCALER map
	Potential nickel, cobalt and alloys smelters	32	General map / SCALER map
	Primary & secondary Zinc	5	General map / SCALER map
	Primary Zinc	9	General map
	Secondary zinc and lead	1	General map / SCALER map
	Secondary Zinc	6	General map / SCALER map
	Tin smelter	2	General map / SCALER map
Organic chemicals	All organic chemical plants	543	General map
	Ethyl Acetate Production	7	SCALER map
	Ethylbenzene and Styrene	13	SCALER map
	Formaldehyde	28	SCALER map
	Hydrogen peroxide	23	SCALER map
	Phenol	8	SCALER map
	Steam crackers – First list	11	SCALER map
	Steam crackers – Second list	10	SCALER map
	Vinyl Chloride monomer	26	SCALER map
Paper	All paper sites (does not include recycled paper installations)	982	General map
	Paper	873	
	Pulp	113	SCALER map
	Pulp & paper	31	SCALER map

	Recycled paper	82	General map
Pharmaceuticals	Pharmaceutical preparation	249	General map / SCALER map
	Pharmaceutical products	443	General map
Refineries	Refineries & Steam crackers	23	General map / SCALER map
	Refineries	74	General map / SCALER map
Slaughterhouses	All Slaughterhouses	1038	General map / SCALER map
	Poultry Slaughter	348	-
	Other meat slaughterhouses	730	-
Steel	Coke ovens	42	General map / SCALER map
	Pelletisation plants	7	General map / SCALER map
	Primary and secondary steel	3	General map / SCALER map
	Primary steelmaking	34	General map / SCALER map
	Processing of steel	281	General map
	Secondary steelmaking	177	General map / SCALER map
Textiles	Textiles	402	General map / General map
	Tanning	79	General map / SCALER map
Waste incineration	Non-hazardous wastes incineration	434	General map / SCALER map
Wastewater treatment plants	All WWTP (from 0 to 11 206 250 PE)	30 437	WWTP map
	WWTP > 150 000 PE	912	General map / SCALER map
	WWTP 40 000 – 150 000 PE	2 923	General map
	Industrial WWTP	129	SCALER map
TOTAL General Map*		**10226**	
TOTAL SCALER Map*		**6656**	

** by removing duplicates during mapping activities*

2.1 General map

The General map of industrial facilities in Europe demonstrates key results:

- The large hotspots discovered in EPOS are confirmed: Northern France – Belgium – Netherlands – Western Germany, Northern Italy and British Midlands are huge hotspots with a high density of industrial facilities.
- A new large hotspot based in Valencia (Spain) is discovered with also a very high density of industrial facilities
- Smaller hotspots also appear around large cities: Barcelona, Madrid, Lisbon, Lyon, Paris, Stuttgart, Leipzig, Praha, Brno, Krakow, London, and Northern Slovenia.

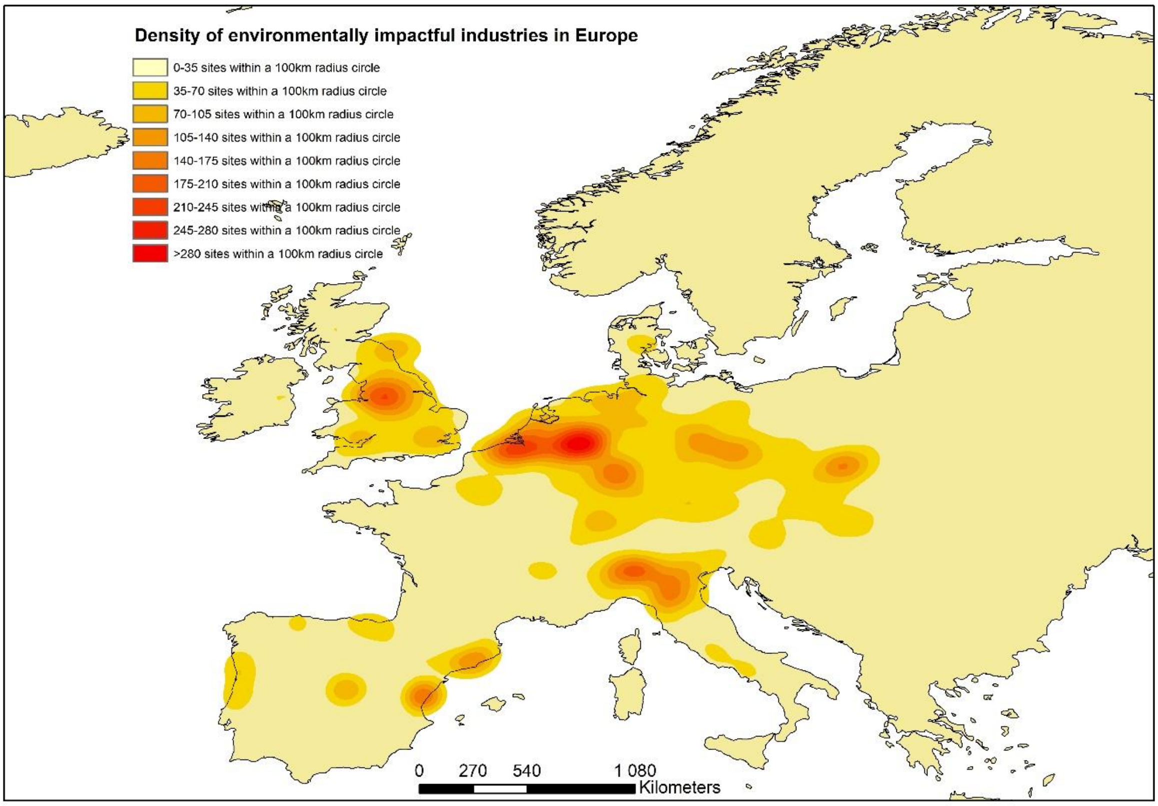


Figure 4 Density of environmentally impactful industries in Europe (source: Strane)

Industrial synergies are most likely to occur within these hotspots where the large density of industrial facilities can facilitate the finding of partners. Make deeper analysis on that map was impossible due to technical issue. Indeed, the large number of installations did not allow to use a GIS software to quantify distances between couples of sites. The GIS software crashed on every attempt even though a high-performance computer was used.

The Table 2 summarises the total number of installations in Europe for each sector and the distribution is represented in the Figure 5.

Table 2: Number of sites for each industrial sector in General Map (Source: Strane)

Industrial sectors	Number of installations	Share
Agro-industries	165	1%
Cement & Lime	353	3%
Ceramic	1302	11%
LCP	2051	18%
Fertilisers	185	2%
Glass	481	4%
Inorganic chemicals	660	6%
Non-ferrous metals	752	6%

Organic chemicals	543	5%
Paper	982	8%
Pharmaceuticals	692	6%
Refineries	97	1%
Slaughterhouses	1038	9%
Steel	544	5%
Textiles	481	4%
Waste incineration	434	4%
WWTP	912	8%

Combustion plants are the most represented industries in Europe with 18% of the total number of sites. This figure is to consider with caution with the ongoing massive wave of coal combustion plants closure.

The second sector the most represented is the ceramic sector with 11% of the total number of installations in EU. The huge amount of ceramic installations is directly related to the plants size. Indeed, ceramics companies have installations smaller than other large volumes process industries which explain the

Medium and large WWTP, Inorganic chemical, Pharmaceuticals, Slaughterhouses, non-ferrous metals (in particular due to the large number of metal processing installations) and paper production come in third place with 6 – 8% of share. In the general map, inorganic and organic chemicals also include small and medium size sites. These industries are similarly represented in Europe and the repartition will be analysed in the next section.

All other sectors present a weak number of sites in Europe compared to the other ones. It is important to note that agro-industries only consider sugar and starch production. EPOS sectors are large volume process industries that is why the number of refineries, cement and steel plants are not significant compared to the other sectors with also medium size installations. Refineries are low than 100 in EU. Steel remain a sector well represented due to the large number of secondary steel (EAF) and steel processing installations.

These figures do not integrate farming activities that are too many, including small size farming, to be compared with process industries.

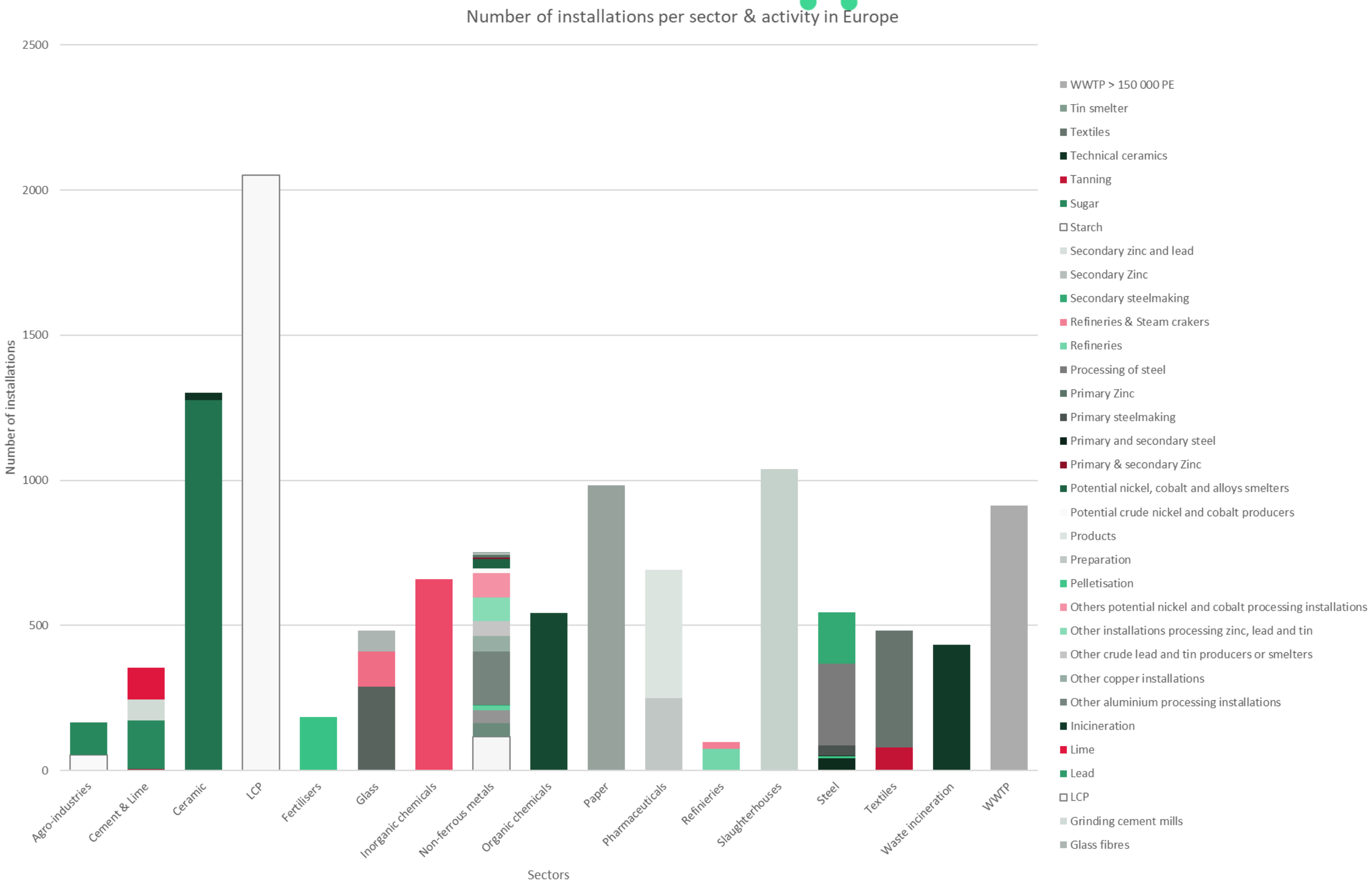


Figure 5: General Map – Number of installations distribution (Source: Strane)

2.2 SCALER map

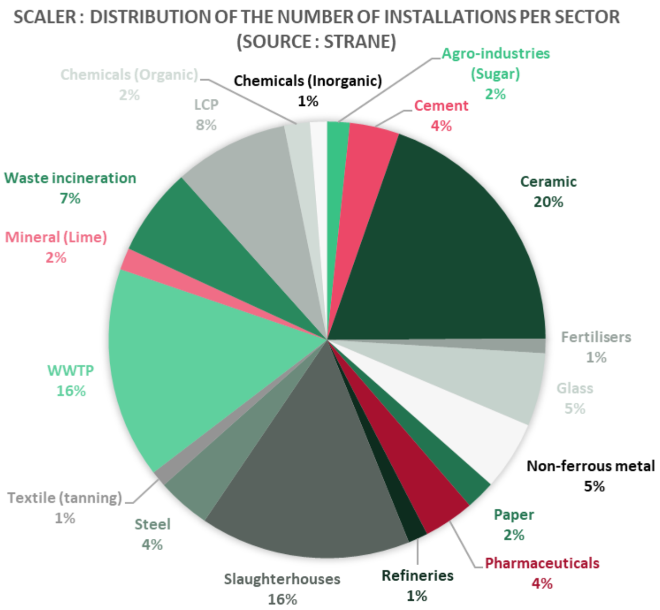
2.2.1 SCALER IS potential

The SCALER map was created to identify and geolocate all installations that could be involved with the 100 most promising synergies full implementation across Europe.

The Table 3 summarises the total number of installations in Europe for each sector and the distribution is represented in the Figure 3

Table 3: SCALER installations distribution (Source: Strane)

Sectors	Number of installations	Share
Agro-industries	111	0,8%
Fertilisers	72	0,5%
Cement & Lime	353	2,7%
Ceramic	1302	9,8%
LCP	563	4,2%
Glass	360	2,7%
Inorganic chemicals	84	0,6%
Non-ferrous metals	341	2,6%
Organic chemicals	126	0,9%
Paper	145	1,1%
Pharmaceuticals	249	1,9%
Refinieries	97	0,7%
Slaughterhouses	1038	7,8%
Steel	263	2,0%
Textiles	79	0,6%
Waste incineration	434	3,3%
WWTP	1041	7,8%
Total	6658	100%



Figures and distribution are quite similar with the general map. Most remarkable differences are because the SCALER map focuses on large process industries AND for synergies involved in the 100 synergies:

- integrates solely coal combustion plant and gasification/liquefaction installation. So, the LCP share is much less important than in the general map (only 4%)
- focus on large volume inorganic and organic chemicals: all other small and medium productions are not considered
- involves only tanning activities in the textile sector (100 synergies)
- Steel and non-ferrous metals do not consider all processing sites

The Figure 6 clearly shows large volume process industries do not cover all type of installations in Europe. As an example, LVOC (Large Volume Organic Chemicals only covers 23% of the total number of organic chemical installations in Europe). Nevertheless, hollow glass production is the most represented glass industry in Europe so the SCALER map covers 66% of the glass sector.

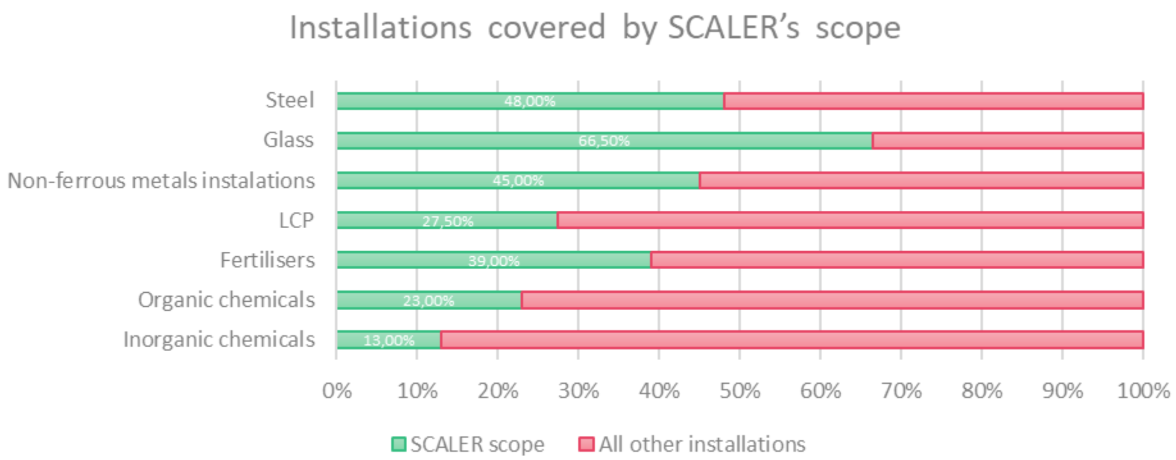


Figure 6: Installations covered by SCALER'scope (Source: Strane)

The analysis of distance between all sites and for all specific synergies selected (Section 3) has been done based on the mapping (*Figure 7*) of all type installation quantified in Table 3.

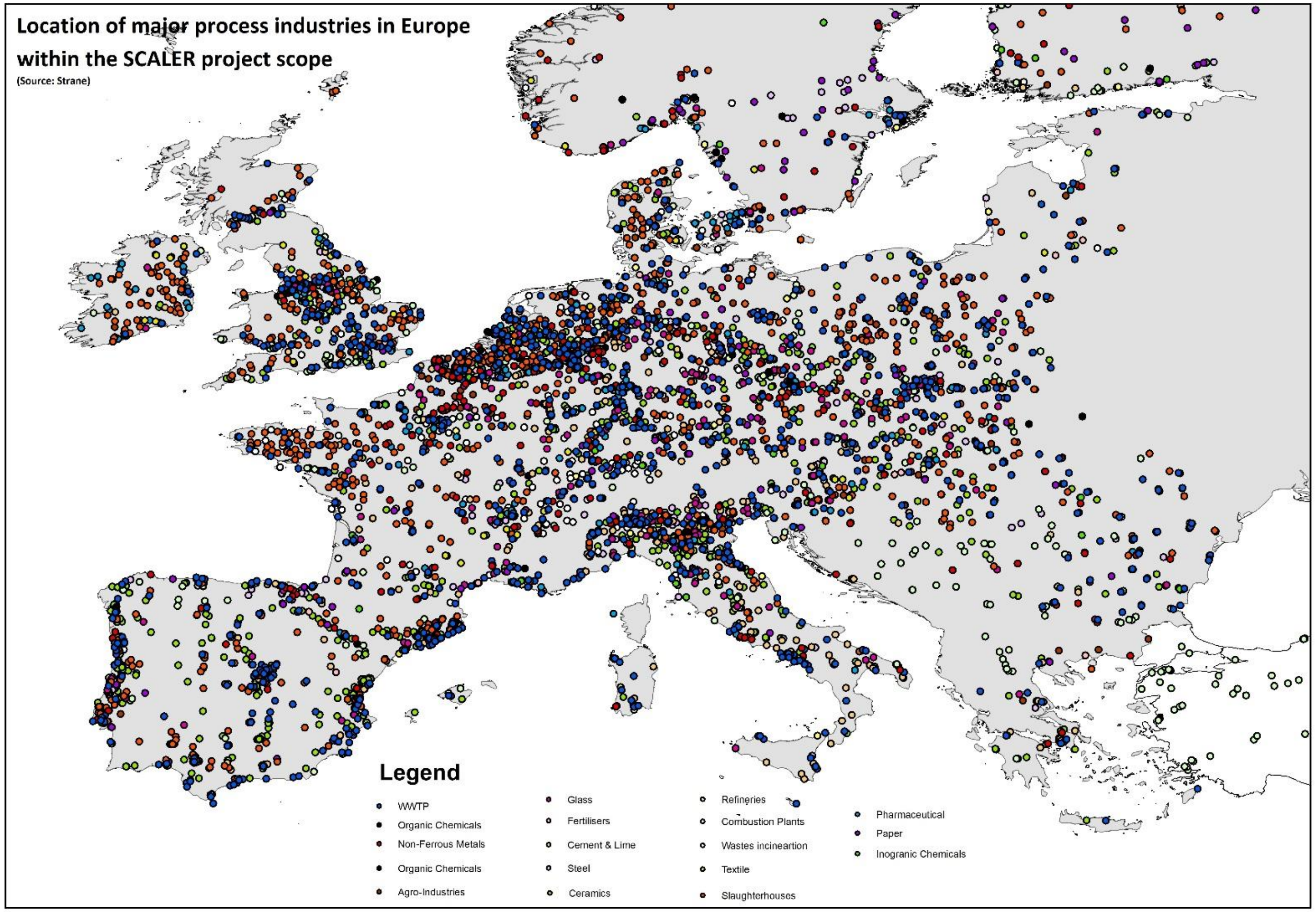


Figure 7: Location of major process industries in Europe within the SCALER project scope (*Source: Strane)*

All following figures and statistics are given in “number of couple of installations”. Each couple of installations corresponds to a potential synergy in Europe. The methodology used enable identifying all potential combinations from one facility to all other installations mapped within SCALER map, then quantifying all distances between the potential emitting installations and the potential receiving installations. To perform this activity all coordinated of geolocated installations were gathered in a database then exported to a GIS software. All potential combinations and associated distances were generated in a table with the GIS software.

The total number of couples considered in the scope of the SCALER map is around 43 million of combinations. By removing all double-counting, the number of potential combinations is 21,5 million of combinations. We have approached the limit of the GIS software's capabilities to calculate distance for this amount of iteration. Data were exported in CSV file to reduce the file size.

GIS analysis exploitation was initially planned to be performed with spreadsheets. It was finally impossible due to the limited number of rows in conventional spreadsheets software (around 1 million rows). The solution adopted was to use a statistical computing tool. For the SCALER project, R project for statistical computing was used with R programming language. Like for the GIS analysis, we approached the limits of the statistical numeric tool with the 43 million combinations analysis.

Boxplot enables to identify potential outliers of the dataset and quantify minimum, maximum, first quartile, median and third quartile value to give an overview of the repartition of the elements of the dataset (Figure 8).

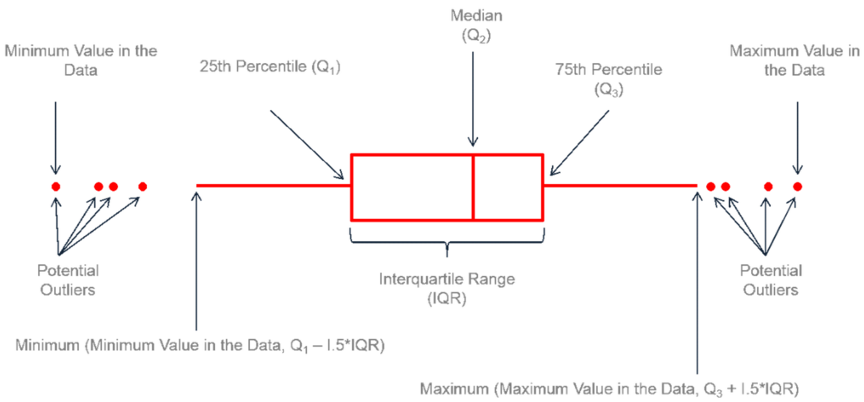


Figure 8: Boxplot anatomy (Source: [9])

The boxplot of all the combinations of distances between couple of installations is presented in Figure 9. All pairs of installations with distances upper than 2 874 km are considered as outliers. In the case of an IS project analysis, it makes totally sense because resources would not be transported on such a distance. Moreover, some industrial sites are often near Europe borders so that distances to the most remote sites is huge.

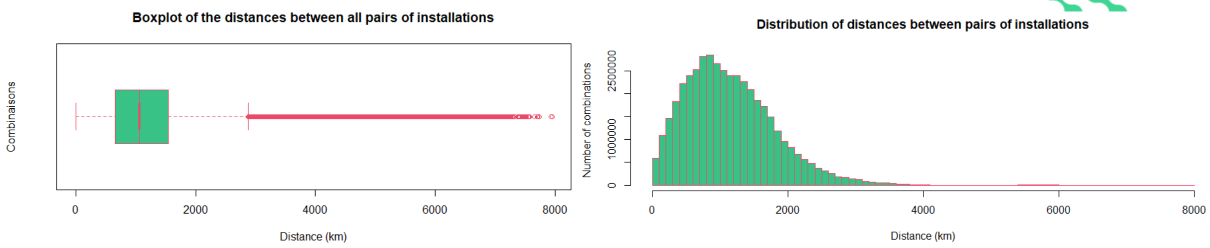


Figure 9: Boxplot of the distances between all pairs of sites (source: Strane)

A second boxplot removing outliers is presented Figure 10 to focus on relevant ranges of distances. 4 give an overview of the boxplot statistics.

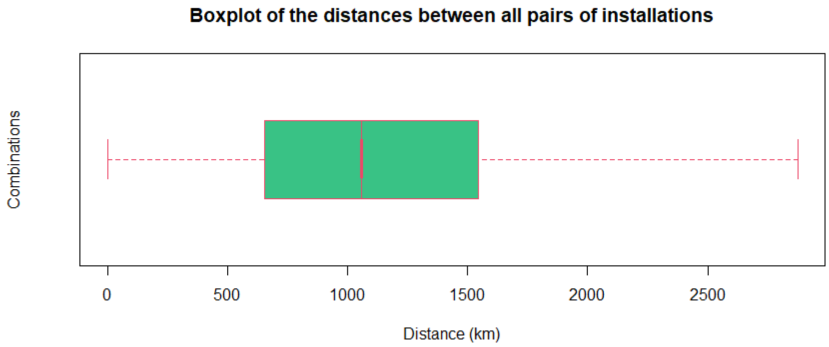


Figure 10: Boxplot – Distances between all pairs of installations without outliners (Source: Strane)

Boxplot results	Distance (km)
« Min » (Minimum value in the data, Q1-1,5*IQR)	0
25th Percentile (Q1)	655
Median(Q2)	1 058
75th Percentile (Q3)	1 542
« Maximum » (Maximum value in the data, Q3+1,5*IQR)	2 874
Potential outliers (maximum values in the data)	> 2 874

Decile	Distance (km)
10%	369.6
20%	566.4
30%	738.0
40%	892.0
50%	1058.8
60%	1241.3
70%	1433.1
80%	1666.3
90%	2020.9
100%	7950.0

Table 4: Boxplot statistics and quantile distribution of distances (Source: Strane)

Minimum value approaches 0km since some sites are very close. Some companies have several installations and type of activities on the same area. We decided to remove all combinations of couple of sites with a distance lower than 50 meters to avoid double counting potentially coming from the combination of several datasets.

10% of combinations couples have a distance lower than 370 km which is very convenient for resources transportation. For specific most promising resources, the analysis is performed in the section 3.

The analysis of quartile distribution clearly shows that 25% of the combinations are under a 655km distance. Combinations within this radius enables resources transportation with trucks by road or railroad and make practicable IS project in national or even international level. The median value is around 1 000 km which is still a viable distance for some materials resources. Potential synergies would therefore mainly concern pairs of sites at relatively long distances.

75% of distances between pairs of sites are lower than 1 500km. This distance is still acceptable. As an example, in 2018, around 20 Million tonnes of steel scrap were exported from the EU [10] to Turkey, India, Pakistan, USA, Egypt, Bangladesh and Switzerland. The last 25% (pairs of installations separated by more than 1 500km) are not suitable for IS projects except in the case of truly profitable resources.

Figure 11 gives the distribution of distances between all pairs of installations in Europe and the share of the total number of possible pairs. This figure enables appreciating the global IS potential at national and international levels (EU). Table 5 presents the number of pairs of installations per distance range, associated share and cumulated share.

The Figure 12 and the Table 21 provide a focus on the range 0 – 200km to have an overview of the potential at a regional/national scale. Figure 13/Table 7 and Figure 14/Table 8 give the same type of information respectively at local and a very local scale with two focus : 0 – 50 (per 5km) and 0 – 20 (per km) focus.

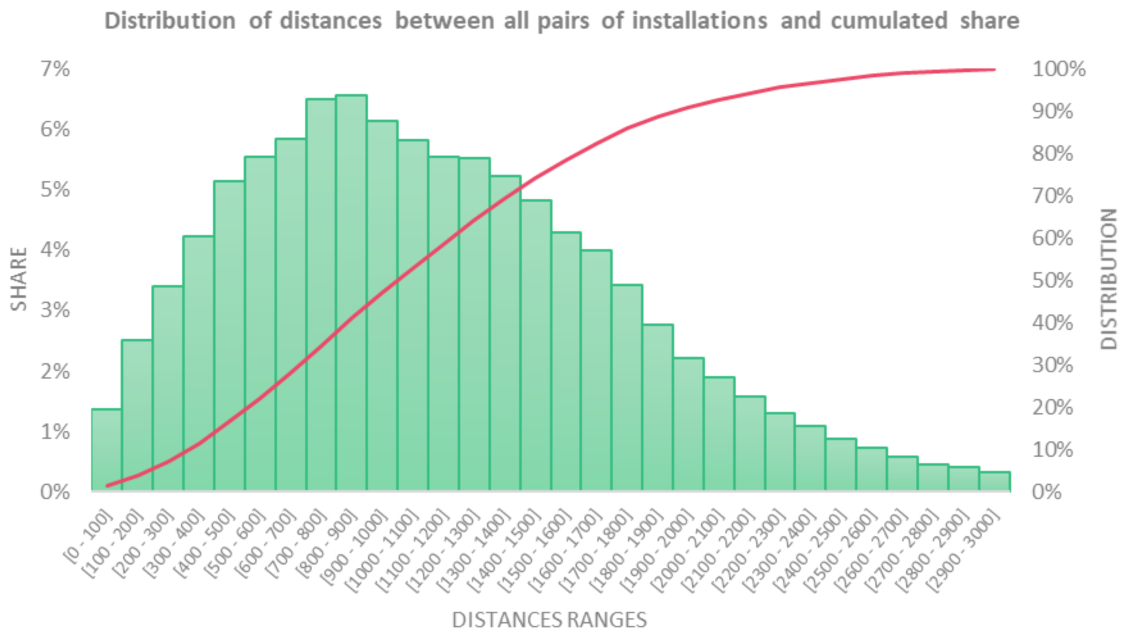


Figure 11: Distribution of distances between all pairs of installations and cumulated share (Source: Strane)

Table 5: Pairs of installations on the range 0 – 200km (source: Strane)

Distance range	Number of combinations	Share	Distribution
[0 - 100]	587 272	1%	1%
[100 - 200]	1 088 052	3%	4%
[200 - 300]	1 467 350	3%	7%
[300 - 400]	1 830 344	4%	11%
[400 - 500]	2 222 224	5%	17%
[500 - 600]	2 396 932	6%	22%
[600 - 700]	2 523 990	6%	28%
[700 - 800]	2 812 910	6%	34%
[800 - 900]	2 840 438	7%	41%
[900 - 1000]	2 655 676	6%	47%
[1000 - 1100]	2 513 456	6%	53%
[1100 - 1200]	2 396 856	6%	59%
[1200 - 1300]	2 387 122	6%	64%
[1300 - 1400]	2 261 414	5%	69%
[1400 - 1500]	2 087 726	5%	74%
[1500 - 1600]	1 859 720	4%	78%
[1600 - 1700]	1 728 816	4%	82%
[1700 - 1800]	1 484 434	3%	86%
[1800 - 1900]	1 193 726	3%	89%
[1900 - 2000]	957 736	2%	91%
[2000 - 2100]	820 968	2%	93%
[2100 - 2200]	682 058	2%	94%
[2200 - 2300]	561 954	1%	96%
[2300 - 2400]	474 716	1%	97%
[2400 - 2500]	379 080	1%	98%
[2500 - 2600]	311 984	1%	98%
[2600 - 2700]	250 496	1%	99%
[2700 - 2800]	191 586	0%	99%
[2800 - 2900]	176 448	0%	100%
[2900 - 3000]	142 882	0%	100%

The number of opportunities increase continuously from 0 to 800 km starting from a 1% share and finishing with a 7% share per range of 100km. The peak of collaboration opportunities occurs at 900 km a little bit higher than in the EPOS project involving only 3 sectors (steel, refineries and cement) [11]. As indicated before with the median value, the average value of distances between all pairs of installations is situated around 1 050km. Potential synergies would therefore be between relatively remoted installations at regional, national and with adjacent countries. After the average distance, the share reduces continuously and after 2 200km, the share become lower than the first range 0 – 100km. The probability to find a new type of partner (different that all installations in the radius 0 – 2 200km) at that far seems to be very limited or even non-existent

Considering such distances and distribution, transports are the main factor for IS wide implementation in Europe. But it depends mainly on the resource transported value. Synergies are detailed in that sense in the third section.

Analysis on specific focuses were done to apprehend differences between several range of distances:

- 0 – 200km: conventional transportation distance by road or railroad
- 0 – 50km: local transportation with limited transportation coats (Figure 13/Table 7)
- 0 – 20 km: very local transportation enabling pipeline transportation or with limited transportation cost by road/railroad (Figure 14/Table 8).

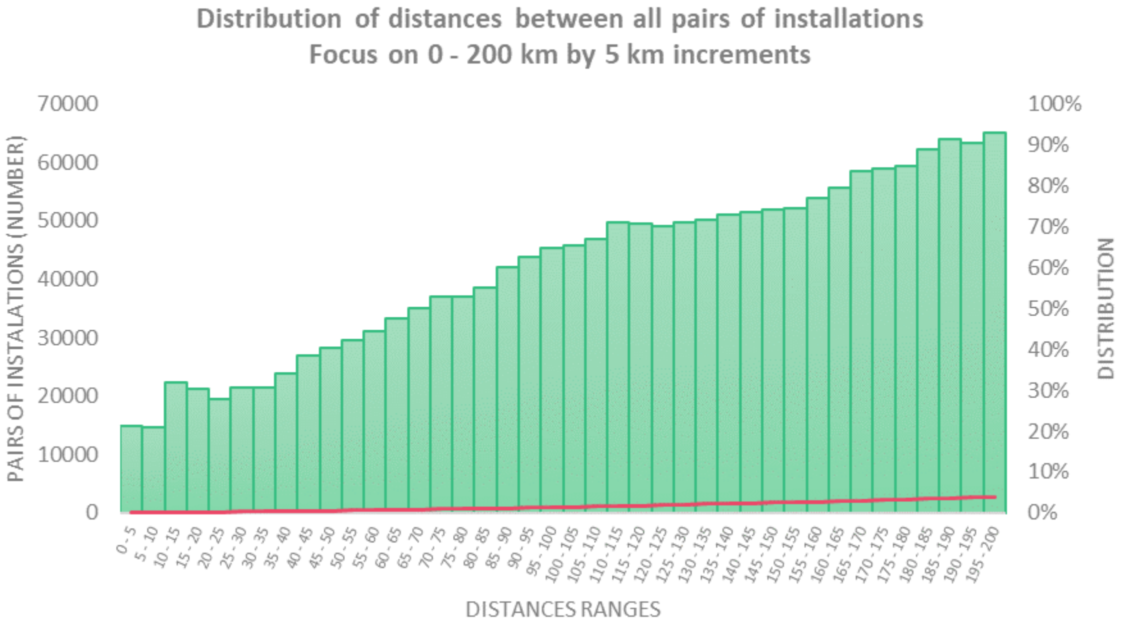


Figure 12: Distribution of distances between all pairs of installations Focus on the range 0 - 200km by 5km increments (Source: Strane)

Table 6: Figures of the 0 - 200km focus (Source: Strane)

Distance range	Number of combinations	Cumulated share
0 - 5	14 924	0,0%
5 - 10	14 636	0,1%
10 - 15	22 410	0,1%
15 - 20	21 146	0,2%
20 - 25	19 532	0,2%
25 - 30	21 436	0,3%
30 - 35	21 548	0,3%
35 - 40	23 768	0,4%
40 - 45	26 902	0,4%
45 - 50	28 346	0,5%
50 - 55	29 508	0,6%
55 - 60	31 028	0,6%
60 - 65	33 286	0,7%
65 - 70	35 040	0,8%
70 - 75	36 970	0,9%
75 - 80	37 000	1,0%
80 - 85	38 516	1,1%
85 - 90	42 080	1,2%
90 - 95	43 840	1,3%
95 - 100	45 356	1,4%
100 - 105	45 708	1,5%

105 - 110	46 788	1,6%
110 - 115	49 716	1,7%
115 - 120	49 426	1,8%
120 - 125	49 036	1,9%
125 - 130	49 690	2,0%
130 - 135	50 254	2,1%
135 - 140	50 978	2,3%
140 - 145	51 474	2,4%
145 - 150	51 904	2,5%
150 - 155	52 098	2,6%
155 - 160	53 874	2,7%
160 - 165	55 600	2,9%
165 - 170	58 494	3,0%
170 - 175	59 024	3,1%
175 - 180	59 442	3,3%
180 - 185	62 206	3,4%
185 - 190	63 896	3,6%
190 - 195	63 408	3,7%
195 - 200	65 036	3,9%

The range 0 – 200km corresponds to a regional scale where pairs of installations are close from each other. Couples of installations remoted from low than 200km represents only 4% of total of all potential combinations for industries within SCALER scope.

In the 5 first kilometres, there are already about 15,000 opportunities in Europe. It seems to appear an outburst of opportunities that will be detailed in the 0 - 20km focus. Then, the share increases continuously from 20km to 115km (0,2 to 2% of share per range).

Between 115 and 160 km, the increase is slighter then increase again significantly until 200km.

Learnings from the 0 – 200km analysis is that 4% of the total share, corresponding to 1.675 million opportunities, are at regional level. All these opportunities could be implemented by road and railroad transportation and foster local and regional / cross regional collaboration. It could be promoted and funded by public regional authorities.

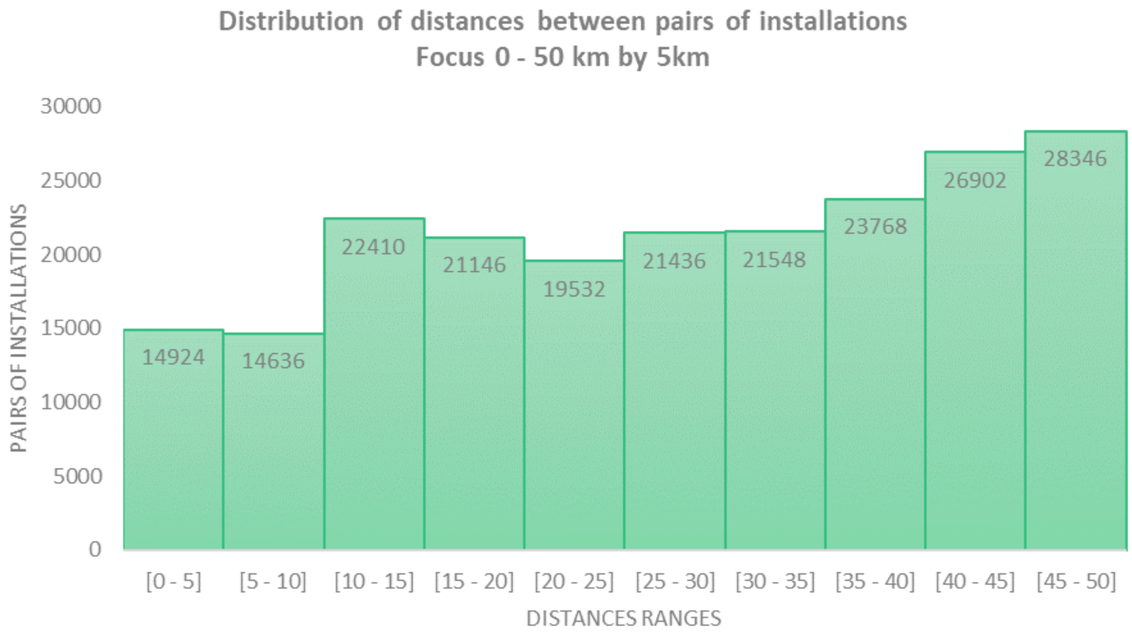


Figure 13:Distribution of distances between pairs of installations - Focus 0 - 50km by 5km (Source: Strane)

Table 7: Figures of the 0 - 50km focus (Source: Strane)

Distance Range	Pairs of installations (number)	Share	Cumulated share
0 - 5	14 924	0,03%	0,0%
5 - 10	14 636	0,03%	0,1%
10 - 15	22 410	0,05%	0,1%
15 - 20	21 146	0,05%	0,2%
20 - 25	19 532	0,05%	0,2%
25 - 30	21 436	0,05%	0,3%
30 - 35	21 548	0,05%	0,3%
35 - 40	23 768	0,05%	0,4%
40 - 45	26 902	0,06%	0,4%
45 - 50	28 346	0,07%	0,5%

The 0 – 50km focus confirms the initial statement of the outburst at 10 – 15km. It also appears a slighter increase of the share for 20 – 25 km distance range. After 25 km, the share keeps increasing continuously until 50km and the cumulated share reach 0.5% with more than 200 000 opportunities (214 648). Even within a restricted distance, IS potential is significant with an important number of opportunities. This potential can be promoted and funded by local to regional authorities (cities, intermunicipal entities, department or even regions).

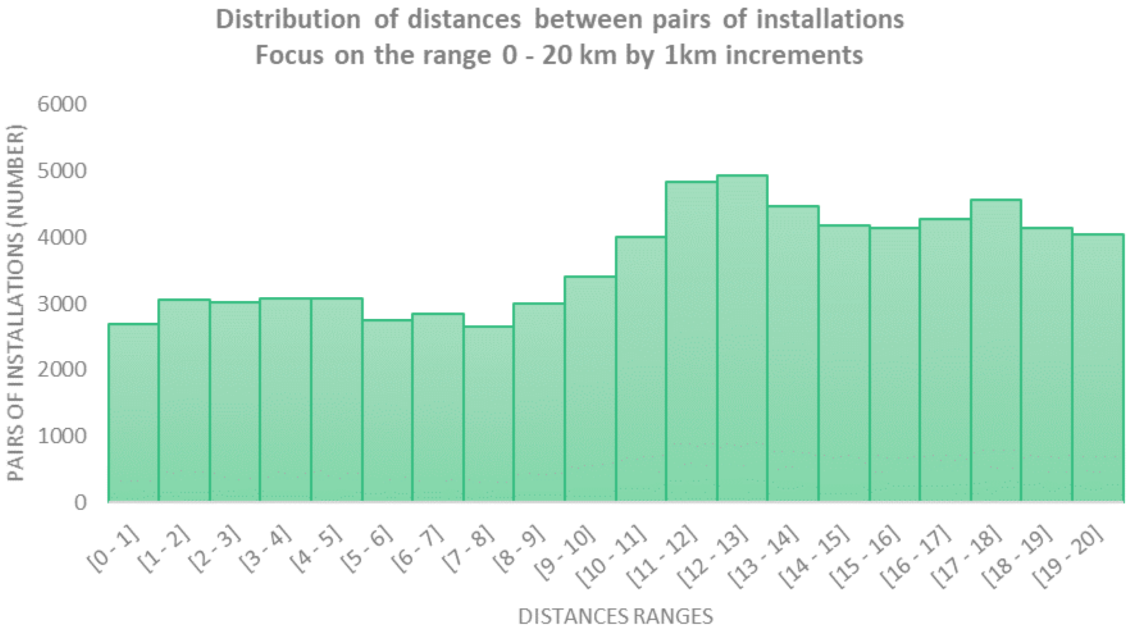


Figure 14: Distribution of distances between pairs of installations Focus on the range 0 - 20km by 1km increments (Source: Strane)

Table 8:Figures of the 0 – 20 focus (Source: Strane)

Distance range	Pairs of installations (Number)	Share	Cumulated share
[0 - 1]	2 682	0,006%	0,01%
[1 - 2]	3 054	0,007%	0,01%
[2 - 3]	3 022	0,007%	0,02%
[3 - 4]	3 086	0,007%	0,03%
[4 - 5]	3 080	0,007%	0,03%
[5 - 6]	2 754	0,006%	0,04%
[6 - 7]	2 840	0,007%	0,05%
[7 - 8]	2 644	0,006%	0,05%
[8 - 9]	3 002	0,007%	0,06%
[9 - 10]	3 396	0,008%	0,07%
[10 - 11]	3 994	0,009%	0,08%
[11 - 12]	4 836	0,011%	0,09%
[12 - 13]	4 930	0,011%	0,10%
[13 - 14]	4 474	0,010%	0,11%
[14 - 15]	4 176	0,010%	0,12%
[15 - 16]	4 134	0,010%	0,13%
[16 - 17]	4 272	0,010%	0,14%
[17 - 18]	4 566	0,011%	0,15%
[18 - 19]	4 134	0,010%	0,16%
[19 - 20]	4 040	0,009%	0,17%

Figures in the 1rst km are to be consider with caution due to the aggregation of many datasets. But, after removing all pairs of installation with a distance lower than 50 meters, the figure for the first kilometre seems to be consistent.

About 2 700 opportunities are directly in the first kilometre and the next 9 km are in the same order of magnitude (2700 – 3 000 opportunities). A first peak of opportunities is clearly identified between 11 – 13 km with around 10 000 iterations. All these potential relationships could be very profitable for nearby installations and some synergies could be exploited by pipeline transportation for very valuable gaseous and liquid resources.

These figures might be considered with caution because they are very local. So, efforts may have already been made to create synergies. It remains a challenge to quantify the gap between synergies already implemented and the full potential.

At this very local scale, public authorities (cities, metropoles, etc.) and specific entities (local industries association, companies club, clusters, etc.) could foster collaboration and the implementation of new projects.

The analysis per resources and per types of installations is performed directly for the most promising synergies of the 100 in the section 3. This analysis is carried out to highlight specific couple of sectors and activity issues and geographical constraints for specific synergies.

The geographical distribution clearly shows that IS opportunities can be deployed very locally in a limited way but mostly at regional, national and close international scale. It is therefore crucial identifying best locations for IS implementation to support financially and technically the IS implementation in the adequate areas.

2.2.2 Geographical density of industrial installations

Learnings from the geographical distribution analysis encourage looking for best regional locations for IS deployment. Industries are historically located close to material resources stores but also close to the sea and river transportation for international supplies and importation. That is the case for most process industries in particular refining, chemicals, etc. But SCALER scope also integrates other type of installations that do not require petrol as raw materials but other resources: paper, slaughterhouses, textiles, agro-industries, etc. It remained a challenge to identify locations of all type installations at Europe level.

After mapping all installations (SCALER map), the GIS software was used to automatically quantify the density of installations. Figure 15 presents the density of industrial sites in a 100km radius and the hotspots revealed.

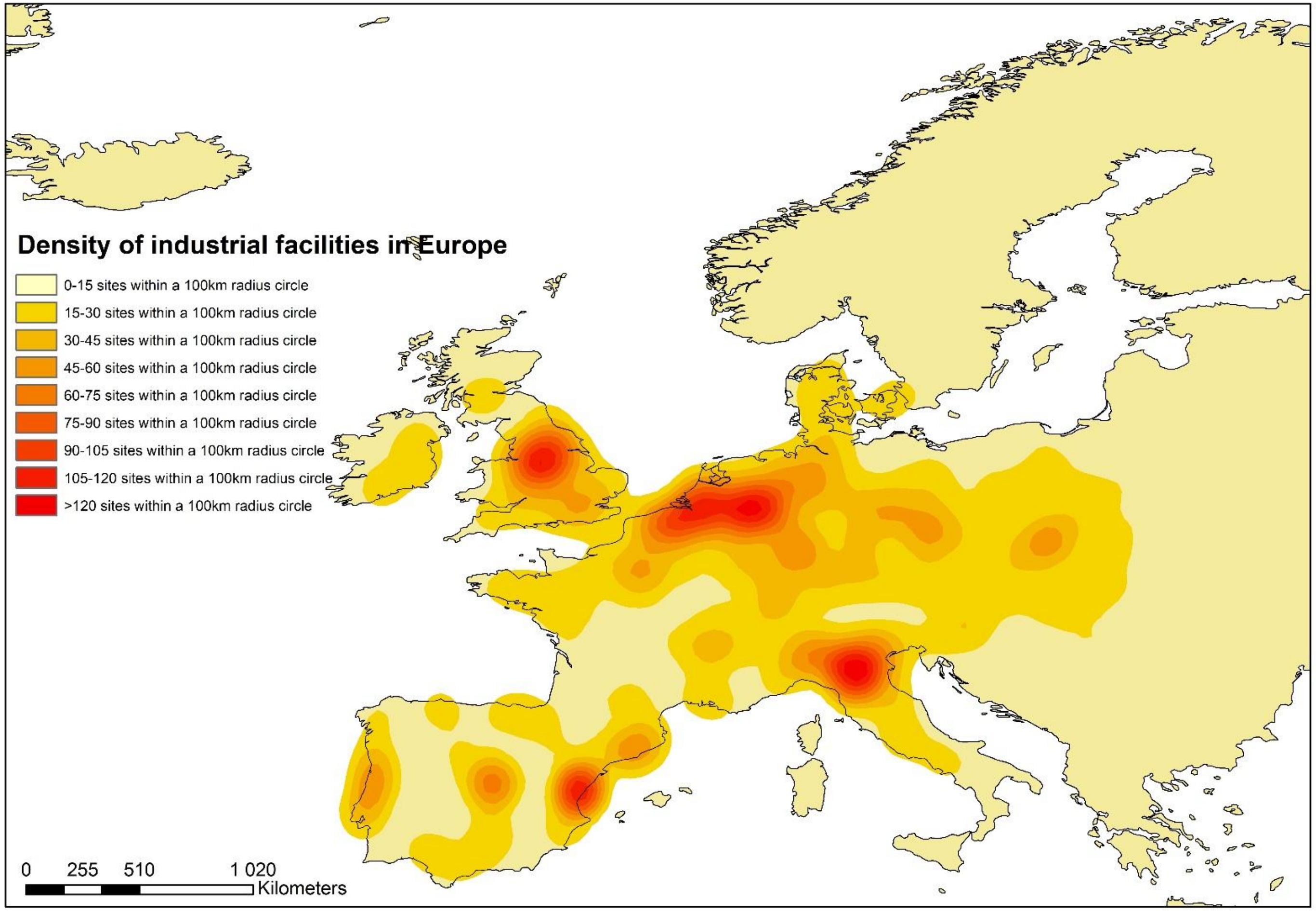


Figure 15: Density of industrial facilities in Europe (Source: Strane)

The SCALER map reveals several hotspots

- 4 major hotspots denser than 105 and even 120 sites in a 100 km radius. 2 of them were already identified as major hotspots [11] and one as a medium hotspot in the EPOS project.
  - Benelux, West Germany and North of France
  - Northern Italy
  - Valencia region & the industrial district of Castellon
  - UK midlands
- 8 medium hotspots with a density around 45 – 60 installations in a 100 km radius. Only one of them was already identified in EPOS project [11]. Some of them findings in EPOS project like Bible
  - Madrid Region
  - Barcelona & Catalonia region
  - Est Germany & Prague region
  - Krakow region
  - Lisbon Region & west coast of Portugal
  - London region
  - Lyon Region "Chemical Valley"
  - Paris & Ile de France
- Areas with a relatively high density (15 – 30 sites per 100 km) mainly as extensions of denser hotspots cited above:
  - Bask country in Spain
  - Britain in France
  - Marseille region in France
  - Whole Denmark and Copenhagen region
  - A large area across Poland, Czech Republic and Slovakia
  - Middle Italy from Florence including Rome and finishing at Naples
  - Switzerland
- Minor isolated hotspots with no direct link with others hotspots: Gijon & Asturias in Spain, Glasgow and Edinburg region in Scotland, West Ireland

All remaining installations are relatively isolated limiting close opportunities in particular for low intrinsic value resources. But the geographical distribution highlighted the peak of opportunities around 900km and the medium value for possible couple of installations around 1 050: even for these isolated installations, it remains possible to valorise waste streams and supply these sites with alternative raw materials.

The industrial density strongly reminds the Nitrogen dioxide emission maps published by ESA in 2019 [12] represented in Figure 16. Hot areas are very similar except for the Valencia region. Heavy industries contribute widely to the emission of pollutants (including NO2). Indeed, main sources of NOx are wastes, agriculture, industrial process and product use, Road transportation, non-road transport, energy use in industry and energy production [13]. IS is thus a key driver to better management resources and energy and reduce pollutants emissions.

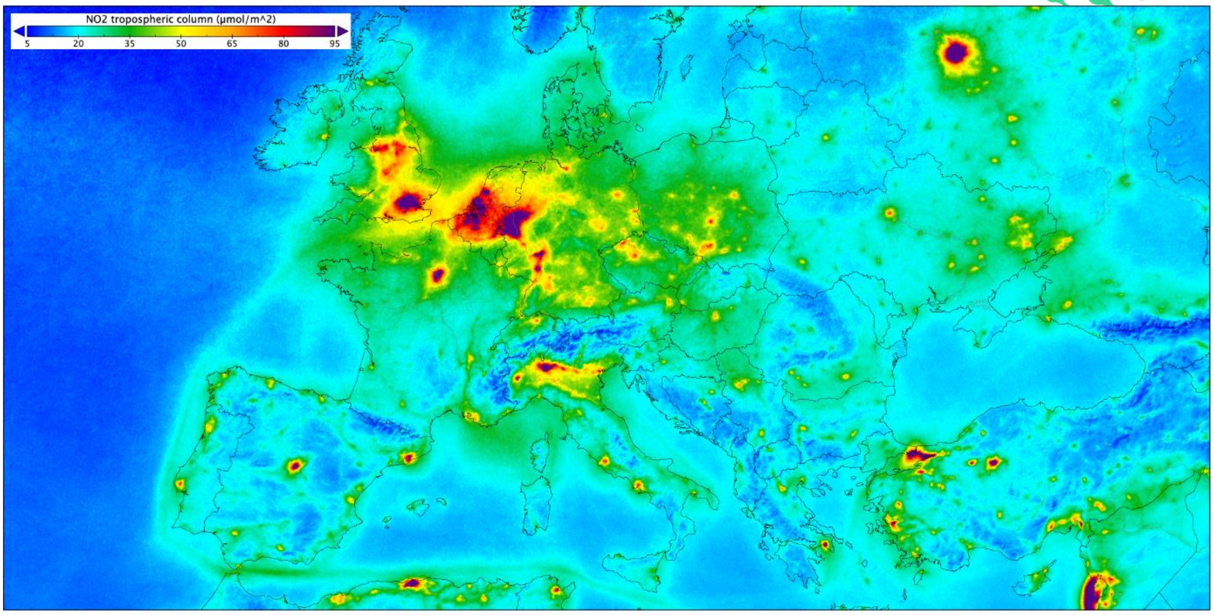


Figure 16: Nitrogen dioxide over Europe (Source : ESA [12])

The Figure 17 presents the distribution of installations within all hotpots compared to the rest of EU. Major and medium hotpots highlighted gather around 42% of all industrial installations in EU. 52% of EU installations are then not directly close to big industrial areas. The Benelux region represents itself 14% of all industrial installation in EU. Around 1 facility over 6 is located in this area. The Northern Italy hotspot corresponds to the half of Benelux hotspot in terms of number of sites. Est Germany, UK midlands and Valencia region are quite similar in terms of number of sites. Others hotspots are smaller with 0 – 3% of the total number of installations in EU.

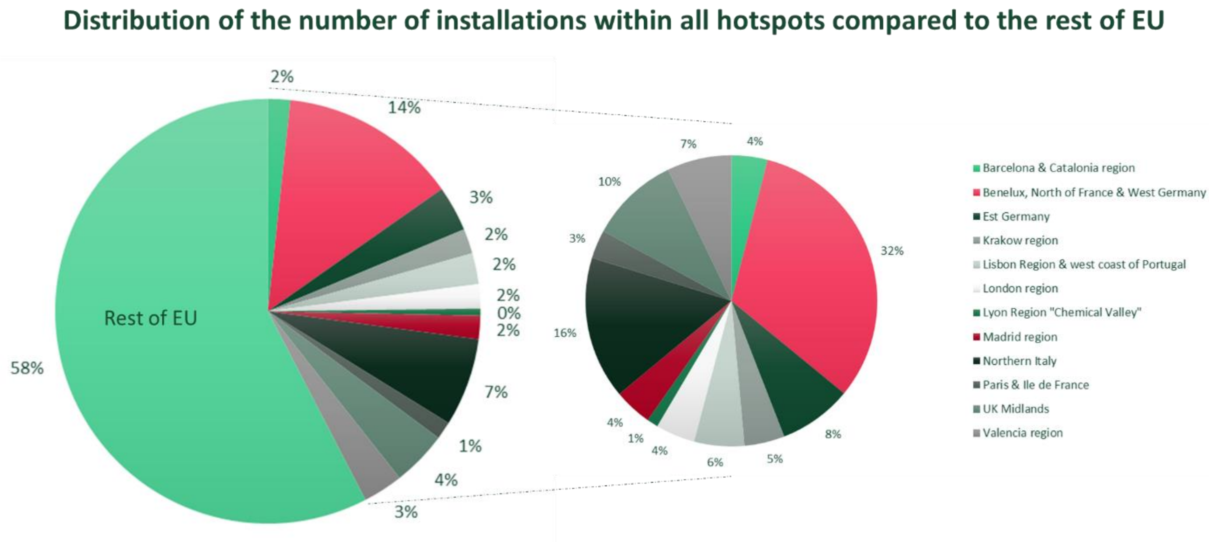


Figure 17: Distribution of the number of installations compared to the EU (Source: Strane)

Once hotspots identified, the aim was to understand local contexts within hotspots areas. The distribution of sites per sector and hotspot is presented in the Figure 18 and the and number of sites is detailed in Table 9.

As observed in Table 3, Europe Union presents a large number of ceramic installations, WWTP and slaughterhouses. Others sectors are more evenly distributed. By excluding

- The Benelux hotspots, the biggest in Europe include all type of activity studied in the SCALER scope. As for all EU, this area is represented by a large number of medium to large WWTP, ceramic installations and slaughterhouses (numerous industries for human feeding and wastewater management in high population density areas but generally smaller than Large Volume Chemicals for example). Non-ferrous metals industries, LCP and waste incinerators are well represented with around 60 - 70 installations in the area. Between 40 and 50 installations are dedicated to pharmaceuticals, steel and glass production. Other sectors are less represented.
- The Northern Italy hotspot gathers a large amount of ceramic plants with 13% of the total number of ceramic plants in Europe. Steel, glass, textiles and tanning, slaughterhouses incinerators, cement are in the second wave of the most represented sectors. Other companies are less represented. The EPOS project highlighted that many EAF and cement plants are located in this area.
- As the others major hotspots, UK Midlands is composed by 32% of ceramic facilities. WWTP, Glass industries, slaughterhouses share respectively 10, 11 and 13%. LCP (8%), non-ferrous metals (8%) and incinerators (8%) are also well represented.
- The Valencia region hotspot differs to the other because 85% of the installations are ceramics plants in particular within the ceramic industrial district of Castellon. It would be difficult to implement IS within this hotspot due to the weak variety of industrial installations. IS deployment would require to use transportation to join the nearest hotspots: Lisbon, Barcelona, Madrid, Lyon or Northern Italia by sea boat transportation.
- Madrid Region: Apart from ceramic plans representing around 45% of the area, WWTP and slaughterhouses; sectors mainly represented are glass and non-ferrous metals industries. Some steel installations are also referenced.
- Barcelona and Cataluña region: Apart from ceramic plants, WWTP and slaughterhouses this hotspot industrial context is composed by glass industries and organic chemical plants (6). Tanning plants are not negligible.
- The Est Germany & Prague region is relatively well balanced. Ceramic industries are less predominant so that the that the number of glass (31), LCP (30) and even non-ferrous metals industries (18) have a more predominant place.
- Krakow region is very represented by steel (19), LCP (33), and to lower extend by glass industries (8)
- Lisbon Region & western coast of Portugal also reveals a majority of ceramic (46%), WWTP (17%) and slaughterhouses (15%). Apart from that the industrial fabric is composed by glass (7) and pulp paper (5) plants.

- London region: a large amount of LCP (18) and incinerators (17) are on the London industrial area (in addition to WWTP, slaughterhouses and ceramic fabrics)
- Lyon Region "Chemical Valley" is a pharmaceutical cluster. Chemicals are not negligible compared to the other areas in Europe but as SCALER involve only Large Volume Chemicals, maybe some medium organic and inorganic chemical plants are missing.
- In contrary to other hotspots, Paris and Ile de France one has very low density in terms of ceramic installations. But as for London a large number of incinerator sand WWTP is closely related to the high population density. Pharmaceuticals, non-ferrous metals industries and agro-industries with several sugar plants are also key industrial actors within this area.

Fertilisers companies seems to be located outside these hotpots except Benelux region. Agro industries are also mainly in Benelux regions. Only 20% of all paper (only pulp production) are inside these densest areas. The rest of the EU. Around 60% of the 97 refineries are also on remoted locations.

Cement, LCP, refineries, fertilisers and pharmaceuticals installations have a low number of installations within hotspots areas compared to the other types of installations (20 – 36%). It is probably mainly due to the related nuisances and the infrastructure massive ground footprint. All other sectors have between 40 – 54% of all their installations that are located in the 12 hotspots.

The analysis of each specific activity per hotspot is detailed in the following section

Table 9: Number of installations in major and medium density industrial hotspots (Source: Strane)

Sector	Barcelona & Catalonia region	Benelux, North of France & West Germany	Est Germany	Krakow region	Lisbon Region & west coast of Portugal	London region	Lyon Region "Chemical Valley"	Madrid region	Northern Italy	Paris & Ile de France	UK Midlands	Valencia region	Total all hotspots	Total 4 Major hotspots	TOTAL Europe	Share of the all hotspots by sector	Share of the 4 Major hotspots by sector
Agro-industries (Sugar)	0	24	4	1	2	1	0	0	7	5	0	0	44	31	111	**39,6%**	27,9%
Cement	0	36	5	2	1	1	2	1	26	2	0	0	76	62	245	**31,0%**	25,3%
Ceramic	26	121	40	7	73	25	4	58	166	6	88	173	787	548	1302	**60,4%**	42,1%
Fertilisers	0	12	4	2	3	0	0	0	2	1	1	1	26	16	72	**36,1%**	22,2%
Glass	6	49	31	8	7	1	1	5	28	4	32	2	174	111	360	**48,3%**	30,8%
Non-ferrous metals	3	68	18	6	3	4	2	6	9	11	23	1	154	101	341	**45,2%**	29,6%
Paper	0	9	4	2	5	2	0	0	4	1	1	1	29	15	145	**20,0%**	10,3%
Pharmaceuticals	1	43	9	3		4	7	1	6	10	5	0	89	54	249	**35,7%**	21,7%
Refineries	1	16	3	2	1	1	1	0	4	1	1	1	32	22	97	**33,0%**	22,7%
Slaughterhouses	33	147	19	7	23	16	4	15	33	3	35	9	344	224	1038	**33,1%**	21,6%
Steel	1	39	7	19	3	1	1	2	29	3	10	0	115	78	263	**43,7%**	29,7%
Textile (tanning)	3	8	1	0	1	0	1	0	25	0	3	0	42	36	79	**53,2%**	45,6%
WWTP	25	133	26	27	27	31	6	29	56	13	27	11	411	227	1041	**39,5%**	21,8%
Mineral (Lime)	3	19	3	6	2	0	0	1	7	0	4	1	46	31	108	**42,6%**	28,7%
Waste incineration	4	66	14	0	2	18	5	1	28	24	23	0	185	117	434	**42,6%**	27,0%
LCP	1	61	30	33	1	17	0	0	7	6	21	1	178	90	563	**31,6%**	16,0%
Chemicals (Organic)	6	30	8	0	1	1	0	0	7	0	2	1	56	40	126	**44,4%**	31,7%
Chemicals (Inorganic)	0	21	4	1	2	0	1	0	3	0	3	0	35	27	84	**41,7%**	32,1%
Total	113	902	230	126	157	123	35	119	447	90	279	202	2823	1830	6658	**42,4%**	27,5%
Share by hotspot	**1,7%**	**13,5%**	**3,5%**	**1,9%**	**2,4%**	**1,8%**	**0,5%**	**1,8%**	**6,7%**	**1,4%**	**4,2%**	**3,0%**	**42,4%**	**27,5%**	**100,0%**		

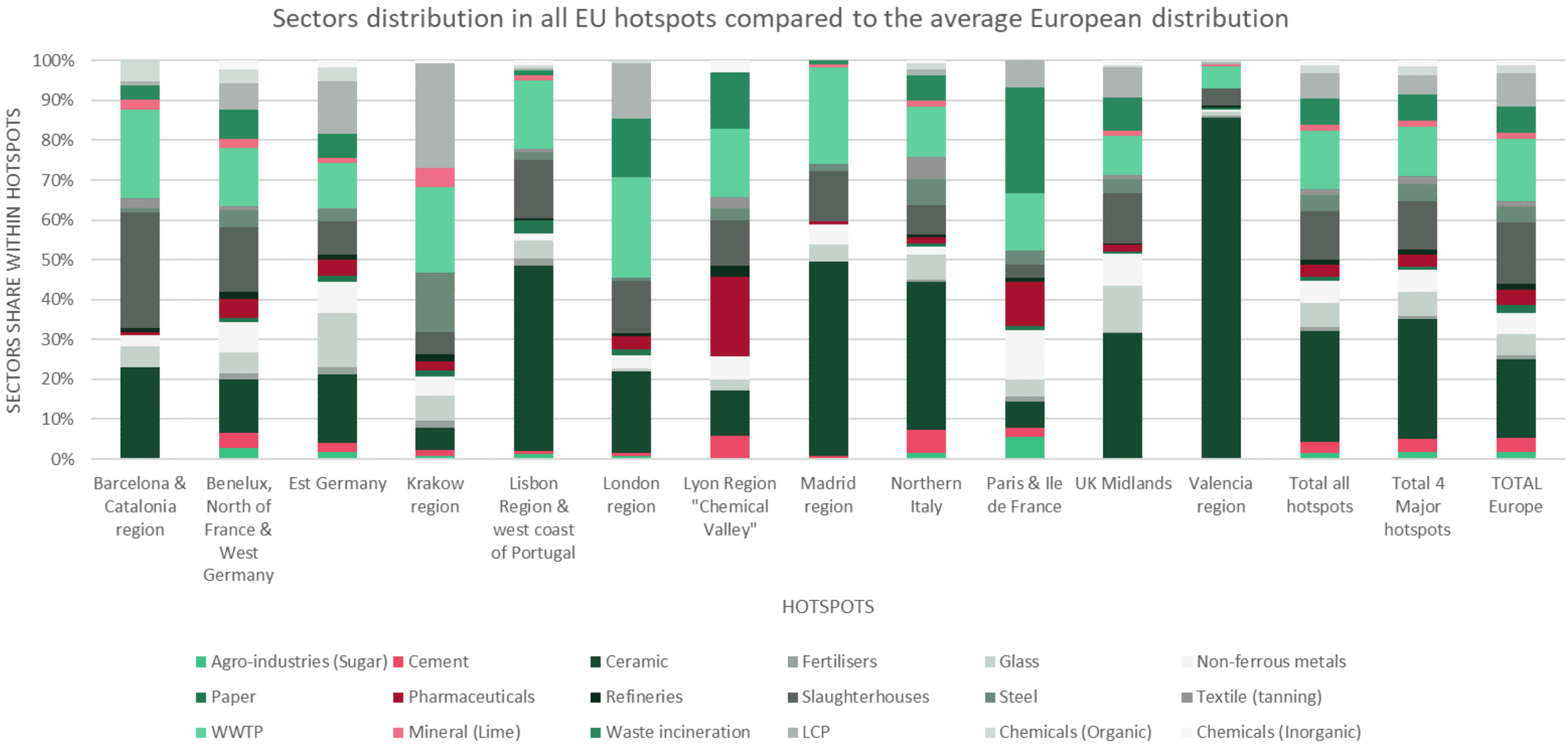


Figure 18: Distribution of industrial sectors per hotspots compared to the EU (Source: Strane)

2.2.3 Analysis of hotspots area industrial activity

This sub section details the analysis of individual hotspots per type of activity for the biggest hotpots and for the medium hotspots all together.

a. Benelux, North of France, Western Germany, Netherlands hotspot

The first hotspot is the densest in terms of number of sites and it is the largest one. Table 10 gather all sectors and activity distribution compared to the whole EU.

Table 10: Benelux, North of France, Western Germany and Netherlands hotspot type of sectors and activity (Source: Strane)

Sector	Number of installations	Percentage compared with the number of sites in EU	TOTAL Europe
Agro-industries (Sugar)	24	22%	111
Cement	36	15%	245
Ceramic	121	9%	1302
Fertilisers	12	17%	72
Glass	49	14%	360
Non-ferrous metals	68	20%	341
Paper	9	6%	145
Pharmaceuticals	43	17%	249
Refineries	16	16%	97
Slaughterhouses	147	14%	1038
Steel	39	15%	263
Textile (tanning)	8	10%	79
WWTP	133	13%	1041
Mineral (Lime)	19	18%	108
Waste incineration	66	15%	434
LCP	61	11%	563
Chemicals (Organic)	30	24%	126
Chemicals (Inorganic)	21	25%	84
Total	902	14%	6658
Share by hotspot	13,5%	14%	100,0%

Sector	Activity	Number of installations	Percentage compared with the number of sites in EU	TOTAL Europe
Agro-industries	Sugar plants	24	22%	111
Cement	Clinker plant	2	40%	
	Full cement plant	19	11%	168
	Grinding Cement Mill	15	21%	72
Ceramic	Bricks and roof tiles	118	9%	1276
	Technical ceramics	3	12%	26
Fertilisers	AN CAN	3	20%	15
	NPK	6	16%	37
	UREA	3	15%	20
Glass	Glass fibres	10	14%	71
	Hollow glass	39	13%	289
Non-ferrous metals	Potential crude nickel and cobalt producers	2	11%	18
	Potential nickel, cobalt and alloys smelters	7	22%	32
	Aluminium and alloys smelters	17	15%	117
	Copper and alloys smelting	11	24%	46
	Crude Aluminium	9	20%	44
	Crude copper	3	18%	17
	Lead	1	50%	2
	Other crude lead and tin producers or smelters	13	25%	51
	Primary zinc & secondary zinc	1	20%	5
	Secondary zinc	3	50%	6
	Tin smelter	1	50%	2
Paper	Pulp	2	2%	114
	Pulp & paper	7	23%	31
Pharmaceuticals	Pharmaceutical preparations	43	17%	249
Refineries	Refineries	12	16%	74
	Refineries & Steam cracker	4	17%	23
Slaughterhouses	Slaughterhouses	147	14%	1038
Steel	Coke ovens	5	12%	42
	Pelletisation plant	1	14%	7
	Primary and secondary steelmaking (BF/BOF EAF)	0	0%	3
	Primary steelmaking (BF and/or BOF + Sinter plant)	7	21%	34
	Secondary steelmaking (EAF)	26	15%	177
Textile	Tanning	8	10%	79
WWTP	Industrial WWTP	13	10%	129
	WWTP (> 150 000 PE)	120	13%	912
Mineral	Lime	19	18%	108
Waste incineration	Waste incineration	66	15%	434
LCP	Coal combustion	55	12%	458
	Gasification & liquefaction	6	6%	105
Chemicals (Organic)	Ethyl Acetate production	1	14%	7
	Ethylbenzene & Styrene	4	31%	13
	Formaldehyde	7	25%	28
	Phenol	3	38%	8
	Steam cracker	8	38%	21
	Vinyl chloride monomer	7	27%	26
Chemicals (Inorganic)	Calcium Carbide	3	27%	11
	Carbon Black	2	25%	8
	Precipitated silica	4	44%	9
	Precipitated silica and silica gel	0	0%	1
	Pyrogenic silica	1	17%	6

	Silica gel	1	100%	1
	Soda ash	2	12%	17
	Sodium chlorate	0	0%	11
	Sodium silicate	4	50%	8
	Titanium Dioxide	4	33%	12
	Total	902	14%	6634
	Share by hotspot	13,6%	14%	100,0%

This area presents a wide variety of process industries that can be found across Europe confirming a propitious context for IS. Around 14% of all European process industries are located in this area. Sectors that are well represented are:

- Organic and inorganic chemicals involving around 25% of the total number of LVOC and LVIC in particular for ethyl acetate, ethylbenzene & styrene, formaldehyde, phenol, lower olefins, Vinyl chloride monomer, calcium carbide, carbon black, silica gel, sodium silicate. It is important to note that some of these activities do not have a large number of installations across EU.
- Agro-industries are well represented with 22% of European sugar plants.
- Non-ferrous metals production with 20% of all EU sites in particular for lead, tin, zinc, aluminium, nickel and cobalt
- Pharmaceuticals, steel, refineries, fertilisers and cement are also well represented in lower extend.

Sectors that are not significantly represented are:

- It is interesting to be note that ceramic installations are not very represented in this area, in contrary with all a lot of other hotspots.
- Pulp production industries are not located in the area (Only 6%)
- Only 10% of tanning activities and large combustion plants.
- There are 13% of medium size and major WWT located in this hotspot which is present in this area which is quite surprising by considering high densities of both population and industrial installations.

b. Northern Italy

The second hotspots area covers the whole of northern Italy. About 6.7% of all industrial sites in EU are located in this area. Table 11 gathers all sectors and activity distribution compared to the whole EU.

Table 11: Northern Italy hotspot type of sectors and activity (Source: Strane)

Sector	Number of installations	Percentage compared with the number of sites in EU	TOTAL Europe	Rest of EU
Agro-industries (Sugar)	7	6%	111	104
Cement	26	11%	245	219

Ceramic	166	13%	1302	1136
Fertilisers	2	3%	72	70
Glass	28	8%	360	332
Non-ferrous metals	9	3%	341	332
Paper	4	3%	145	141
Pharmaceuticals	6	2%	249	243
Refineries	4	4%	97	93
Slaughterhouses	33	3%	1038	1005
Steel	29	11%	263	234
Textile (tanning)	25	32%	79	54
WWTP	56	5%	1041	985
Mineral (Lime)	7	6%	108	101
Waste incineration	28	6%	434	406
LCP	7	1%	563	556
Chemicals (Organic)	7	6%	126	119
Chemicals (Inorganic)	3	4%	84	81
Total	447	7%	6658	6211
Share by hotspot	6,7%	7%	100,0%	93%

Sector	Activity	Number of installations	Percentage compared with the number of sites in EU	TOTAL Europe
Agro-industries	Sugar plants	7	6%	111
Cement	Clinker plant	1	20%	
	Full cement plant	17	10%	168
	Grinding Cement Mill	8	11%	72
Ceramic	Bricks and roof tiles	163	13%	
	Technical ceramics	3	12%	26
Fertilisers	AN CAN	0	0%	15
	NPK	1	3%	37
	UREA	1	5%	20
Glass	Glass fibres	3	4%	71
	Hollow glass	25	9%	289
Non-ferrous metals	Potential crude nickel and cobalt producers	0	0%	18
	Potential nickel, cobalt and alloys smelters	3	9%	32
	Aluminium and alloys smelters	3	3%	117
	Copper and alloys smelting	2	4%	46
	Crude Aluminium	0	0%	44
	Crude copper	0	0%	17
	Lead	0	0%	2
	Other crude lead and tin producers or smelters	0	0%	51
	Primary zinc & secondary zinc	0	0%	5
	Secondary zinc	1	17%	6
	Tin smelter	0	0%	2
Paper	Pulp	4	4%	114
	Pulp & paper	0	0%	31
Pharmaceuticals	Pharmaceutical preparations	6	2%	249
Refineries	Refineries	4	5%	74
	Refineries & Steam cracker	0	0%	23
Slaughterhouses	Slaughterhouses	33	3%	1038
Steel	Coke ovens	1	2%	
	Pelletisation plant	0	0%	7
	Primary and secondary steelmaking (BF/BOF EAF)	0	0%	3
	Primary steelmaking (BF and/or BOF + Sinter plant)	0	0%	34
	Secondary steelmaking (EAF)	28	16%	177

Textile	Tanning	25	32%	79
WWTP	Industrial WWTP	9	7%	129
	WWTP (> 150 000 PE)	47	5%	912
Mineral	Lime	7	6%	108
Waste incineration	Waste incineration	28	6%	434
LCP	Coal combustion	5	1%	458
	Gasification & liquefaction	2	2%	105
Chemicals (Organic)	Ethyl Acetate production	0	0%	7
	Ethylbenzene & Styrene	1	8%	13
	Formaldehyde	5	18%	28
	Phenol	1	13%	8
	Steam cracker	0	0%	21
	Vinyl chloride monomer	0	0%	26
Chemicals (Inorganic)	Calcium Carbide	0	0%	11
	Carbon Black	2	25%	8
	Precipitated silica	0	0%	9
	Precipitated silica and silica gel	0	0%	1
	Pyrogenic silica	0	0%	6
	Silica gel	0	0%	1
	Soda ash	0	0%	17
	Sodium chlorate	1	9%	11
	Sodium silicate	0	0%	8
	Titanium Dioxide	0	0%	12
	Total	447	7%	6634
	Share by hotspot	6,7%	7%	100,0%

Textile tanning seems to be an enormous know how of the Northern Italy hotspot since 32% of the European tanning activities are located in that area. Cement plant, including clinker production are well represented (10%) as well as steel, mostly secondary with about 16% of all EU EAF installations. This area is of interest particularly for EAF slags, dusts and refractory products synergies detailed in section 3. As for Spanish hotspots and for historical reasons, 166 ceramic plants (13% of EU brook and roof tiles plants and 12% of technical ceramics) are referenced in his area.

Agro-industries are well represented with 7 sugar plants (6%), glass sector in particular container glass, Lime production with 7 sites. Some specific activities of inorganic and organic chemicals respectively like Carbon Black production and Formaldehyde are region industrial know-how.

Unexpectedly, there are not numerous slaughterhouses in this area. This will be compared with the livestock farming map in the next section. A very weak of pulp production companies is the direct consequence of a poor proportion of total forest area compared to the land area in Northern Italy [14]. The number of LCP is very low compared to other hotspots with only 5 coal combustion plants and 2 gasification and liquefaction installations. This is probably due to the use of other type of LCP or source of energy. Strangely, because the region has some chemical production skills, only two companies produce large volume fertilisers (does not include other fertilisers than AN CAN, NPK and UREA) and 6/249 (2%) of EU pharmaceuticals activities. The only non-ferrous metals activities in the area are nickel, cobalt, aluminium, copper and all associated alloys smelting.

c. Valencia region & the industrial district of Castellon

The Valencia region and the industrial district of Castellon is the new hotspot identified in SCALER. The well-known activity of this region is the ceramic production. 3% of the total number of installations in EU are located in this area. The ceramics cluster occupies a large area of approximately 30 km in the province of Castellón, bounded to the north by Alcora and Borriol, to the west by Onda and Ribesalbes, to the south by Nules and to the east by the city of Castellón. Ceramic activity is also present in a second ring of contiguous municipalities, both inland (Vilafamés, Vall d'Alba) and on the coast (Moncofa, Xilxes). The whole of this territory had a total population of around 450,000 inhabitants in 2014 (INE, population census) and around 16,000 direct jobs in the ceramics cluster (2013), with a turnover volume of just over 4.1 billion euros (2013) [15].

Table 12 gathers all sectors and activity distribution compared to the whole EU.

Table 12: Valencia region & the industrial district of Castellon hotspot type of sectors and activity (Source: Strane)

Sector	Number of installations	Percentage compared with the number of sites in EU	TOTAL Europe	Rest of EU
Agro-industries (Sugar)	0	0%	111	111
Cement	0	0%	245	245
Ceramic	173	13%	1302	1129
Fertilisers	1	1%	72	71
Glass	2	1%	360	358
Non-ferrous metals	1	0%	341	340
Paper	1	1%	145	144
Pharmaceuticals	0	0%	249	249
Refineries	1	1%	97	96
Slaughterhouses	9	1%	1038	1029
Steel	0	0%	263	263
Textile (tanning)	0	0%	79	79
WWTP	11	1%	1041	1030
Mineral (Lime)	1	1%	108	107
Waste incineration	0	0%	434	434
LCP	1	0%	563	562
Chemicals (Organic)	1	1%	126	125
Chemicals (Inorganic)	0	0%	84	84
Total	202	3%	6658	6456
Share by hotspot	3,0%	3%	100,0%	97%

Sector	Activity	Number of installations	Percentage compared with the number of sites in EU	TOTAL Europe
Agro-industries	Sugar plants	0	0%	111
Cement	Clinker plant	0	0%	
	Full cement plant	0	0%	168
	Grinding Cement Mill	0	0%	72

Ceramic	Bricks and roof tiles	173	14%	
	Technical ceramics	0	0%	26
Fertilisers	AN CAN	0	0%	15
	NPK	1	3%	37
	UREA	0	0%	20
Glass	Glass fibres	0	0%	71
	Hollow glass	2	1%	289
Non-ferrous metals	Potential crude nickel and cobalt producers	0	0%	18
	Potential nickel, cobalt and alloys smelters	0	0%	32
	Aluminium and alloys smelters	1	1%	117
	Copper and alloys smelting	0	0%	46
	Crude Aluminium	0	0%	44
	Crude copper	0	0%	17
	Lead	0	0%	2
	Other crude lead and tin producers or smelters	0	0%	51
	Primary zinc & secondary zinc	0	0%	5
	Secondary zinc	0	0%	6
	Tin smelter	0	0%	2
Paper	Pulp	1	1%	114
	Pulp & paper	0	0%	31
Pharmaceuticals	Pharmaceutical preparations	0	0%	249
Refineries	Refineries	1	1%	74
	Refineries & Steam cracker	0	0%	23
Slaughterhouses	Slaughterhouses	9	1%	1038
Steel	Coke ovens	0	0%	
	Pelletisation plant	0	0%	7
	Primary and secondary steelmaking (BF/BOF EAF)	0	0%	3
	Primary steelmaking (BF and/or BOF + Sinter plant)	0	0%	34
	Secondary steelmaking (EAF)	0	0%	177
Textile	Tanning	0	0%	79
WWTP	Industrial WWTP	0	0%	129
	WWTP (> 150 000 PE)	11	1%	912
Mineral	Lime	1	1%	108
Waste incineration	Waste incineration	0	0%	434
LCP	Coal combustion	1	0%	458
	Gasification & liquefaction	0	0%	105
Chemicals (Organic)	Ethyl Acetate production	0	0%	7
	Ethylbenzene & Styrene	0	0%	13
	Formaldehyde	1	4%	28
	Phenol	0	0%	8
	Steam cracker	0	0%	21
	Vinyl chloride monomer	0	0%	26
Chemicals (Inorganic)	Calcium Carbide	0	0%	11
	Carbon Black	0	0%	8
	Precipitated silica	0	0%	9
	Precipitated silica and silica gel	0	0%	1
	Pyrogenic silica	0	0%	6
	Silica gel	0	0%	1
	Soda ash	0	0%	17
	Sodium chlorate	0	0%	11
	Sodium silicate	0	0%	8
	Titanium Dioxide	0	0%	12
	Total	202	3%	6634
	Share by hotspot	3,0%	3%	100,0%

As identified before, ceramics production is the main activity of this hotspot. Alone, this area contains 13% of the total number of ceramic installations in Europe (173). Nevertheless, the ceramic production concern mainly bricks and roof tiles manufacturing because no plant is dedicated to technical ceramic production. Ceramic machines and vitrified clay pipes are also produced [15].

One formaldehyde (organic chemical) installation, one refinery, one NPK fertiliser company constitute all petrochemicals activities on the territory.

Others activities like agro (sugar), cement, pharmaceuticals and textile productions(tanning) are non-existent. Stranger, the number of incinerators (no installation) and combustion plants (1) are surprisingly low because they are directly linked with industrial activities and population density. Electricity sources in Spain are mostly from nuclear power plants (around 20%), hydraulic installations (16%), wind turbines (25,4%), gas (14,3%) and solar panels (13,3%) [16], explaining the low number of LCP. The number of urban WWTP seems to be consistent but there are not specific industrial WWTP.

The Valencia region is a specific case with low industrial variety. It would be difficult to implement a large number of cross sectorial synergies in this area. Nevertheless, maybe some synergies could be found with large volume chemicals and some specific synergies (56 on ceramic wastewater, 66 and 77 on the reuse of steel slag in ceramics, 69 on the use of fly ashes in bricks and roof tiles manufacturing) could be implemented with other hotpots.

d. UK midlands

UK midlands is the last major hotspot identified. 4.2% of EU industrial installations are located in this area.

Table 13: UK midlands region & the industrial district of Castellon hotspot type of sectors and activity (Source: Strane)

Sector	Number of installations	Percentage compared with the number of sites in EU	TOTAL Europe	Rest of EU
Agro-industries (Sugar)	0	0%	111	111
Cement	0	0%	245	245
Ceramic	88	7%	1302	1214
Fertilisers	1	1%	72	71
Glass	32	9%	360	328
Non-ferrous metals	23	7%	341	318
Paper	1	1%	145	144
Pharmaceuticals	5	2%	249	244
Refineries	1	1%	97	96
Slaughterhouses	35	3%	1038	1003
Steel	10	4%	263	253
Textile (tanning)	3	4%	79	76
WWTP	27	3%	1041	1014
Mineral (Lime)	4	4%	108	104

Waste incineration	23	5%	434	411
LCP	21	4%	563	542
Chemicals (Organic)	2	2%	126	124
Chemicals (Inorganic)	3	4%	84	81
Total	279	4%	6658	6379
Share by hotspot	4,2%	4%	100,0%	96%

Sector	Activity	UK Midlands	Percentage compared with the number of sites in EU	TOTAL Europe
Agro-industries	Sugar plants	0	0%	111
Cement	Clinker plant	0	0%	
	Full cement plant	0	0%	168
	Grinding Cement Mill	0	0%	72
Ceramic	Bricks and roof tiles	85	7%	1276
	Technical ceramics	3	12%	26
Fertilisers	AN CAN	0	0%	15
	NPK	1	3%	37
	UREA	0	0%	20
Glass	Glass fibres	7	10%	71
	Hollow glass	25	9%	289
Non-ferrous metals	Potential crude nickel and cobalt producers	6	33%	18
	Potential nickel, cobalt and alloys smelters	5	16%	32
	Aluminium and alloys smelters	5	4%	117
	Copper and alloys smelting	1	2%	46
	Crude Aluminium	1	2%	44
	Crude copper	1	6%	17
	Lead	0	0%	2
	Other crude lead and tin producers or smelters	4	8%	51
	Primary zinc & secondary zinc	0	0%	5
	Secondary zinc	0	0%	6
	Tin smelter	0	0%	2
Paper	Pulp	1	1%	114
	Pulp & paper	0	0%	31
Pharmaceuticals	Pharmaceutical preparations	5	2%	249
Refineries	Refineries	1	1%	74
	Refineries & Steam cracker	0	0%	23
Slaughterhouses	Slaughterhouses	35	3%	1038
Steel	Coke ovens	4	10%	42
	Pelletisation plant	0	0%	7
	Primary and secondary steelmaking (BF/BOF EAF)	0	0%	3
	Primary steelmaking (BF and/or BOF + Sinter plant)	1	3%	34
	Secondary steelmaking (EAF)	5	3%	177
Textile	Tanning	3	4%	79
WWTP	Industrial WWTP	0	0%	129
	WWTP (> 150 000 PE)	27	3%	912
Mineral	Lime	4	4%	108
Waste incineration	Waste incineration	23	5%	434
LCP	Coal combustion	9	2%	458
	Gasification & liquefaction	12	11%	105
Chemicals (Organic)	Ethyl Acetate production	0	0%	7
	Ethylbenzene & Styrene	1	8%	13
	Formaldehyde	0	0%	28
	Phenol	0	0%	8
	Steam cracker	0	0%	21

	Vinyl chloride monomer	1	4%	26
Chemicals (Inorganic)	Calcium Carbide	1	9%	11
	Carbon Black	0	0%	8
	Precipitated silica	0	0%	9
	Precipitated silica and silica gel	1	100%	1
	Pyrogenic silica	0	0%	6
	Silica gel	0	0%	1
	Soda ash	1	6%	17
	Sodium chlorate	0	0%	11
	Sodium silicate	0	0%	8
	Titanium Dioxide	0	0%	12
	Total	279	4%	6634
	Share by hotspot	4,2%	4%	100,0%

Glass industries are well represented with 10% of glass fibres and 9% of container glass EU installations. Non-ferrous metals are produced in this area particularly nickel and cobalt. 3 technical ceramic producers representing 12% of the whole EU installations are

Petrochemicals and inorganic chemicals activities include a limited number of installations: refining mineral oil and gas, ethylbenzene and styrene production, Vinyl chloride monomer, precipitated silica and silica gel manufacturing, soda ash production.

Some secondary steel plants are in this area but the major part of steel activity concerns coke ovens (4) with 10% of the European installations.

Many gasification and liquefaction installations are on the territory (10% of the whole EU) and come coal combustion plants are

This zone presents an interesting potential for IS due to variety of production (to lower extend compared to the Benelux Region)

e. All others areas with a medium industrial density

Number of site distribution per sector and activity of all other dense areas are in the Table 14.

Table 14: other hotspots type of sectors and activity (Source: Strane)

Sector	Barcelona & Catalonia region	%	Est Germany	%	Krakow region	%	Lisbon Region & west coast of Portugal	%	London region	%	Lyon Region "Chemical Valley"	%	Madrid region	%	Paris & Ile de France	%	TOTAL Europe
Agro-industries (Sugar)	0	0%	4	4%	1	1%	2	2%	1	1%	0	0%	0	0%	5	5%	111
Cement	0	0%	5	2%	2	1%	1	0%	1	0%	2	1%	1	0%	2	1%	245
Ceramic	26	2%	40	3%	7	1%	73	6%	25	2%	4	0%	58	4%	6	0%	1302
Fertilisers	0	0%	4	6%	2	3%	3	4%	0	0%	0	0%	0	0%	1	1%	72
Glass	6	2%	31	9%	8	2%	7	2%	1	0%	1	0%	5	1%	4	1%	360
Non-ferrous metals	3	1%	18	5%	6	2%	3	1%	4	1%	2	1%	6	2%	11	3%	341
Paper	0	0%	4	3%	2	1%	5	3%	2	1%	0	0%	0	0%	1	1%	145
Pharmaceuticals	1	0%	9	4%	3	1%		0%	4	2%	7	3%	1	0%	10	4%	249
Refineries	1	1%	3	3%	2	2%	1	1%	1	1%	1	1%	0	0%	1	1%	97
Slaughterhouses	33	3%	19	2%	7	1%	23	2%	16	2%	4	0%	15	1%	3	0%	1038
Steel	1	0%	7	3%	19	7%	3	1%	1	0%	1	0%	2	1%	3	1%	263
Textile (tanning)	3	4%	1	1%	0	0%	1	1%	0	0%	1	1%	0	0%	0	0%	79
WWTP	25	2%	26	2%	27	3%	27	3%	31	3%	6	1%	29	3%	13	1%	1041
Mineral (Lime)	3	3%	3	3%	6	6%	2	2%	0	0%	0	0%	1	1%	0	0%	108
Waste incineration	4	1%	14	3%	0	0%	2	0%	18	4%	5	1%	1	0%	24	6%	434
LCP	1	0%	30	5%	33	6%	1	0%	17	3%	0	0%	0	0%	6	1%	563
Chemicals (Organic)	6	5%	8	6%	0	0%	1	1%	1	1%	0	0%	0	0%	0	0%	126
Chemicals (Inorganic)	0	0%	4	5%	1	1%	2	2%	0	0%	1	1%	0	0%	0	0%	84
Total	113	2%	230	3%	126	2%	157	2%	123	2%	35	1%	119	2%	90	1%	6658
Share by hotspot	2%	2%	3%	3%	2%	2%	2%	2%	2%	2%	1%	1%	2%	2%	1%	1%	100%

Sector	Activity	Barcelona & Catalonia region	%	Est Germany		Krakow region		Lisbon Region & west coast of Portugal		London region		Lyon Region "Chemical Valley"		Madrid region		Paris & Ile de France		TOTAL Europe
Agro-industries	Sugar plants	0	0%	4	4%	1	1%	2	2%	1	1%	0	0%	0	0%	5	5%	111
Cement	Clinker plant	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	
	Full cement plant	0	0%	4	2%	1	1%	0	0%	0	0%	2	1%	0	0%	1	1%	168
	Grinding Cement Mill	0	0%	1	1%	1	1%	1	1%	1	1%	0	0%	1	1%	1	1%	72
Ceramic	Bricks and roof tiles	26	2%	38	3%	7	1%	73	6%	24	2%	4	0%	57	4%	6	0%	
	Technical ceramics	0	0%	2	8%	0	0%	0	0%	1	4%	0	0%	1	4%	0	0%	26
Fertilisers	AN CAN	0	0%	1	7%	1	7%	1	7%	0	0%	0	0%	0	0%	0	0%	15

	NPK	0	0%	1	3%	0	0%	1	3%	0	0%	0	0%	0	0%	1	3%	37
	UREA	0	0%	2	10%	1	5%	1	5%	0	0%	0	0%	0	0%	0	0%	20
Glass	Glass fibres	1	1%	8	11%	3	4%	0	0%	0	0%	0	0%	2	3%	1	1%	71
	Hollow glass	5	2%	23	8%	5	2%	7	2%	1	0%	1	0%	3	1%	3	1%	289
Non-ferrous metals	Potential crude nickel and cobalt producers	0	0%	0	0%	0	0%	0	0%	0	0%	1	6%	0	0%	0	0%	18
	Potential nickel, cobalt and alloys smelters	0	0%	2	6%	1	3%	0	0%	0	0%	0	0%	1	3%	0	0%	32
	Aluminium and alloys smelters	1	1%	6	5%	4	3%	2	2%	3	3%	1	1%	4	3%	2	2%	117
	Copper and alloys smelting	2	4%	4	9%	0	0%	0	0%	0	0%	0	0%	0	0%	4	9%	46
	Crude Aluminium	0	0%	1	2%	0	0%	0	0%	0	0%	0	0%	0	0%	1	2%	44
	Crude copper	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	17
	Lead	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	2
	Other crude lead and tin producers or smelters	0	0%	3	6%	0	0%	1	2%	1	2%	0	0%	1	2%	4	8%	51
	Primary zinc & secondary zinc	0	0%	0	0%	1	20%	0	0%	0	0%	0	0%	0	0%	0	0%	5
	Secondary zinc	0	0%	1	17%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	6
	Tin smelter	0	0%	1	50%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	2
Paper	Pulp	0	0%	2	2%	2	2%	5	4%	0	0%	0	0%	0	0%	1	1%	114
	Pulp & paper	0	0%	2	6%	0	0%	0	0%	2	6%	0	0%	0	0%	0	0%	31
Pharmaceuticals	Pharmaceutical preparations	1	0%	9	4%	3	1%	0	0%	4	2%	7	3%	1	0%	10	4%	249
Refineries	Refineries	0	0%	2	3%	2	3%	1	1%	1	1%	0	0%	0	0%	1	1%	74
	Refineries & Steam cracker	1	4%	1	4%	0	0%	0	0%	0	0%	1	4%	0	0%	0	0%	23
Slaughterhouses	Slaughterhouses	33	3%	19	2%	7	1%	23	2%	16	2%	4	0%	15	1%	3	0%	1038
Steel	Coke ovens	0	0%	0	0%	9	21%	0	0%	0	0%	0	0%	0	0%	0	0%	
	Pelletisation plant	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	7
	Primary and secondary steelmaking (BF/BOF EAF)	0	0%	0	0%	1	33%	0	0%	0	0%	0	0%	0	0%	0	0%	3
	Primary steelmaking (BF and/or BOF + Sinter plant)	0	0%	0	0%	3	9%	0	0%	0	0%	0	0%	0	0%	0	0%	34
	Secondary steelmaking (EAF)	1	1%	7	4%	6	3%	3	2%	1	1%	1	1%	2	1%	3	2%	177
Textile	Tanning	3	4%	1	1%	0	0%	1	1%	0	0%	1	1%	0	0%	0	0%	79
WWTP	Industrial WWTP	1	1%	9	7%	6	5%	0	0%	0	0%	3	2%	0	0%	2	2%	129
	WWTP (> 150 000 PE)	24	3%	17	2%	21	2%	27	3%	31	3%	3	0%	29	3%	11	1%	912
Mineral	Lime	3	3%	3	3%	6	6%	2	2%	0	0%	0	0%	1	1%		0%	108
Waste incineration	Waste incineration	4	1%	14	3%	0	0%	2	0%	18	4%	5	1%	1	0%	24	6%	434
LCP	Coal combustion	1	0%	28	6%	33	7%	1	0%	3	1%	0	0%	0	0%	1	0%	458
	Gasification & liquefaction	0	0%	2	2%	0	0%	0	0%	14	13%	0	0%	0	0%	5	5%	105
Chemicals (Organic)	Ethyl Acetate production	1	14%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	7
	Ethylbenzene & Styrene	1	8%	3	23%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	13
	Formaldehyde	1	4%	1	4%	0	0%	1	4%	0	0%	0	0%	0	0%	0	0%	28
	Phenol	0	0%	1	13%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	8

	Steam cracker	1	5%	1	5%	0	0%	0	0%	1	5%	0	0%	0	0%	0	0%	21
	Vinyl chloride monomer	2	8%	2	8%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	26
Chemicals (Inorganic)	Calcium Carbide	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	11
	Carbon Black	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	8
	Precipitated silica	0	0%	0	0%	0	0%	0	0%	0	0%	1	11%	0	0%	0	0%	9
	Precipitated silica and silica gel	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	1
	Pyrogenic silica	0	0%	1	17%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	6
	Silica gel	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	1
	Soda ash	0	0%	2	12%	0	0%	1	6%	0	0%	0	0%	0	0%	0	0%	17
	Sodium chlorate	0	0%	0	0%	0	0%	1	9%	0	0%	0	0%	0	0%	0	0%	11
	Sodium silicate	0	0%	1	13%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	8
	Titanium Dioxide	0	0%	0	0%	1	8%	0	0%	0	0%	0	0%	0	0%	0	0%	12
	Total	113	2%	230	3%	126	2%	157	2%	123	2%	35	1%	119	2%	90	1%	6634
	Share by hotspot	1,7%	2%	3,5%	3%	1,9%	2%	2,4%	2%	1,9%	2%	0,5%	1%	1,8%	2%	1,4%	1%	100,0%

Barcelona region presenting some specific activities:

- Organic chemicals especially ethyl acetate, ethylbenzene and styrene production, formaldehyde, lower olefins, and vinyl chloride monomer
- Textile production with tanning activities
- Slaughterhouses

Est Germany & Prague region relatively well balanced in term of industrial activity:

- Glass industries with glass fibres and container glass production (around 8 – 11% of the EU number of installations)
- Organic chemicals (6% of the EU number of installations) with ethylbenzene and styrene, formaldehyde, phenol, lower olefins and vinyl chloride monomer
- LCP with 28 coal combustion plants
- Inorganic chemicals producing silica, soda ash and sodium silicate
- Non-ferrous metals in particular with tin, zinc, lead, copper, aluminium, nickel and cobalt and all associated alloys

Krakow region mainly focused on steel, mineral extraction and LCP

- Steel with 9 coke ovens and 4 primary steel installations and 7 EAF locations.
- Mineral extraction with 6% of the total of EU lime production sites
- 33 coal combustion plants. Indeed, coal is the major source of Poland energy with around 70% of electricity supplies [16]

Lisbon region & western coast of Portugal

- The medium hotspot producing the most of ceramics (6% of all EU installations)
- Fertilisers even it corresponds to only 3 large volume installations
- Some pulp factories probably because forest proportion is significant in Portugal [14]
- A few chemical plants (3) including inorganic (soda ash, sodium chlorate) and organic (formaldehyde) productions

London region

- With a lot of gasification and liquefaction activities (13% of the EU installations)
- On refinery and some pharmaceuticals preparation plants
- Incineration plants for waste management (18 sites) and 31 WWTP for water management of the urban area

Lyon region with numerous pharmaceuticals facilities

Madrid region with a lot of ceramics activities and WWTP

Paris and Ile de France with many sugar plants (5), pharmaceuticals preparation production units (10), incinerators, gasification and liquefaction installations (5) and some non-ferrous metals as copper lead, tin, aluminium and all associated alloys.

Using two criteria, number of sites compared to the UE and the variety of industrial sites within the hotspots, best locations for IS implementation are:

1. Benelux, North of France, Western Germany, Netherlands
2. Northern Italy
3. Est Germany / UK midlands
4. Krakow region & Prague / Lisbon region and western coasts of Portugal
5. Valencia region
6. Paris and Ile de France / Barcelona and Catalonia / London Region
7. Madrid region
8. Lyon region

2.3 Other maps

In order to avoid a geographical and statistical bias, some industrial sites were removed from the general and SCALER maps. Indeed, there are too many WWTP and livestock farming and raising installations to integrate them with all other sites.

a. WWTP map

Several sources were used to identify WWTP locations throughout Europe. Wastewater treatment plants were separated in several categories:

- WWTP with a capacity lower than 40 000 PE
- WWTP with a 40 000- 150 000 capacity range (medium size WWTP in EU)
- WWTP with capacity upper than 150 000 PE (Large capacities)
- Industrial WWT¨P that are directly operated by industrial companies themselves nearby to their installations. This map may not include all industrial WWTP in Europe but only industrial installations declaring wastewater treatment activities in the EPRTR report.

Other small WWTP are not integrated in the map. The WWTP map is presented in Figure 19 and the density of major and medium size WWTP is presented in Figure 20.

Major hotspots:

- Midlands
- Benelux
- A large part of Germany with a very dense spot nearby Stuttgart region
- Northern Italy in particular in Milan region

- Some same medium hotspots than in the SCALER and general map:
- London
- Madrid

- Valencia region
- Krakow region
- Est Germany and Prague region
- Paris

Same small hotpots than in the SCALER and general map:

- Whole Poland
- The Netherlands
- Lisbon region

Some new small hotpots:

- Britain in France
- South Spain and Gibraltar region

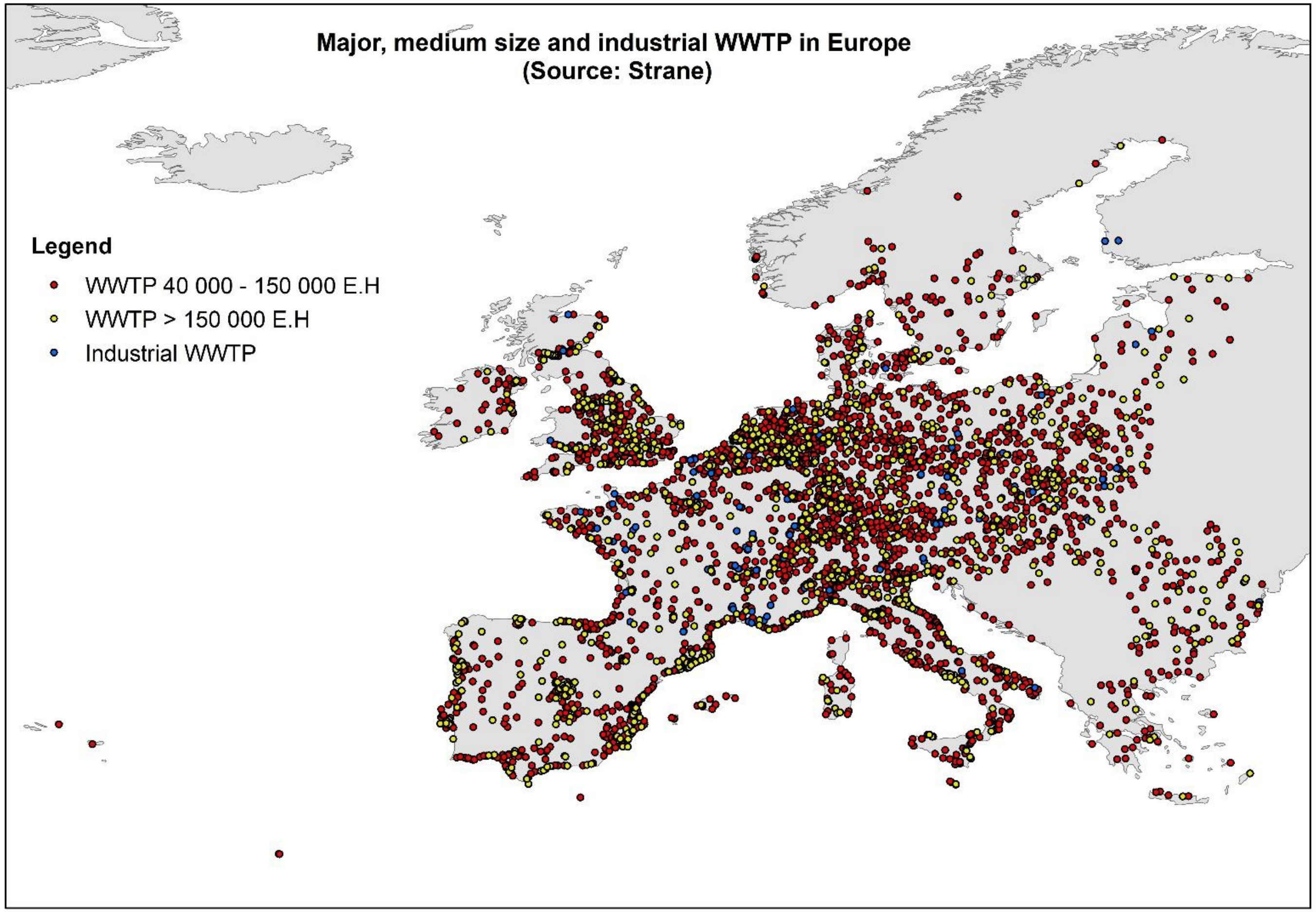


Figure 19: WWTP map (source: Strane)

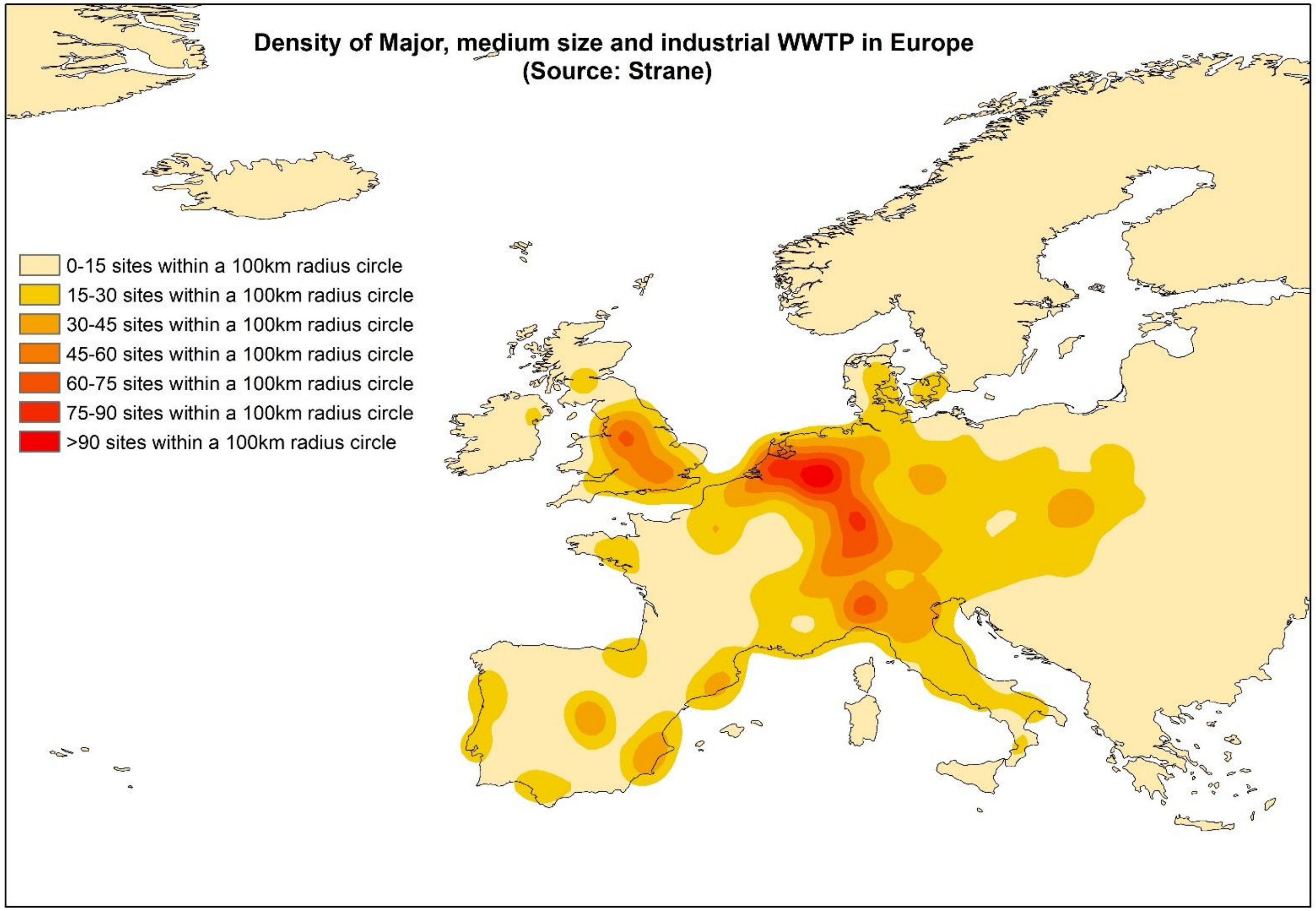


Figure 20: Density of major, medium size and industrial WWTP in Europe

b. Livestock farming map

Animal farming and raising installations were gathered from the EPRTR database. There are a lot of locations in Europe (13 673 animal farming and raising locations and 5 189 poultry raising locations) that is why they were mapped separately in order to avoid bias in the statistical analysis

Regions with a large number of animal farming and raising activities are:

- UK Midlands
- Britain in France
- Benelux region
- North Est of Spain
- Denmark
- Northern Italy
- Poland
- Romania
- Ukraine

Some others regions like south of Spain and Portugal have also a lot of locations.

On strange fact to note is the difference between the number of animal farming and raising location sand the number of slaughterhouses

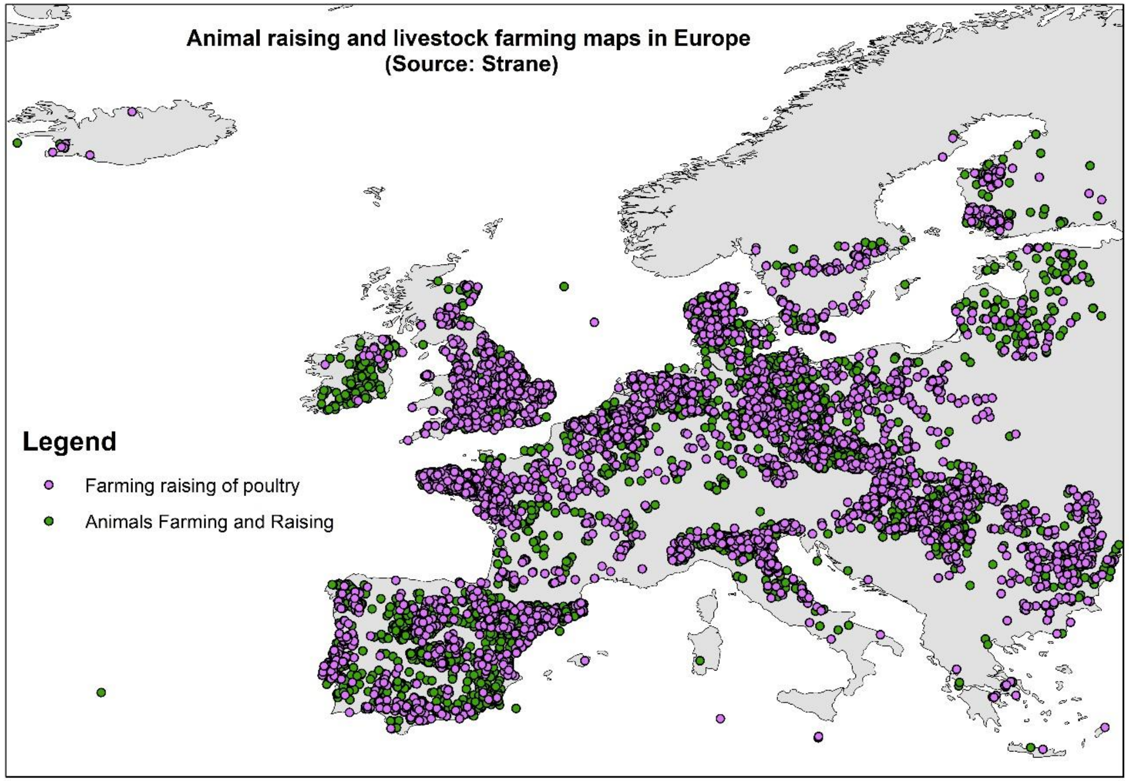


Figure 21: Livestock farming map (Source: Strane)

c. Mining and quarrying operations (Source: Strane)

Mineral production is also a SPIRE Sector that is why this map was built. The mapping was feasible for 3 main types of mineral extractions:

- Hard coal and lignite
- Gravel and sand pits, mining of clay and kaolin
- Ornamental and building stones, limestones, gypsum, chalk and slate

This map may not include all mining and quarrying operations but gather all available resources that have been found. Key mining areas in Europe are easily spotted in:

- UK Midlands
- Rest of UK
- Atlantic coast of France
- South Est of France
- Krakow region
- Belgium and Western Germany

These locations are quite different from the other areas identified in the general map and SCALER map so there is not a direct link and proximity between the mining / quarrying operations and other process industries (do not concern ferrous and non-ferrous metals ores) so the supply is probably performed by lorry, trains or naval shipping.

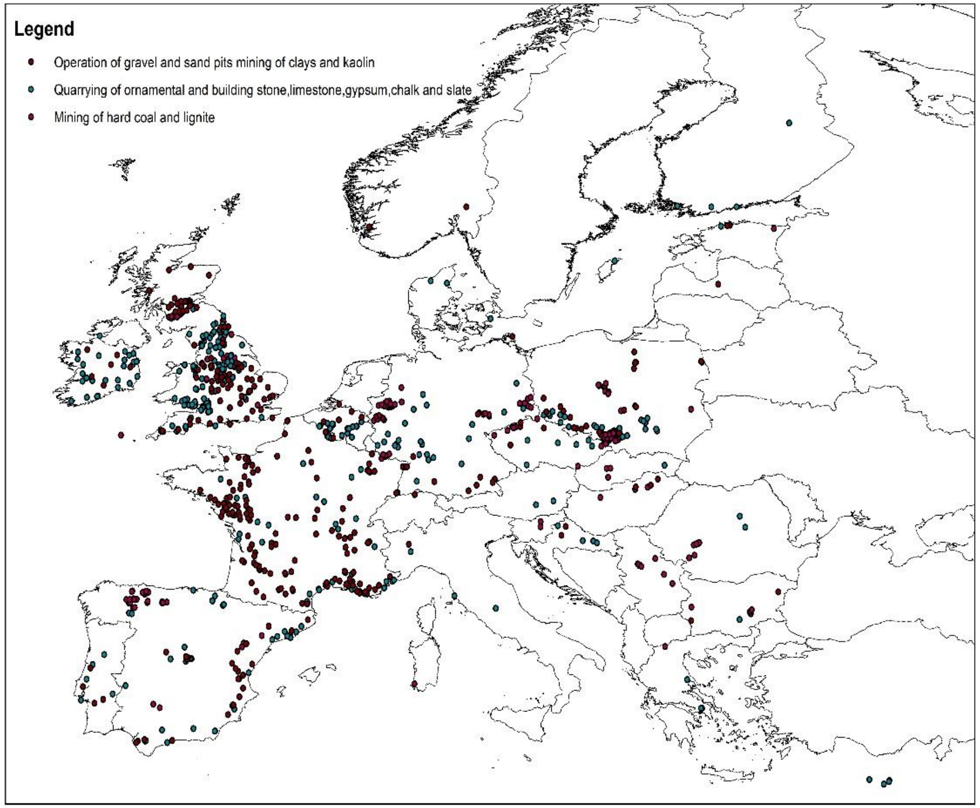


Figure 22: Quarrying and mining map (Source: Strane)

2.4 Industrial installations locations / Cities / Functional Urban Area (FAU)

This section details the work performed to quantify the number of sites and theirs repartition within urban areas and cities.

The definition of a City by the European commission and the OECD "works in four basic steps and is based on the presence of an 'urban centre' a new spatial concept based on high-density population grid cells." Basic steps are defined in [17]. Cities list was found on the Eurostat Cities Database [18].

The Functional urban area (FUA) consists of the city and its commuting zone [17]. Conditions to be considered as a commuting zone are:

- *"If 15 % of employed persons living in one city work in another city, these cities are treated as a single city.*
- *All municipalities with at least 15 % of their employed residents working in a city are identified; this means that these cities will have a single shared commuting zone. To identify which municipalities should be included, the commuting to both cities will be added together.*
- *Municipalities surrounded by a single functional area are included and non-contiguous municipalities are dropped"*

The functional urban area shapefiles were gathered from the OECD data [19].

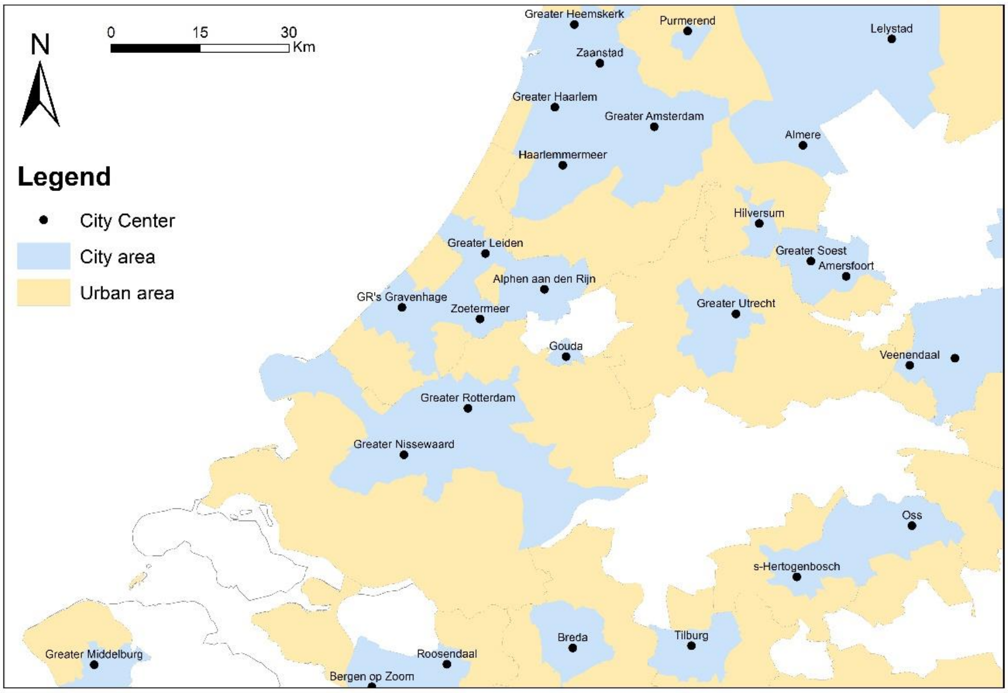


Figure 23: Example of mapping cities downtowns, cities and urban areas for the Rotterdam/Amsterdam regions (Source: Strane)

Then, all industrial installations were mapped and an intersection function enable keeping only in two separated maps:

- Industrial installations within the geographical scope of cities (e.g. Figure 24 → Map of the Lisbon region and installations within the geographical scope of cities)
- Industrial installations within the geographical scope of functional urban area (e.g. Figure 25 → Map of the Lyon region and installation within the geographical scope of FUA)

Both maps have been created at European level (not only specific regional areas). The intersection mapping between FAU and industrial installation is presented in Figure 26.

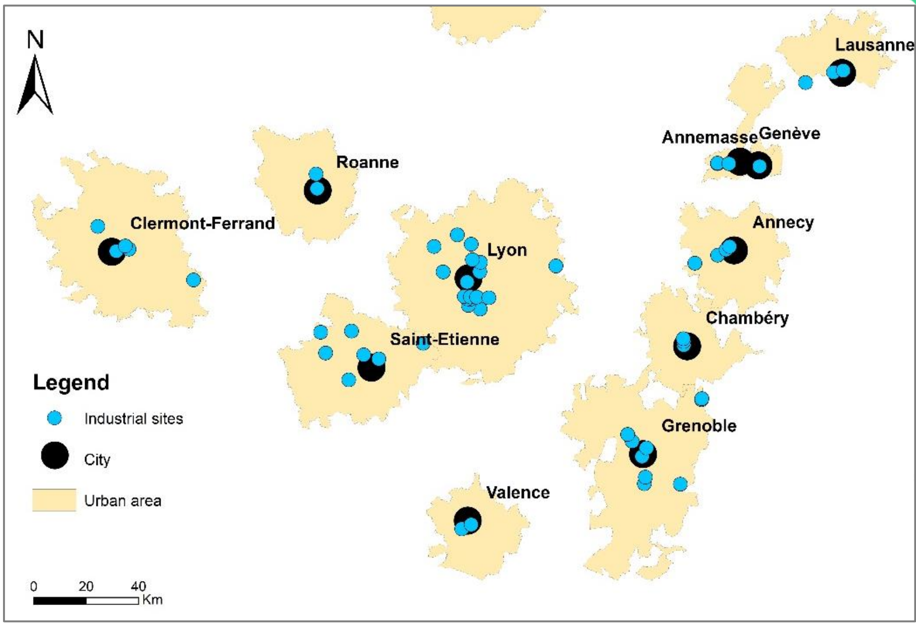


Figure 24: Example of industrial installations selection within the geographical scope of FUA (Source: Strane)

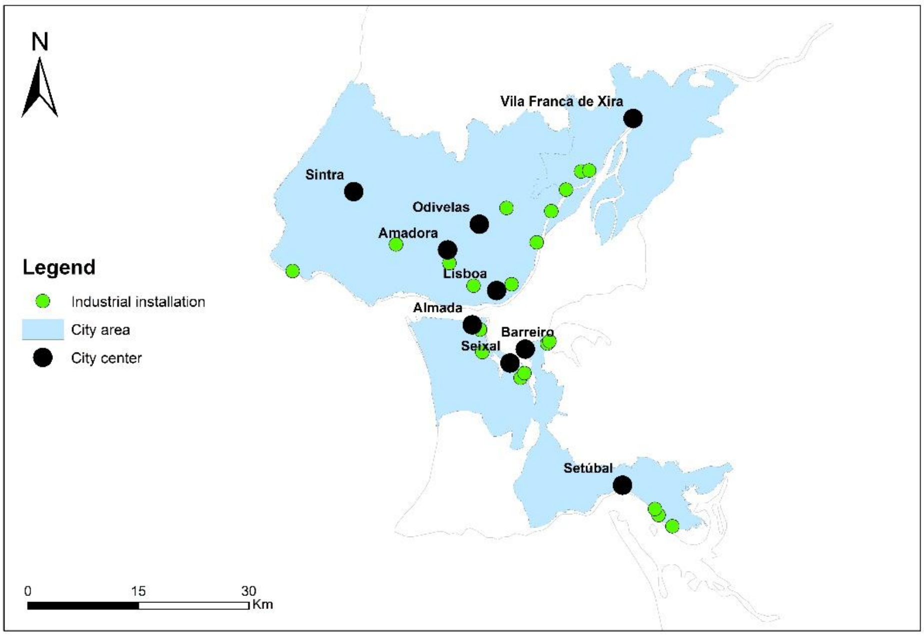


Figure 25: Example of industrial installations selection within the geographical scope of cities (Source: Strane)

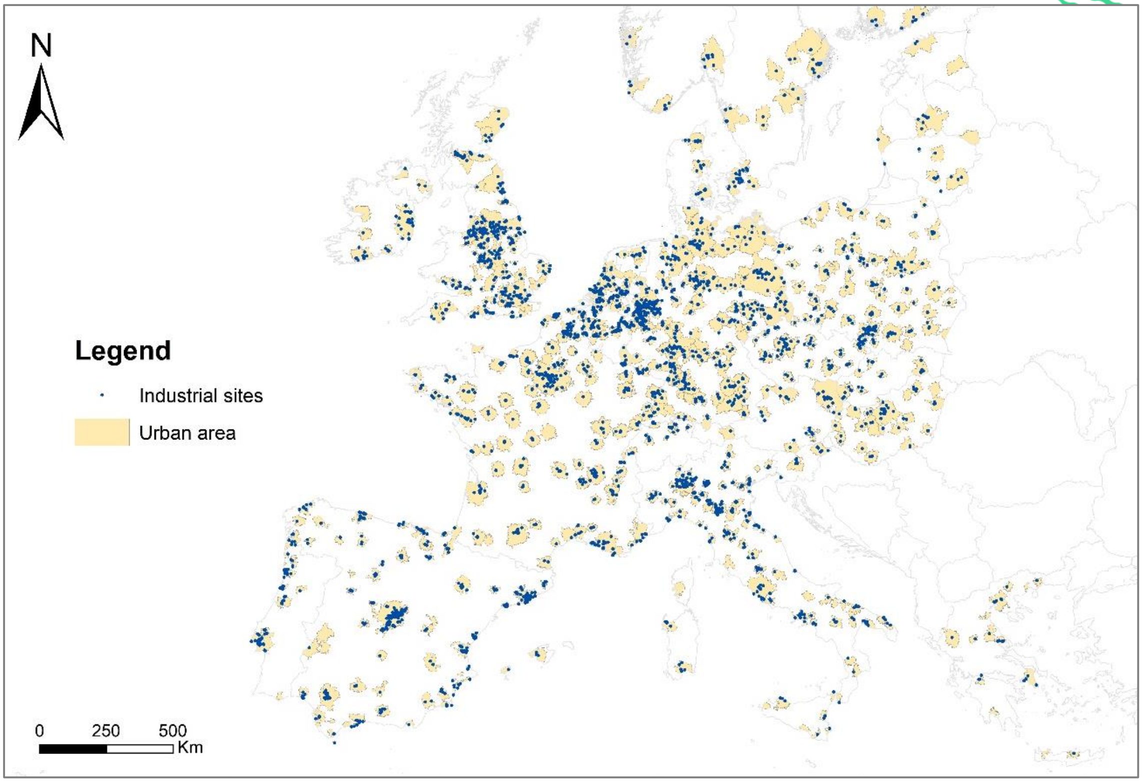


Figure 26: Intersection map between FAU and industrial installations (Source: Strane)

The two maps lead to obtain the number of installations within FAUs and core cities as indicated in Table 15.

Table 15: Number of installations within FUAs and core cities (source: Strane)

Geographical areas	Number of installations	Share (% of total number of sites)
Cities	1 969	29.6%
Functional Urban Area	3 462	52.0%

Around half of industrial sites are located within FAU areas that consists of a densely inhabited city and of a surrounding area (commuting zone) whose labour market is highly integrated with the city [19].

Half of industrial installations are outside FAU, probably to avoid nuisances and impacts on the community. The difference between the number of sites within FAU and core cities is probably due to the massive land footprint of process industries. Nevertheless, we note that industrial sites are located in inhabited areas and probably contribute to the territories attractiveness.

For industrial symbiosis, advantages to be located on dense and active areas are:

- Well-developed road networks facilitating resources transfers and collaborations with partners
- Support from local authorities who wish to remain attractive areas for their residents
- Possibility to collaborate with consultancies, facilitators, logistics services or waste management companies to implement synergies
- Possibility to find receivers for the resources without applications

Drawbacks to be situated in core cities or urban areas are that can affect industrial symbiosis implementation:

- Traffic jams and sometimes difficult access to industrial sites
- Industrial nuisances and impact on the community (CO_2 emissions, pollutants, noise, odours, etc.)
- Community complaints can have an impact on industrial activities

In a general way, it is an advantage to have around 30% of the installations in the core city geographical scope and 50% in FUA. Be situated in FUA is a better location because these areas are less dense than core cities but are still very close to commodities, services and fields of actions of other companies. Therefore, the number of concerned installations is very encouraging for industrial symbiosis implementation.

2.5 District heating assessment

One of the major objectives with industrial symbiosis implementation is to develop district heating from industrial waste heat recovery. A methodology was adopted to identify all district heating opportunities across Europe by locating installations that could implement a district heating program. Based on the industrial database built for the T3.1., we identified some industrial activities that generate waste heat:

- Refineries
- Cement
- Synthetic Amorphous Silica
- Slaughterhouses
- Pulp & Paper (Paper)
- Waste incineration
- Coal combustion
- Gasification and liquefaction
- Ethylbenzene and Styrene
- Hydrogen peroxide production

This list is a non-exhaustive sample but we are sure that they generate waste heat. Other industrial installations could complete this list and would increase the potential. Furthermore, this study does not take into account the amount of energy available per each type of site. This analysis will be performed in the last section of the document.

Once industrial installation emitting heat identified, it was necessary to spot areas with high population densities. That is why data and shapefiles were collected specifically collected: cities and downtowns locations.

Heat producers were mapped with FAU, cities, and downtown locations as indicated in Figure 27.

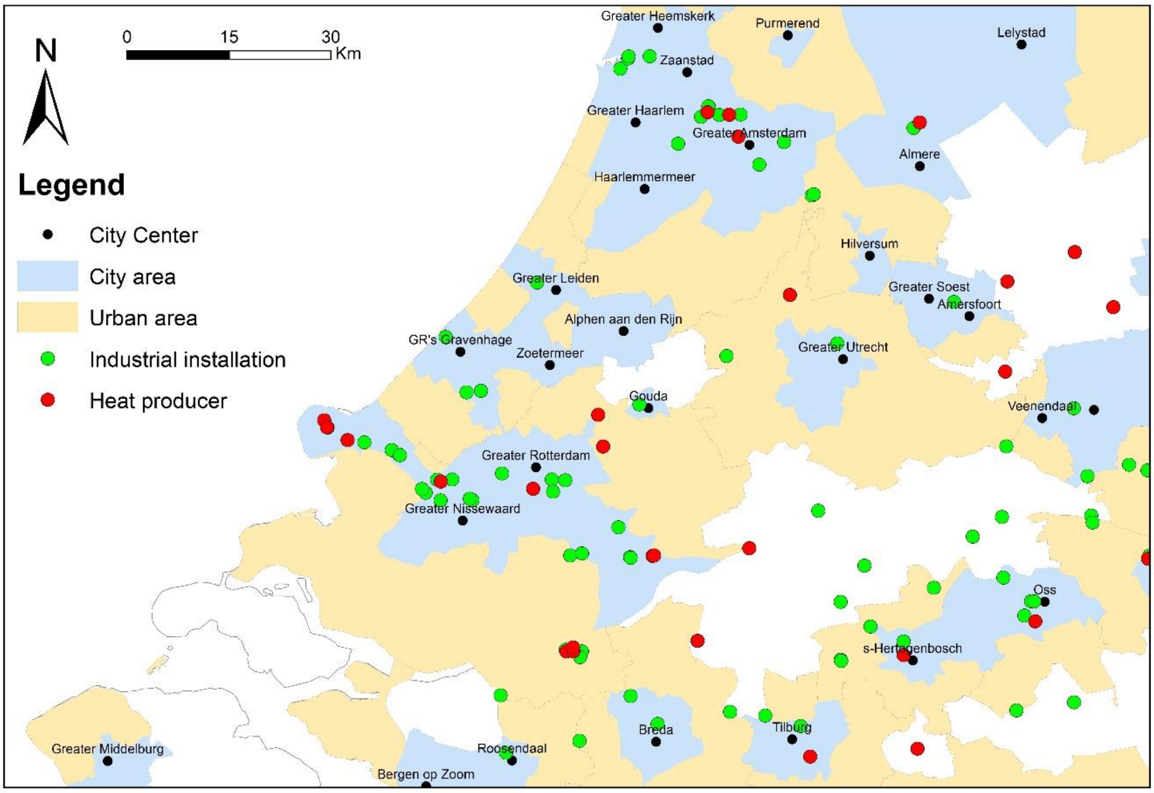


Figure 27: Heat producers mapping (Source: Strane)

This map was built at a European level and was used to obtain three main outcomes:

- The number of heat emitters in FUA
- The number of heat emitter in core cities
- The distances and distribution of distance between heat emitters and the nereast city downtowns

Examples of maps at a regional level (Dortmund / Dusseldorf area in Germany) and European level are presented in Figure 28 and Figure 29.

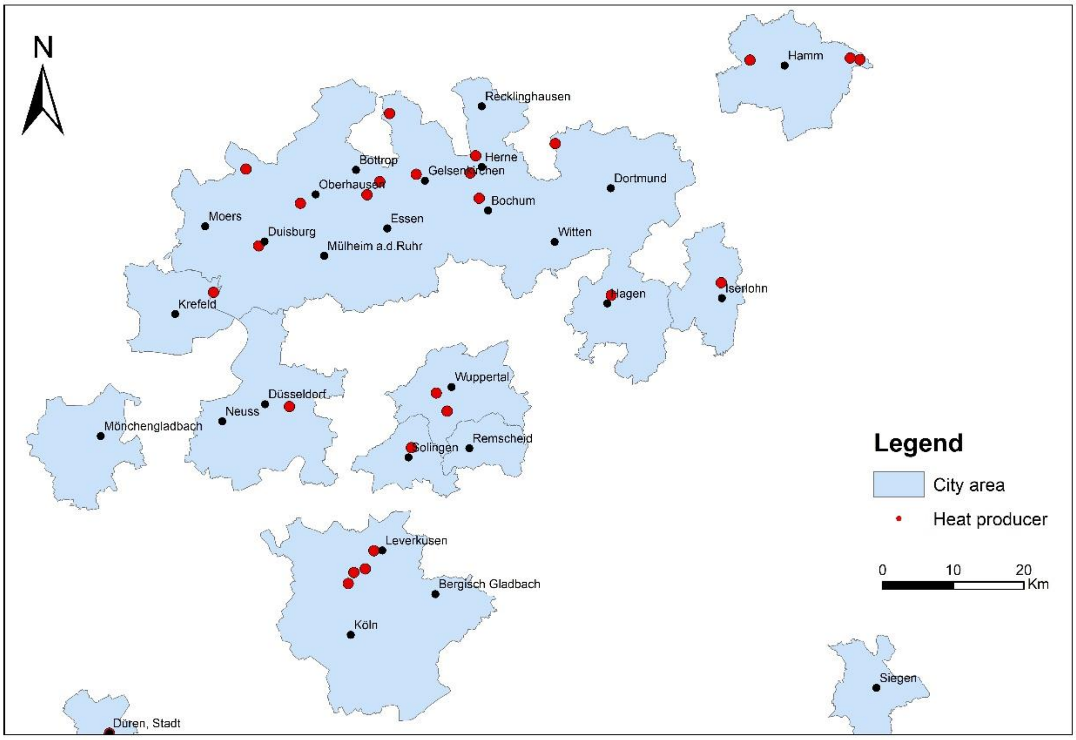


Figure 28: Heat producers of the Dortmund / Dusseldorf area in Germany (source: Strane)

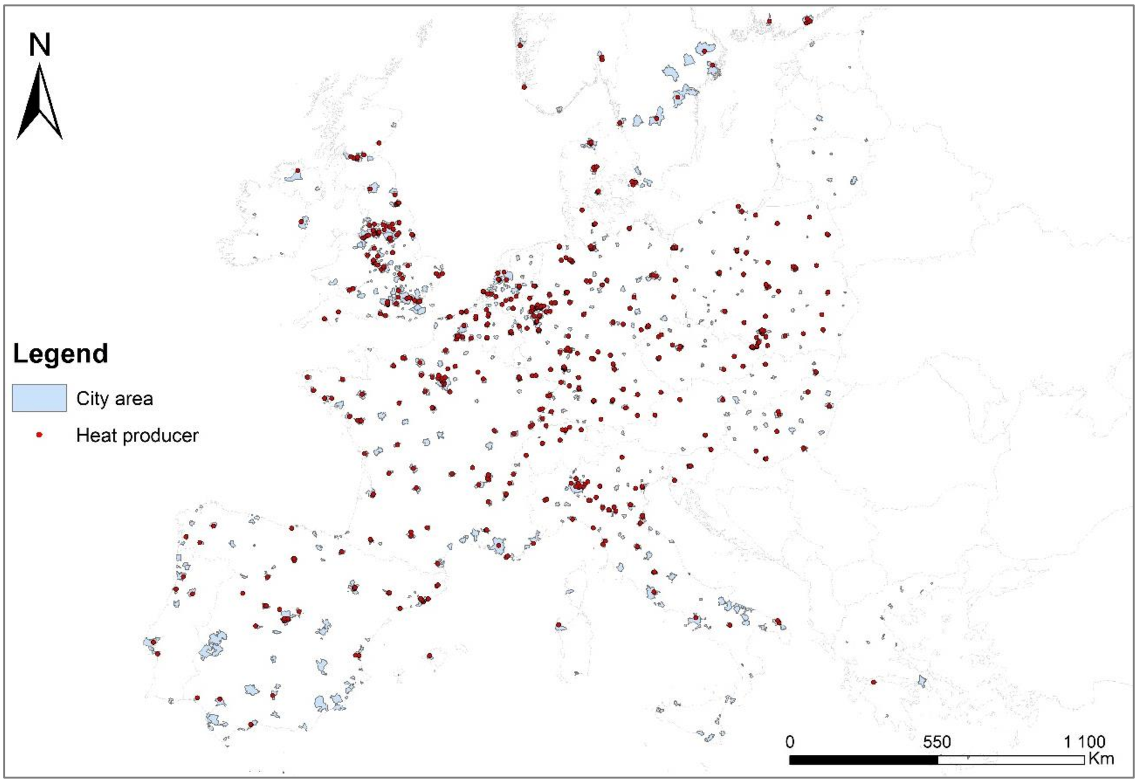


Figure 29: Intersection between heat emitters and core cities (Source: Strane)

Keys figures of maps analysis are presented in Table 16.

Table 16: Figures of the intersection maps (source : Strane)

Geographical areas	Number of installations	Share (% of total number of sites)
Cities	591	26.5%
Functional Urban Area	1023	45.8%

591 heat generator installations that mean around 27% of all heat emitting installations are directly located within core cities area so in urban dense areas with a large number of housing and work offices. Therefore, these installations are mostly close to urban centre and could provide heat for district heating.

1023 installations emitting waste heat are located in FUA that mean additional 432 facilities (additional 19,3 points) are located in urban areas so in densely inhabited city and of a surrounding area (commuting zone) where waste heat could probably be used for district heating (even if it is not for big cities but for residential districts).

Then, the distance between all heat emitting installations and the nearest city downtown (by sorting by distance and removing all duplicates) were quantified. The analysis of distances dataset is presented in Figure 30 and the distribution of distance (

Table 17) was represented as well as focus on 0 – 100km, 0 – 50 km and 0 – 20 km.

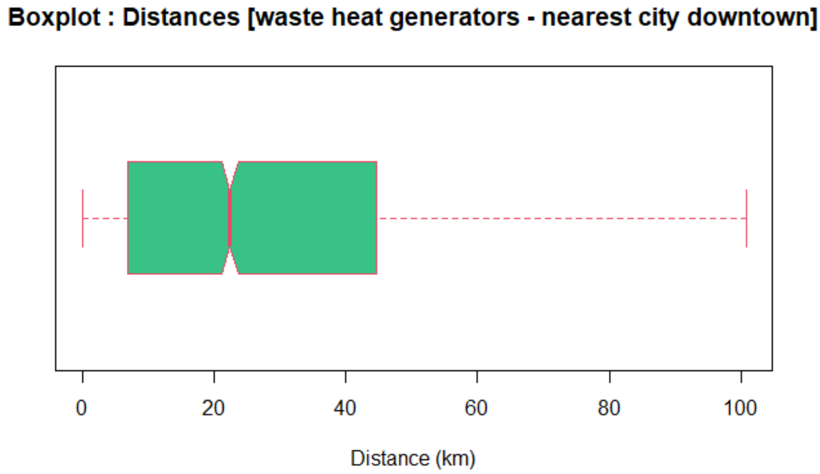


Figure 30: Boxplot of distances between waste heat generators and the nearest city downtown (Source: Strane)

Decile	Distance (km)
10%	2.79
20%	5.07
30%	9.10
40%	15.46
50%	22.37
60%	30.28
70%	38.74
80%	53.17
90%	82.93
100%	3635.38

Table 17: Distribution of distance between waste heat generator and the nearest city downtown (source: Strane)

Distance	Number of district heating opportunities	Cumulated %
1	42	2%
5	432	20%
10	701	32%
20	1019	46%
50	1738	79%
100	2038	93%
500	2187	99%
1000	2201	100%
2000	2202	100%
3000	2203	100%

More than 2 200 opportunities were assessed. 10% are under 2.8 km which is a very close distance for district heating implementation. 50% are closer than 22.5km that still acceptable. The boxplot of distance between heat emitters and nearest city downtown clearly shows most of opportunities (90%) are in an 80km radius. So that, the Figure 31 focus on the range 0 – 100km.

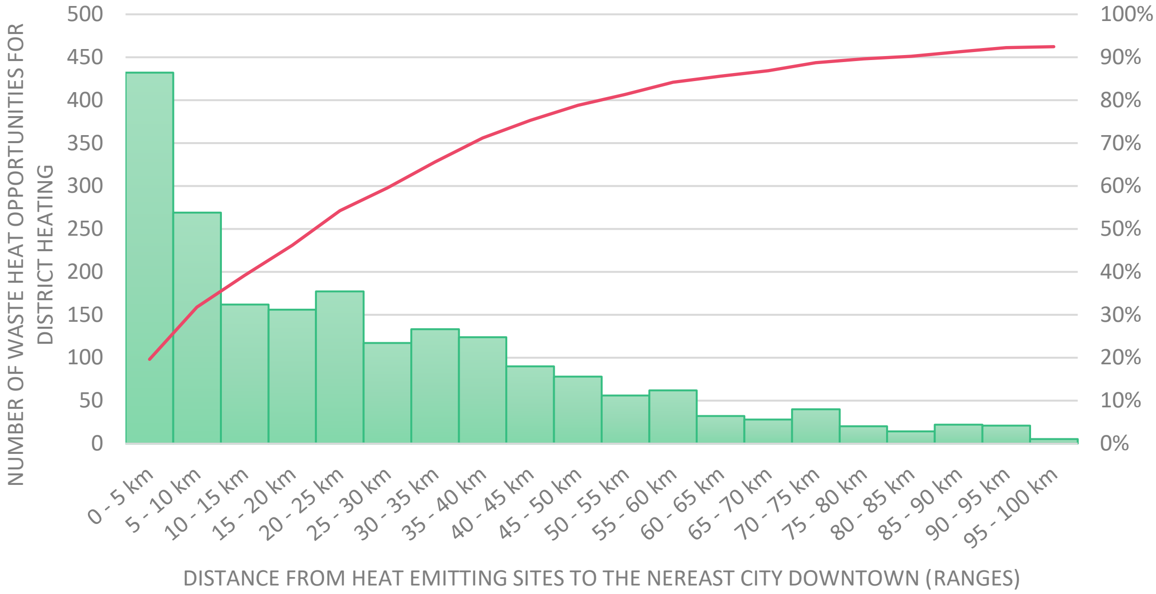


Figure 31: Number of waste heat opportunities for district heating – Focus on 0 – 100km (Source: Strane)

Most opportunities are in the first 5 and 10 km. After that, we can note a continuous decrease of urban district opportunities (with a few exceptions at 20 – 25km, 30 – 35km for examples). 100 km is a too big distance for district heating. Therefore, a focus is done on two ranges: 0 – 50km and 0 – 20km.

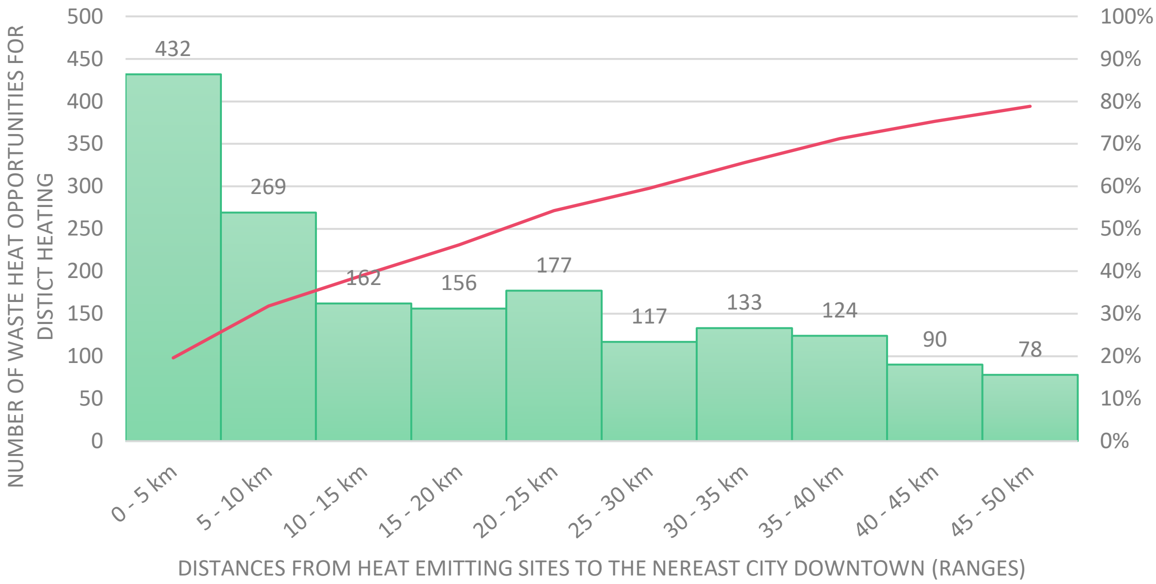


Figure 32: Number of waste heat opportunities for district heating – Focus on 0 – 50km (Source: Strane)

There are 432 opportunities in the first 5 km and 269 in the next 5 – 10 km. That means around 700 opportunities are directly eligible for a district heating program in a very reasonable distance. After that, there are around 120 – 180 opportunities each 5km until an 40km radius. Finally, a focus is performed in the range 0 – 20km because district heating can only be developed for very short distances.

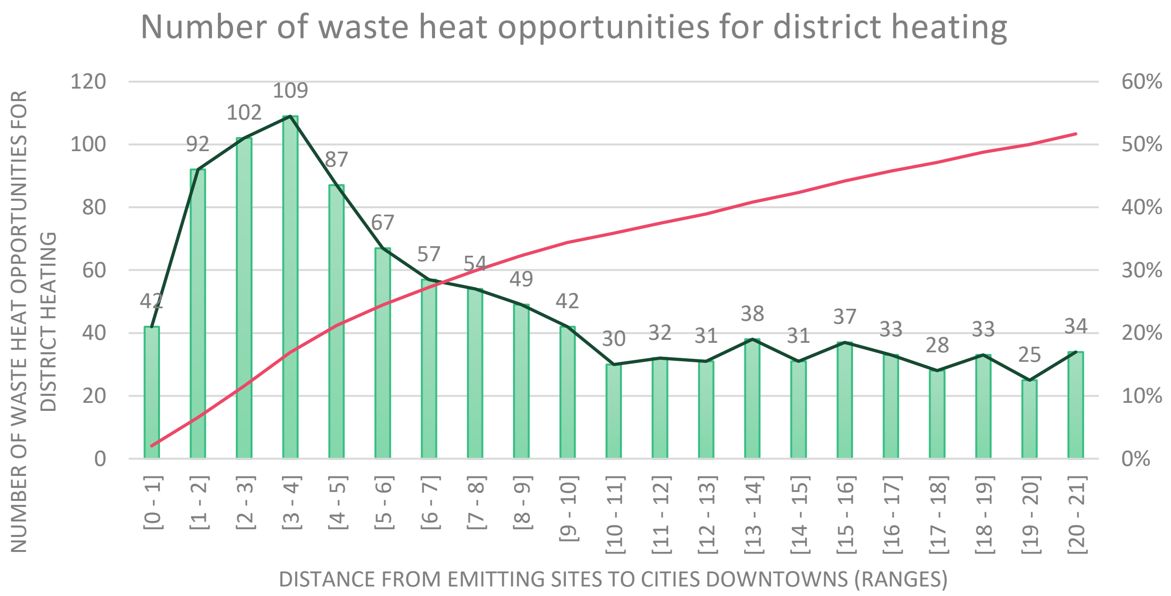


Figure 33: Number of waste heat opportunities for district heating – Focus on 0 – 20km (Source: Strane)

The peak of opportunities is around 3 – 4 kms which is a very reasonable distance for district heating. 345 opportunities are in the first 4 km. The number of opportunities decrease from 87 to 30 per km between 5 and 10km (700 opportunities in this radius).

In general, the two last studies (industrial sites locations and district heating analysis) clearly shows that the proximity between heat emitting industrial installations and cities / urban areas reveals a district heating potential.

Nevertheless, the result of this section is to consider with caution because around 45% of the installations are slaughterhouses

2.6 Synthesis of the mapping activities

The industrial sectors represented in the General map count a total of 10 226 (without duplicates), mainly LCP (2 052), ceramic industries (1 302), Paper (982), Slaughterhouses (1 038), medium and large WWTP (912), Non-ferrous metals (752 including non-ferrous metals processing), Inorganic chemicals plants (660), Organic chemical plants (543), Pharmaceuticals (692), Steel (544 including primary and secondary). Large hotspots discovered in EPOS are confirmed: Northern France – Belgium – Netherlands – Western Germany, Northern Italy and British Midlands. A new large hotspot based in Valencia (Spain) is discovered. Smaller hotspots also appear around large cities: Barcelona, Madrid, Lisbon, Lyon, Paris, Stuttgart, Leipzig, Praha, Brno, Krakow, London, and Northern Slovenia. The number of sites in the *General Map* was too high to enable calculating all combinations distances with a GIS software. Therefore, a map focusing only on large volume process industries and industries involved in the 100 synergies sample was built and analysed.

The industrial sectors in the SCALER map count a total of 6 656 mainly with ceramic, slaughterhouses, WWTP, LCP, incinerators, etc. Installations covered by SCALER are large volume process industries. It does not cover all type of installations in Europe (e.g. LVCO represent 23% of the total number of organic chemical installations). The total number of combinations of sites is around 43 Million in Europe. The peak of opportunity is situated at a 900km. The average value of distances between all pairs of installations is situated around 1 050km and the median value is around 1 000km. Around 1.675 million combinations (Share: 4%) are in a 200 km radius, 200 000 opportunities below 50 km (Share: 0.5%). All these opportunities could be implemented by road and railroad transportation and foster local and regional / cross regional collaboration. It could be promoted and funded by public regional authorities. Set-up short distance synergies is also possible with about 2 700 opportunities in the first kilometre and additional 2700 – 3 000 combinations in the 9 next km. A first small peak of opportunities is clearly identified between 11 – 13 km with around 10 000 iterations. All these potential relationships could be very profitable for nearby installations and some synergies could be exploited by pipeline transportation for very valuable gaseous and liquid resources.

Similar hotspots as the General Map were identified that means the analysis of SCALER sectors is representative of all industrial installations involved in the general map. 4 major hotspots denser than 105 and even 120 sites in a 100 km radius: Benelux, Western Germany and North of France; Northern Italy; Valencia region & the industrial district of Castellon; UK midlands.

- The main one is the Benelux, Western Germany and North of France hotspot. It spans over 210,000 km2. It totals 14% of sites with a very well-balanced distribution of sites by sector. This is the best location for Industrial Symbiosis implementation.
- The second one is Northern Italy with about 6.7% of all EU industrial sites. Main activities are tanning, cement plants and secondary steel.

- UK midlands was previously identified as a medium hotspots (EPOS). With all scaler installations it appears as a major hotspot with 4.2% of EU industrial installations mainly composed by glass, non-ferrous metals and other petrochemical activities.
- The last new hotspot identified here is the Valencia region & the industrial district of Castellon. This is a large area of approximately 30 km. The whole territory had a total population of around 450,000 inhabitants in 2014 (INE, population census) and around 16,000 direct jobs in the ceramics cluster (2013), with a turnover volume of just over 4.1 billion euros (2013). The major drawback of this territory is the homogeneity of industry types, mostly composed by ceramic plants. Indeed, it is not the best locations for cross-sectorial synergies deployment.

The other medium hotspots represent between 1 (Paris and Lyon regions) and 3% (Est Germany & Prague region) of the share of industrial sites in EU. Others hotspots are around 2%. Some of them are very well-balanced and adequate for industrial symbiosis (Est Germany & Prague region); others have several main type of activities (Barcelona, Krakow, Lisbon, Paris) and could be relevant locations for resources exchanges; and the last ones present only one major industrial activity (Lyon, Madrid) which is not an adapted set-up to build cross-sectorial synergies.

Around half of industrial sites are located within FAU areas that consists of a densely inhabited city and of a surrounding area (commuting zone) whose labour market is highly integrated with the city. Around 30% are directly in core cities. The difference between the number of sites within FAU and core cities is probably due to the massive land footprint of process industries. Advantages to be located in dense areas are the access to well-developed road networks, support from local authorities, collaboration with consultancy/facilitators/logistics services/waste management companies/etc., even if the industrial activity may be disrupted by traffic jams or complaints about industrial nuisances. The probability to identify a partner for resources valorisation in dense area is also higher. FUA seems to be great locations because these areas are less dense than core cities (avoid nuisances for residents) but are still very close to commodities, services and fields of actions of other companies. The number of concerned installations is very encouraging for industrial symbiosis implementation.

27% (591) of all heat emitting installations are directly located within core cities area so in urban dense areas with a large number of housing and work offices. Additional 432 facilities (additional 19.3 points) are located in Functional Urban Areas so in densely inhabited city and of a surrounding area. All these installations are located in area where it makes sense to engage district heating programs.

2 200 opportunities of district heating (distance between heat producer and the nearest city downtown) were assessed and 10% are under 2.8 km which is a very close distance for district heating implementation. Most opportunities are in the first 5 – 10 km and the peak of opportunities is at 3 – 4 km (345 in the 4 first km) which is a very reasonable distance for

district heating. The potential in term of locations is very high but the potential in term of energy quantity generated is made in the next section.

3. IS potential of the 100 most promising synergies

3.1 Final assessment of the 100 Synergies

The identification of the 100 most promising synergies in Europe was performed in the T3.2 and exposed in the D3.1. The assessment of the 100 synergies was performed in others previous tasks 3.3 [20], 3.4 [2] and 3.5 [3]. The challenge in the final task 3.6 was to compile all relevant information to prioritise synergies considering their technical feasibility, their environmental impacts and their socio-economic impacts.

Each chapter of this section start with a summary of all activities carried out in previous tasks then build a common assessment considering all results.

3.1.1 Synergies identification

100 synergy types have been selected for assessing the potential of industrial symbiosis in Europe. We have followed an ambitious methodology to produce a list of 100 synergy types that are representative of the diversity of cases in industrial symbiosis, and credible in terms of technical feasibility, economic viability and potential impact.

The level of confidence in these 100 synergy types is high since most of them were validated and confirmed by an external source of information. Around one third of the synergy types listed are fully new and has been selected to help exploring new opportunities for industrial symbiosis.

This list of synergies was used in the tasks T3.3, T3.4 and T3.5 for a deeper analysis of the technical, environmental and socio-economic aspects, before the assessment of the European potential of industrial symbiosis in this deliverable.

3.1.2 Technical assessment

Technical assessment previous results (Source: ISQ)

The third WP3 task (exposed in D3.2 [20, p. 2]) identified and characterised procedures and technologies associated to the valorisation of the 100 synergy types selected as most promising at European level in D3.1. The Technology database (TDB) developed includes the description and technical characterization of both, implemented solutions at industrial scale and emerging technologies. Besides the procedure/technology characterisation, relevant information to support its economic and environmental assessment (T3.5 and T3.4) is presented. The technical viability of the solutions presented considers its usability at industrial scale and its commercial availability as main decision criteria.

Strane's methodology for synergies identification shown to be a very reliable methodology for the definition of new synergy types for intersectoral sectors. From the initial 39 Synergies almost 67 % were technically valuated as viable.

The technical characterisation accuracy is highly dependent on the existence of full procedure or single technology involved in the synergy. Technical assessments on multi process procedure is normally unavailable. Assumptions on those cases present high uncertain results.

Technical data on technology productivity and consumables is highly dependent on the scale used. Better approximations can be obtained by productivity range pre-definition.

Data collecting on the economic assessment variables is the biggest challenging process for quantitative evaluation. Data protection, dependence on technology scalability and variability on information sources were the biggest barriers found.

The different taxonomy used for processes, technologies and materials identification within different databases limits its wider utilization. This normalization process could increase data availability for technical characterization.

Concerning all data unavailable presented as "Not Fond" in the TDB, the future acquisition by industry contact, database sharing and research projects can increase the accuracy of the results, better conclusions and development of the TDB.

The direct valorisation of by-products (for example sludges) is highly dependent on their chemical/mineralogical composition to fill specified requirements of the receiver sector and process. Due to the variation on those by product characteristics associated to raw materials used in sender process, technology /procedure identification are highly variable.

It is also important to note that despite a by-product being unsuitable for certain application, for instance, raw material for cement production, it could be suitable for other applications with lower quality requirements within the sector, for instance as aggregates for concrete production. Additionally, a by-product could also be suitable as a raw material for a specific manufacturing process, however, the final product quality is inferior and not suitable for the original application. Nonetheless, a new market for these products could be unfold.

Innovative synergies (identified only by Strane's methodology and not confirmed by another source) identified in D3.1 were the most challenging as no significant background was available.

Indirect Synergies analysis was in the technical perspective a more exhaustive research challenge due to the different amount of processes involved and correspondent characterizations required.

There is a huge potential for resource valorisation associated to the synergy type technically defined as non-technically viable in the D3.3 [20, p. 2]. At most of them, the resource is highly available, but technologies were not scaled, adapted or properly developed to valorise the resource. In some cases, there was also a lack of information regarding whether or not the valorisation of a by-product is possible as there are no precedents of its direct utilization on a specific receiver sector. In some of those cases information could be found regarding the same element of interest on the same type of by-product, albeit of different industrial processes, and there are general procedures/technologies that could be applied to a great variability of by-products (dusts, sludges, slags). In those cases, the final viability resume could be indicated as positive (GO).

Even some GO results shown that technologies are commercially available and used at some industrial sites, their implementation is still not widely spread. Incentives and barriers should be taken into consideration on the analysis to improve their scalability.

The actual TDB template and guidelines for use and update, intent to fill the gap found in terms of available tools to support industries, decision makers and researchers on the identification and mostly, the evaluation of the technical viability of IS processes.

The TDB developed present a huge potential for R&D+i mostly associated to the barriers identified during GO and NO/GO synergy type technical characterisation. To surpass those barriers, further research is required including intersectoral demonstration projects between critical sectors, a huge opportunity for future work in this area.

The work presented can significantly contribute with relevant data to be included in further BREF updates, as well as considered as current Best Practices.

Technical final assessment

The results of the T3.3 (D3.2. [20]) supports the final assessment on the most promising synergies at European level potential evaluation by providing many data on the technical feasibility of the synergy and reveal required technical procedures and technologies involved to treat the streams.

- Synergies characterisation
- Procedure and technology general description
- Transport
- Viability resume
    - Availability (commercially available)
    - Usability (Industrial scale)
    - Final comments
- Final conclusions
    - GO/NOGO (Technical viability)
- Key costs

- Procedure/Technology inputs
- Economic characterisation
- Procedure/Technology outputs

"Viability resume" and the "Final conclusions" are the main element to consider in the final assessment as known costs were integrated in the SEA [3] and the synergies avoided impacts were compared to procedures and transports impacts in the screening LCA [2]. To obtain a more synthetic visualisation (only crucial data for the final synergies assessment) and to compile this data with other activities performed, SCALER partners performed a new classification. Moreover, "Finals conclusions" included a GO/NOGO data for each synergy. This terminology was not sufficient enough to avoid any misunderstanding. For example, in the case of a NO GO synergy, the reader might understand that this synergy is not technical viable anyway when it means that no procedure/technology is being developed at the moment. And in fact, it would make sense to work on the development of such a technology since the associated synergy could avoid massive environmental impacts and generate significant socio-economic benefits. For all these reasons, the following classification was set up in the Table 27.

The first new classification data is the **"Usability at industrial scale"**. Four categories were defined:

- **Industrial scale** – There are references concerning the wide usage of the technology/procedure at industrial level
- **Industrial pilot** – There are references concerning technology/procedure usage at industrial level although still at an experimental stage
- **Laboratory scale** – There are references concerning technology/procedure usage at laboratory scale
- **Under development** – There are no references concerning technology usage. Theoretical concepts are already developed

The second data is the **"Final technical assessment"** to suggest a final judgment on the technical feasibility of the synergy:

- **Feasible: Low technical requirements** – Lower technical complexity procedure, comprising mechanical and physical treatment or only transport (normally associated to direct synergies)
- **Feasible: High technical requirements** – Higher technical complexity procedure and/or number of intermediary processes required (normally associated to indirect synergies)
- **Feasible: Limited potential** – The procedure associated to this synergy presents relevant antecedents but constraints related to technical data (waste composition, receiver quality standards, logistic and infrastructure) limits its final accurate analysis. Further evaluation is advised.

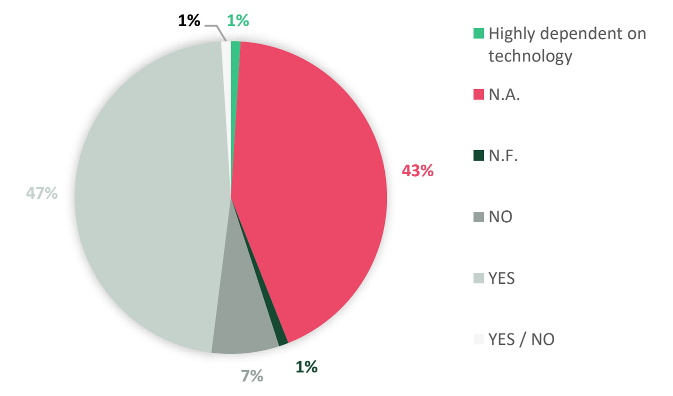
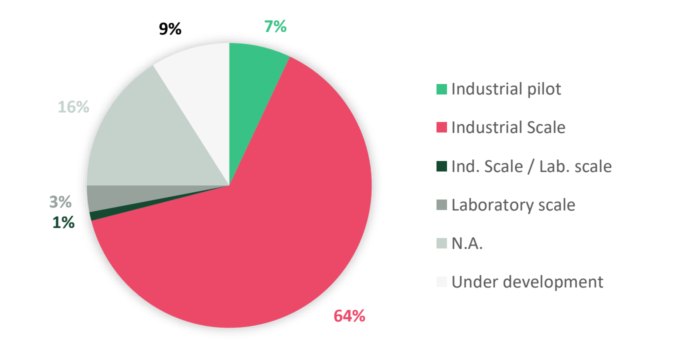
- **Not feasible: Unavailable support data** – No antecedents or technology have been found and/or lack of support data to sustain a final positive technical decision. Further evaluation regarding technical feasibility for implementation is needed.
- **Not feasible: Underdeveloped technology** – There are no reliable technologies available for a specific waste stream valorisation

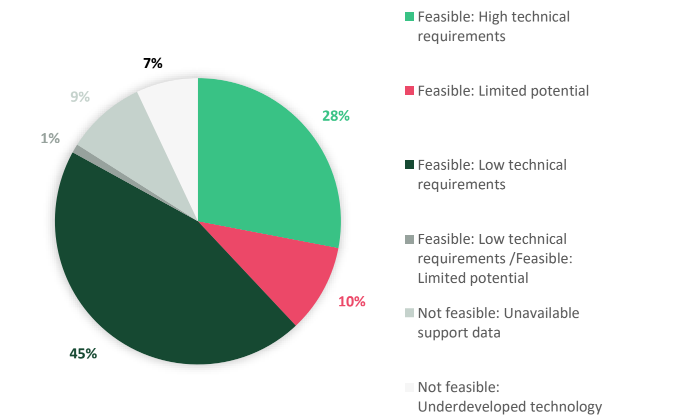
The commercial availability is also presented with the following values: YES/NO/N.A.

The technical qualitative data is not used to prioritise the 100 synergies but to provide the development stage and the feasibility notice.

Technical assessments are presented and analysed in Table 18.

Table 18: Technical assessment basic statistics (Source: Strane)

AVAILABILITY		Around half of the synergies require procedures or technologies directly available on the market. For 43% of the synergies are note concerned by the availability on the market because they do not require any type of complex technology. 7% are not available on the market, and the reason is basically explained in the For one synergy, information were not found on public resources.
USABILITY		Most of the procedures and technologies (65%) are usable at industrial scale. In 7 cases, technologies are currently tested in industrial pilot cases and would probably be available soon. Around 10% of the synergies require technologies that are currently under development. 16% of the technologies identified are on ongoing development at laboratory scale. They probably have a 3 – 4 TRL.

<table>
<tr>
<td>TECHNICAL ASSESSMENT</td>
<td>
</td>
<td>10% of the synergies are technically feasible but have a limited potential.

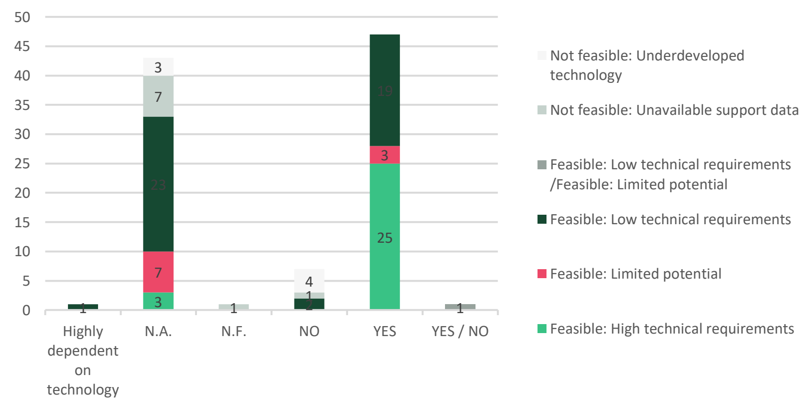
Around 30% of the synergies have high technical requirements so the implementation is feasible but complicated.

A good figure is that 45% of the synergies do not require high technical requirements and enable a quick and massive deployment of the synergies.

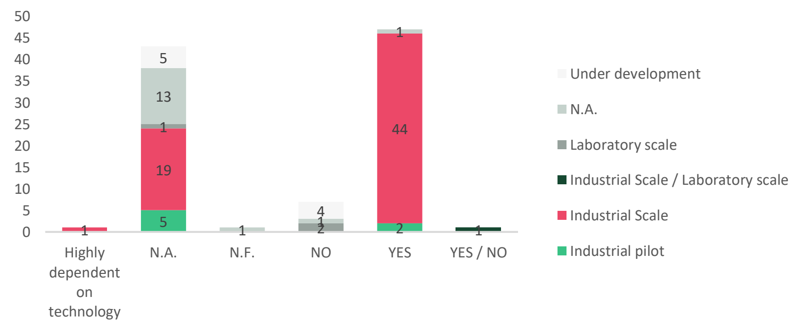
7% of the synergy types are not feasible because no technologies are available to treat the type of flows involved.

Around 10% of the synergies are classified as “not feasible” but it is mainly due to the lack of data to assess the feasibility.</td>
</tr>
</table>

Table 19: Technical assessment cross statistics (sources: Strane)

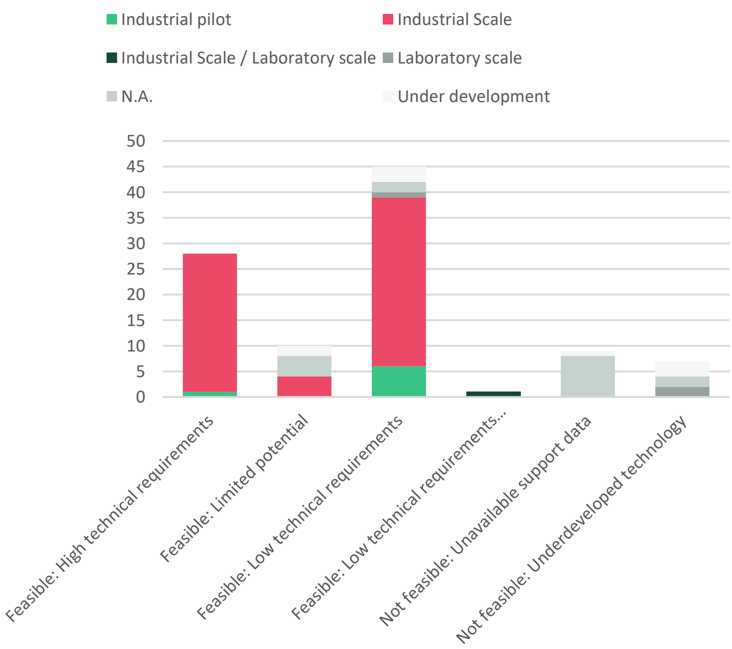
<table>
<tr>
<td>AVAILABILITY / TECHNICAL FEASIBILITY</td>
<td>
</td>
<td>As expected, all available technologies are related to feasible synergies.

Technologies categorised as “N.A.” are mainly associated to direct synergies that do not involve a treatment procedure.

Technologies not available involve a feasible with low technical requirement that could be quickly developed and under developed technologies.</td>
</tr>
<tr>
<td>AVAILABILITY / USABILITY</td>
<td>
</td>
<td>As expected, most of available technologies are usable at industrial scale (only one as industrial pilot TRL)

Technologies categorised as “N.A.” are mainly associated to direct synergies.

Technologies not available are at laboratory scale or under development.</td>
</tr>
</table>

<table>
<tr>
<td>TECHNICAL ASSESSMENT / USABILITY</td>
<td>
</td>
<td>The lack of data to support the assessment was the main reason for a "non-feasible" classification. Other non-feasible synergy types involved laboratory scale and not yet developed technologies.

Feasible synergies with low technical requirement involve mostly technologies at industrial scale but also some technologies that are currently deployed with industrial pilots, at laboratory scale. As we talk about low technical requirement synergies, these technologies will probably be commercialised soon. Even for synergies with low technical requirements, some technologies are still not on development.

Feasible synergies with high technical requirements are all at industrial scale or on ongoing development in industrial pilots (only 11)</td>
</tr>
</table>

All synergies were characterised with this new classification in the Table 27.

3.1.3 Environmental assessment

Environmental assessment previous results (Source: Quantis)

The screening LCA of the 100 synergy types was performed in the D3.3. [2] to quantify avoided environmental impacts in the case of a wide implementation of synergies at European scale. The study was meant to provide a hotspot analysis and preliminary recommendations for the most promising scenarios and/or configurations from a sustainability perspective based on the current status of data available.

Of the 74 synergy types that could be modelled an estimated total climate change savings of 122 million tons CO2-eq was calculated, equivalent to removing approximately 29 million cars off the road or 27 coal fired power plants. Other indicators confirm this environmental and human health benefits. These results clearly show the potential of industrial symbiosis in Europe from an environmental and human health perspective. Industrial symbiosis is thus a key driver to leverage the circular economy in Europe.

Major contributors to the savings are the steel (slag and coke oven gas) and waste treatment industries (prepared fuel), identified as key sender sectors. With respect to the receiver sectors, the cement industry is key along with various sectors receiving prepared fuels from the waste treatment industry. The latter confirms the important role of intermediaries in industrial symbiosis, which is in line with the findings from Deliverable 2.1.

Other sectors present high IS potential; for example, the glass and ceramic industries, mainly for indirect synergies.

A sensitivity analyses of some specific synergies as well as a comparison of modes and distances of transport allowed us to further investigate specific environmental impacts' and benefits' contributions. Key learnings include: (1) lorry transport is not necessarily negligible, but in general, long distances are needed for the impacts to outweigh the benefits of the synergy; (2) some procedures (including technologies) have very high energy requirements, which may outweigh the environmental benefits of the synergy; (3) in general, transport by train and/or barge should be chosen if possible, as their environmental and human health impacts are lower than that of lorry transport.

Data quality and availability was identified as one of the main challenges of this work. Despite an in-depth and extensive search for data, some synergies could not be evaluated due to a lack of data specifically needed from a life cycle assessment perspective. Primary industrial data are required to confidently model an accurate LCA. Although the scope of this work does not encompass modelling to this level of detail, secondary data allowed us to perform a screening level LCA, with a certain degree of uncertainty.

Future work and recommendations

While the following study provides a good first indication of potential environmental and human health benefits from industrial symbiosis in Europe, a more detailed assessment of some key sectors and resources/wastes would provide additional value, particularly for the waste treatment industries sector as well as steel and cement synergies. This would require additional effort to collect and fill data gaps related to waste flows (quantity, description) based on primary data from industry.

A direct contact with industry may lead to improved granularity of the results. Specific points to address may include:

- Refining baseline scenarios for a given synergy type
- Quantifying the distribution of synergies already in place within a synergy type in order to distinguish the practices already in place vs potential future synergies. This would assist in linking the environmental results to key enablers, incentives or barriers, ultimately contributing to defining the boundary conditions needed to produce the savings potential of these untapped synergies.
- Including more detailed transport and technology procedure data
- Considering more operational factors/issues

Final assessment and ranking

At the end of the task 3.4 and in the D3.3 [2], results were quantitatively presented with LCA indicators :

- Climate change (IPCC 2013) [kg CO2-eq]
- Human health [DALY]
- Ecosystem quality [PDF.m2. y]
- Resources [MJ]
- Freshwater withdrawal [m3]

LCA indicators are fully independent. It does not exist any correlation between these indicators. As an example, a synergy could avoid massive CO2 emission, and then lead to avoid huge climate change, without generating a significant benefit for the human health or the eco-system quality.

There was therefore a need to create a method for obtaining an overall score taking into account all the environmental benefits, i.e. all LCA indicators. The aim of this method was also to prioritise synergies by classifying them according to the environmental benefits they could generate at EU level.

The methodology uses decile classification to classify synergies by range of environmental benefits and grade them. Synergies are finally ranked.

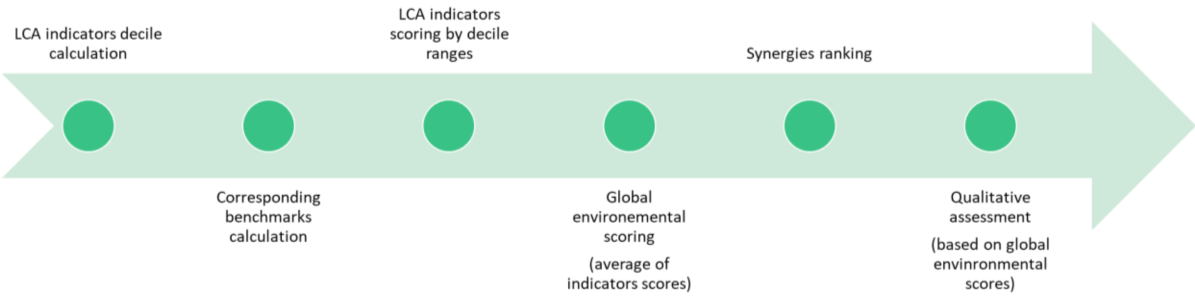


Figure 34: Overview of the environmental scoring methodology (Source: Strane)

The first step was to calculate deciles considering all values of each indicator as presented in Table 20. Corresponding benchmarks are provided to facilitate understanding/reading and also to appreciate orders of magnitudes with conventional and usual benchmarks.

Table 20: Environmental indicators decile range calculation and corresponding benchmarks (Source: Strane)

Climate change

Decile	Climate change (IPCC 2013) [kg CO2-eq]	Cars not driven
Maximum benefit	-17 850 755 000	-4 311 777

Human health [DALY]

Decile	Human health [DALY]	Cigarettes not smoken
Maximum benefit	-29 515	- 1 412 177 895

90%	- 5 041 695 900	-1 217 801
80%	- 1 393 841 600	-336 677
70%	-654 785 280	-158 161
60%	-147 424 950	- 35 610
50%	-61 604 124	- 14 880
40%	-27 825 336	-6 721
30%	-13 309 202	-3 215
20%	-1 767 716	-427
10%	-9 536	-2
Minimum benefit	-1	-0

90%	- 5 119	-244 952 024
80%	- 1 789	-85 579 010
70%	-737	-35 261 887
60%	-245	-11 717 333
50%	-95	-4 563 503
40%	-34	-1 643 377
30%	-21	-996 811
20%	-2	-108 232
10%	-0	-513
Minimum benefit	-0	-1

Ecosystem quality [PDF.m2.y]

Decile	Ecosystem quality [PDF.m2.y]	ha deforested*
Maximum benefit	- 8 138 684 400	-813 868
90%	- 1 847 710 400	-184 771
80%	- 398 934 180	-39 893
70%	- 105 422 790	-10 542
60%	-59 764 167	-5 976
50%	-24 095 060	-2 410
40%	-10 349 157	-1 035
30%	- 5 836 166	-584
20%	-656 495	- 66
10%	- 1 135	-0
Minimum benefit	-6	-0

**And converted to concrete*

Resources [MJ]

Decile	Resources [MJ]	Barrels of oil
Maximum benefit	-553 951 520 000	-94 563 250
90%	-72 080 234 000	-12 304 581
80%	-19 913 455 000	-3 399 361
70%	-12 877 988 000	-2 198 359
60%	-3 446 385 900	-588 321
50%	-2 075 919 200	-354 373
40%	-407 841 800	- 69 621
30%	-245 875 920	- 41 973
20%	-45 002 321	-7 682
10%	- 144 908	- 25
Minimum benefit	- 7	-0

Freshwater withdrawal [m3]

Decile	Freshwater withdrawal [m3]	Olympic size swimming pool
Maximum benefit	-464 334 270	-185 734
90%	-113 129 060	-45 252
80%	-72 587 192	-29 035
70%	-18 224 047	-7 290
60%	-5 516 107	-2 206
50%	-3 978 960	-1 592
40%	-1 651 017	- 660
30%	-562 579	- 225
20%	- 48 734	-19
10%	-379	-0
Minimum benefit	-0	-0

After defining decile ranges, the conversion from decile range to score was performed for each indicator by following the rules of correspondence presented in the Table 21.

Table 21: Conversion from LCA indicators decile range to score (Source: Strane)

Qualitative assessment	Score
[Maximum benefit - 90%]	10
[90% - 80%]	9
[80% - 70%]	8
[70% - 60%]	7
[60% - 50%]	6
[50% - 40%]	5
[40% - 30%]	4

[30% - 20%]	3
[20% - 10%]	2
[10% - Minimum benefit]	1

The average score of all indicators was calculated to obtain a global score, representative of all positive environmental indicators (Climate change, Human health, Ecosystem quality, Resources and Freshwater withdrawal). This global score helped to rank al synergies modelled from an environmental point of view. A qualitative assessment has also been established to enable the reader getting a quick and general sense of the environmental benefits that can be generated.

Table 22: Environmental global score & corresponding qualitative assessment (Source: Strane)

Global score deciles ranges

Decile	Global score
Min. score	1
10%	1.4
20%	2.6
30%	3.8
40%	4.2
50%	5.4
60%	6.6
70%	7.2
80%	8
90%	9.4
Max. score	10

Corresponding qualitative assessment

Score decile range	Qualitative assessment
[Min. score - 10%]	VERY LOW
[10% - 20%]	
[20% - 30%]	LOW
[30% - 40%]	
[40% - 50%]	MEDIUM
[50% - 60%]	
[60% - 70%]	SIGNIFICANT
[70% - 80%]	
[80% - 90%]	VERY HIGH
[90% - Max. score]	

At the end of this step, all data generated during the task 3.4 (and presented in the D3.4 [2]) were used to :

1. Score each kind of environmental benefits
2. Score globally environmental impacts avoided
3. Rank synergies

Synergies that have not been modelled during the T3.4 were not assessed and ranked. They are marked ‘NM – Not Modelled”.

Even if LCA indicators present a high level of uncertainty, this methodology is relevant for comparing all synergies to each other.

As a reminder, total savings calculated from synergy types modelling are:

Table 23: Total environmental saving calculated from synergy types modelling (Source: Quantis, D3.4 [2])

Indicator	Potential savings (max)	Units	Benchmark
Climate change	122	million t CO_2-eq	29 million cars not driven[1]
Human health	138’000	DALYs	6.6 billion cigarettes not smoked[2]
Ecosystem quality	26	Billion PDF.m^2.y	3.6 million ha of forest saved from conversion to concrete[3]
Resources	2.1x10^{12}	MJ	350 million barrels of oil not extracted[4]
Water withdrawal	2.9	Billion m^3	1.1 million Olympic size swimming pools[5]

[1] Assumption one car travels 20'000 km/year
[2] 2.09E-05 DALY / cigarette
[3] 10’000 PDF.m^2.y / ha forest converted to concrete
[4] 5’858 MJ primary energy / barrel of oil
[5] 2’500 m3 water/Olympic size swimming pool

3.1.4 Socio-economic assessment

Socio-economic assessment previous results (Source: Strane)

The screening SEA of the 100 synergy types was performed in the D3.4.[3] **to quantify the potential socio-economic benefits in the case of a wide implementation of synergies at European scale. Despite an in-depth and extensive search for data, the screening socio-economic assessment (T3.5) allowed to model 81 synergy types over 100.** The socio-economic assessment of the 100 synergy types lead to quantify the industrial symbiosis potential in EU according to specific indicators defined by the methodology:

- A 33 500 M€ added value thorough Europe
- A 7 000 M€ VAT
- 15 500 M€ of labour share
- 350 000 direct jobs created
- 175 000 to 1 000 000 induced indirect jobs
- The economic equivalence of the environmental impacts is about 100 000 M€, probably over estimated due to the high uncertainty of the data provided for the LCA T3.4
- A 7 500 000M€ carbon tax decrease (probably overestimate since calculation is based on the climate change LCA indicator)
- A 2 200 000M€ waste tax decrease
- 41 000M€ of waste management costs avoided

Synergies with the highest socio-economic impact involve heat recovery, EAF dusts (zinc residues), BOF slags, fuel wastes, red mud, steel sector gas (BFG, BOFG and COG), fly ash, aluminium oxides, BF slags, steam, coal combustion plant slags, refractory products (steel EAF), hydrogen recovery, cooling water.

A second more sensitive assessment considering the 18 most profitable synergy types' implementation level lead to refine the results and characterise the remaining industrial symbiosis potential: 2 500 M€/y added value, 6 000 M€/y of labour share, 130 000 direct jobs created and between 66 000 and 400 000 indirect jobs.

Other indicators confirm the socio-economic benefits. These results clearly show the potential of industrial symbiosis in Europe from a socio-economic point of view, in particular regarding the added value generated and jobs creation. Industrial symbiosis is thus a key driver to leverage the circular economy in Europe.

Studying waste streams usable both as combustible and raw material (with a high LHV e.g. hydrogen, methanol, benzene, etc.) highlights one major key learning: unfortunately, the material exchange is not economically relevant instead of a direct incineration on site. However, considering the economic benefits of the avoided environmental impacts makes it possible to turn the synergy viable and give an additional life to these reused wastes.

In case of non-profitable synergy (economically), the use of avoided environmental economic values allows to turn the synergy viable. This argument can motivate especially local authorities to support the synergies implementation (e.g. for example with subsidies that will be profitable in the long term).

Data quality and availability was identified as one of the main challenges of this work. Despite an in-depth and extensive search for data, some synergies could not be evaluated due to a lack of data specifically needed from a socio-economic assessment perspective. Primary industrial data are required to confidently model an accurate socio-economic assessment. Although the scope of this work does not encompass modelling to this level of detail, secondary data allowed us to perform a screening level socio-economic assessment, with a certain degree of uncertainty. Some other limitations of the methodology are explained. The use of LCA indicators which were calculated from wide range and uncertain data probably overestimate the equivalent economic values of avoiding environmental impacts.

The final methodology chosen focuses on the resource intrinsic value improvement by the synergy implementation and do not consider some important value in a socio-economic analysis perspective (raw material provider and waste management companies' financial losses). When a market price is not available, the resource price estimation is a key challenge that could conduct to overestimate the financial benefits.

The work performed in T3.5 constitutes a relevant and innovative step forward to assess the socio-economic impact of a 100 synergy types sample. The main advantage of this work is to make synergies implementation comparison easier and to quantify economic benefits and associated jobs creation order of magnitude.

Combination with geographical analysis

The integration of geolocated data on the next section allow to control the viability distances for each synergy types with various transportation options (in particular for gaseous stream transportation by pipeline, not including in this deliverable).

Socio-economic final assessment and ranking

At the end of the task 3.5 and in the D3.4.[3], results were quantitatively presented with a serial of indicators mostly directly linked (linked indicators are in bold) :

- Value added
- VAT
- Labour share
- Direct jobs creation
- Induced indirect jobs creation
- Landfilling taxes
- Avoided waste management costs
- Economic viability radius
- Total investment required in EU

The other indicators (not bold) depend on the resources' volumes and intrinsic value. The same method as the environmental assessment one was applied to one main indicator.

Figure 35: Overview of the SE scoring methodology (Source: Strane)

Table 24: Socio-economic indicator decile range calculation (Source: Strane)

Decile	Number of jobs created	Number of jobs created per country (Average)
Minimum benefit	0	0
10%	2	0
20%	44	2

30%	155	6
40%	434	16
50%	675	25
60%	987	37
70%	1 642	61
80%	4 966	184
90%	18 818	697
Maximum benefit	61 118	2 264

Table 25: Conversion from SEA indicator decile ranges to score and qualitative assessment (Source: Strane)

Decile range	SEA Score	Qualitative assessment
No benefit	0	NO BENEFIT
[Minimum benefit - 10%]	1	VERY LOW
[10% - 20%]	2	
[20% - 30%]	3	LOW
[30% - 40%]	4	
[40% - 50%]	5	MEDIUM
[50% - 60%]	6	
[60% - 70%]	7	SIGNIFICANT
[70% - 80%]	8	
[80% - 90%]	9	VERY HIGH
[90% - Maximum benefit]	10	

Synergies that have not been modelled during the T3.5 were not assessed and ranked. They are marked “NM” (Not Modelled).

The cross analysis between SEA and LCA qualitative assessment show interesting interactions represented in the

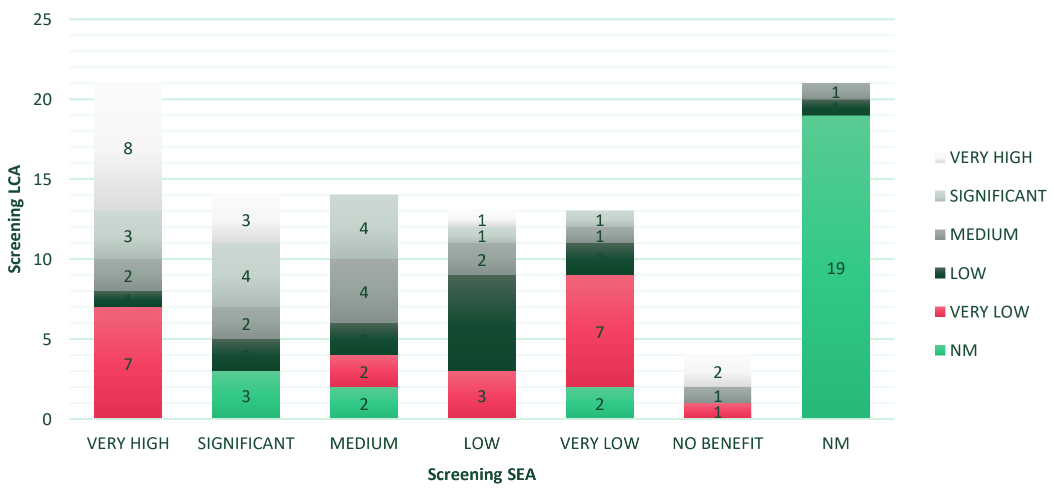
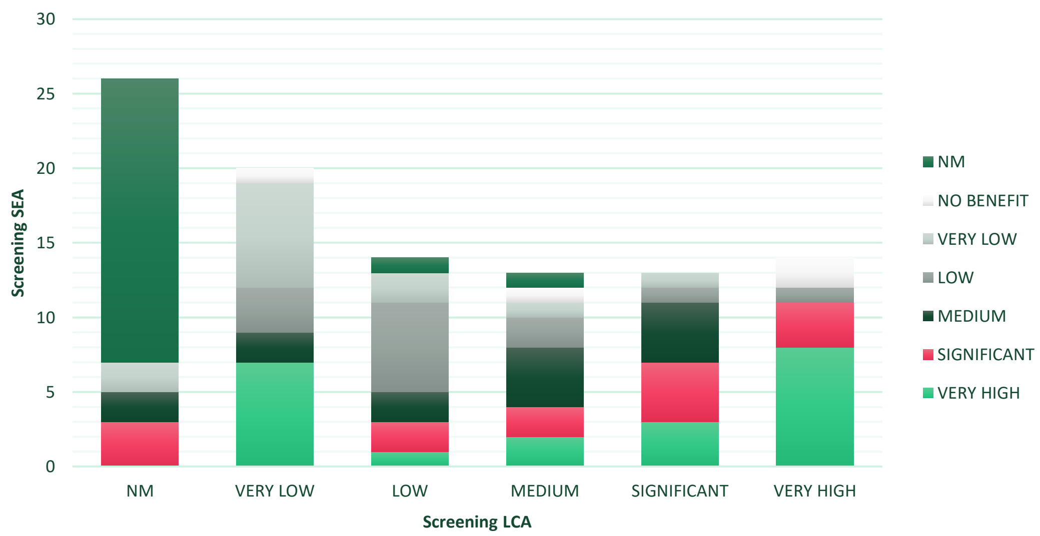


Figure 36: SEA & LCA cross analysis (Source: Strane)

8 synergies have both high environmental and economic benefits. 7 synergies with a very high economic impact have a **very low** environmental benefit. It will be easier to convince industrial actors to implement this type of synergy because they will earn a direct economic profit. 7 synergies have a very high environmental benefit compared to the economic benefit they could generate. In that case, it will be difficult to convince industrial responsible to make efforts with no direct earnings associated. External value like carbon tax avoided, landfilling or incineration tax avoided could be interested arguments to convince decision makers. Most of the time, these types of synergies are related to gas (e.g. hydrogen) valorisation which is usually directly burn on site.



A correlation helped identifying a link between LCA and SEA results (Figure 28). It appears a small correlation between the SEA and LCA score as well as between SEA score and LCA indicators values. The correlation coefficient is not high (Around 0.3) but it shows a small link between values and indicators.

These results do not have any scientist validation but it just highlights a learning that could be explore in a new research project: a combination of benefits between environmental impacts and socio-economic impacts.

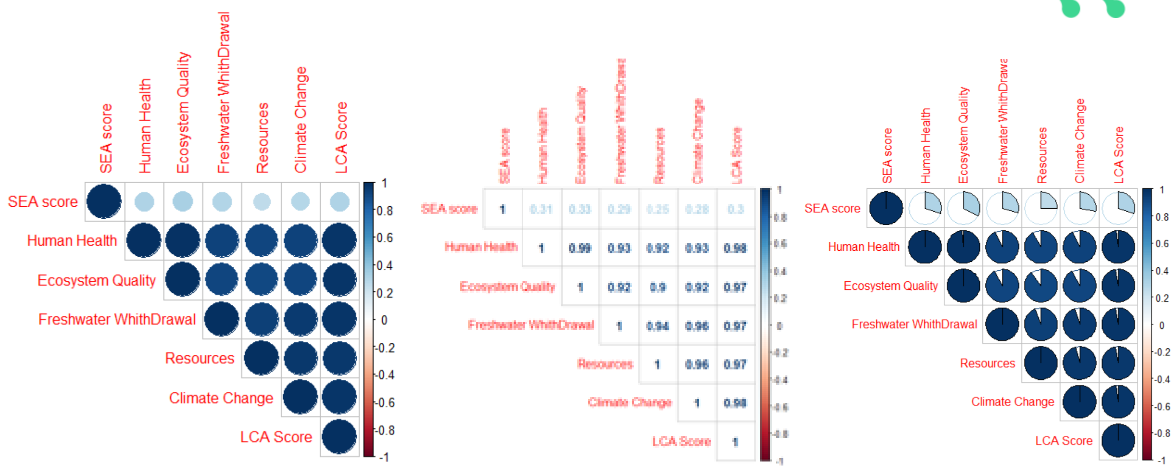


Figure 37: Correlation between LCA and SEA scores (Source: Strane)

3.1.5 Final combined assessment & selection of synergies for geographical analysis

Synergies with a "VERY HIGH" (VH) or "SIGNIFICANT" (S) positive impact from an environment or socio-economic point of view were selected for the geographical analysis:

Table 26: Synergies selected for geographical analysis (Source: Strane)

#	BY-PRODUCT	Both Env. & Socio-Eco. benefits	VH or S environmental benefit	VH or S socio-economic benefit
1	COKE OVEN GAS		■	
2	COKE OVEN GAS		■	
4	COKE RESIDUES		■	
5	EMISSIONS			■
6	BASIC OXYGEN FURNACE SLAG	■	■	■
8	GYPSUM			■
9	OFF-GAS		■	
10	SULPHURIC ACID	■	■	■
12	SALT		■	
17	OFF_GAS			■
19	PROCESS GASES	■	■	■
22	REFRACTORY PRODUCTS	■	■	■
23	SLAG	■	■	■
24	SLAG		■	
29	RED MUD			■
30	SLAG	■	■	■
31	SALT SLAG	■	■	■
32	SALT SLAG		■	
35	EAF SLAG	■	■	■
39	SULPHURIC ACID		■	
47	COKE OVEN GAS	■	■	■
48	BLAST FURNACE GAS			■
49	BASIC OXYGEN FURNACE GAS			■
50	LIMESTONE FINES			■
66	BLAST FURNACE AND CONVERTER SLAG	■	■	■
67	COOLING WATER			■
68	FLY ASH		■	
69	FLY ASH	■	■	■
81	CRUDE ATMOSPHERIC DISTILLATION WW		■	

82	WOOD WASTE			
86	CARCASE			
87	WOOD WASTE			
89	COOLING WATER			
91	HEAT			
93	STEAM			
95	SOLID WASTE FUEL FEEDSTOCK			
97	OIL			
98	BITUMEN			
100	GAS OIL			

This selection of synergies include all synergies highlighted in the D3.4 [3] that cover more than 90% of the total IS potential of the 100 synergies shortlist [3].

The full final combined assessment synthesis is presented in Table 27.

Table 27: Synthesis of all SCALER's results on the 100 synergies assessment (Source: Strane, Quantis and ISQ)

#	BY-PRODUCT	ELEMENT OF INTEREST	SENDER SECTOR AND PROCESS	RECEIVER SECTOR AND PROCESS	AVAILABILITY - Commercially	USABILITY	TECHNICAL FEASIBILITY	FINAL COMMENTS	TECHNICAL GO/NOGO	Climate change Grade	Human health Grade	Ecosystem quality Grade	Resources Grade	Freshwater withdrawal Grade	Global LCA Grade	Environmental Ranking	Qualitative assessment	SEA : Job creation (direct)	SEA Grade	Socio-Economic Ranking	Qualitative Assessment
1	COKE OVEN GAS	HYDROGEN	S : STEEL P : COKE OVEN PLANTS	S : REFINING MINERAL OIL AND GAS P : HYDROCRACKING PROCESS	YES	Industrial Scale	Feasible: High technical requirements	Popular technic ammong Hydrogen separation plants	GO	9	8	8	9	10	8,8	11	VERY HIGH	0	0	66	NO BENEFIT
2	COKE OVEN GAS	METHANOL	S : STEEL P : COKE OVEN PLANTS	S : REFINING_MINERAL_OIL_AND_GAS P : ISOMERISATION_PROCESS	YES	Industrial Scale	Feasible: High technical requirements	Well developed technology, under operation in many plants	GO	10	10	9	10	10	9,8	3	VERY HIGH	0	0	66	NO BENEFIT
3	PRIMARY LIQUID FUEL	ACETALDEHYDE DIETHYL ETHER ETHYL ACETATE ETHYL PROPIONATE	S : ORGANIC CHEMICALS P : ETHYL ACETATE PRODUCTION	S : CEMENT P : BURNING	YES	Industrial Scale	Feasible: Low technical requirements	Distillation makes about 95% of all current industrial separation processes. It has been used in chemical industries, pharmaceutical and food industries, environmental technologies and in petroleum-refineries.	GO	3	2	2	3	2	2,4	58	VERY LOW	23	2	53	VERY LOW
4	COKE RESIDUES	COKE	S : ORGANIC CHEMICALS P : STEAM CRACKING	S : STEEL P : SINTER PLANTS MANUFACTURING	N.A.	Industrial Scale	Feasible: Low technical requirements	The coke can be reused in the receiver sector.	GO	7	7	7	8	6	7	23	SIGNIFICANT	27	2	53	VERY LOW
5	EMISSIONS	Zn	S : STEEL P : ELECTRIC ARC FURNACE STEELMAKING AND CASTING MANUFACTURING	S : NON FERROUS METALS INDUSTRIES P : ZINC PRODUCTION	YES	Industrial Scale	Feasible: High technical requirements	Highly implemented.BAT for EAF dust processing. Waelz kiln technology is already implemented for secondary Zinc production. EAF Dust can be directly sent to this receiver.	GO	2	2	2	2	2	2	60	VERY LOW	47455	10	1	VERY HIGH
6	BASIC OXYGEN FURNACE SLAG	SILICIUM ALUMINIUM CALCIUM IRON	S : STEEL P : BASIC OXYGEN STEELMAKING AND CASTING MANUFACTURING	S : CEMENT P : RAW MATERIALS PREPARATION	N.A.	Laboratory scale	Feasible: Low technical requirements	The proposed procedure makes BOF slags compliant with its use as raw material for cement production. Due to the simplicity of the procedure involved, it is considered a promising procedure to be scaled up at industrial sites.	GO	10	9	10	9	9	9,4	8	VERY HIGH	32099	10	1	VERY HIGH
7	GYPSUM	GYPSUM	S : INORGANIC CHEMICALS P : SULPHATE PROCESS	S : CEMENT P : GRINDDING CEMENT MILL	N.A.	Industrial Scale	Feasible: Low technical requirements	Red Gypsum can be a safe substitute for natural gypsum without decreasing the quality of the produced cements	GO	5	9	8	5	5	6,4	30	MEDIUM	311	4	40	LOW
8	GYPSUM	GYPSUM	S : COMBUSTION PLANT P : COAL COMBUSTION	S : CEMENT P : GRINDDING CEMENT MILL	N.A.	Industrial pilot	Feasible: Low technical requirements	BREF_CLM document already considers the use of FGD gypsum as a raw material. A technology is proposed to improve the handling of FGD gypsum during manufacturing operations	GO	6	7	8	6	5	6,4	30	MEDIUM	1639	7	21	SIGNIFICAN T
9	OFF-GAS	SULPHURIC ACID	S : NON FERROUS METALS INDUSTRIES P : PRIMARY COPPER SMELTING PYROMETALLURGICAL ROUTE	S : INORGANIC CHEMICALS P : SULPHATE PROCESS	YES	Industrial Scale	Feasible: High technical requirements	Sulphuric acid recovery is highly efficient process and already a standard in this sender sector. Equipment to produce Sulphuric Acid is already available at this sender process	GO	6	8	7	7	8	7,2	22	SIGNIFICANT	966	6	27	MEDIUM
10	SULPHURIC ACID	SULPHURIC ACID	S : NON FERROUS METALS INDUSTRIES P : LEAD AND TIN PRODUCTION	S : INORGANIC CHEMICALS P : SULPHATE PROCESS	YES	Industrial Scale	Feasible: High technical requirements	Sulphuric acid recovery is a highly efficient process and already a standard in this sender sector. Equipment to produce Sulphuric Acid is already available at this sender process	GO	7	8	8	7	9	7,8	17	SIGNIFICANT	1505	7	21	SIGNIFICAN T
11	LIME	LIME	S : FOOD DRINK AND MILK INDUSTRIES P : SUGAR BEET	S : INORGANIC CHEMICALS P : CALCIUM CARBIDE MANUFACTURING	N.A.	Under development	Not feasible: Unavailable support data	At the moment there are no reported utilizations in this synergy scenario. Highly dependent on metal oxide composition. If composition is in accordance with receiver requirements, then the synergy can be applied. On the other hand, in case of uncompliant composition complementary treatments might be needed	NO GO	5	5	5	5	6	5,2	37	MEDIUM	889	6	27	MEDIUM
12	SALT	SALT	S : NON FERROUS METALS INDUSTRIES P : SALT SLAG	S : INORGANIC CHEMICALS P : SODIUM CHLORATE PRODUCTION	N.A.	Industrial Scale	Feasible: Low technical requirements	This operation only can be considered in plants that have partial recycling of salt slag.	GO	7	7	7	6	7	6,8	25	SIGNIFICANT	753	6	27	MEDIUM
13	SALT	SALT	S : SLAUGHTERHOUSES AND ANIMAL BY PRODUCTS INDUSTRIES P : SHEEP SLAUGHTER PROCESS	S : INORGANIC CHEMICALS P : SODIUM CHLORATE PRODUCTION	N.A.	Industrial Scale	Feasible: Low technical requirements	The leather industry usually recycles sodium chloride to reduce the impact of the disposal and send it to another sectors.	GO	3	4	5	3	5	4	47	LOW	47	3	46	LOW
14	COKE	COKE	S : ORGANIC CHEMICALS P : VINYL CHLORIDE MONOMER MANUFACTURING	S : STEEL P : BLAST FURNACES MANUFACTURING	N.A.	N.A	Feasible: Limited potential	The coke can be reused in the receiver sector, but there is no information available with an example of a blast furnace plant that already reuses coke from vinyl chloride production.	GO	2	2	2	2	2	2	60	VERY LOW	2	1	59	VERY LOW
15	LIME	LIME	S : PRODUCTION OF PULP PAPER AND BOARD P : THE KRAFT PULPING PROCESS	S : STEEL P : ELECTRIC ARC FURNACE STEELMAKING AND CASTING MANUFACTURING	N.A.	N.A	Not feasible: Unavailable support data	At the moment there are no reported utilizations in this synergy scenario. Due to the high requirements for limestone grade in Steelmaking industry, the implementation of this synergy is limited by the composition of the Lime sludge	NO GO	4	3	4	3	4	3,6	51	LOW	335	4	40	LOW
16	AIR EMISSIONS	H2SO4	S : STEEL P : COKE OVEN PLANTS	S : PRODUCTION OF PULP PAPER AND BOARD P : THE SULPHITE PULPING PROCESS	YES	Industrial Scale	Feasible: High technical requirements	Highly efficient process	GO	1	1	1	1	1	1	65	VERY LOW	148	3	46	LOW
17	OFF_GAS	HYDROGEN	S : ORGANIC CHEMICALS P : STYRENE MANUFACTURING BY DEHYDROGENATION	S : REFINING MINERAL OIL AND GAS P : ISOMERISATION PROCESS	YES	Industrial Scale	Feasible: Low technical requirements	Popular technology among Hydrogen separation plants	GO	4	3	3	5	4	3,8	49	LOW	1493	7	21	SIGNIFICAN T
18	EMISSIONS	HYDROGEN	S : INORGANIC CHEMICALS P : SODIUM CHLORATE PRODUCTION	S : REFINING MINERAL OIL AND GAS P : HYDROCRACKING PROCESS	YES	Industrial Scale	Feasible: High technical requirements	Technic used in EU. Continuous process is energy intensive but offers possibility for the utilisation of secondary heat.	GO	5	3	3	5	5	4,2	41	LOW	313	4	40	LOW
19	PROCESS GASES	HYDROGEN	S : ORGANIC CHEMICALS P : STEAM CRACKING	S : REFINING MINERAL OIL AND GAS P : HYDRODESULPHURISATION PROCESS	YES	Industrial Scale	Feasible: Low technical requirements	Processing of off-gases is already a standard in this sender process. If the proposed technology is already implemented at the sender process, then the Hydrogen is already a by-product and can be directly sent to final users	GO	8	7	6	9	8	7,6	20	SIGNIFICANT	4441	8	14	SIGNIFICAN T
20	EMISSIONS	Ni	S : STEEL P : BASIC OXYGEN STEELMAKING AND CASTING MANUFACTURING	S : NON FERROUS METALS INDUSTRIES P : NICKEL PRODUCTION	NO	Under development	Not feasible: Underdeveloped technology	There are established processes using this technology such as "The Cawse Process", "The bulong process",but this processes are for nickel processing from ores. Technology implementation for nickel residues recovery is still unavailable	NO GO	1	2	2	1	1	1,4	64	VERY LOW	565	5	33	MEDIUM
21	EMISSIONS	SULPHUR	S : STEEL P : COKE OVEN PLANTS	S : PRODUCTION OF PULP PAPER AND BOARD P : THE SULPHITE PULPING PROCESS	YES	Industrial Scale	Feasible: High technical requirements	Claus process is the standard for Sulphur recovery units	GO	4	5	4	5	3	4,2	41	LOW	53	3	46	LOW
22	REFRACTORY PRODUCTS	REFRACTORY PRODUCTS	S : STEEL P : ELECTRIC ARC FURNACE STEELMAKING AND CASTING MANUFACTURING	S : GLASS P : CONTAINER GLASS MANUFACTURING WITHOUT ABATEMENT SYSTEM	N.A.	Under development	Not feasible: Underdeveloped technology	High value refractory recycling remains limited due to low purity of output streams of the processing technologies. Automated sorting and technological advances could potentially increase purity of output stream and open new recycling opportunities. New technologies may involve the use of automated in-line sorted systems such as Laser induced breakdown spectroscopy (LIBS) object of study of the European FP7-project REFRASORT project h2020	NO GO	7	7	7	6	7	6,8	25	SIGNIFICANT	7065	9	8	VERY HIGH
23	SLAG	SLAG	S : COMBUSTION PLANT P : COAL COMBUSTION	S : GLASS P : STONE AND SLAG WOOL MANUFACTURING	N.A.	N.A.	Not feasible: Unavailable support data	Although the boiler slag could potentially be used for mineral wool production, the stability and presence of toxic compounds needs to be carefully evaluated	NO GO	8	8	8	8	8	8	15	SIGNIFICANT	7327	9	8	VERY HIGH
24	SLAG	SLAG	S : STEEL P : BLAST FURNACES MANUFACTURING	S : GLASS P : STONE AND SLAG WOOL MANUFACTURING	N.A.	Industrial Scale	Feasible: Low technical requirements	Receiving sector already manufactures mineral wool using slag wastes	GO	9	9	9	9	9	9	10	VERY HIGH	340	4	40	LOW

25	LIME	CALCIUM	S : FOOD DRINK AND MILK INDUSTRIES P : SUGAR BEET	S : CEMENT P : RAW MATERIALS PREPARATION	N.A.	N.A.	Feasible: Low technical requirements	Sugar sludges could potentially be used directly for cement production. Dependent on sludge composition.	GO	5	5	5	5	6	5,2	37	MEDIUM	889	6	27	MEDIUM
26	LIME	CALCIUM	S : PRODUCTION OF PULP PAPER AND BOARD P : THE KRAFT PULPING PROCESS	S : CEMENT P : RAW MATERIALS PREPARATION	N.A.	N.A.	Feasible: Low technical requirements	Acceptance of this waste by the cement industry could be decided depending on the application. Having in mind the limitations on the mechanical strength.	GO	4	5	5	4	5	4,6	40	MEDIUM	556	5	33	MEDIUM
27	SLUDGE	CALCIUM ALUMINIUM	S : STEEL P : SINTER PLANTS MANUFACTURING	S : CEMENT P : RAW MATERIALS PREPARATION	NO	N.A.	Not feasible: Unavailable support data	Although the sinter sludge could potentially be used as a raw material for the cement industry due to the presence of important elements such as Calcium and Aluminium, the stability and presence of toxic compounds needs to be carefully evaluated.	NO GO	3	5	5	5	3	4,2	41	LOW	75	3	46	LOW
28	SAND	SAND	S : FOOD DRINK AND MILK INDUSTRIES P : STRACH	S : CEMENT P : RAW MATERIALS PREPARATION	N.A.	N.A.	Feasible: Limited potential	Even though no reported utilisations were found, this synergy seems possible in case the sands meets the requirements for the cement industry	GO	2	3	3	2	3	2,6	55	VERY LOW	76	3	46	LOW
29	RED MUD	IRON	S : NON FERROUS METALS INDUSTRIES P : ALUMINA PRODUCTION	S : CEMENT P : RAW MATERIALS PREPARATION	N.A.	Industrial Scale	Feasible: Limited potential	Red mud can be used as a raw material for clinker production. Alkalinity and red mud concentration used for cement production should be evaluated.	GO	3	6	6	3	3	4,2	41	LOW	31435	10	1	VERY HIGH
30	SLAG	SILICIUM ALUMINIUM CALCIUM	S : STEEL P : BLAST FURNACES MANUFACTURING	S : CEMENT P : RAW MATERIALS PREPARATION	N.A.	Industrial Scale	Feasible: Low technical requirements	Blast furnace slag constitutes a current practice for the utilization in the cement industry.	GO	10	10	10	10	10	10	1	VERY HIGH	7976	9	8	VERY HIGH
31	SALT SLAG	ALUMINIUM OXIDES	S : NON FERROUS METALS INDUSTRIES P : SALT SLAG	S : CEMENT P : RAW MATERIALS PREPARATION	YES	Industrial Scale	Feasible: High technical requirements	Processing of salt slag is already a standard in this sender process. Aluminium oxides separation is already implemented and can be directly sent to final users	GO	9	10	10	10	10	9,8	3	VERY HIGH	8709	9	8	VERY HIGH
32	SALT SLAG	ALUMINIUM OXIDES	S : NON FERROUS METALS INDUSTRIES P : SALT SLAG	S : GLASS P : STONE AND SLAG WOOL MANUFACTURING	YES	Industrial Scale	Feasible: Limited potential	Aluminium oxides separation is already implemented and can be directly sent to final users. After salt slag processing and the recovery of the aluminium oxides, these could potentially be sent to the production of mineral wool.	GO	9	10	10	10	10	9,8	3	VERY HIGH	See S 31 & 32	See S 31 & 32	NM	See S 31 & 32
33	BOTTOM ASH	FERROUS-METALS	S : WASTE INCINERATION P : THERMAL TREATMENT H	S : STEEL P : PELLETISATION PLANTS MANUFAACTURING	YES	Industrial Scale	Feasible: High technical requirements	Highly implemented	GO	3	3	3	2	3	2,8	54	LOW	496	5	33	MEDIUM
34	BOTTOM ASH	FERROUS-METALS	S : COMBUSTION PLANT P : COAL COMBUSTION	S : STEEL P : PELLETISATION PLANTS MANUFAACTURING	N.A.	N.A.	Not feasible: Underdeveloped technology	Even though a beneficiation treatment may be implemented, bottom ash low iron content seems unsuitable for use in pelletizing plant operations.	NO GO	4	6	6	4	4	4,8	39	MEDIUM	180	4	40	LOW
35	EAF SLAG	SILICIUM ALUMINIUM CALCIUM	S : STEEL P : ELECTRIC ARC FURNACE STEELMAKING AND CASTING MANUFACTURING	S : CEMENT P : GRINDDING CEMENT MILL	N.A.	Industrial Scale	Feasible: Limited potential	No technology is required for direct use of EAF slags in cement industry. However, applications are more limited compared to Blast Furnace slags	GO	9	9	9	9	8	8,8	11	VERY HIGH	2351	8	14	SIGNIFICANT
36	LIME	LIME	S : PRODUCTION OF PULP PAPER AND BOARD P : THE KRAFT PULPING PROCESS	S : WASTE INCINERATION P : FLUE GAS TREATMENT NH	N.A.	N.A.	Feasible: Limited potential	Lime sludges could potentially be utilized directly in dry flue-gas treatment units due to its CaCO3 composition. For semi-dry and wet flue-gas treatment units, a calcination (lime kiln) process is required to produce CaO	GO	4	3	4	3	4	3,6	51	LOW	335	4	40	LOW
37	EMISSIONS	Zn	S : STEEL P : ELECTRIC ARC FURNACE STEELMAKING AND CASTING MANUFACTURING	S : NON FERROUS METALS INDUSTRIES P : LEAD AND TIN PRODUCTION	YES	Industrial Scale	Feasible: High technical requirements	Highly implemented. BAT for EAF Dust processing	GO	2	2	2	2	2	2	60	VERY LOW	0	0	66	NO BENEFIT
38	COKE OVEN GAS	BENZENE	S : STEEL P : COKE OVEN PLANTS	S : ORGANIC CHEMICALS P : ETHYLBENZENE MANUFACTURING	YES	Industrial Scale	Feasible: High technical requirements	Benzene is one of the residues of coke oven gas and can be valorised for another sector, as ethylbenzene manufacturing.	GO	2	1	1	2	2	1,6	63	VERY LOW	619	5	33	MEDIUM
39	SULPHURIC ACID	SULPHURIC ACID	S : NON FERROUS METALS INDUSTRIES P : LEAD AND TIN PRODUCTION	S : INORGANIC CHEMICALS P : PRECIPITATED SILICA AND SILICA GEL MANUFACTURING	YES	Industrial Scale	Feasible: High technical requirements	Sulphuric acid recovery is already a standard in this sender sector. Equipment to produce Sulphuric Acid is already available at this sender process. Highly efficient process	GO	9	7	7	7	8	7,6	20	SIGNIFICANT	95	3	46	LOW
40	SLAG	NON-FERROUS METALS	S : STEEL P : BLAST FURNACES MANUFACTURING	S : NON FERROUS METALS INDUSTRIES P : SECONDARY COPPER SMELTING PYROMETALLURGICAL ROUTE	N.A.	N.A.	Not feasible: Unavailable support data	No precedents of utilization of Iron Blast Furnace slags neither of a representative copper quantity to be used in a secondary zinc production	NO GO	5	4	4	4	4	4,2	41	LOW	NM	NM	NM	NM
41	ASHES	ASHES	S : WASTE INCINERATION P : THERMAL TREATMENT H	S : NON FERROUS METALS INDUSTRIES P : SECONDARY COPPER SMELTING PYROMETALLURGICAL ROUTE	YES	Industrial Scale	Feasible: High technical requirements	Processing of ash is current practice in this sender sector	GO	5	4	4	4	4	4,2	41	LOW	1	1	59	VERY LOW
42	SLUDGE	NON FERROUS METALS & ORGANIC MATERIALS	S : REFINING MINERAL OIL AND GAS P : CRUDE ATMOSPHERIC DISTILLATION	S : NON FERROUS METALS INDUSTRIES P : SECONDARY COPPER SMELTING PYROMETALLURGICAL ROUTE	NO	Laboratory scale	Not feasible: Underdeveloped technology	Tests were carried out in lab scale with promising results. No references concerning industrial scale utilization were found.	NO GO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
43	SLUDGE	NON FERROUS METALS & ORGANIC MATERIALS	S : STEEL P : SINTER PLANTS MANUFACTURING	S : NON FERROUS METALS INDUSTRIES P : SECONDARY COPPER SMELTING PYROMETALLURGICAL ROUTE	YES	N.A.	Feasible: Limited potential	Copper Solvent Extraction - Electrowinning is considered a commercially available technology. EMEW supplies this technology. No precedents were found associated with its utilisation in sinter sludges	GO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
44	SAND	SAND	S : FOOD DRINK AND MILK INDUSTRIES P : STRACH	S : NON FERROUS METALS INDUSTRIES P : PRIMARY ZINC PRODUTION	N.A.	N.A.	Not feasible: Unavailable support data	Highly dependant on the composition of the sand. If Flux material composition in sand is in adequate quantities sand could be used as a flux material	NO GO	2	3	3	2	3	2,6	55	VERY LOW	76	3	46	LOW
45	SLUDGE	NON FERROUS METALS & CHROMIUM	S : INORGANIC CHEMICALS P : SODIUM CHLORATE PRODUCTION	S : NON FERROUS METALS INDUSTRIES P : LEAD AND TIN PRODUCTION	NO	Laboratory scale	Not feasible: Underdeveloped technology	Tests were carried out in lab scale with promising results. No references concerning industrial scale utilization were found.	NO GO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
46	SLUDGE	NON FERROUS METALS & ORGANIC MATERIALS	S : STEEL P : SINTER PLANTS MANUFACTURING	S : NON FERROUS METALS INDUSTRIES P : LEAD AND TIN PRODUCTION	N.F.	N.A.	Not feasible: Unavailable support data	Caustic soda leaching proved to be successful for the recovery of zinc and lead in EAF dust. Further studies are advised to prove technical feasibility in sinter sludges	NO GO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
47	COKE OVEN GAS	COKE OVEN GAS	S : STEEL P : COKE OVEN PLANTS	S : COMBUSTION PLANT P : IRON AND STEEL PROCESS GASES COMBUSTION	N.A.	Industrial Scale	Feasible: High technical requirements	Recovery and treatment of COG is already implemented. Cleaned COG can be sent directly to receiving process	GO	10	10	10	9	10	9,8	3	VERY HIGH	22882	10	1	VERY HIGH
48	BLAST FURNACE GAS	BLAST FURNACE GAS	S : STEEL P : BLAST FURNACES MANUFACTURING	S : COMBUSTION PLANT P : IRON AND STEEL PROCESS GASES COMBUSTION	N.A.	Industrial Scale	Feasible: High technical requirements	Blast furnaces around the world apply BF gas cleaning systems. In the EU, wet scrubbing is the technique most commonly applied as a second step in BF gas treatment.	GO	6	5	4	6	7	5,6	35	MEDIUM	31046	10	1	VERY HIGH
49	BASIC OXYGEN FURNACE GAS	BASIC OXYGEN FURNACE GAS	S : STEEL P : BASIC OXYGEN STEELMAKING AND CASTING MANUFACTURING	S : COMBUSTION PLANT P : IRON AND STEEL PROCESS GASES COMBUSTION	N.A.	Industrial Scale	Feasible: High technical requirements	Suppressed combustion and subsequent BOF gas recovery is the most common process.	GO	6	4	4	6	7	5,4	36	MEDIUM	2977	8	14	SIGNIFICANT
50	LIMESTONE FINES	LIMESTONE FINES	S : INORGANIC CHEMICALS P : SOLVAY PROCESS	S : CEMENT P : RAW MATERIALS PREPARATION	N.A.	Industrial Scale	Feasible: Low technical requirements	Limestone fines could potentially be used directly in the manufacture of cement products and substitute natural raw materials.	GO	3	4	5	4	4	4	47	LOW	2308	8	14	SIGNIFICANT
51	SEMI-WET SORPTION RESIDUES	LIME	S : WASTE INCINERATION P : FLUE GAS TREATMENT NH	S : STEEL P : SINTER PLANTS MANUFACTURING	N.A.	N.A.	Not feasible: Underdeveloped technology	Most common practices for flue-gas cleaning residues are treatment for landfilling or internal recycling.	NO GO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
52	ELECTROLYTE BLEED	ACID	S : NON FERROUS METALS INDUSTRIES P : PRIMARY COPPER SMELTING PYROMETALLURGICAL ROUTE	S : WASTE TREATMENTS INDUSTRIES P : PHYSICO CHEMICAL TREATMENTS	YES	Industrial Scale	Feasible: High technical requirements	GO	4	3	3	3	4	3,4	53	LOW	5,302396	5	53	VERY LOW	

53	WATER ELECTROPORCELAIN AFTER FLOCCULATION	Ni COBALT ALUMINIUM ZINC	S : REFINING MINERAL OIL AND GAS P : VACUUM DISTILLATION	S : FERTILISERS P : NPK FERTILISER PRODUCTION	YES	Industrial pilot	Feasible: High technical requirements	Although no studies were found concerning this specific water residue, the recovery of each element is technically possible using the proposed technology	GO	NM	NM	NM	NM	NM	NM	NM	NM	0	1	59	VERY LOW
54	VACUUM DISTILLATION WASTE WATER	NH3	S : REFINING MINERAL OIL AND GAS P : VACUUM DISTILLATION	S : FERTILISERS P : NPK FERTILISER PRODUCTION	YES	Industrial Scale	Feasible: Low technical requirements	Well developed technology and under operation in many plants	GO	NM	NM	NM	NM	NM	NM	NM	NM	579	5	33	MEDIUM
55	GAS SEPARATION WASTE WATER	NH3	S : REFINING MINERAL OIL AND GAS P : GAS SEPARATION PROCESSES	S : FERTILISERS P : UREA PRODUCTION	YES	Industrial Scale	Feasible: Low technical requirements	Well developed technology and under operation in many plants	GO	NM	NM	NM	NM	NM	NM	NM	NM	See S 54 & 55	See S 54 & 55	NM	See S 54 & 55
56	WATER ELECTROPORCELAIN AFTER FLOCCULATION	Zn	S : CERAMIC P : ELECTROPORCELAIN MANUFACTURING	S : NON FERROUS METALS INDUSTRIES P : LEAD AND TIN PRODUCTION	YES	Industrial Scale	Feasible: High technical requirements	The technology is already implemented in industry	GO	NM	NM	NM	NM	NM	NM	NM	NM	0	1	59	VERY LOW
57	FILTER DUST	ALUMINIUM	S : NON FERROUS METALS INDUSTRIES P : SECONDARY ALUMINIUM	S : IRON AND STEEL P : BASIC OXYGEN STEELMAKING	YES	Industrial Scale	Feasible: High technical requirements	Aluminium is used as a dioxidizer in a basic oxygen furnace.	GO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
58	ELECTROLYTE BLEED	ACID	S : NON FERROUS METALS INDUSTRIES P : SECONDARY COPPER SMELTING PYROMETALLURGICAL ROUTE	S : ORGANIC CHEMICALS P : PHENOL MANUFACTURING	YES	Industrial Scale	Feasible: High technical requirements	GO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
59	SLAG ASH	SLAG OR NON FERROUS METALS	S : WASTE INCINERATION P : THERMAL TREATMENT NH	S : NON FERROUS METALS INDUSTRIES P : SECONDARY COPPER SMELTING PYROMETALLURGICAL ROUTE	YES	Industrial Scale	Feasible: High technical requirements	Processing of ash is current practice in this sender sector	GO	5	4	3	4	3	3,8	49	LOW	633	5	33	MEDIUM
60	DRINKING WATER TREATMENT SLUDGE	NUTRIENTS NITROGEN PHOSPHORUS POTASSIUM MAGNESIUM CALCIUM	S : WASTE WATER TREATMENT INDUSTRIES P : DRINKING_WATER_TREATMENT_PROCESS	S : FERTILISERS P : CAN PRODUCTION	N.A.	Industrial pilot	Feasible: Low technical requirements	Production of biosolid-derived fertilizers is already implemented at industrial scale. Relvão Eco-park, Portugal has already established and implemented this synergy. Organo-mineral fertilizers can be produced from sewage sludge. Restraints on the establishment of this synergy could be derived from heavy metal content and organic pollutants in the sludge	GO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
61	WASTE PLASTICS (AMP)	WASTE PLASTICS (AMP)	S : ENGINEERING P : PLASTIC PART MANUFACTURING	S : ENGINEERING P : BLAST MEDIA PRODUCTION	YES	Industrial Scale	Feasible: Low technical requirements	The use of plastic media blasting is strongly implemented in the aeronautic and automotive industry. Even do there is no direct reference on BREF documents to the transformation of recycling plastic media process	GO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
62	YEAST SLUDGE AND SLURRY	YEAST NUTRIENTS	S : PHARMACEUTICAL P : FERMENTATION PROCESS	S : AGRO-INDUSTRIAL PRODUCTION P : LIVESTOCK FEEDING	YES	Industrial Scale	Feasible: Low technical requirements	Novo Nordisk A/S established at Kalundborg industrial park have been running successfully for 30 years this symbiotic relation with pig farm producers (around 800.000 pigs fed per year)	GO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
63	POULTRY DEJECTIONS	EXTRACELLULAR ENZYMES	S : AGRO-INDUSTRIAL PRODUCTION P : INTENSIVE_POULTRY_FARMING	S : TEXTILE P : TANNING	YES	Industrial pilot	Feasible: Low technical requirements	Even tanning with PD was recovered from ancient principals, Life PODEBA dehodorization technology is considered to be included as a BAT in tanning BREF.	GO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
64	SILICA	SILICA	S : MINERALS P : MICRONIZED_SILICA_MANUFACTURING	S : INORGANICS_CHEMICAL P : SODIUM SILICATE MANUFACTURING	N.A.	Industrial pilot	Feasible: Low technical requirements	Synergy represents a real case study from Bussi Chemical site, Italy. Synergy already implemented. Further contact with the involved entities is advised.	GO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
65	SULPHUR	SULPHUR	S : REFINING MINERAL OIL AND GAS P : HYDRODESULPHURISATION_PROCESS	S : FERTILISERS P : ATS_FERTILISER	YES	Industrial Scale	Feasible: Low technical requirements	Commercially available technology to produce ammonium thiosulfate from flue gas. Industrially implemented in Kalundborg Industrial Park, Denmark.	GO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
66	BLAST FURNACE AND CONVERTER SLAG	BLAST FURNACE SLAG	S : STEEL P : BLAST_FURNACES_MANUFACTURING	S : CERAMIC P : BRICKS_AND_ROOF_TILES_MANUFACTURING	N.A.	Industrial pilot	Feasible: Low technical requirements	Feasibility depends on the incorporation percentage and for which application is the brick designed to. Industrial-scale trials were performed	GO	9	8	8	8	7	8	15	SIGNIFICANT	3315	8	14	SIGNIFICANT
67	COOLING WATER	COOLING WATER	S : REFINING MINERAL OIL AND GAS P : ALL PROCESSES	S : COMBUSTION_PLANT P : COAL_COMBUSTION	N.A.	Industrial Scale	Feasible: Low technical requirements	Both pipelines and pumps are available in industrial scale, that are the best approach to transport water between enterprises.	GO	NM	NM	NM	NM	NM	NM	NM	NM	1643	8	14	SIGNIFICANT
68	FLY ASH	SILICIUM ALUMINIUM CALCIUM	S : COMBUSTION_PLANT P : INTEGRATED_GASIFICATION_COMBINED_CYCLE	S : GLASS P : CONTAINER_GLASS_MANUFACTURING_WITH_ABATEMENT_SYSTEM	N.A.	Under development	Feasible: Limited potential	Coal fly ashes could potentially be used directly in the manufacture of glass products.	GO	8	8	8	7	8	7,8	17	SIGNIFICANT	675	5	33	MEDIUM
69	FLY ASH	SILICIUM ALUMINIUM CALCIUM	S : COMBUSTION_PLANT P : COAL_COMBUSTION	S : CERAMIC P : BRICKS_AND_ROOF_TILES_MANUFACTURING	N.A.	Industrial pilot	Feasible: Low technical requirements	Coal fly ashes could potentially be used directly in the manufacture of ceramic products and substitute natural raw materials	GO	10	10	10	10	10	10	1	VERY HIGH	12723	9	8	VERY HIGH
70	ACID	HCl	S : INORGANIC_CHEMICALS P : UNDEFINED	S : COMBUSTION_PLANT P : INTEGRATED_GASIFICATION_COMBINED_CYCLE	YES	Industrial Scale	Feasible: Low technical requirements	GO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	
71	ANODE SLIME	Pd	S : NON FERROUS METALS INDUSTRIES P : PRIMARY COPPER SMELTING PYROMETALLURGICAL ROUTE	S : REFINING_MINERAL_OIL_AND_GAS P : CATALYTIC_CRACKING_FCC_PROCESS	YES	Industrial Scale	Feasible: High technical requirements	Due to the high prices of precious metals is worthy to recover it from anode slimes, even when small quantities are identified.	GO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
72	GREEN LIQUOR SLUDGE	Cr	S : PRODUCTION OF PULP PAPER AND BOARD P : THE KRAFT PULPING PROCESS	S : STEEL P : ELECTRIC_ARC_FURNACE_STEELMAKING_AND_CASTING_MANUFACTURING	NO	Under development	Not feasible: Underdeveloped technology	"Suitable applications for green liquor dregs still remain limited. GLD and LM present very low valorisation alternatives where landfilling after drying process is the most extended practice at the moment. "	NO GO	1	1	1	1	1	1	65	VERY LOW	2	1	59	VERY LOW
73	SPENT CATALYST METAL OXIDE	Pt	S : ORGANIC CHEMICALS P : METAL OXIDE PROCESS	S : REFINING_MINERAL_OIL_AND_GAS P : CATALYTIC_CRACKING_FCC_PROCESS	YES	Industrial Scale	Feasible: High technical requirements	https://www.researchgate.net/publication/260303129_Automotive_spent_catalysts_treatment_and_platinum_recovery	GO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
74	ANODE SLIME	Rh	S : NON FERROUS METALS INDUSTRIES P : PRIMARY COPPER SMELTING PYROMETALLURGICAL ROUTE	S : REFINING_MINERAL_OIL_AND_GAS P : CATALYTIC_CRACKING_FCC_PROCESS	YES	Industrial Scale	Feasible: High technical requirements	Due to the high prices of precious metals is worthy to recover it from anode slimes, even when small quantities are identified.	GO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
75	EMISSIONS	Sb	S : LIME P : LIME MANUFACTURING MIXED FEED SHAFT KILN	S : NON_FERROUS_METALS_INDUSTRIES P : SECONDARY_COPPER_SMELTING_PYROMETALLURGICAL_ROUTE	YES	Industrial Scale	Feasible: High technical requirements	https://link.springer.com/content/pdf/10.1007/978-3-642-36199-9_206-1.pdf	GO	1	1	1	1	1	1	65	VERY LOW	32	2	53	VERY LOW
76	BASIC OXYGEN FURNACE SLAG	Al2O3	S : STEEL P : BASIC OXYGEN STEELMAKING AND CASTING MANUFACTURING	S : NON_FERROUS_METALS_INDUSTRIES P : ALUMINA_PRODUCTION	N.A.	N.A.	Not feasible: Unavailable support data	NO GO	6	6	6	6	6	6	33	MEDIUM	NM	NM	NM	NM	
77	BASIC OXYGEN FURNACE SLAG	Al2O3	S : STEEL P : BASIC OXYGEN STEELMAKING AND CASTING MANUFACTURING	S : CERAMIC P : ELECTROPORCELAIN_MANUFACTURING	N.A.	N.A.	Not feasible: Unavailable support data	NO GO	6	6	6	6	6	6	33	MEDIUM	0	0	66	NO BENEFIT	

78	TAR	TAR	S : ORGANIC_CHEMICALS P : HYDROGEN_PEROXIDE_MANUFACTURING	S : COMBUSTION_PLANT P : WASTE_CO-INCINERATION	N.A.	Under development	Feasible: Limited potential	" No reference was found on actual industrial utilization even though it presents high potential depending the chemical composition. The transformation of liquid waste streams into liquid fuel streams proved the repeatable and stable operating conditions;"	GO	2	2	2	3	2	2,2	59	VERY LOW	3	2	53	VERY LOW
79	TAR	TAR	S : ORGANIC_CHEMICALS P : STYRENE_MANUFACTURING_BY_DEHYDROGENATION	S : CEMENT P : BURNING	N.A.	Industrial Scale	Feasible: Low technical requirements	Tars from styrene production can be reused as a fuel in cement sector.	GO	7	6	6	7	5	6,2	32	MEDIUM	898	6	27	MEDIUM
80	SPENT SOLVENTS	SPENT_SOLVENTS	S : ORGANIC_CHEMICALS P : STYRENE_MANUFACTURING_BY_HYDROGENATION	S : CEMENT P : BURNING	N.A.	Industrial Scale	Feasible: Low technical requirements	Spent solvents could be sent to incineration and co-incineration plants.	GO	3	2	2	4	2	2,6	55	VERY LOW	27	2	53	VERY LOW
81	CRUDE ATMOSPHERIC DISTILLATION WASTE WATER	OIL	S : REFINING_MINERAL_OIL_AND_GAS P : CRUDE_ATMOSPHERIC_DISTILLATION	S : STEEL P : BLAST_FURNACES_MANUFACTURING	YES	Industrial Scale	Feasible: Low technical requirements	GO	7	6	7	8	6	6,8	25	SIGNIFICANT	978,1061	978	27	MEDIUM	
82	WOOD WASTE	WOOD WASTE BARK SAWDUST	S : PRODUCTION_OF_PULP_PAPER_AND_BOARD P : THE_SULPHITE_PULPING_PROCESS	S : COMBUSTION_PLANT P : INTEGRATED_GASIFICATION_COMBINED_CYCLE	YES	Industrial Scale	Feasible: Low technical requirements	An integrated sulphite pulp mill incinerates all organic residues on site (bark, wood waste, fibre sludge, sludge from biological treatment), even though non used surpluses can be forward to other combustion plants.	GO	8	9	9	8	9	8,6	13	VERY HIGH	1316	7	21	SIGNIFICANT
83	SOIL AND GREEN WASTES	SLUDGE	S : FOOD_DRINK_AND_MILK_INDUSTRIES P : SUGAR_BEET	S : COMBUSTION_PLANT P : WASTE_CO-INCINERATION	NO	Under development	Feasible: Low technical requirements	Although no studies were found for the use of sugar beet sludges, it could potentially be valorised in a co-incineration process. Sludge composition and its Lower Heating Value may promote its feasibility	GO	6	6	5	9	7	6,6	28	MEDIUM	1	1	59	VERY LOW
84	SLUDGE	SLUDGE	S : ORGANIC_CHEMICALS P : VINYL_CHLORIDE_MONOMER_MANUFACTURING	S : COMBUSTION_PLANT P : WASTE_CO-INCINERATION	NO	Under development	Feasible: Low technical requirements	Although no studies were found for the use of vinyl chloride manufacturing sludges, it could potentially be valorised in a co-incineration process. Sludge composition and its Lower Heating Value may promote its feasibility	GO	1	1	1	1	1	1	65	VERY LOW	1	1	59	VERY LOW
85	VISBREAKING WASTE WATER	OIL	S : REFINING_MINERAL_OIL_AND_GAS P : VISBREAKING_PROCECSS	S : NON_FERROUS_METALS_INDUSTRIES P : WAELZ_KILN_OPERATION	YES	Industrial Scale	Feasible: Low technical requirements	Processing of wastewaters containing oil is already a standard technology in this sender process. Recovered oil can be directly sent to final users	GO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
86	CARCASE	CARCASE	S : SLAUGHTERHOUSES_AND_ANIMAL_BY_PRODUCTS_INDUSTRIES P : POULTRY_SLAUGHTER_PROCESS	S : CEMENT P : BURNING	N.A.	Industrial Scale	Feasible: Low technical requirements	The incineration of MBM, in particular has, therefore, developed into a relatively large scale activity since the use of animal proteins in animal feed was banned. Some MSs co-incinerate MBM and other animal meals in municipal waste incinerators, hazardous waste incinerators, sewage sludge incinerators, coal-fired power stations, cement works, gasification plants and residue incinerators in paper plants.	GO	7	8	9	7	8	7,8	17	SIGNIFICANT	1001	7	21	SIGNIFICANT
87	WOOD WASTE	WOOD	S : PRODUCTION_OF_PULP_PAPER_AND_BOARD P : THE_SULPHITE_PULPING_PROCESS	S : LIME P : LIME_MANUFACTURING_LONG_ROTARY_KILN	N.A.	Industrial Scale	Feasible: Low technical requirements	Fuels to feed the long rotary kilns, which are used in lime manufacture, are pulverised solid fossil fuels, waste fuels and biomass. Wood can be sent directly to lime plants to incinerate.	GO	8	9	9	8	9	8,6	13	VERY HIGH	1316	7	21	SIGNIFICANT
88	CRUDE ATMOSPHERIC DISTILLATION WASTE WATER	OIL	S : REFINING_MINERAL_OIL_AND_GAS P : CRUDE_ATMOSPHERIC_DISTILLATION	S : INORGANIC_CHEMICALS P : FURNACE_BLACK_PROCESS	YES	Industrial Scale	Feasible: Low technical requirements	N.A.	GO	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
89	COOLING WATER	COOLING WATER	S : PRODUCTION_OF_PULP_PAPER_AND_BOARD P : MECHANICAL_PULPING_AND_CHEMIMECHANICAL_PULPING	S : REFINING_MINERAL_OIL_AND_GAS P : ALL_PROCESSES	N.A.	Industrial Scale	Feasible: Low technical requirements	Pipelines is the most common way to transport water used by industries.	GO	NM	NM	NM	NM	NM	NM	NM	NM	3577	8	14	SIGNIFICANT
90	COOLING WATER	COOLING WATER	S : PRODUCTION_OF_PULP_PAPER_AND_BOARD P : MECHANICAL_PULPING_AND_CHEMIMECHANICAL_PULPING	S : FERTILISERS P : CAN_PRODUCTION	YES	Industrial Scale	Feasible: Low technical requirements	"Pipelines is the most common way to transport water used by industries. "	GO	NM	NM	NM	NM	NM	NM	NM	NM	See S 89 & 90	See S 89 & 90	NM	See S 89 & 90
91	HEAT	HEAT	S : DIFFERENT: SEE ANNEXED TABLES (D 3.1) P : DIFFERENT: SEE ANNEXED TABLES (D 3.1)	S : DIFFERENT: SEE ANNEXED TABLES (D 3.1) P : DIFFERENT: SEE ANNEXED TABLES (D 3.1)	Dependent on technology	Industrial Scale	Feasible: Low technical requirements	" To take advantage of the potential of industrial waste heat, it is therefore essential to look into and analyse the industrial processes used in large energy consuming industries and to investigate what suitable waste heat recovery methods can be applied to the systems of each sector. The selection of heat recovery methods and techniques largely depends on key factors such as the quality, quantity and the nature of heat source in terms of suitability and effectiveness"	GO	1	1	1	1	1	1	65	VERY LOW	61118	10	1	VERY HIGH
92	HEAT	HEAT	S : DIFFERENT: SEE ANNEXED TABLES (D 3.1) P : DIFFERENT: SEE ANNEXED TABLES (D 3.1)	S : DIFFERENT: SEE ANNEXED TABLES (D 3.1) P : DIFFERENT: SEE ANNEXED TABLES (D 3.1)	YES/NO	Industrial Scale / Laboratory scale	Feasible: Low technical requirements /Feasible: Limited potential	The use of thermodynamic cycles procedure is widely implemented at industrial scale, Organic Rankine cycle and Kalina Cycle shows potential technical advantages over traditional Klausius Rankine cycle in specific conditions. Direct electrical conversion devices are not widely used/implemented at industrial scale at the moment, Prototype and lab scale are their actual development stage. https://www.sciencedirect.com/science/article/pii/S2451904918300015	GO	See S92	See S92	See S92	See S92	See S92	See S92	NM	See S92	See S 91 & 92	See S 91 & 92	NM	See S 91 &92
93	STEAM	STEAM	S : DIFFERENT: SEE ANNEXED TABLES (D 3.1) P : DIFFERENT: SEE ANNEXED TABLES (D 3.1)	S : DIFFERENT: SEE ANNEXED TABLES (D 3.1) P : DIFFERENT: SEE ANNEXED TABLES (D 3.1)	YES	Industrial Scale	Feasible: Low technical requirements	The use of thermodynamic cycles procedure is widely implemented at industrial scale , Organic Rankine cycle and Kalina Cycle shows potential technical advantages over traditional Klausius Rankine cycle in specific conditions. In the case of clean steam, Rankine cycles are highly efficient. In case of contaminated steam ORC and KC are the most extended technologies around industrial sites	GO	1	1	1	1	1	1	65	VERY LOW	7383	9	8	VERY HIGH
94	STEAM	STEAM	S : DIFFERENT: SEE ANNEXED TABLES (D 3.1) P : DIFFERENT: SEE ANNEXED TABLES (D 3.1)	S : DIFFERENT: SEE ANNEXED TABLES (D 3.1) P : DIFFERENT: SEE ANNEXED TABLES (D 3.1)	YES	Industrial Scale	Feasible: Low technical requirements	"As a baseline, all pipping operating at temperatures above 200 °C and diameters of more than 200 mm should be insulated and good condition of this insulation should be checked on a periodic basis (e.g. prior to turnarounds via IR scans of piping systems). In addition, any surfaces that reach temperatures of higher than 50 ºC where there is a risk of staff contact, should be insulated. BREF ENE"	GO	See S93	See S93	See S93	See S93	See S93	See S93	NM	See S93	See S 93 & 94	See S 93 & 94	NM	See S 93 & 94

95	SOLID WASTE FUEL FEEDSTOCK	Various waste - See table n°	S : DIFFERENT: SEE ANNEXED TABLES (D 3.1) P : DIFFERENT: SEE ANNEXED TABLES (D 3.1)	S : WASTE TREATMENTS INDUSTRIES P : WASTE TREATMENT AIMED PRODUCE MATERIAL USED AS FUEL	YES	Industrial Scale	Feasible: Low technical requirements	" The demonstration of energy recovery from specific waste plastic streams in full-scale tests has been going on over a sufficiently long time period to prove the repeatable and stable operating conditions;"	GO	1	1	1	1	1	1	65	VERY LOW	31698	10	1	VERY HIGH
96	LIQUID WASTE FUEL FEEDSTOCK	Various waste - See table n°	S : DIFFERENT: SEE ANNEXED TABLES (D 3.1) P : DIFFERENT: SEE ANNEXED TABLES (D 3.1)	S : WASTE TREATMENTS INDUSTRIES P : WASTE TREATMENT AIMED PRODUCE MATERIAL USED AS FUEL	YES	Industrial Scale	Feasible: High technical requirements	" The transformation of liquid waste streams into liquid fuel streams proved the repeatable and stable operating conditions;"	GO	See S95	See S95	See S95	See S95	See S95	See S95	NM	See S95	See S 95 - 100	See S 95 - 100	NM	See S 95 - 100
97	OIL	OIL	S : WASTE TREATMENTS INDUSTRIES P : WASTE TREATMENT AIMED PRODUCE MATERIAL USED AS FUEL	S : See table n° P : See table n°	YES	Industrial Scale	Feasible: Low technical requirements	The valorisation of recovered waste oil for combustion purposes is highly implemented due to economic advantages on raw material substitution. Waste oil is used as a fuel in a number of power stations in the UK, in IED plants permitted for burning hazardous waste. (BREF WT)	GO	10	9	9	10	9	9,4	8	VERY HIGH	See S 95 - 100	See S 95 - 100	NM	See S 95 - 100
98	BITUMEN	BITUMEN	S : WASTE TREATMENTS INDUSTRIES P : WASTE TREATMENT AIMED PRODUCE MATERIAL USED AS FUEL	S : See table n° P : See table n°	N.A.	Industrial Scale	Feasible: Low technical requirements	The clinker firing process is well suited for various alternative fuels, the goal is to optimize process control and alternative fuel consumption while maintaining clinker product quality. Many years of industrial experience have shown that the use of wastes as alternative fuels by cement plants is both ecologically and economically justified. if the waste produced bitumen composition and thermal properties are adequate according to receiver standards then its valorisation is possible for combustion purposes.	GO	8	7	7	7	6	7	23	SIGNIFICANT	See S 95 - 100	See S 95 - 100	NM	See S 95 - 100
99	METHANOL	METHANOL	S : WASTE TREATMENTS INDUSTRIES P : WASTE TREATMENT AIMED PRODUCE MATERIAL USED AS FUEL	S : See table n° P : See table n°	N.A.	Under development	Feasible: Low technical requirements	There is no specific studies concerning the usability of methanol from renewable sources in this receiver sector. However, if the methanol is compliant with the required specifications can be reused in this sector.	GO	8	5	5	8	7	6,6	28	MEDIUM	See S 95 - 100	See S 95 - 100	NM	See S 95 - 100
100	GAS OIL	GAS OIL	S : WASTE TREATMENTS INDUSTRIES P : WASTE TREATMENT AIMED PRODUCE MATERIAL USED AS FUEL	S : See table n° P : See table n°	YES	Industrial Scale	Feasible: Limited potential	The valorisation of recovered Gas oil for combustion purposes has high potential due to economic advantages on raw material substitution.	GO	10	10	10	10	9	9,8	3	VERY HIGH	See S 95 - 100	See S 95 - 100	NM	See S 95 - 100

3.2 Geographical analysis of the most impacting synergies

For all synergies selected in Table 26, a geographical statistical analysis is performed in this section. Each synergy is analysed by a datasheet divided in four parts (Figure 38):

- Distribution of distance for all potential combinations between emitting and receiving sites at EU levels. The viability distance is presented with a red vertical line (profitability and viability).
- Combinations number per range of distance in a relevant and restricted geographical scope. The viability distance is presented with a red vertical line.
- Tables
  - **A:** Total number of combinations across Europe per range of distance
  - **B:** Total number of combinations within a profitable standard radius (transport costs less than 10% of the price of the materials transported)
  - **B':** Number of synergies in a profitable radius assuming that one emitting site sends its entire flow to the nearest receiving facility
  - **C:** Total number of combinations within the viability radius limit (transport costs less than the price of the materials transported)
  - **C':** Number of synergies within the viability radius assuming that one emitting site sends its entire flow to the nearest receiving facility
- Results interpretation and analysis.

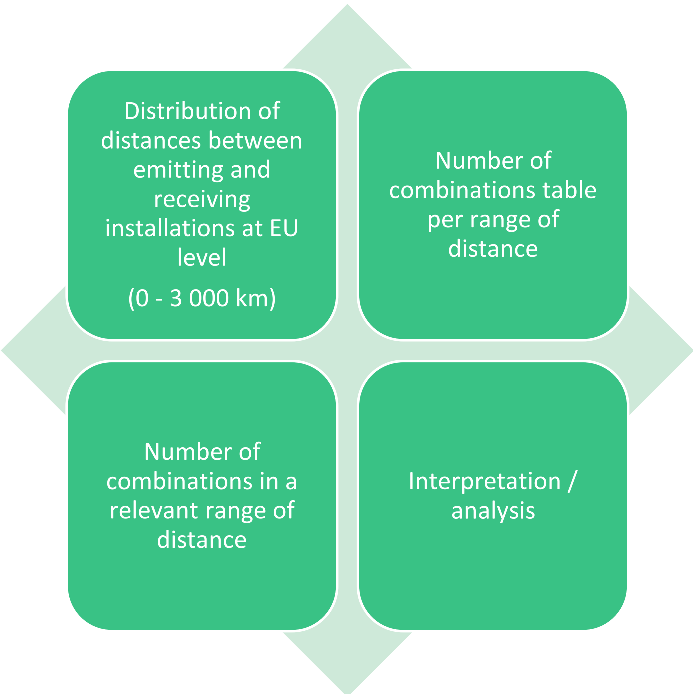


Figure 38: Synergies datasheet organisation (Source: Strane)

Viability distance

It was assumed that a pipeline costs on average about 1.4 M€ per kilometre (Smith, 2015). The economics of pipelines depends on the resource to be transported, its physical characteristics (e.g. corrosion, temperature, risks, porosity, etc.) requiring different types of pipelines (materials, isolation, protections…), as well as its local characteristics (land ownership, type of land, landscape…).

Truck transportation generic price was provided by an industrial partner. It is assumed that the truck transportation costs are between 0,15 and 0,2 €/t/km. This generic price is not applicable for specific or exceptional lorry transportation (e.g. pressurised gas transportation).

Table 28: Transportation modes price (Source: Strane)

Transport modes	CAPEX	OPEX	Unit	Source
Pipeline	1400000	85000	€/km	Smith, 2015
Trucks		0,0298841	€/t/km	Strane
Trucks		15 – 20 0,15 – 0,2	€/t/100km €/t/km	Industrial partner

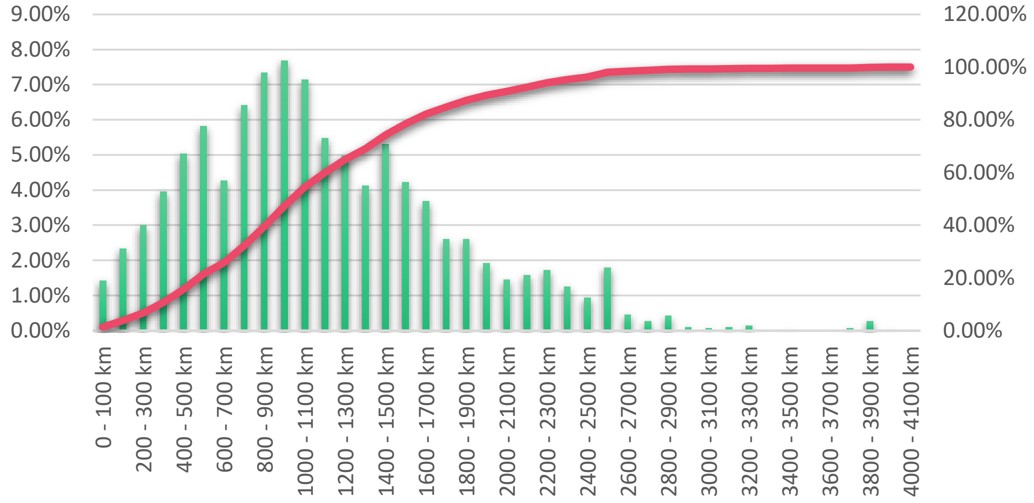
In this study, the viability distance assessed for lorry transportation is a rough estimation [21]. It considers the costs of transportation price for one ton of resource. The distance radius of viability is a data made in relation with the price of the resource studied. The formula used does not depend on the resources volume.

$$\boldsymbol{Viability\ radius} = \frac{\boldsymbol{Resource\ valuable\ volume}\ (\boldsymbol{t}) * \boldsymbol{Raw\ material\ susbtitiuted\ price}\ (€.\boldsymbol{t})}{\boldsymbol{Tranport\ generic\ price}\ (€.\boldsymbol{t}.\boldsymbol{km}) * \boldsymbol{Resource\ valuable\ volume}\ (\boldsymbol{t})}$$

Two viability distances are indicated on graphs. The first one, named “profitability radius” is common logistic freight transportation concept assuming the transportation costs must not exceed 10% of the transported merchandise value. In the case of waste transportation, this hypothesis is too restrictive so a second data is provided on the maximum viability distance corresponding to the distance for which costs transportation are equal to the resource transported intrinsic economic value.

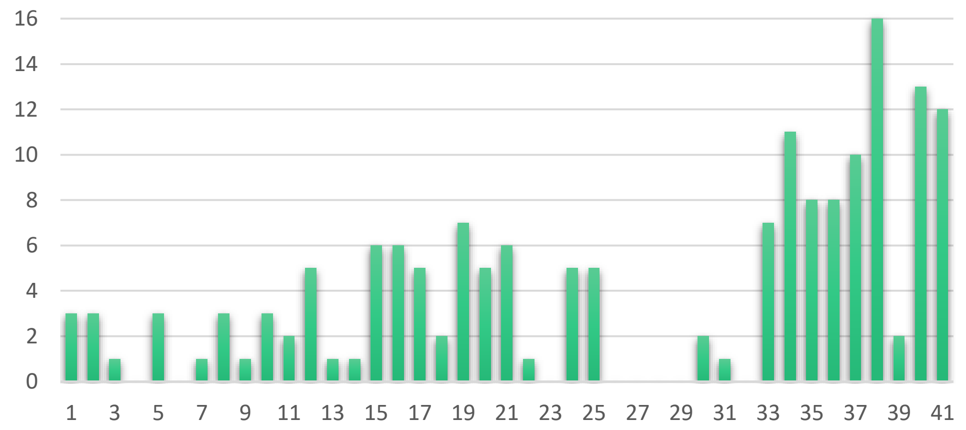
All most impacting synergies are analysed in the next tables.

Synergy type 1 & 2 datasheet: COG from Coke Ovens (STEEL) conversion to hydrogen or methanol for refineries



Quartile	Distance
0	1,8
0,1	368,3
0,2	566,6
0,3	767,5
0,4	905,7
0,5	1034,6
0,6	1202,8
0,7	1421,1
0,8	1634,3
0,9	2034,3
1	4162,6

Distance	A	B	B'	C	C'
1	0	0	0	0	0
5	3	3	3	3	3
10	6	6	5	6	5
20	7	7	6	7	6
50	18	18	10	18	10
100	58			58	23
500	641				
1000	1925				
2000	3638				
3000	4043				

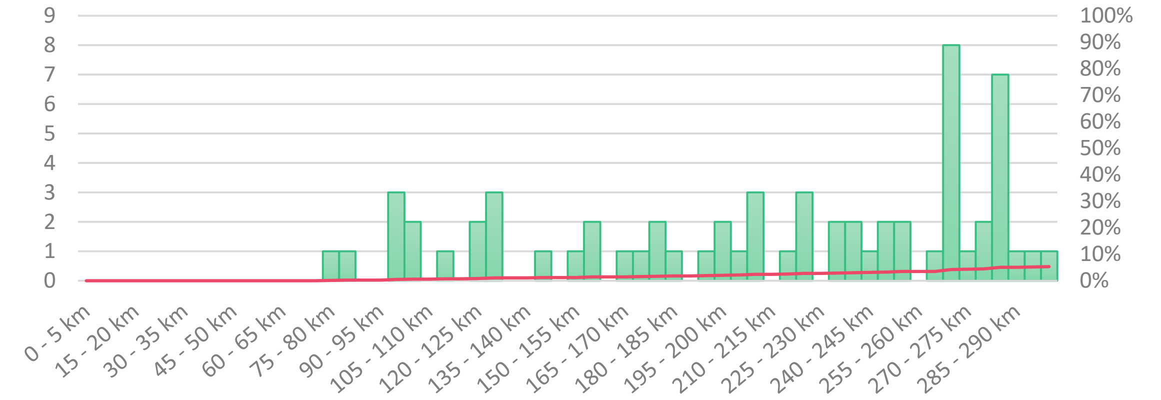


This synergy is not economically viable but several synergies could be implemented between nearby installations to avoid a huge environmental impact associated to the production of hydrogen or methanol. Pipeline transportation is advised between nearby facilities. In the first 10 km, 6 opportunities could be supplied with pipelines. Gaseous hydrogen can be transported in small to medium quantities in compressed gas containers. Liquid hydrogen or methanol can be transported in liquid hydrogen trailers. In a 50 km radius, 18 synergies opportunities could be implemented by using gas trailers. Over longer distance it is usually more cost-effective to transport gas in liquid form since a liquid gas can hold substantially more gas than a pressurized gas tank. Gas containers could be used by train or truck mobility. 58 opportunities have a distance lower than 100 km and 640 in a 500km radius. External benefits quantified in the D3.5 could help to implement these synergy type: in particular the carbon tax avoided per each site (1 760 M€)

Synergy type 3 datasheet: Primary liquid fuels from organic chemicals (ethyl acetate cleaning operation) to the cement sector (clinker production)

Quartile	Distance
0	75,7
0,1	412,2
0,2	595,2
0,3	743,7
0,4	893,5
0,5	1033,6
0,6	1178,9
0,7	1348,0
0,8	1607,8
0,9	2035,2
1	3418,3

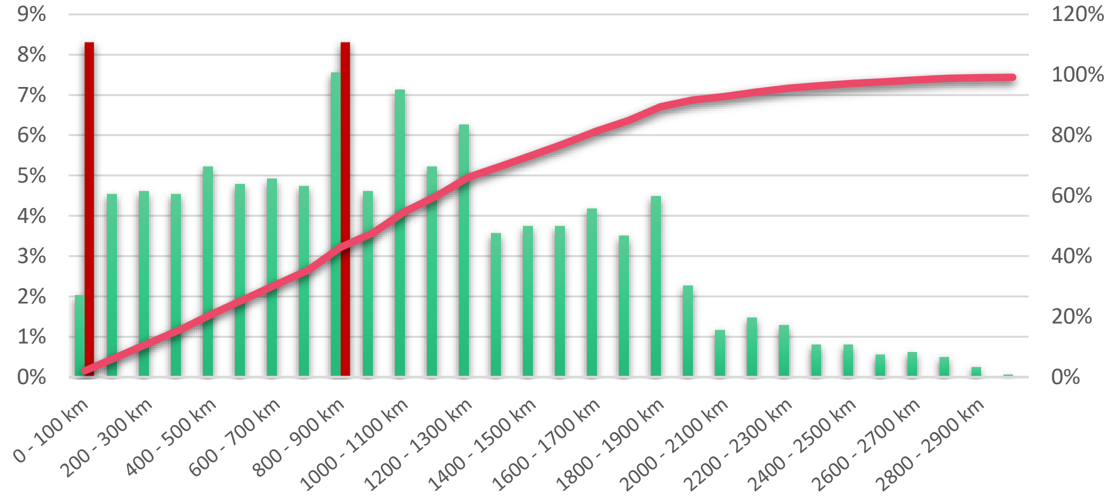
Distance	A	B	B'	C	C'
1	0	0	0	0	0
5	0	0	0	0	0
10	0	0	0	0	0
20	0	0	0	0	0
50	0	0	0	0	0
100	5	5	3	5	3
500	171	171	7	171	7
1000	576	576	7	576	7
2000	1093	939	7	1093	7
3000	1215			1215	



PLF are recovered from ethyl acetate cleaning operation. After a factional distillation, organic fractions are separated from the acid one. The use of primary liquid fuels in cement industries is really viable. Only 7 ethyl acetate production units exist in Europe so only 7 synergies are possible. All synergies distances are between 75 and 385 km. Transport can therefore be carried out by tanker truck for all cases.

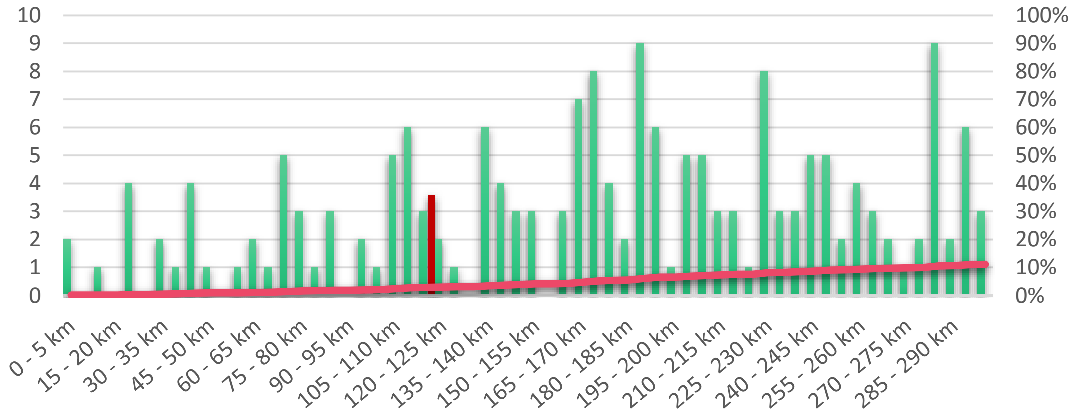
# Synergy	Distance (km)
1	75,7
2	96,2
3	99,9
4	151,7
5	232,8
6	362,1
7	384,3

Synergy type 4 datasheet: Coke residues from organic chemicals (steam crackers cleaning operations) to steel sector (sinter plants and BF)



Quartile	Distance
0	2,9
0,1	280,7
0,2	487,9
0,3	684,2
0,4	866,1
0,5	1026,9
0,6	1200,7
0,7	1409,9
0,8	1672,3
0,9	1917,3
1	3707,8

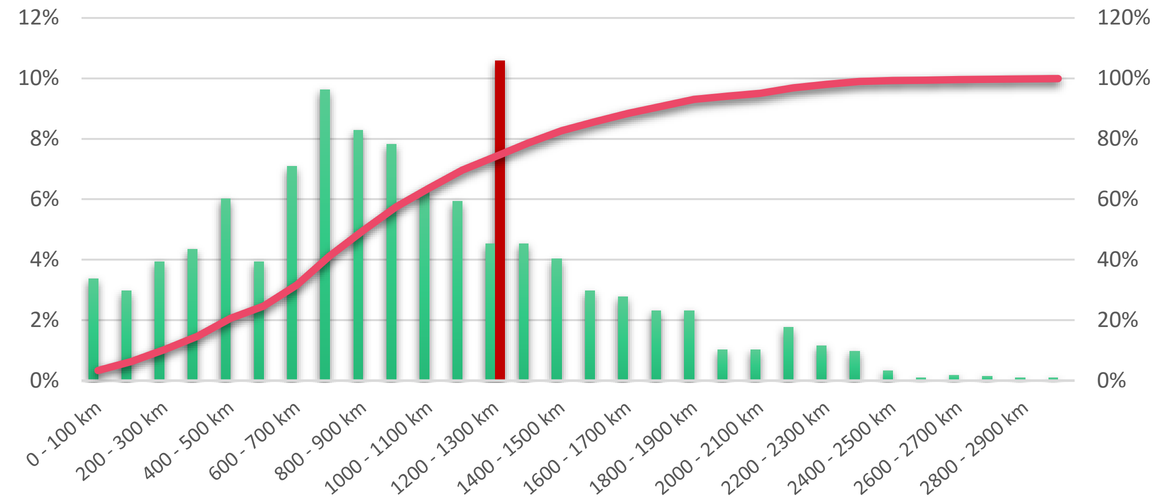
Distance	A	B	B'	C	C'
1	0	0	0	0	0
5	2	2	2	2	2
10	2	2	2	2	2
20	3	3	3	3	3
50	15	15	11	15	11
100	33	33	17	33	17
500	341	49	20	341	42
1000	774			742	44
2000	1492				
3000	1614				



Coke residues and breeze are recovered from the cracker tubes decoking. The coke can be use directly in a sinter plant, in case of small particles, or in blast furnace plants. The main costs are from the coke residues storage and transportation.

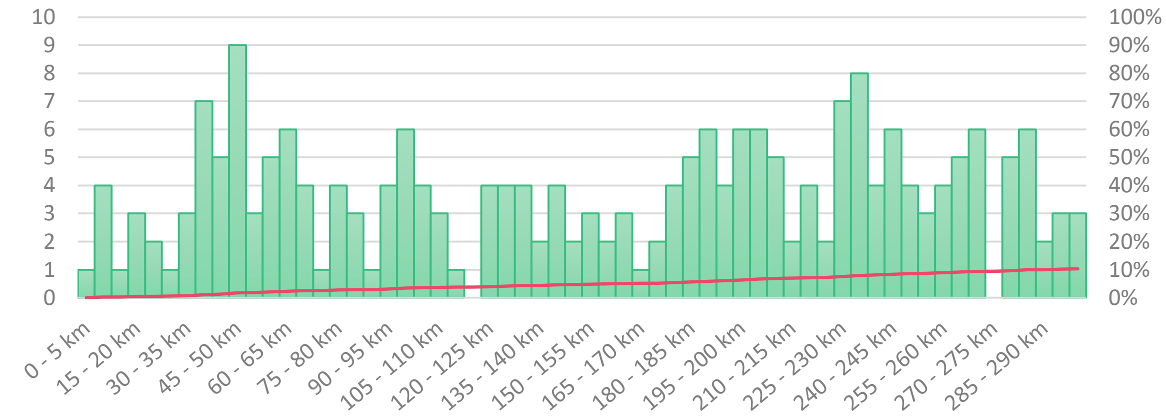
49 combinations are possible in a 120 km radius (10% of the total amount of the transported resource) and a number of **20 synergies** could be implemented by considering that one emitting site send its entire flow to the nearest partners. 742 combination are possible in a viability radius (total value of the resource transported), and **44 synergies** could be implemented within a 960km radius.

Synergy type 5 datasheet: EAF dusts from steel sector (EAF) to secondary zinc production



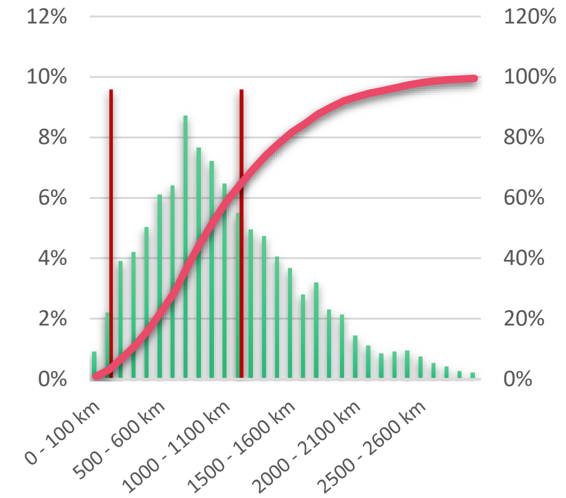
Quartile	Distance
0	3
0,1	290
0,2	481
0,3	677
0,4	784
0,5	904
0,6	1043
0,7	1213
0,8	1425
0,9	1769
1	3133

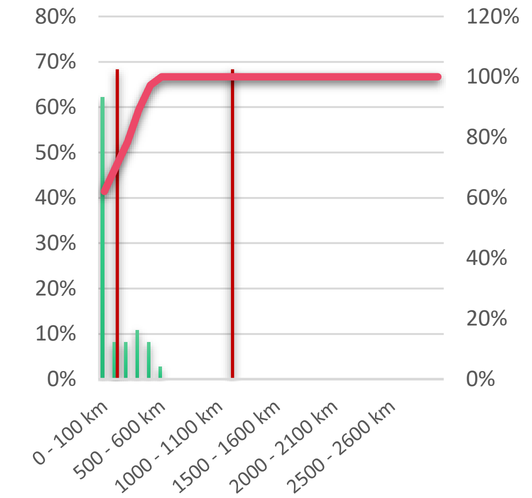
Distance	A	B	B'	C	C'
1	0	0	0	0	0
5	1	1	1	1	1
10	5	5	5	5	5
20	9	9	9	9	9
50	36	36	34	36	34
100	73	73	66	73	66
500	446	446	160	446	160
1000	1240	1240	178	1240	178
2000	2032	1623	178	2032	180
3000	2158			2158	



Zinc rich dusts are generated by EAF. These dusts are commonly sent to waelz kiln operations. Zinc residues annually consumed in waelz kiln operation represent 603 000 t/y. But EAF generate an average of 1 640 000 tonnes of dusts per year. So, there is still huge potential to valorise EAF dusts.
1 623 combinations are possible in a 1 323 km radius and a number of **178 synergies** could be implemented by considering that one emitting site send its entire flow to the nearest partners.
The number of receiving site is very low with only 11 installations equipped with waelz kiln.

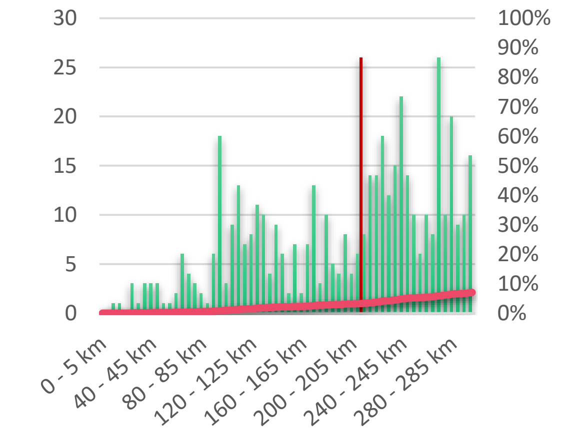
Synergy type 6 datasheet: BOF slag from steel sector (BOF) to cement industries (clinker production)

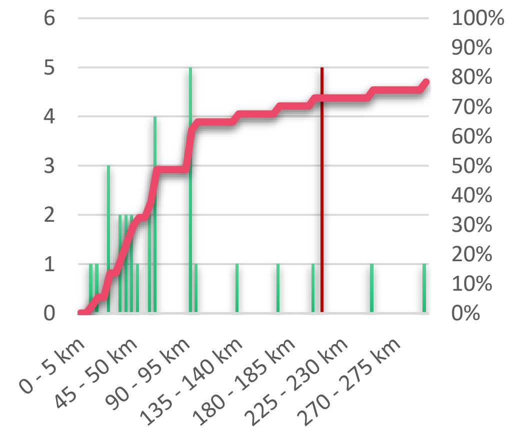




Quartile	Distance
0	14
0,1	371
0,2	560
0,3	713
0,4	832
0,5	967
0,6	1121
0,7	1318
0,8	1542
0,9	1901
1	3607

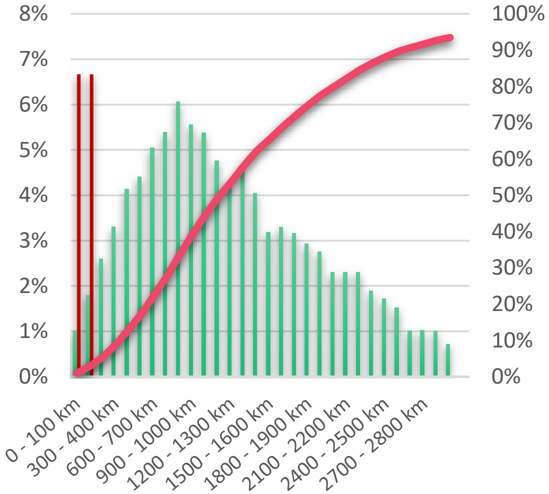
Distance	A	B	B'	C	C'
1	0	0	0	0	0
5	0	0	0	0	0
10	0	0	0	0	0
20	2	2	2	2	2
50	15	15	11	15	11
100	59	59	23	59	23
500	1046	214	27	1046	36
1000	3369			3369	37
2000	5929			4151	37
3000	6408				

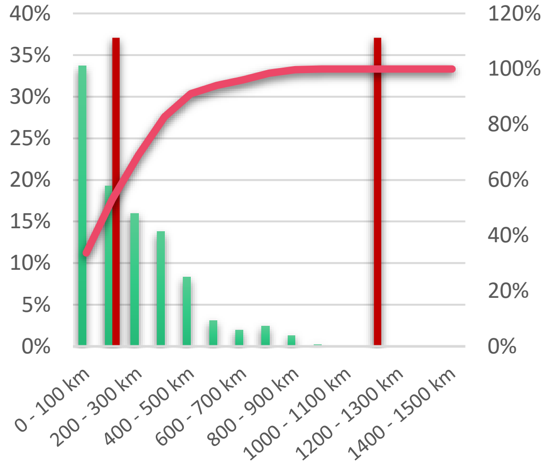




This synergy is not widely used in Europe because BOF have a lower quality than BF slags, highly appreciated by cement manufacturers. Nevertheless, *D3.2 outcome showed that: BOF slag could potentially be directly used as aggregates for concrete production. To improve its quality as a supplementary cementitious material, Hui Guo et al., 2018 proposes a technology to remove the iron oxides consisting in adding a mixture of carbon powder and kaolin. After removal of the iron content, the remaining slag could be much more interesting for the cement industry. The slag is usually packed in bags of paper or jute. Transportation is done by road or railroad. (by* trucks or train). Around 6 408 combinations are possible in Europe. The peak of opportunity is between 700 - 800 km within a viable radius. 241 opportunities are within a 212 km and could lead to the creation of 27 synergies between the nearest sites. 23/27 are in the first 100 km which is a very good argument for deploying this synergy. Extend the radius to 600 km would lead to involve 10 other primary steel installations to exchange this by-product while remaining economically viable. There is still a huge potential knowing that both environmental and social benefits are significant.

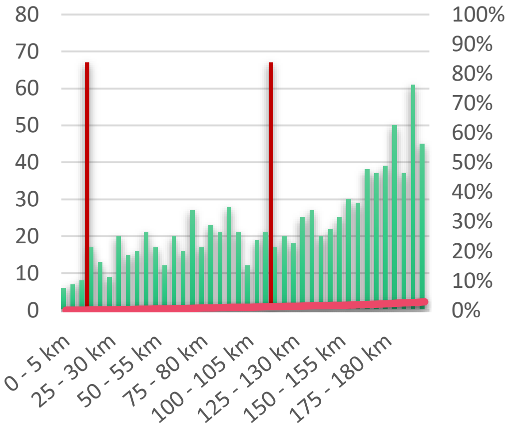
Synergy type 8 datasheet: Gypsum from coal combustion plants to cement (gridding cement mill)

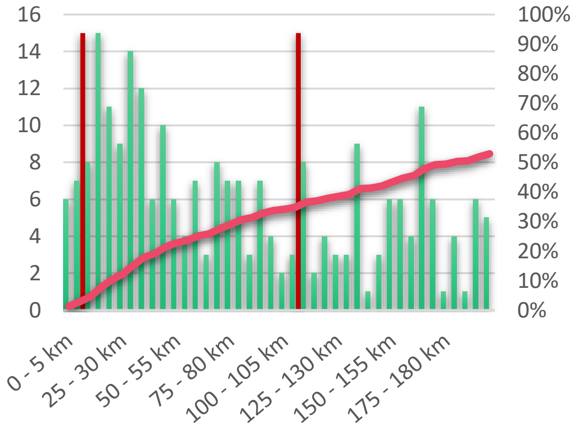




Quartile	Distance
0	2
0,1	434
0,2	660
0,3	840
0,4	1013
0,5	1212
0,6	1440
0,7	1735
0,8	2103
0,9	2632
1	6093

Distance	A	B	B'	C	C'
1	0	0	0	0	0
5	6	6	6	6	6
10	13	13	13	13	13
20	38	17	17	38	36
50	132			132	98
100	334			334	154
500	4227			383	165
1000	12937				
2000	25546				
3000	30745				

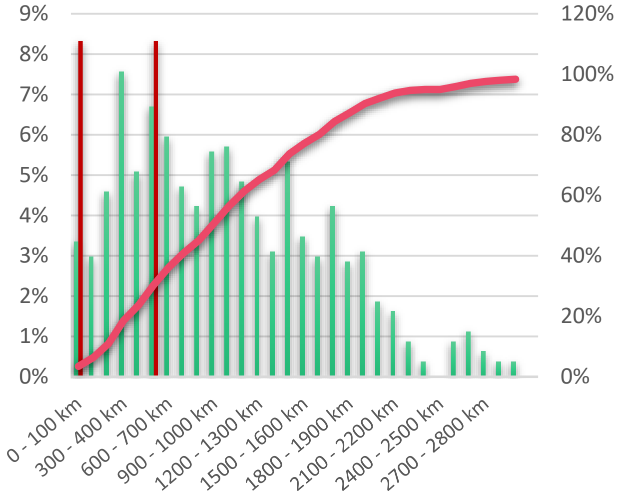


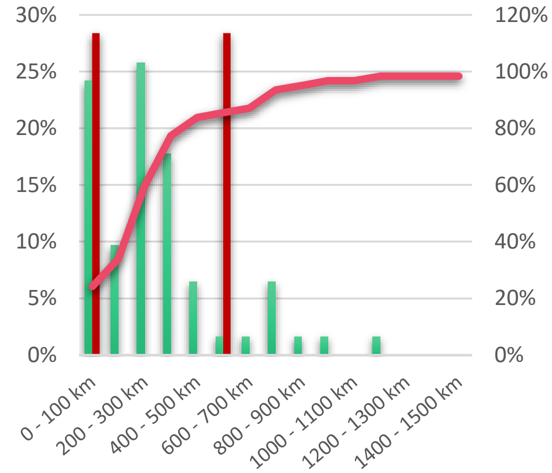


BREF_CLM document already considers the use of FGD gypsum as a raw material. T3.3 activities and D3.2 suggested a technology to improve the handling of FGD gypsum during manufacturing operations. Gypsum requires dry stowage and must not be handled during precipitation. Conveyors can be used for nearby facilities. Otherwise road or railroad would be used.

The number of theoretical opportunities is enormous across Europe (+30 000). The peak of opportunity is around 900km but the economic viability radius is lower. Only 17 synergies are within a profitable radius (transport costs lower than the resource transported value) and 165 within a 114km viable radius (383 if we assume that one emitting site can supply several receivers). Synergies between installations in close proximity might be already implemented but there is probably a lot of synergies to implement with a distance lower than 100 km.

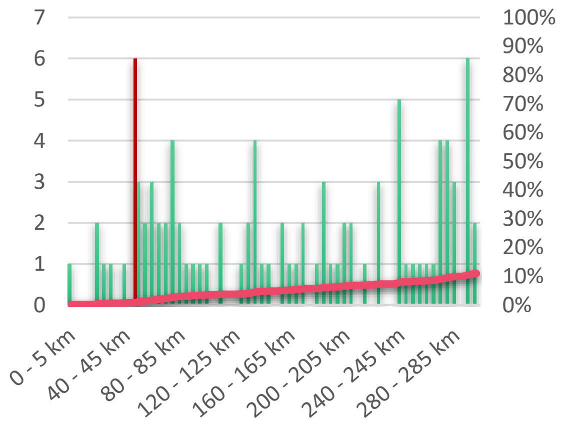
Synergy type 9 datasheet: Sulphuric acid from non-ferrous metals industries (copper) to inorganic chemicals industries (sulphate process)

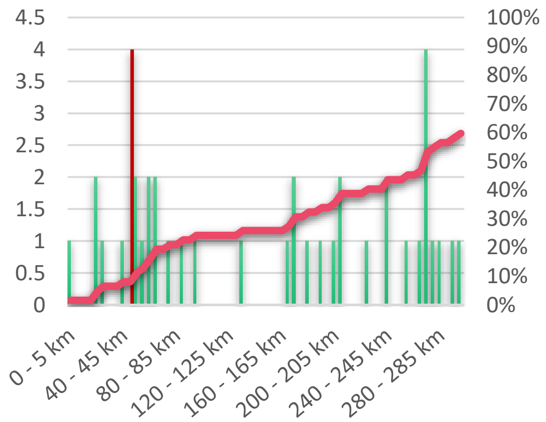




Quartile	Distance
0	4
0,1	291
0,2	427
0,3	598
0,4	772
0,5	989
0,6	1178
0,7	1429
0,8	1694
0,9	1987
1	3618

Distance	A	B	B'	C	C'
1	0	0	0	0	0
5	1	1	1	1	1
10	1	1	1	1	1
20	1	1	1	1	1
50	6	6	5	6	5
100	27	8	6	27	15
500	190			190	52
1000	409			198	53
2000	728				
3000	793				

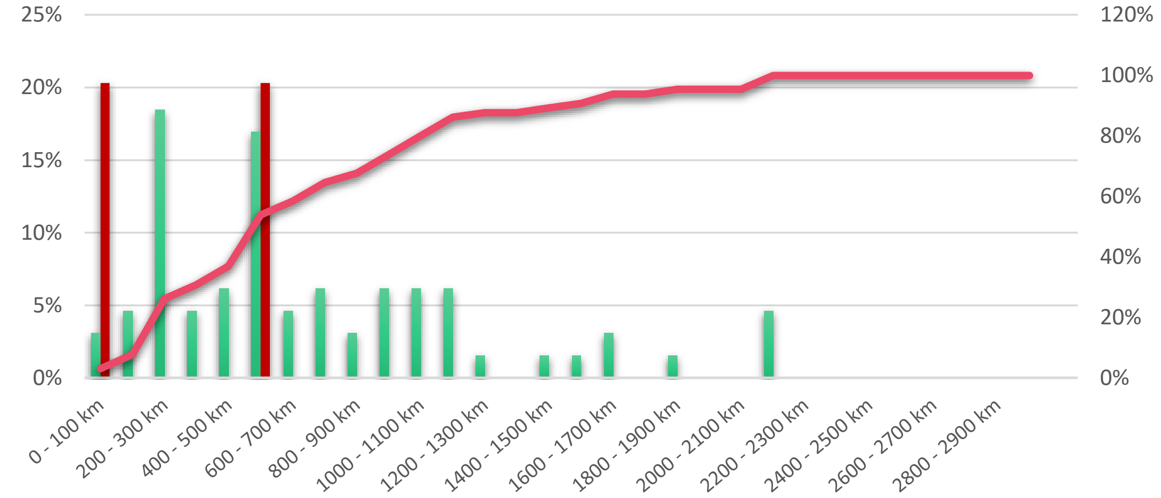




Sulphuric acid can be recovered from non-ferrous metals industries to provide inorganic chemicals plants. Sulphuric acid recovery is already a standard procedure in the copper smelting process. Acid gas feed wet sulphuric acid process. After treatment, sulphuric acid should be packed in UN approved packages – certified steel drums lined with HDPE and can be transported using road or railroad.

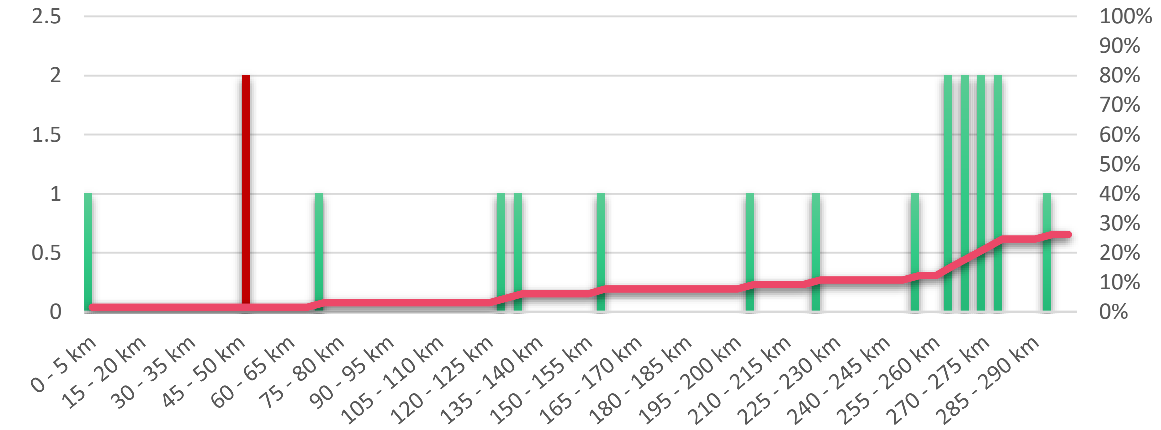
There are 783 opportunities across EU. In a profitable radius of 52km, only 8 companies can create this link. The peak of opportunity is around 400km If the radius research is extended to 500 km, 53 synergies could be implemented.

Synergy type 10 datasheet: Sulphuric acid from non-ferrous metals industries (lead and tin) to inorganic chemicals industries (sulphate process)



Quartile	Distance
0	4
0,1	235
0,2	273
0,3	394
0,4	519
0,5	568
0,6	733
0,7	951
0,8	1082
0,9	1481
1	2186

Distance	A	B	B'	C	C'
1	0	0	0	0	0
5	1	1	1	1	1
10	1	1	1	1	1
20	1	1	1	1	1
50	1	1	1	1	1
100	2	2	2	2	2
500	24			24	5
1000	48			27	5
2000	62				
3000	65				



Sulphuric acid can be recovered from non-ferrous metals industries to provide inorganic chemicals plants. Sulphuric acid recovery is already a standard procedure in the copper smelting process. Acid gas feed wet sulphuric acid process. After treatment, sulphuric acid should be packed in UN approved packages – certified steel drums lined with HDPE and can be transported using road or railroad.

There are only a few potential combinations across EU (65) since the number of both emitting and receiving installations are not numerous combinations. There are only 27 opportunities within a viable radius (even if it is a radius of more than 500 km). Sulphate process is not the best application for non-ferrous metals sulphuric acid due to the week number of installations in EU.

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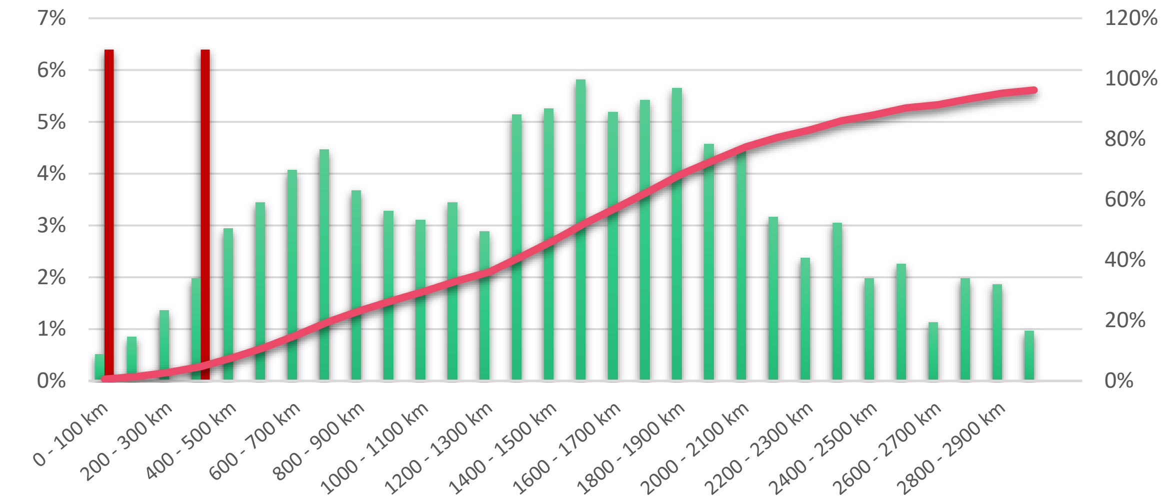
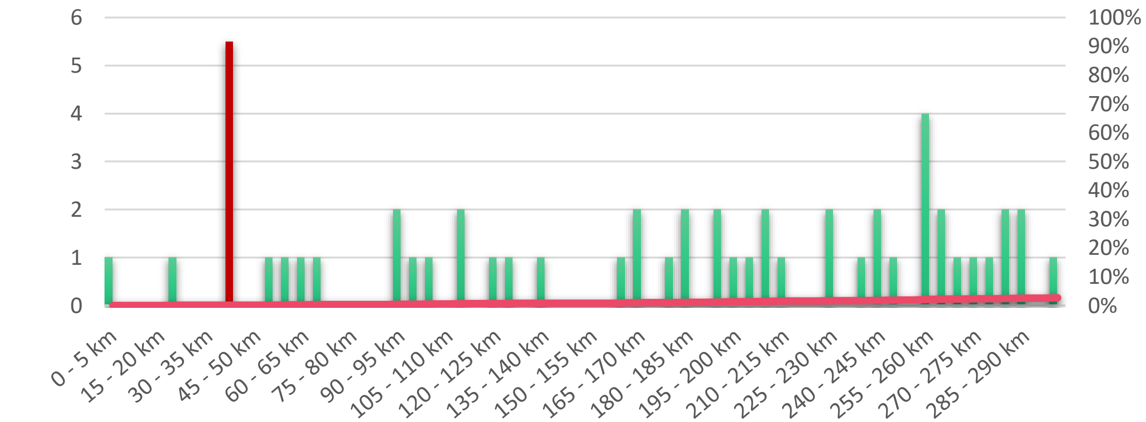
Synergy type 12 datasheet: Salt from non-ferrous metals industries (aluminium) to inorganic chemicals industries (sodium chlorate)



Quartile	Distance
0	4
0,1	575
0,2	819
0,3	1109
0,4	1382
0,5	1555
0,6	1743
0,7	1931
0,8	2170
0,9	2590
1	7521

Distance	A	B	B'	C	C'
1	0	0	0	0	0
5	1	1	1	1	1
10	1	1	1	1	1
20	1	1	1	1	1
50	2	2	2	2	2
100	9			9	8
500	135			75	48
1000	470				
2000	1293				
3000	1704				

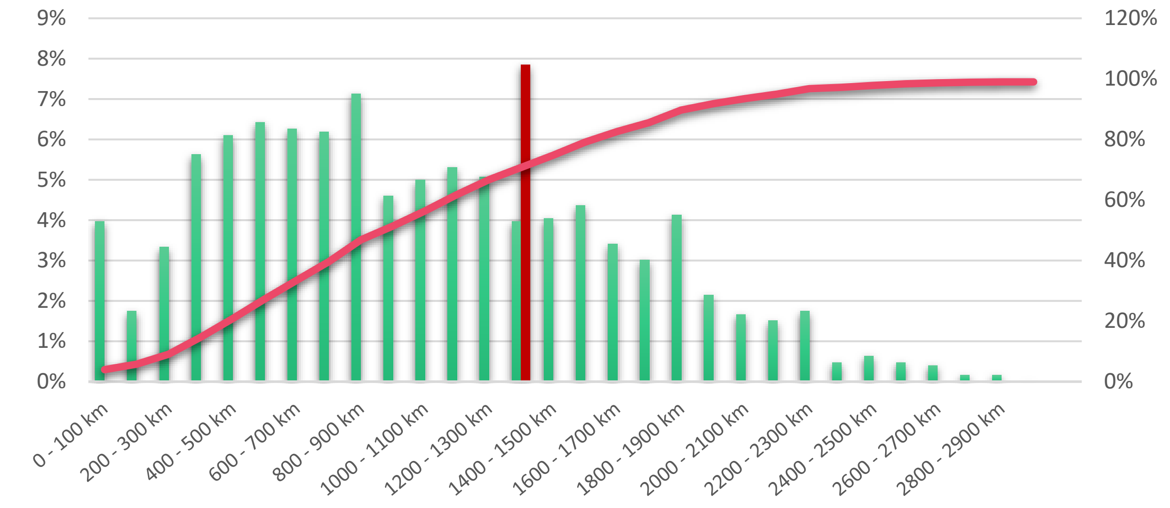


To recover salt and send to resource to the sodium chlorate production, it is necessary to apply a partial recycling to salt slag. It enables to recover a NaCl solution that could be sent directly to the chlorate production process by road or railroad.

The peak of opportunities is around 800 km but is too far for the salt economic value.

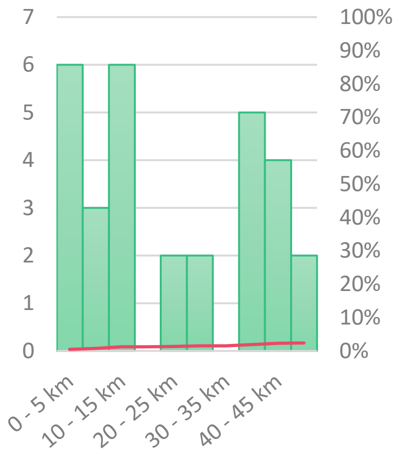
Only two synergies are in a profitable radius for the emitting industry but 75 opportunities could lead to 48 synergies implementation in a viable radius. The most numerous opportunities are in particular between 90 – 140km, 175 – 215 km and 240 – 290 km.

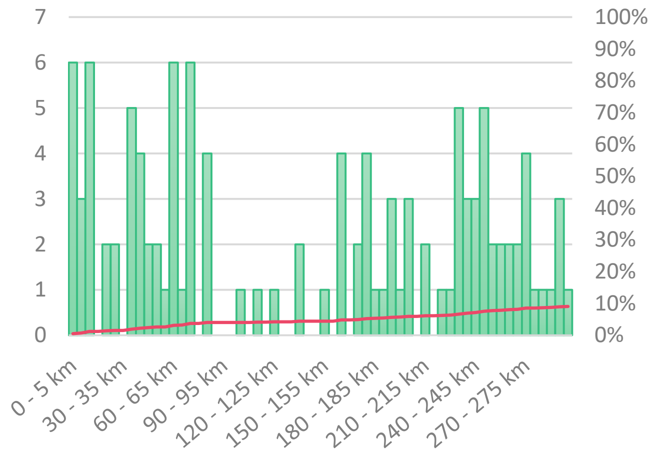
Synergy type 17 datasheet: Hydrogen from inorganic chemicals (sodium chlorate) to refineries (e.g. isomerisation)



Quartile	Distance
0	0
0,1	322
0,2	487
0,3	654
0,4	803
0,5	964
0,6	1171
0,7	1381
0,8	1615
0,9	1917
1	3612

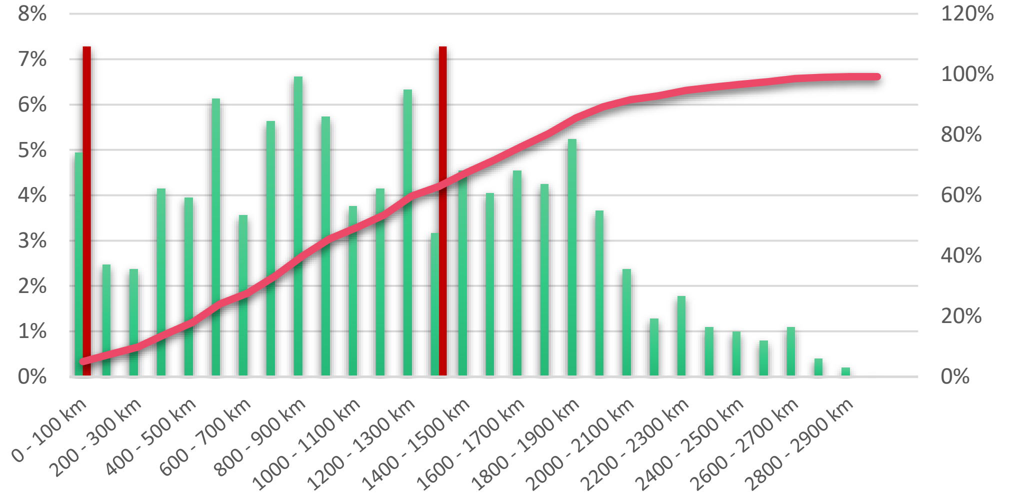
Distance	A	B	B'	C	C'
1	4	4	4	4	4
5	6	6	6	6	6
10	9	9	8	9	8
20	15	15	9	15	9
50	30	30	12	30	12
100	50	50	12	50	12
500	262	262	13	262	13
1000	648	648		648	
2000	1158	842		1158	
3000	1249			1249	





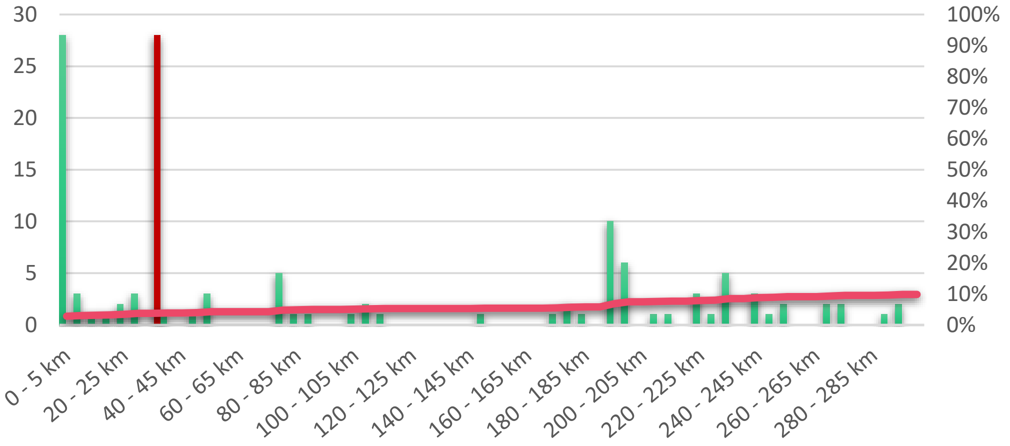
Off-gas from dehydrogenation of ethylbenzene is separated from crude styrene in a phase separator and is finally purified in a PSA unit. Pipeline transportation is advised for near facilities: in that case, there are 9 opportunities in a 10km radius that could led to 8 – 9 synergies exploited via pipelines. Before 20km, 15 combinations are possible without involve new emitter installations. The second peak of opportunities is around 40-50km and involve most of styrene producers (12/13). Supplies could be assured by gas containers transportation or liquid hydrogen trailers. By extending the geographical scope of research and using truck transportation, the number of opportunities could increase around 600 – 1 200. The replication of this synergy is limited because there are only 13 styrene production sites in EU but it could be replicated with other chemical installation emitting hydrogen. There is probably a small error on the viability radius since it is more profitable to burn hydrogen on-site, but in that case since all emitting site can find a receiver in the first 50km.

Synergy type 19 datasheet: Hydrogen from organic chemicals (steam crackers) to refineries (e.g. hydrodesulphurisation)



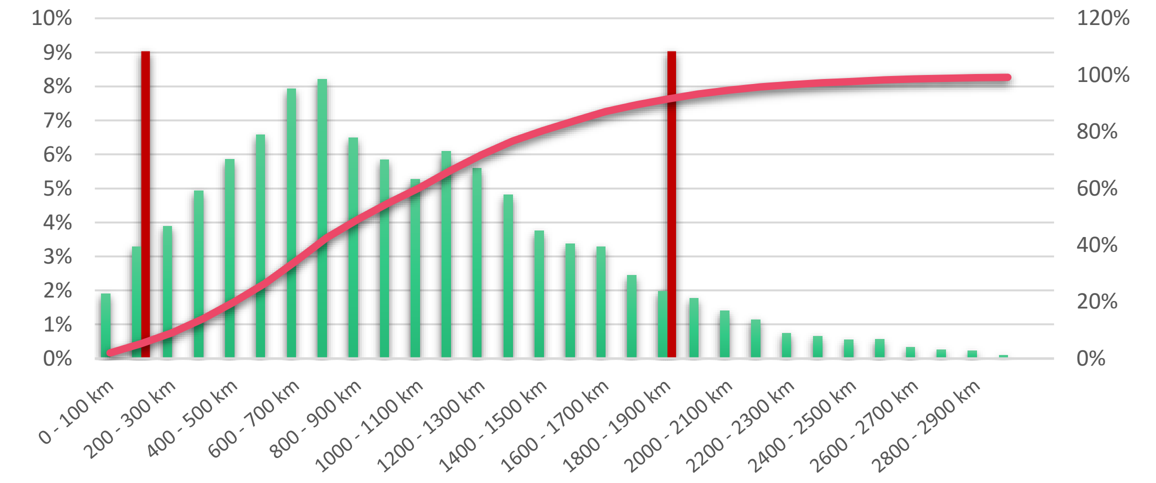
Quartile	Distance
0	0
0,1	322
0,2	528
0,3	753
0,4	903
0,5	1107
0,6	1301
0,7	1567
0,8	1794
0,9	2012
1	3479

Distance	A	B	B'	C	C'
1	23	23	23	23	23
5	28	28	25	28	25
10	31	31	26	31	26
20	33	33	28	33	28
50	40	40	32	40	32
100	50	50	33	50	33
500	181	181	43	181	43
1000	461	461	44	461	44
2000	903	605	44	903	44
3000	1004			1004	44



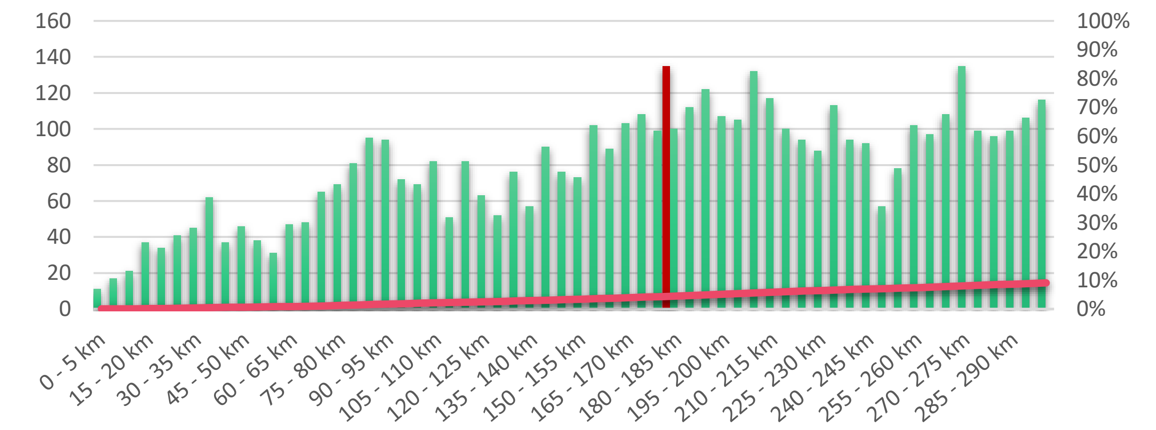
In the last step of steam cracking (co-product fractionation) the co-products are separated using a sequence of splitters and fractionating columns. Hydrogen can be purified with a PSA unit. Processing of off-gases is already a standard in this sender process. Hydrogen is already a by-product and can be sent directly to the receivers.
A lot of steam crackers and lower olefins production sites are directly associated with refineries activities. 24 installations have both refineries and steam cracking installations and are located on the same site. That is why there are 28 opportunities in the 5 first km fitting with pipeline transportation.
The second peak of opportunity appears after 600km and could be only implemented with gas containers or liquid hydrogen trailers.
The potential is limited because the number of steam crackers is not huge.
As for the previous synergy, the viability radius is probably overestimated.

Synergy type 22 datasheet: refractory products from steel sector (EAF) to glass sector (container glass production)



Quartile	Distance
0	1
0,1	322
0,2	502
0,3	648
0,4	765
0,5	916
0,6	1097
0,7	1260
0,8	1486
0,9	1821
1	7577

Distance	A	B	B'	C	C'
1	0	0	0	0	0
5	11	11	9	11	9
10	28	28	18	28	18
20	86	86	42	86	42
50	351	351	96	351	96
100	991	991	152	991	152
500	10338	2363	164	10338	179
1000	28578			28578	180
2000	48532			47038	180
3000	51622				



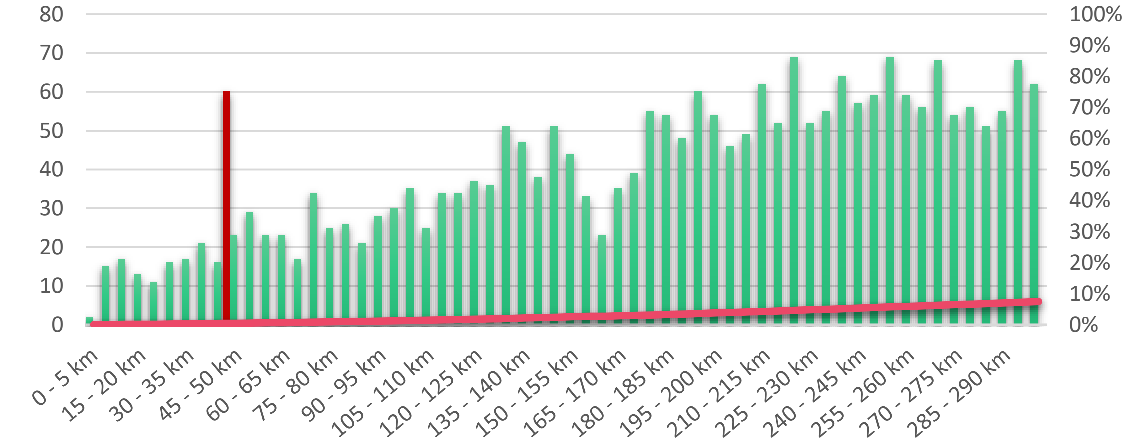
Refractory products from EAF could be valorised in the container glass production. The economic distances were calculated according to an approximation of the prices of used refractory products.

This synergy offers a large number of opportunities, including at a distance of less than 500km.

Synergy type 23 datasheet: slag from coal combustion plants to glass sector (stone and slag wool manufacturing)

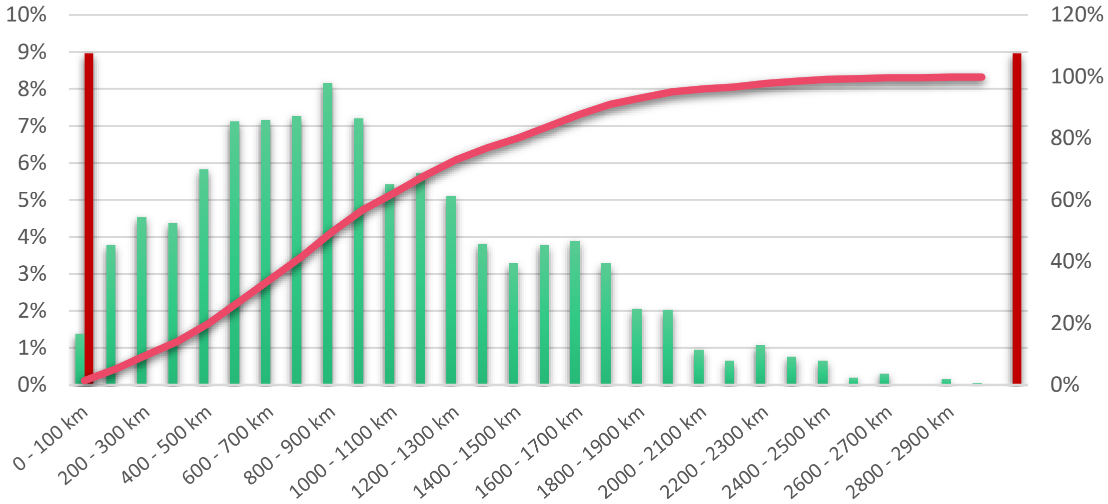
Quartile	Distance
0	1
0,1	367
0,2	566
0,3	734
0,4	896
0,5	1080
0,6	1300
0,7	1538
0,8	1844
0,9	2281
1	4131

Distance	A	B	B'	C	C'
1	0	0	0	0	0
5	2	2	2	2	2
10	17	17	13	17	13
20	47	47	39	47	39
50	151	151	96	151	96
100	407			407	182
500	5358			5222	363
1000	14909				
2000	27259				



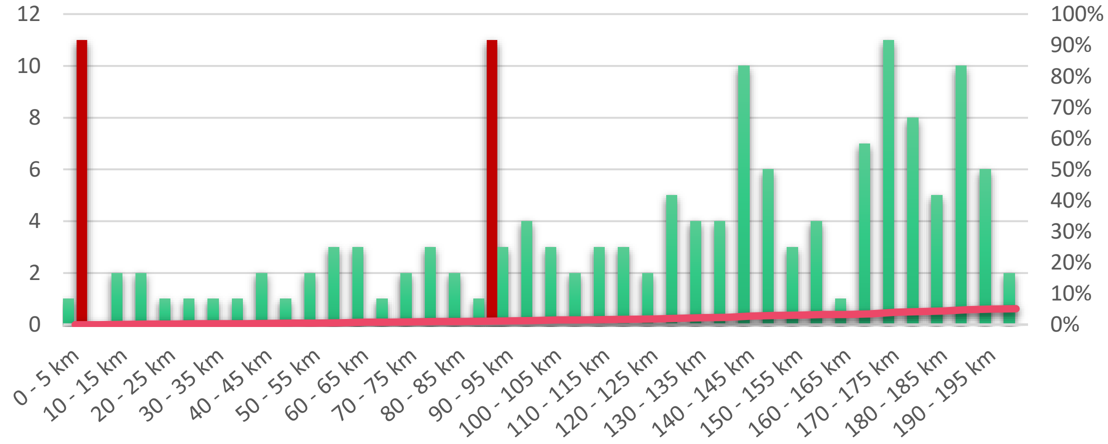
Slag from combustion plants can be used for the production of stone and slag wool. Since Europe counts a large number of coal power plants, the limiting factor is the number of stone and slag wool manufacturing plants. The estimated price is based on the BF slag for cement (replacing clinker) value which is the best slag selling price. This synergy is viable below 500km, representing 3 706 potential relations, and 346 synergies to the closest site.

Synergy type 24 datasheet: Blast furnace slag from steel sector (BF) to glass sector (stone and slag wool manufacturing)



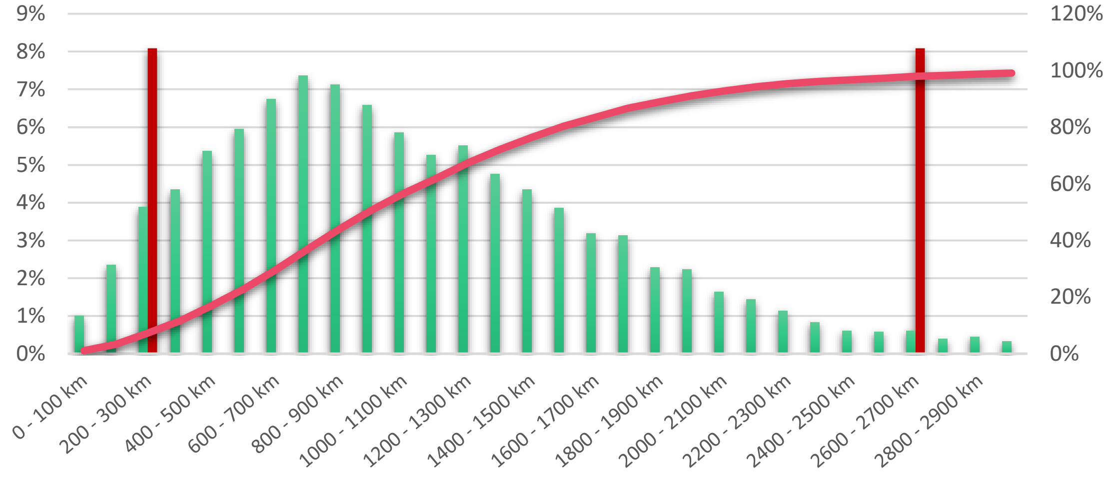
Quartile	Distance
0	3
0,1	310
0,2	501
0,3	648
0,4	779
0,5	902
0,6	1057
0,7	1243
0,8	1499
0,9	1758
1	3236

Distance	A	B	B'	C	C'
1	0	0	0	0	0
5	1	1	1	1	1
10	1			1	1
20	5			5	5
50	12			12	9
100	36			32	18
500	522				
1000	1491				
2000	2497				
3000	2622				



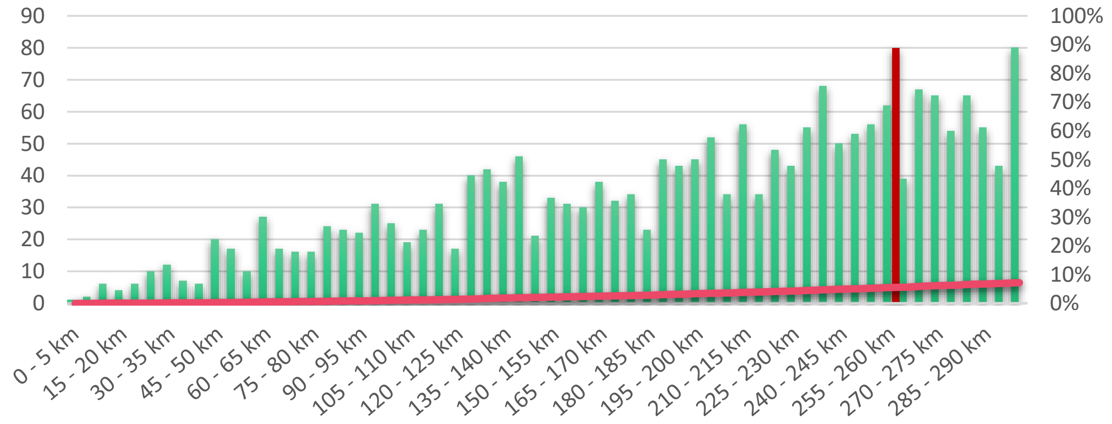
Slags from blast furnaces may provide glass industries and replace clay components.
The economic distance is below 95km. This synergy is thus fairly local, around the steel furnaces.
Only 9 synergies could be envisaged below 10 km, and around 34 synergies with lower profitability below 100 km.
However, this synergy is not technically viable for compliance issues with the receiving sector. Therefore, it is not counted in the final overall potential assessment.

Synergy type 29 datasheet: Red mud from aluminium production to cement industries (clinker raw materials preparation)



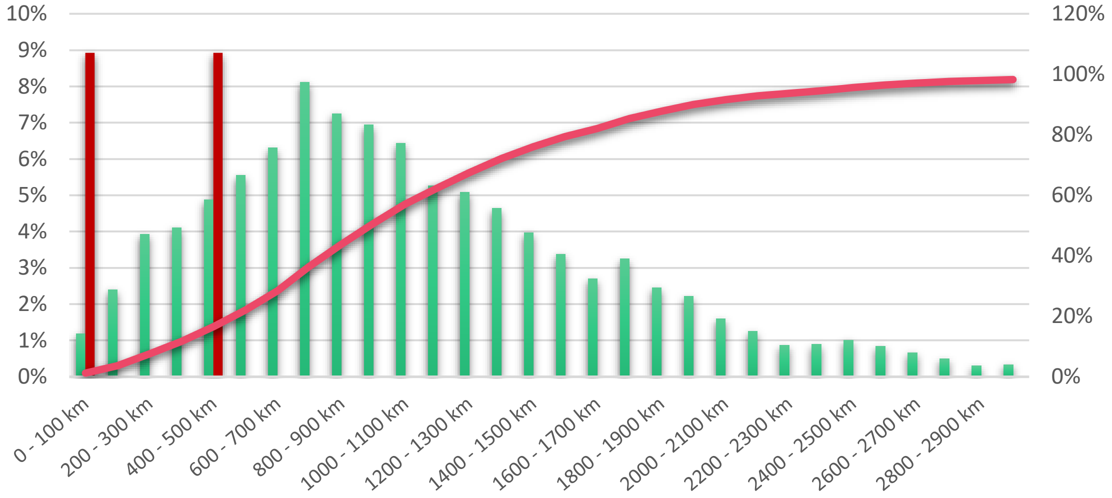
Quartile	Distance
0	4
0,1	367
0,2	553
0,3	705
0,4	841
0,5	990
0,6	1168
0,7	1356
0,8	1594
0,9	1945
1	5002

Distance	A	B	B'	C	C'
1	0	0	0	0	0
5	1	1	1	1	1
10	3	3	3	3	3
20	13	13	10	13	10
50	74	74	46	74	46
100	277	277	92	277	92
500	4714	1583	124	4714	145
1000	14116			14116	156
2000	25368			25368	160
3000	27587			27180	160



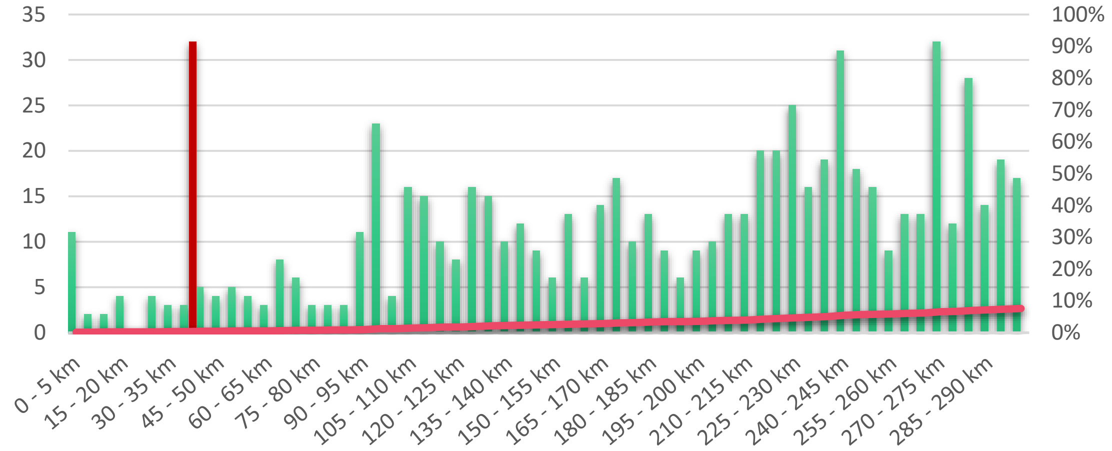
Red mud from the production of aluminium can be a valuable input to cement production, potentially to replace clinker as a binder. The synergy is economically viable, and many opportunities can exist at an economic viability distance.

Synergy type 30 datasheet: Blast furnace slags from steel sector to cement industries



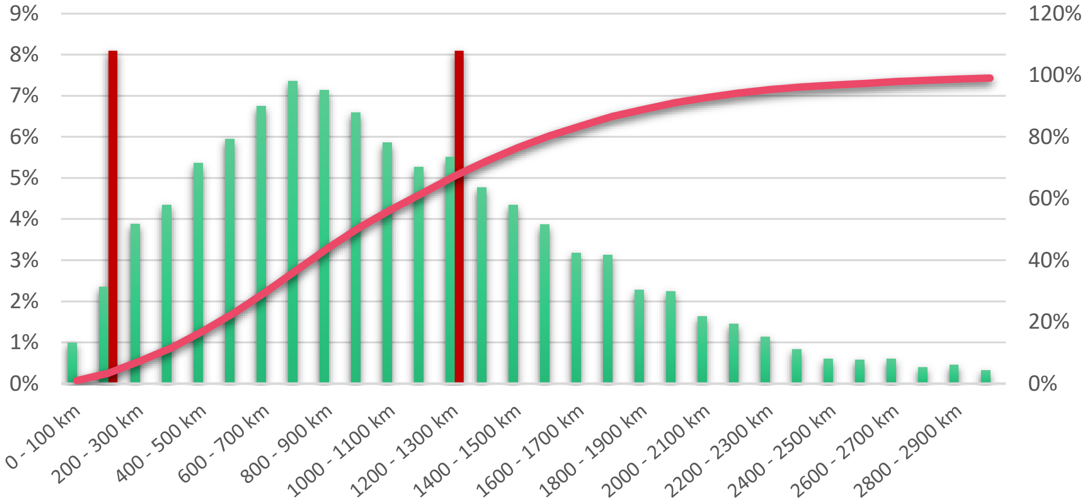
Quartile	Distance
0	0
0,1	361
0,2	562
0,3	719
0,4	849
0,5	989
0,6	1153
0,7	1357
0,8	1619
0,9	2000
1	5079

Distance	A	B	B'	C	C'
1	1	1	1	1	1
5	11	11	9	11	9
10	13	13	10	13	10
20	19	19	13	19	13
50	38	38	19	38	19
100	107			107	26
500	1501			1474	36
1000	4611				
2000	8194				
3000	8942				



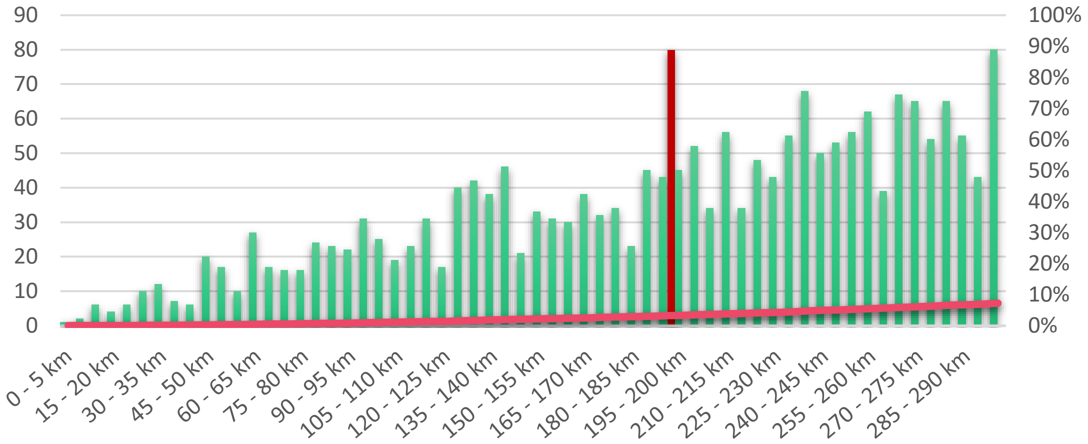
Blast furnace slag is commonly used in the cement industry, as an appreciable alternative to clinker thanks to its binding properties. With a price conservatively assumed to be 86 €/t, the viability distance is below 490km. This synergy is thus fairly local, around the steel furnaces. Only 10 synergies could be envisaged below 10 km, and 25 below 100 km. However, the volumes are important.

Synergy type 31 datasheet: Aluminium oxides from non-ferrous metals industries (aluminium) to cement industries (raw material preparation)



Quartile	Distance
0	4
0,1	367
0,2	553
0,3	705
0,4	841
0,5	990
0,6	1168
0,7	1356
0,8	1594
0,9	1945
1	5002

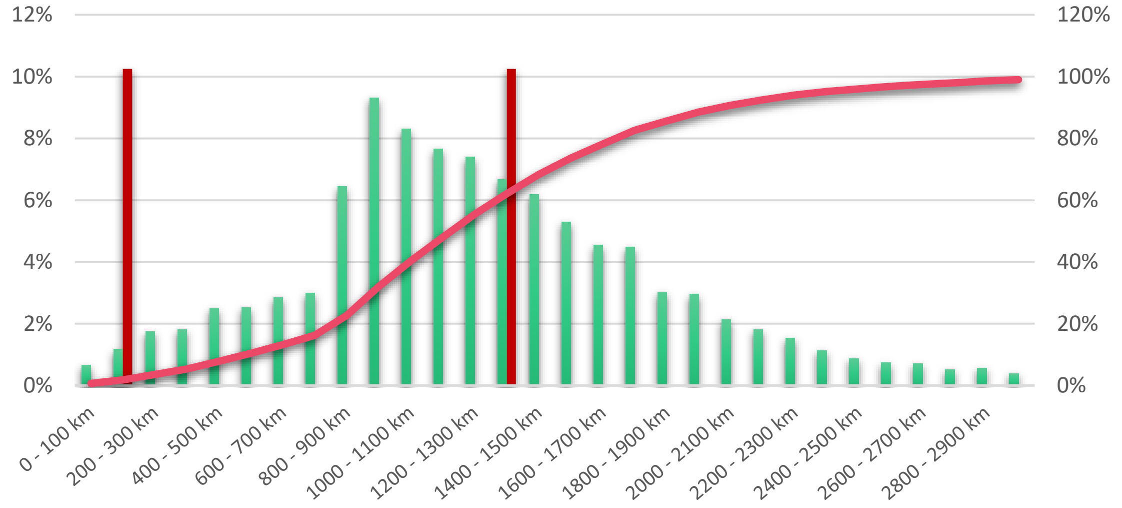
Distance	A	B	B'	C	C'
1	0	0	0	0	0
5	1	1	1	1	1
10	3	3	3	3	3
20	13	13	10	13	10
50	74	74	46	74	46
100	277	277	92	277	92
500	4714	4714	145	4714	145
1000	14116	5778	149	14116	156
2000	25368			25368	160
3000	27587			27587	160



Aluminium oxide from salt slag process can provide cement industries. This is a well-known synergy, and the product has a high viability distance of 1326 km that enable a lot of opportunity of exploitations.

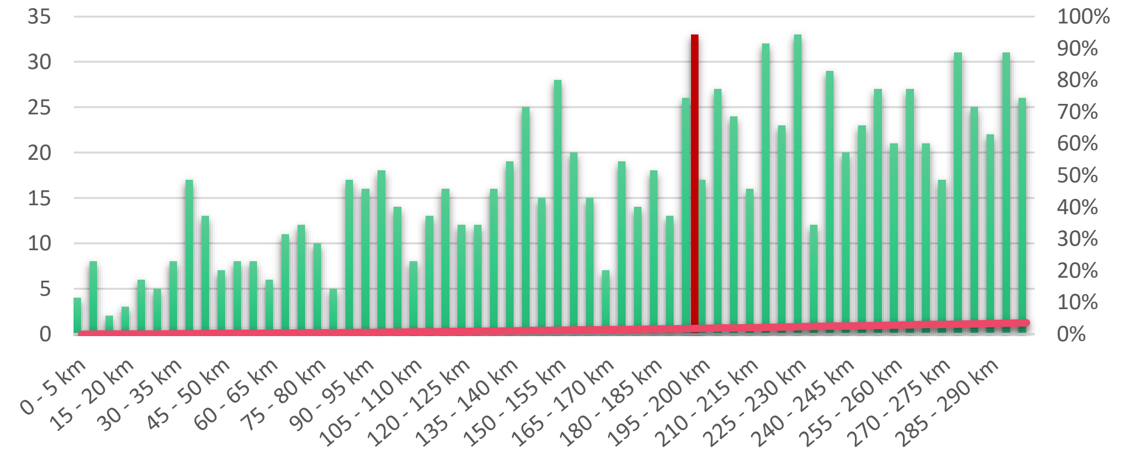
Here, already 116 synergies seem to be viable for a distance of 500 km. However, the peak of opportunity comes at around 800 km.

Synergy type 32 datasheet: Aluminium oxides from non-ferrous metals industries (aluminium) to glass sector (stone and slag wool manufacturing)



Quartile	Distance
0	0
0,1	585
0,2	871
0,3	979
0,4	1095
0,5	1224
0,6	1369
0,7	1533
0,8	1736
0,9	2063
1	5002

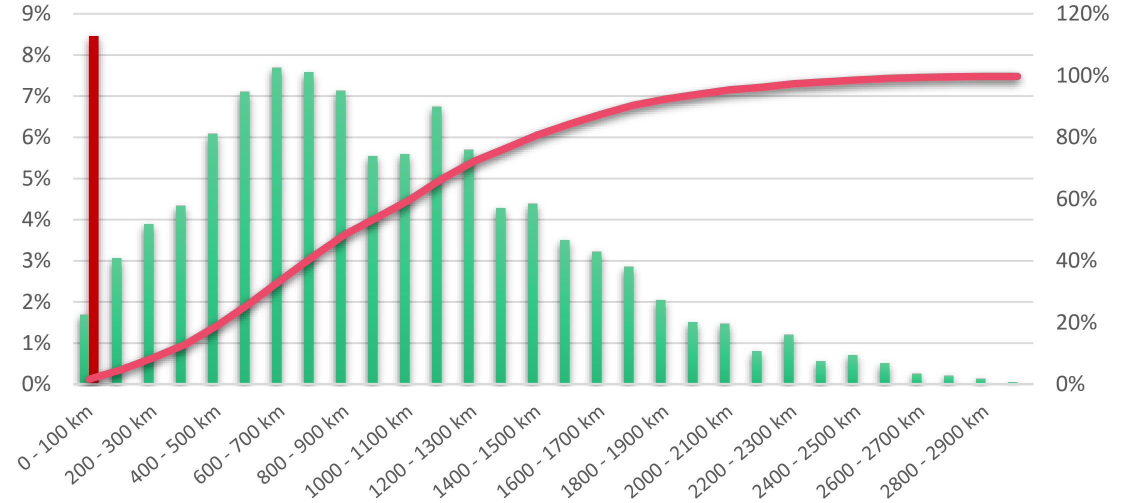
Distance	A	B	B'	C	C'
1	2	2	2	2	2
5	4	4	4	4	4
10	12	12	7	12	7
20	17	17	10	17	10
50	73	73	38	73	38
100	184	184	86	184	86
500	2198	499	125	2198	153
1000	8922			8922	157
2000	24660			15944	158
3000	27560			15944	158



Aluminium oxide from salt slag process can provide glass industries. This is a well-known synergy, and the product has a high viability distance of 1326 km that enable a lot of opportunity of exploitations.

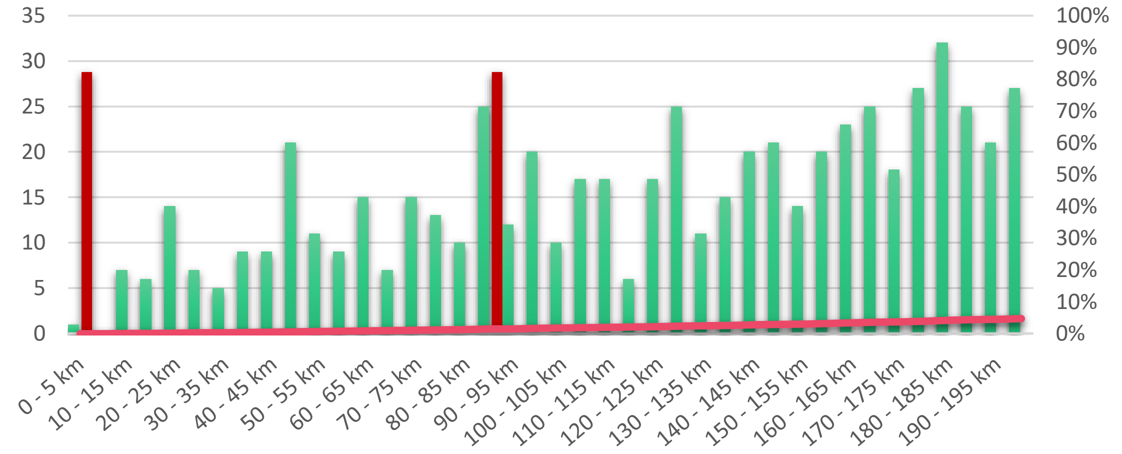
Here, already 125 synergies seem to be viable for a distance of 500 km. However, the peak of opportunity comes at around 1000 km.

Synergy type 35 datasheet: EAF slags from steel sector (EAF) to cement industries (grinding cement mills)



Quartile	Distance
0	2
0,1	335
0,2	514
0,3	654
0,4	780
0,5	925
0,6	1105
0,7	1261
0,8	1478
0,9	1785
1	3564

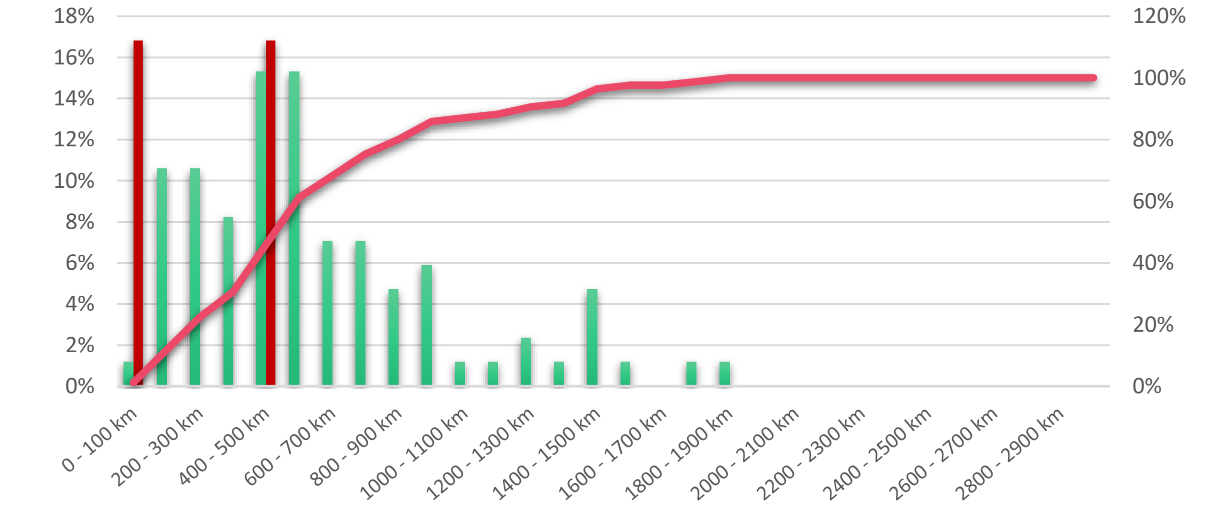
Distance	A	B	B'	C	C'
1	0	0	0	0	0
5	1	1	1	1	1
10	1			1	1
20	14			14	13
50	79			79	58
100	216			196	99
500	2436				
1000	6916				
2000	12004				
3000	12755				



Slags from electric arc furnace can be valorised in the cement. This is a known practice but not totally deployed because only 23,1% of EAF slags have an external use (most interesting for carbon steel) and 10,4 are sold, unlike BF slags which are very covered.

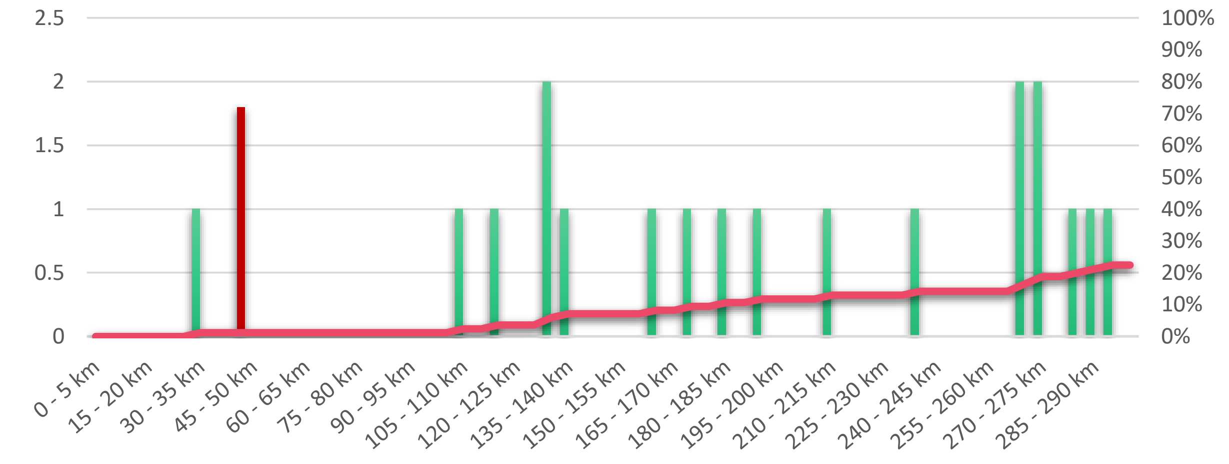
Only one synergy is within the distance radius of 10 % of the product value. However, around 100 combinations could be more or less viable below 94 km. This synergy is thus fairly local.

Synergy type 39 datasheet: Sulphuric acid from non-ferrous metals industries (lead and tin) to inorganic chemicals industries (precipitated silica and silica gel)



Quartile	Distance
0	31
0,1	185
0,2	287
0,3	383
0,4	453
0,5	515
0,6	587
0,7	719
0,8	895
0,9	1230
1	1893

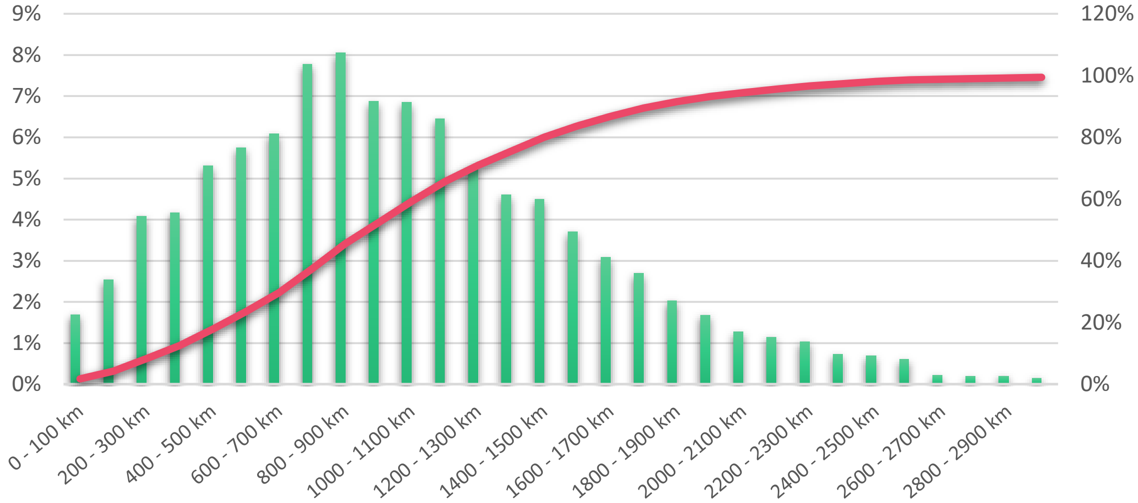
Distance	A	B	B'	C	C'
1	0	0	0	0	0
5	0	0	0	0	0
10	0	0	0	0	0
20	0	0	0	0	0
50	1	1	1	1	1
100	1			1	1
500	39			39	5
1000	73			45	5
2000	85				
3000	85				



Sulphuric acid, as a by-product of copper primary smelting route, can provide sulphate process in inorganic chemical industries.

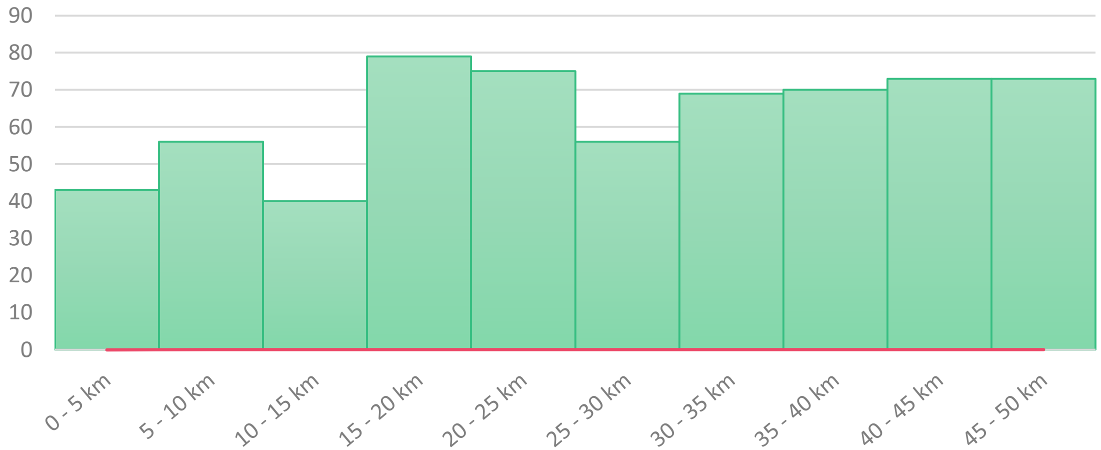
Only one synergy in within the viability radius of 10%of value the product, and only 5 combinations more or less profitable can be studied below the maximum of distance viability.

Synergy type 47 datasheet: COG from steel sector (COG) to combustion plants (process gases combustion)



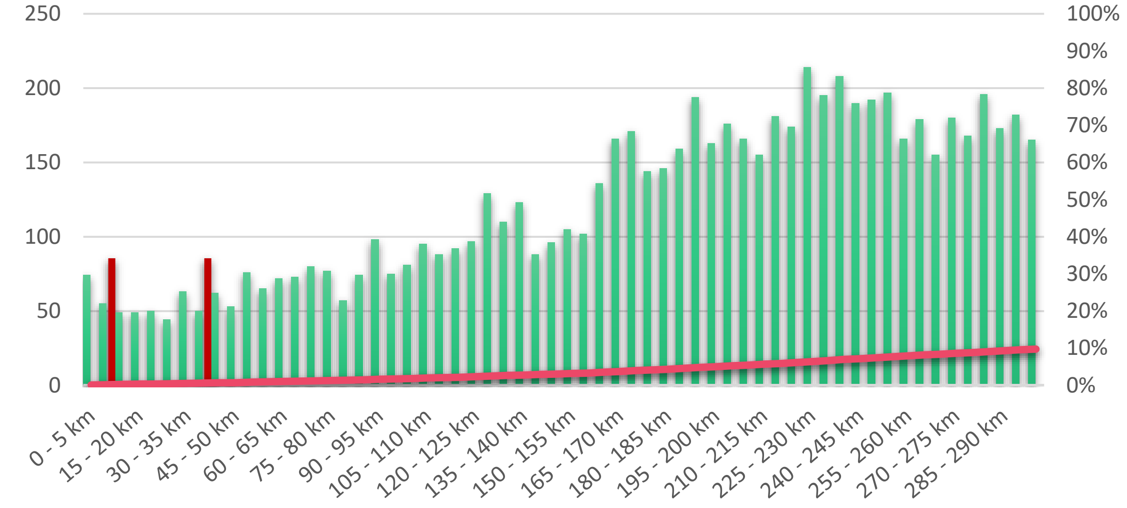
Quartile	Distance
0	0
0,1	336
0,2	537
0,3	704
0,4	832
0,5	969
0,6	1112
0,7	1284
0,8	1500
0,9	1822
1	5443

Distance	A	B	B'	C	C'
1	16	16	14	16	14
5	43	43	21	43	21
10	99	99	25	99	25
20	218	218	33	218	33
50	634			634	37
100	1452				
500	15267				
1000	44892				
2000	79935				
3000	85261				



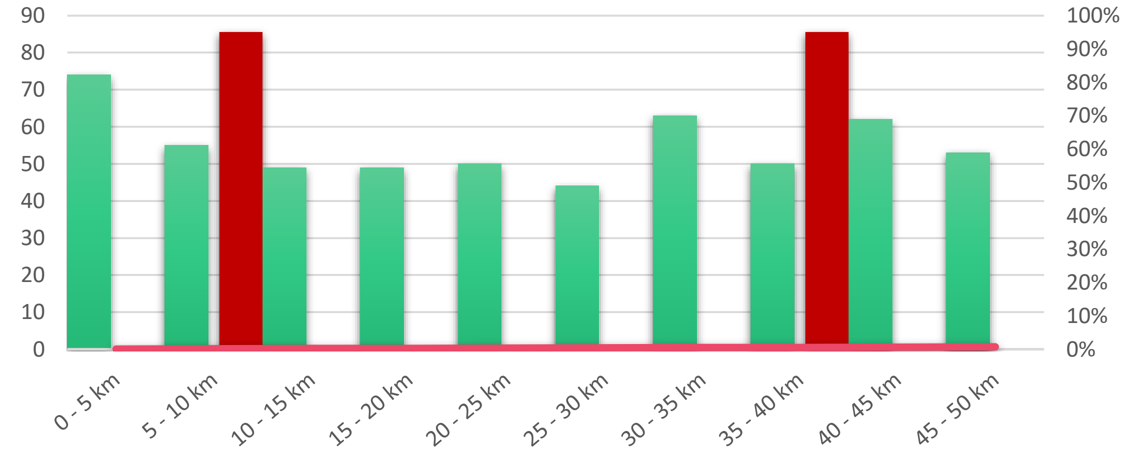
Coke oven gas from coke ovens can provide combustion plants for iron and steel process gases combustion. 60% of COG volume is typically needed for internal processes but it could be use in combustion plants as a complementary gaseous fuel. COG has a very valuable calorific power. This synergy is already a practice in BAT but require pipeline for gas transportation. Nevertheless, it is more profitable to burn directly.33 combinations are possible in the first 20 km that is a practicable distance for pipeline creation. The use of COG could avoid massive environmental negative impact due to the extraction, production and combustion of natural gas.

Synergy type 48 datasheet: BF gas from steel sector (BF) to combustion plants (process gases combustion)



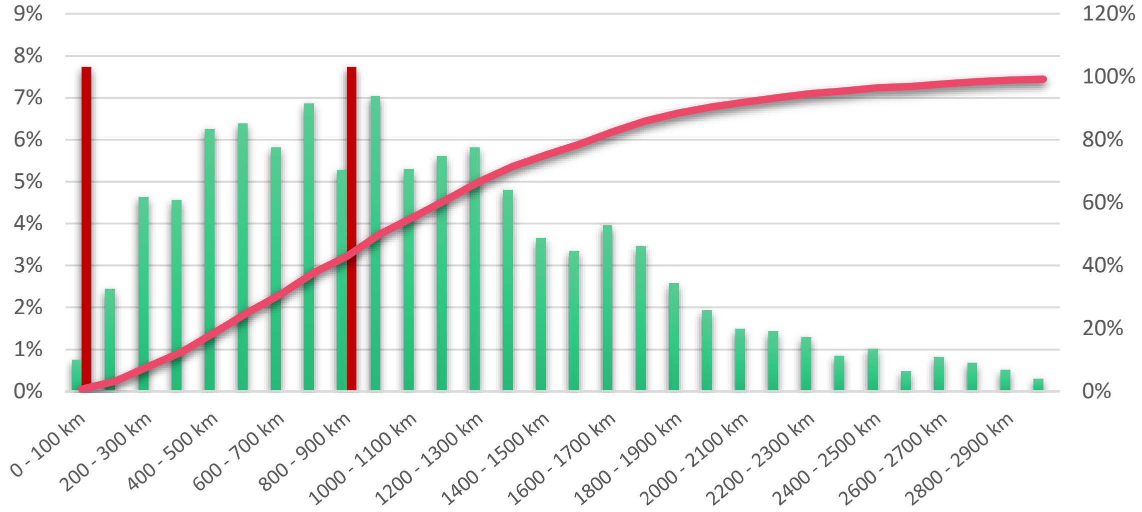
Quartile	Distance
0	0
0,1	305
0,2	497
0,3	677
0,4	837
0,5	990
0,6	1161
0,7	1359
0,8	1608
0,9	1912
1	5516

Distance	A	B	B'	C	C'
1	23	23	17	23	17
5	74	74	33	74	33
10	129	129	33	129	33
20	227	227	36	227	36
50	549			549	37
100	1296				
500	15236				
1000	38285				
2000	69432				
3000	74802				



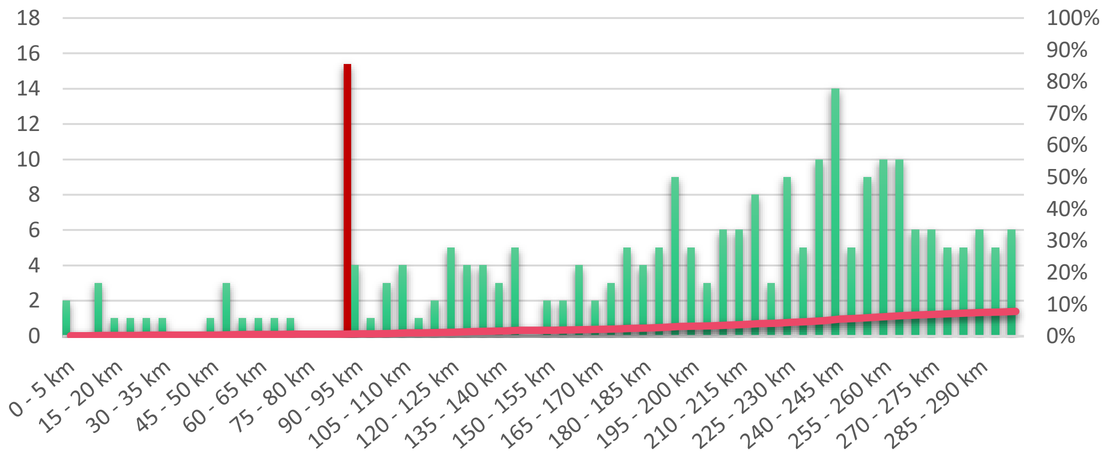
Gas from blast furnace can provide combustion plants for iron and steel process gases combustion. For this kind of synergy that needs an infrastructure network, the arbitrary distance is set at maximum 20 km because of the building cost and investment to make all parties. [22] On the 630MWH of BF gas generated energy content, 231 is directly returned to BF operations (remains 67%). The remaining part is enriched with BOF gas and provide several other operations. 60% of the enriched BOF-BF mix can be sent to a power plant (266,4MW). The calorific power of BF gas is less valuable that COG. This synergy is already a practice in BAT but require pipeline for gas transportation. Nevertheless, it is more profitable to burn directly. 36 combinations are nonetheless possible in the first 20 km that is a practicable distance for pipeline creation. The use of BF could avoid massive environmental negative impact due to the extraction, production and combustion of natural gas.

Synergy type 50 datasheet: Limestone fines from inorganic chemicals (solvay process) to cement industries (raw materials preparation)



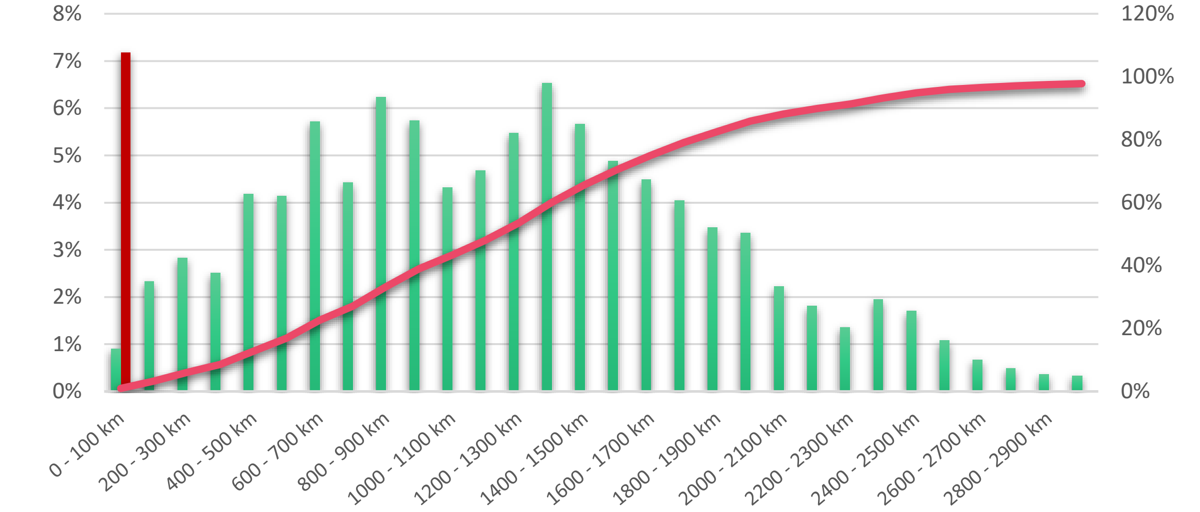
Quartile	Distance
0	2
0,1	348
0,2	526
0,3	691
0,4	843
0,5	1000
0,6	1179
0,7	1361
0,8	1649
0,9	1981
1	3841

Distance	A	B	B'	C	C'
1	0	0	0	0	0
5	2	2	2	2	2
10	2	2	2	2	2
20	6	6	6	6	6
50	10	10	7	10	7
100	22	17	8	22	8
500	551			551	16
1000	1479			1213	16
2000	2675				
3000	2936				



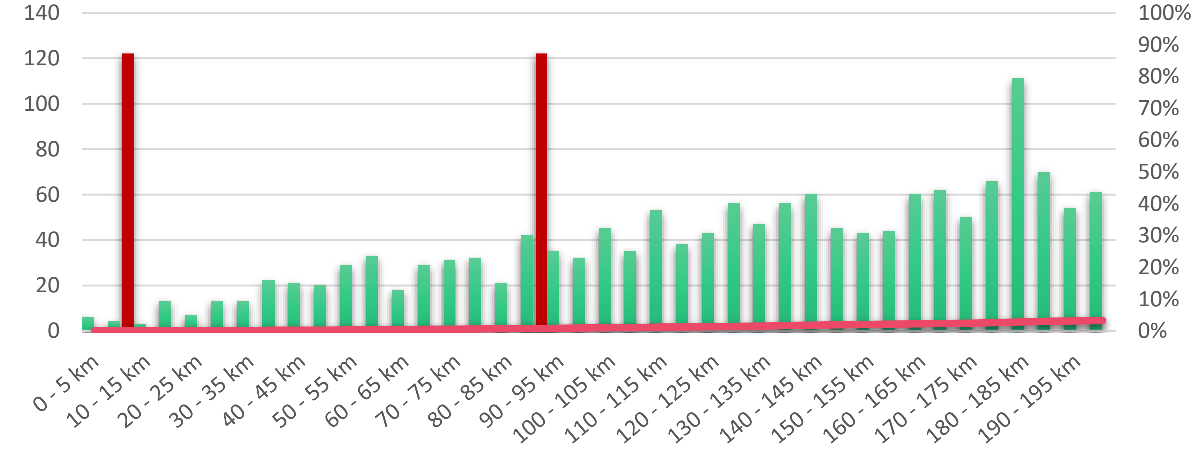
Limestone fines from Solvay process can be sent to raw material preparation in cement industries.
Around 8 synergies can be implemented with a high profitability (within the 10% radius). But a lot of combinations appears by increasing a little bit the distance.
The peak of opportunity below the maximum distance of viability is at around 600 km.
Around 160 combinations are more or less viable, this synergy seems promising.

Synergy type 66 datasheet: BF and BOF slags from steel -BF & BOF) to ceramic industries (bricks and roof tiles)



Quartile	Distance
0	1
0,1	436
0,2	646
0,3	840
0,4	1024
0,5	1240
0,6	1400
0,7	1587
0,8	1818
0,9	2203
1	3770

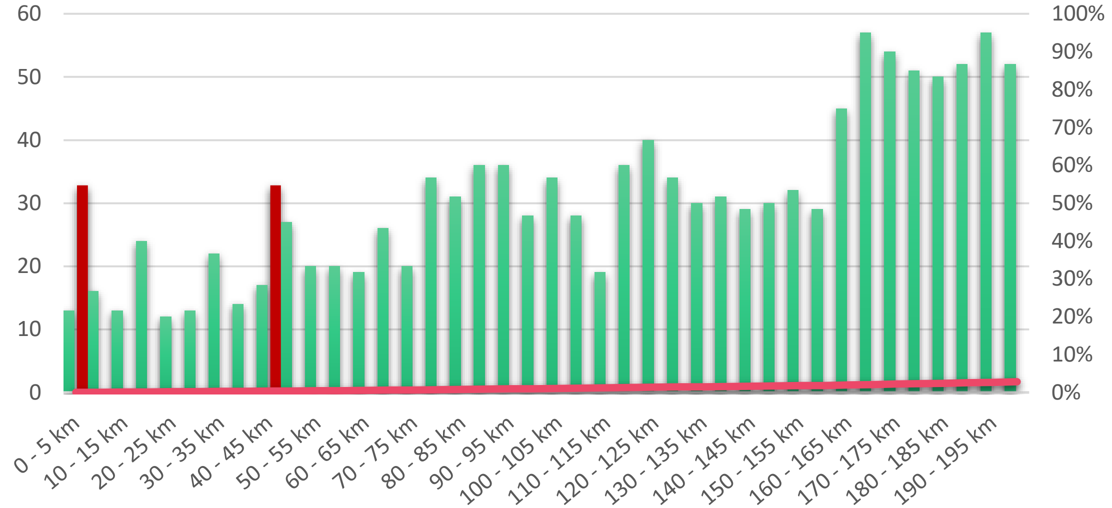
Distance	A	B	B'	C	C'
1	1	1	1	1	1
5	6	6	6	6	6
10	10	10	9	10	9
20	26			26	14
50	122			122	27
100	424			392	34
500	6010				
1000	18397				
2000	40523				
3000	46150				



Slags from blast furnaces can provide ceramic industries and replace clay components.

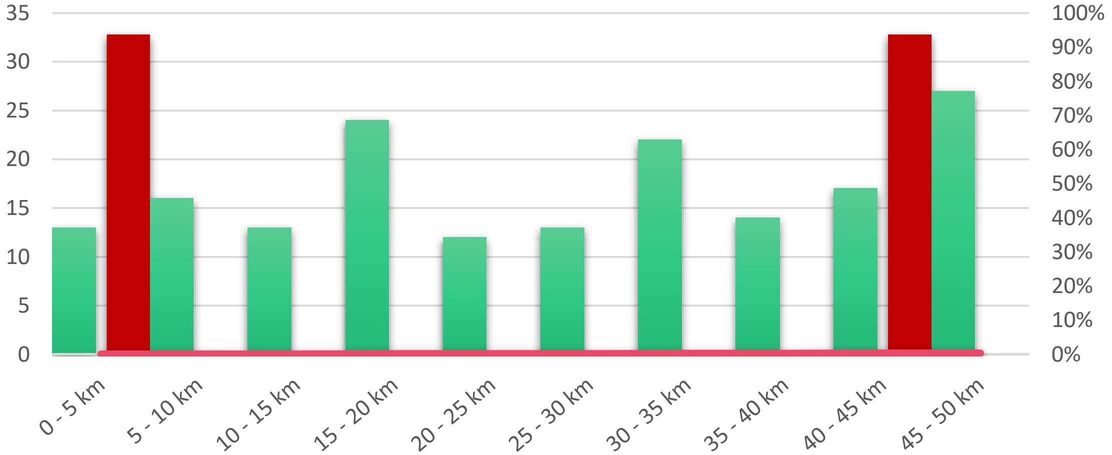
The economic distance is below 95km. This synergy is thus fairly local, around the steel furnaces.
Only 9 synergies could be envisaged below 10 km, and around 34 synergies with lower profitability below 100 km.

Synergy type 67 datasheet: cooling water from refineries to combustion plants



Quartile	Distance
0	0,9
0,1	418,3
0,2	632,3
0,3	820,5
0,4	1008,1
0,5	1214,8
0,6	1441,5
0,7	1684,7
0,8	1981,7
0,9	2438,5
1	5667,6

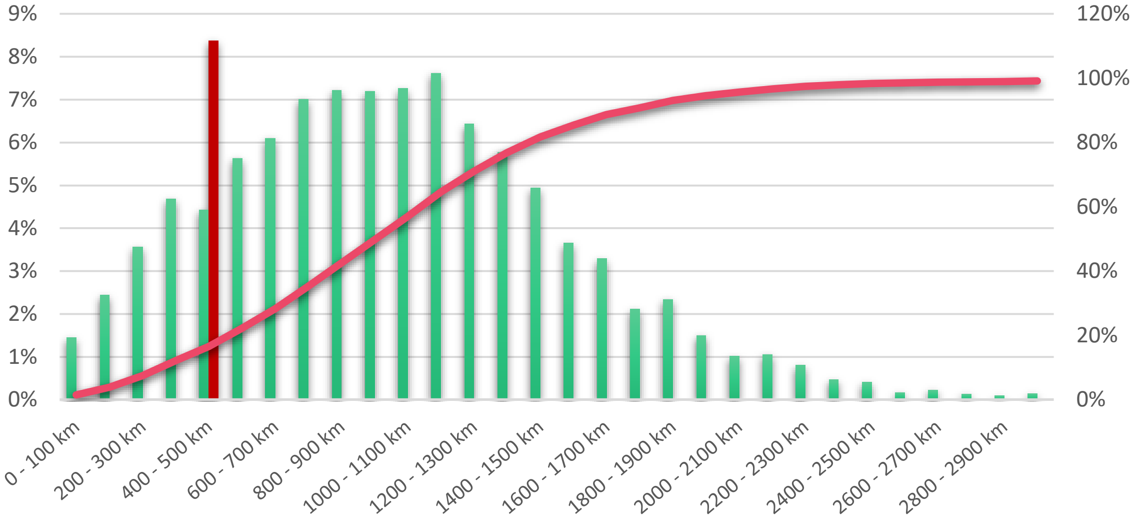
Distance	A	B	B'	C	C'
1	2	2	2	2	2
5	13	13	12	13	12
10	29	29	21	29	21
20	66			66	33
50	171			171	54
100	441				
500	6012				
1000	17523				
2000	35708				
3000	42756				



Cooling water from refining mineral oil and gas plants can supply a combustion plant cooling system.

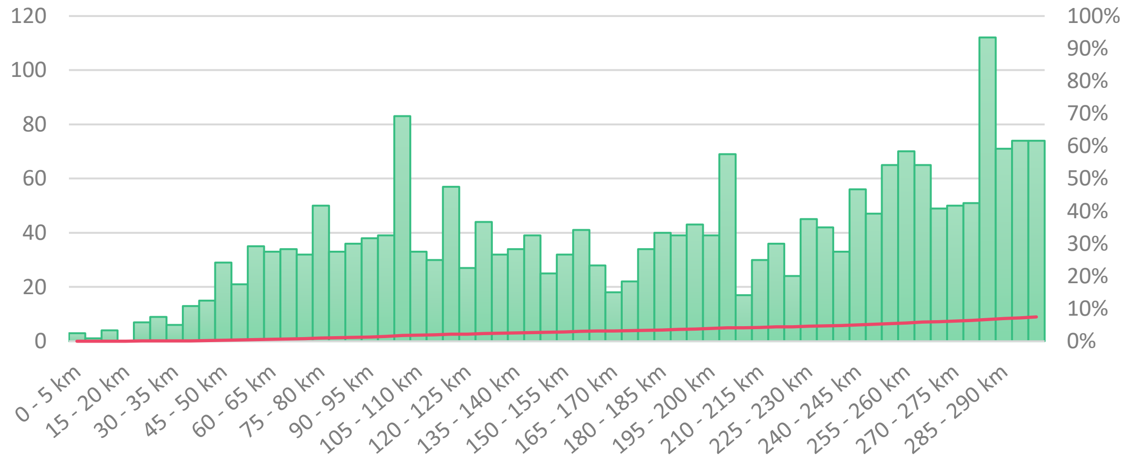
For this kind of synergy that needs an infrastructure network, the arbitrary distance is set at 20 km because of the building cost and investment to make all parties.

Synergy type 68 datasheet: Fly ash from combustion plants (gasification combined cycle) to glass sector (container glass)



Quartile	Distance
0	4,4
0,1	351,9
0,2	564,7
0,3	724,3
0,4	866,9
0,5	1004,2
0,6	1140,6
0,7	1282,5
0,8	1461,7
0,9	1762,4
1	7036,2

Distance	A	B	B'	C	C'
1	0	0	0	0	0
5	3	3	1	3	1
10	4	4	2	4	2
20	8	8	5	8	5
50	87	87	25	87	25
100	438	438	60	438	60
500	5022	5022	105	5022	105
1000	15081			15081	105
2000	28712			28712	105
3000	30081			30081	105

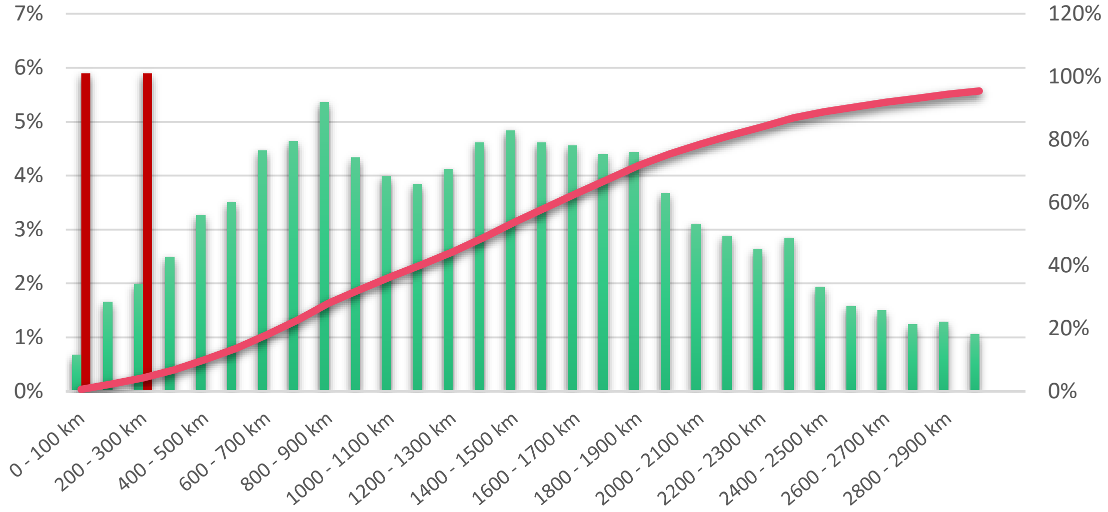


Fly ash can provide glass manufacturing for mineral demands.

The maximum economic distance is 532 km and gives a lot of opportunities of synergy creation with a peak at around 150 km. Several thousands of combinations are theoretically viable.

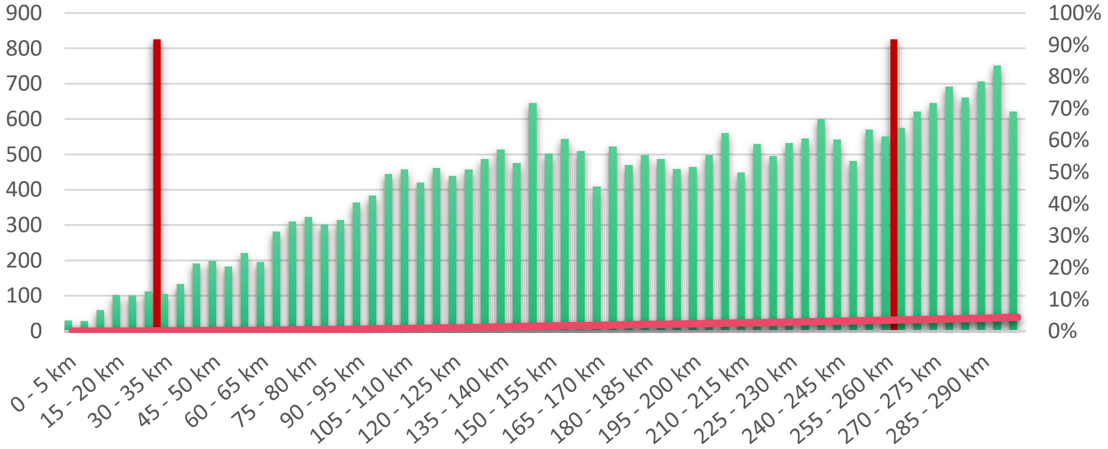
This synergy appears to be interesting, but calculation probably overestimates the value of this flow. Nevertheless, this synergy is very common and must be exploited to the maximum.

Synergy type 69 datasheet: Fly ash from coal combustion plants to ceramic sector (bricks and roof tiles)



Quartile	Distance
0	0,2
0,1	497,7
0,2	743,3
0,3	945,3
0,4	1193,6
0,5	1420,6
0,6	1634,3
0,7	1857,1
0,8	2147,4
0,9	2571,2
1	4593,2

Distance	A	B	B'	C	C'
1	1	1	1	1	1
5	29	29	24	29	24
10	57	57	45	57	45
20	217	217	112	217	112
50	1053	332	148	1053	260
100	3923			3923	333
500	58720			19683	383
1000	188756				
2000	439809				
3000	556570				

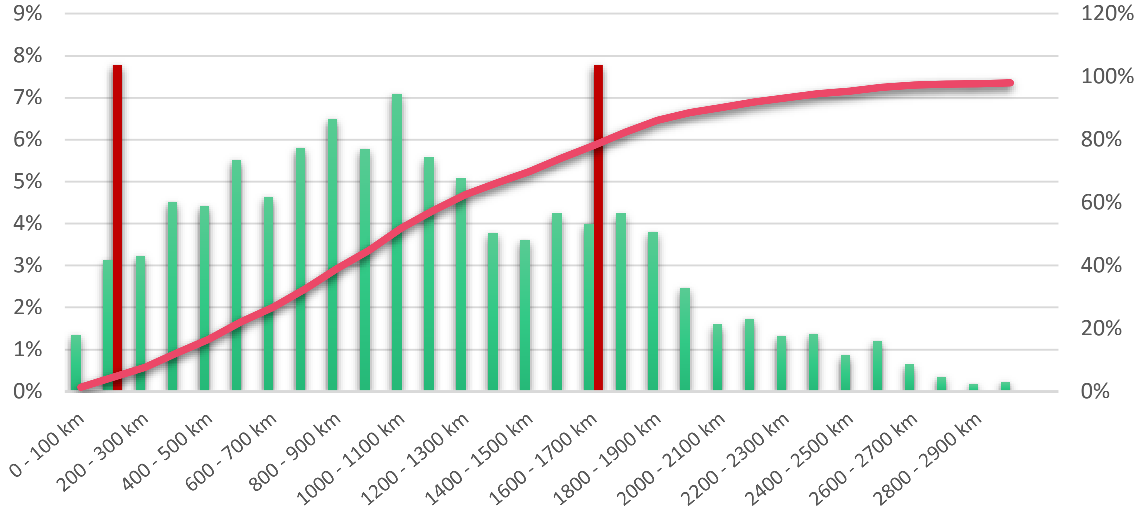


Fly ash can provide brick and roof tiles manufacturing.

With a price of 45€/ton, the maximum economic distance is 258 km and gives a lot of opportunities of synergy creation with a peak at around 150 km. Several thousands of combinations are theoretically.

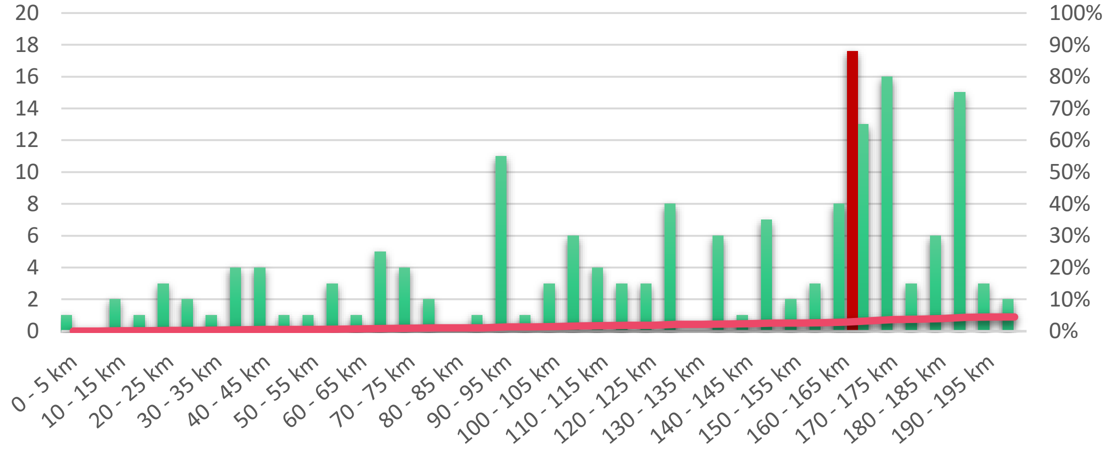
This synergy is very common and must be exploited to the maximum.

Synergy type 81 datasheet: Wastewater from refineries (e.g. crude atmospheric distillation) to steel sector (BF)



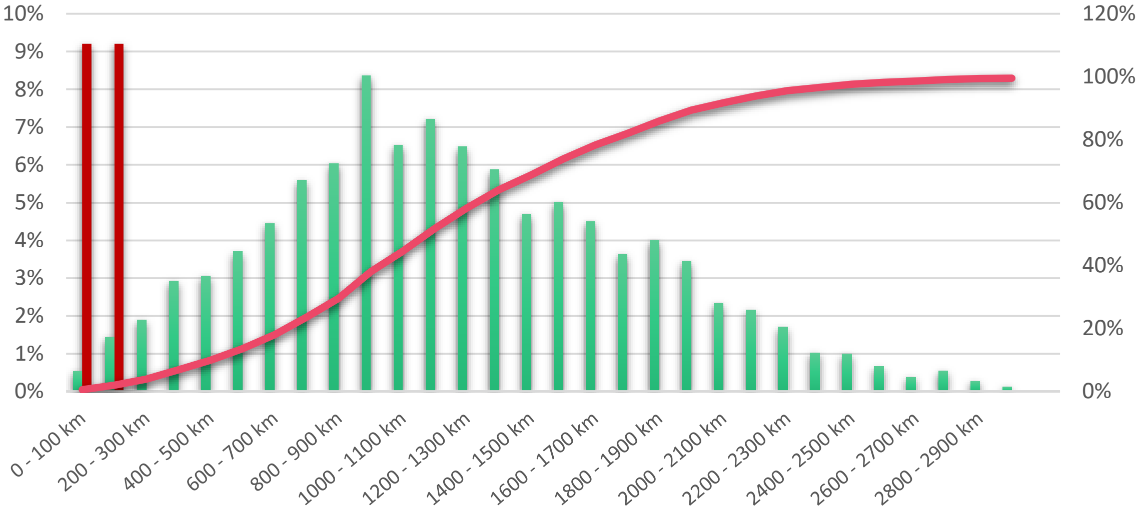
Quartile	Distance
0	1,6
0,1	348,2
0,2	560,4
0,3	759,2
0,4	915,3
0,5	1069,4
0,6	1248,5
0,7	1503,2
0,8	1739,3
0,9	2073,2
1	5028,3

Distance	A	B	B'	C	C'
1	0	0	0	0	0
5	1	1	1	1	1
10	1	1	1	1	1
20	4	4	4	4	4
50	19	19	15	19	15
100	48	48	27	48	27
500	596	102	40	596	87
1000	1608			1608	96
2000	3179			2670	96
3000	3517			2670	96



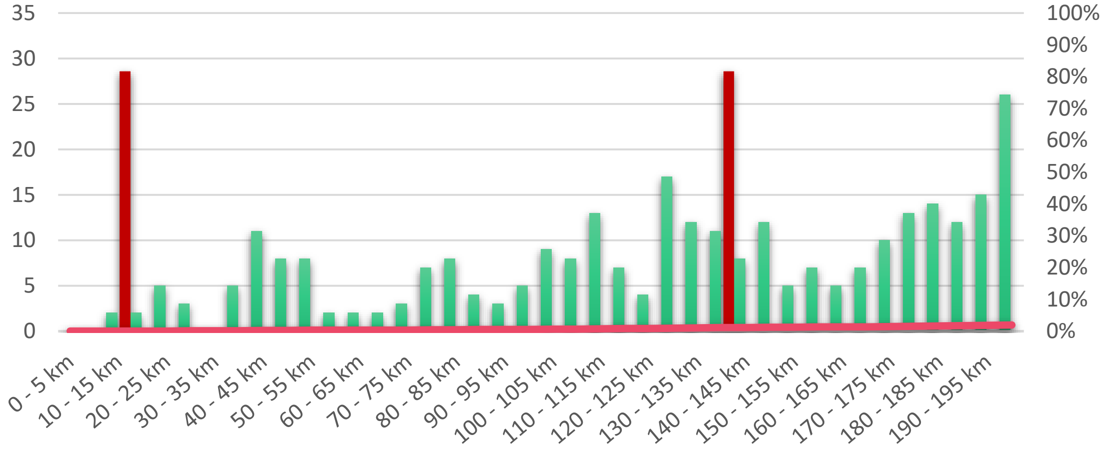
Oil from crude atmospheric distillation wastewater can provide blast furnaces in steel industries.
This synergy has a high level of viability, but it is important to consider that the investment and the operational cost are highly variable.
Considering combinations possible, around 31 are viable including 19 within the 10% of the product price radius. Nevertheless, the viability radius is probably overestimated and this synergy is therefore not taken into account in the overall potential assessment.

Synergy type 82 datasheet: Wood waste from paper sector (sulphite pulp process) to combustion plants (gasification combined cycle)



Quartile	Distance
0	10,0
0,1	502,3
0,2	740,5
0,3	903,5
0,4	1029,2
0,5	1176,9
0,6	1324,5
0,7	1525,3
0,8	1754,7
0,9	2024,2
1	3501,7

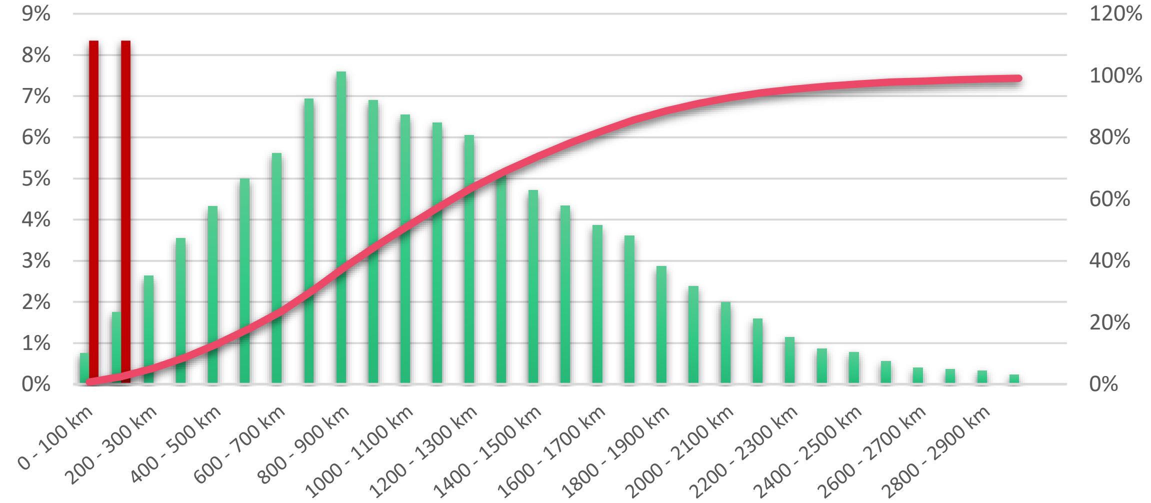
Distance	A	B	B'	C	C'
1	0	0	0	0	0
5	0	0	0	0	0
10	0	0	0	0	0
20	4	2	2	4	4
50	36			36	17
100	80			80	29
500	1479			153	48
1000	5705				
2000	13421				
3000	14946				



Waste wood from pulp and paper production sector can provide combustion plants. The use of wood waste of this sector in another sector is a quite common synergy.

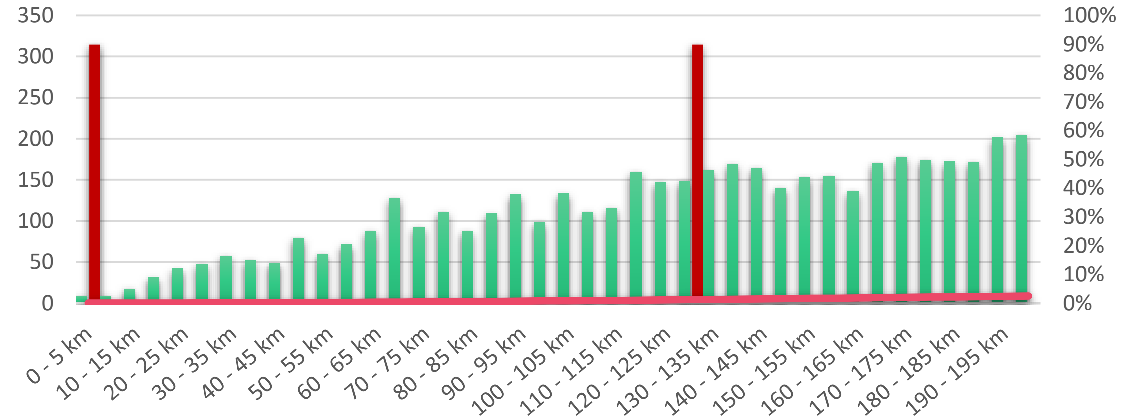
No synergy is inside the 10% viability radius of 13 km, but a few combinations are viable (with less profits) within the maximum radius of viability (<135 km). Around 29 synergies more or less profitable could be studied and set.

Synergy type 86 datasheet: Carcase from slaughterhouses to cement industries (burning phase)



Quartile	Distance
0	1,0
0,1	433,9
0,2	637,8
0,3	792,6
0,4	927,3
0,5	1074,2
0,6	1232,9
0,7	1418,2
0,8	1645,4
0,9	1958,2
1	7210,4

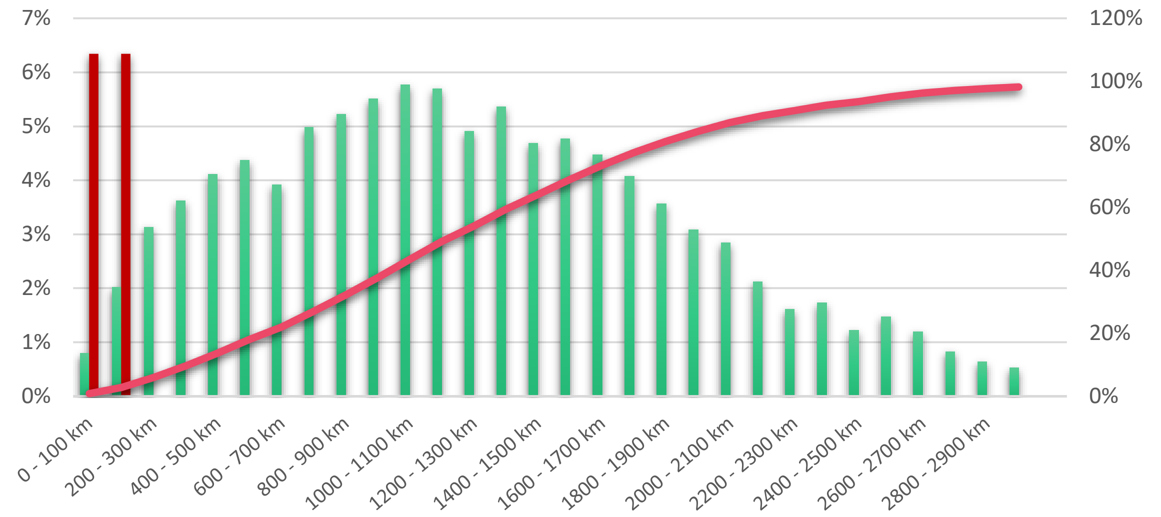
Distance	A	B	B'	C	C'
1	1	1	1	1	1
5	9	9	8	9	8
10	18	18	13	18	13
20	66	35	27	66	48
50	392	35	27	392	213
100	1367	35	27	1367	458
500	23458	35	27	2816	604
1000	81293	35	27	2816	604
2000	164059	35	27	2816	604
3000	178933	35	27	2816	604



Carcase from slaughterhouses can provide burning operation in cement industries.

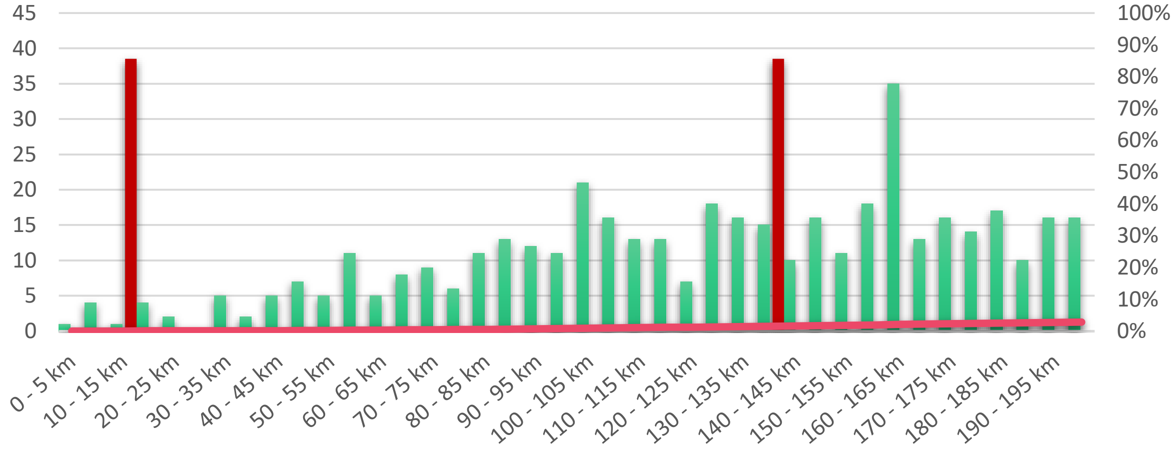
Here, 70 combinations are within the 10% viability radius of 14km (only 41 if the duplications are removed). More than 100 combinations can be set below the limit of viability of 140km. In the real case, this synergy is already well-known and done in several sectors.

Synergy type 87 datasheet: Wood waste from paper sector (sulphite pulp process) to lime manufacturing (long rotary kiln)



Quartile	Distance
0	3,6
0,1	413,4
0,2	652,2
0,3	860,3
0,4	1043,9
0,5	1217,2
0,6	1412,6
0,7	1625,0
0,8	1873,9
0,9	2255,0
1	3923,8

Distance	A	B	B'	C	C'
1	0	0	0	0	0
5	1	1	1	1	1
10	5	5	5	5	5
20	10	7	6	10	9
50	31			31	23
100	122			122	58
500	2109			249	86
1000	5817				
2000	12985				
3000	15177				



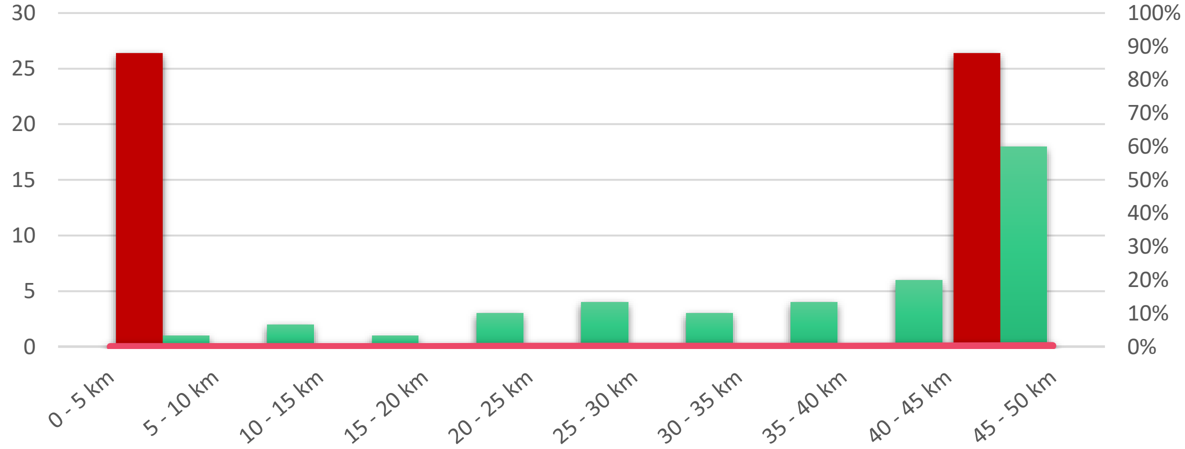
The aim of this synergy is to recover waste wood from pulp and paper production sector, and provide combustion plants.

Low number of synergies (5) are inside the 10% viability radius of 13 km, but a lot of combinations are viable (with less profits) within the maximum radius of viability (<135 km). Around 58 synergies more or less profitable could be studied and set.

Synergy type 89 datasheet: Cooling water from paper sector (mechanical and chemimechanical pulping) to fertilisers production (CAN)

Quartile	Distance
0	8,6
0,1	454,6
0,2	690,5
0,3	887,2
0,4	1081,3
0,5	1274,2
0,6	1486,1
0,7	1703,2
0,8	1979,0
0,9	2406,2
1	5277,0

Distance	A	B	B'	C	C'
1	0	0	0	0	0
5	0	0	0	0	0
10	1	1	1	1	1
20	4	3	3	4	4
50	42			42	21
100	108				
500	1652				
1000	5020				
2000	11176				
3000	13483				



The aim of this synergy is to reuse production of pulp and paper plants cooling water to supply fertilisers industries or refining industries cooling systems.

The distance viability is less than 10 km, and that does not enable combinations with sites targeted in the study. Even if some combinations appear at 10 to 50 km, it seems difficult to set the synergies because of the infrastructure cost.

3.3 IS potential of the most impacting synergies

Benefits quantification of the most impacting synergies

Most impacting synergies (environmentally, socially and economically) were assessed. This assessment provides all potential couple of sites distribution and the reduced combinations number within a viability radius. The first piece of information, all potential couple of sites, corresponds to all potential synergies that could be implemented at EU level. The second one corresponds represent the minimum number of synergies that could be implemented in a viable radius. Synthesis of mapping and distribution calculation results led to create the synoptic Table 29.

Table 29: Synoptic of mapping and distribution results (Source: Strane)

# Synergy	Resource	A	B	B'	C	C'
1	COKE OVEN GAS	4043	18	10	58	23
2	COKE OVEN GAS	4043	18	10	58	23
3	PLF	1215	939	7	1215	7
4	COKE RESIDUES	774	49	20	742	44
5	EAF DUSTS	2158	1623	178	2158	180
6	BASIC OXYGEN FURNACE SLAG	6408	214	27	4151	37
8	GYPSUM	30745	17	17	383	165
9	OFF-GAS	793	8	6	198	53
10	SULPHURIC ACID	65	2	2	27	5
12	SALT FROM SALT SLAG	1704	2	2	75	48
17	OFF_GAS	1249	842	13	1249	13
19	PROCESS GASES	1004	605	44	1004	44
22	REFRACTORY PRODUCTS	51622	2363	164	47038	180
23	SLAG	27259	151	96	5222	363
24	SLAG	2622	1	1	32	18
29	RED MUD	27587	1583	124	27180	160
30	SLAG	8942	38	19	1474	36
31	ALUMINIUM OXIDES FROM SALT SLAG	27587	5778	149	27587	160
32	ALUMINIUM OXIDES FROM SALT SLAG	27560	499	125	15944	158
35	EAF SLAG	12755	1	1	196	99
39	SULPHURIC ACID	85	1	1	45	5
47	COKE OVEN GAS	85261	218	33	634	37
48	BLAST FURNACE GAS	74802	227	36	549	37
49	BASIC OXYGEN FURNACE GAS	74802	227	36	549	37
50	LIMESTONE FINES	2936	17	8	1213	16
66	BLAST FURNACE AND CONVERTER SLAG	46150	10	9	392	34
67	COOLING WATER	42756	29	21	171	54
68	FLY ASH	30081	5540	105	30081	105
69	FLY ASH	556570	332	148	19683	383
81	CRUDE ATMOSPHERIC DISTILLATION WW	3517	102	40	2670	96
82	WOOD WASTE	14946	2	2	153	48
86	CARCASE	178933	35	27	2816	604
87	WOOD WASTE	15177	7	6	249	86
89	COOLING WATER	13483	3	3	42	21
95	SOLID WASTE FUEL FEEDSTOCK	N/A	N/A	N/A	N/A	N/A
97	OIL	N/A	N/A	N/A	N/A	N/A
98	BITUMEN	N/A	N/A	N/A	N/A	N/A
100	GAS OIL	N/A	N/A	N/A	N/A	N/A

Table 30: Number of opportunities synoptic (Source: Strane)

Type of result	Number
A: Total number of combinations across Europe	**1 379 634**
B: Number of combinations within a common profitable radius (transport costs less than 10% of the resource transported intrinsic value)	**21 501**
B': Number of combinations within a common profitable radius assuming that one emitting site sends its entire flow to the nearest receiving facility	**1 490**
C: Total number of combinations within the viability radius limit (transport costs less than the price of the all resources transported intrinsic value)	**195 238**
C': Total number of combinations within the viability radius limit assuming that one emitting site sends its entire flow to the nearest receiving facility	**3 379**

# Synergy	Resource	Unit	Number of emitting sites involved	Total number of installations in EU	Total waste stream quantity in Europe	Total waste stream quantity per site	Total quantity involved	Ratio	Final fraction recovered and valorised
1	COKE OVEN GAS	*Nm3*	*23*	*42*	*22099000000,00*	*526166666,67*	*12101833333,33*	*0,55*	192350,41
2	COKE OVEN GAS	Nm3	*23*	*42*	*22099000000,00*	*526166666,67*	*12101833333,33*	*0,55*	3340740,74
3	PLF	Tonnes	7	7	16800,00	2400,00	16800,00	1,00	7182,00
4	COKE RESIDUES	Tonnes	44	44	17600,00	400,00	17600,00	1,00	17600,00
5	EAF DUSTS	Tonnes	180	180	1654600,00	9192,22	1654600,00	1,00	301334,44
6	BASIC OXYGEN FURNACE SLAG	Tonnes	37	37	15360000,00	415135,14	15360000,00	1,00	14592000,00
8	GYPSUM	Tonnes	165	458	7850000,00	17139,74	2828056,77	0,36	2828056,77
9	OFF-GAS	Tonnes	53	62	63116000,00	1018000,00	53954000,00	0,85	53954000,00
10	SULPHURIC ACID	Tonnes	5	5	500000,00	100000,00	500000,00	1,00	500000,00
12	SALT FROM SALT SLAG	Tonnes	48	161	2050000,00	12732,92	611180,12	0,30	229192,55
17	OFF_GAS	Tonnes	13	13	156000,00	12000,00	156000,00	1,00	124800,00
19	PROCESS GASES	Tonnes	44	44	388027,00	8818,80	388027,00	1,00	310422,00
22	REFRACTORY PRODUCTS	Tonnes	180	180	1009315,00	5607,31	1009315,00	1,00	1009315,00
23	SLAG	Tonnes	363	458	1000000,00	2183,41	792576,42	0,79	792576,42
24	SLAG	Tonnes	18	37	1973340,00	53333,51	960003,24	0,49	960003,24
29	RED MUD	Tonnes	160	160	6510000,00	40687,50	6510000,00	1,00	6510000,00
30	SLAG	Tonnes	36	37	24600000,00	664864,86	23935135,14	0,97	23935135,14
31	ALUMINIUM OXIDES FROM SALT SLAG	Tonnes	160	160	2050000,00	12812,50	2050000,00	1,00	1168500,00
32	ALUMINIUM OXIDES FROM SALT SLAG	Tonnes	158	160	2050000,00	12812,50	2024375,00	0,99	1153893,75
35	EAF SLAG	Tonnes	99	180	13650450,00	75835,83	7507747,50	0,55	7507747,50
39	SULPHURIC ACID	Tonnes	5	5	500000,00	100000,00	500000,00	1,00	500000,00
47	COKE OVEN GAS	*Nm3*	*37*	*42*	*22099000000,00*	*526166666,67*	*19468166666,67*	*0,88*	1063726,06
48	BLAST FURNACE GAS	*Nm3*	*37*	*37*	*186048000000,00*	*5028324324,32*	*186048000000,00*	*1,00*	17414,90
49	BASIC OXYGEN FURNACE GAS	*Nm3*	*37*	*37*	*5017209302,33*	*135600251,41*	*5017209302,33*	*1,00*	14435,39
50	LIMESTONE FINES	Tonnes	16	17	1462500,00	86029,41	1376470,59	0,94	1376470,59
66	BLAST FURNACE AND CONVERTER SLAG	Tonnes	34	37	24600000,00	664864,86	22605405,41	0,92	22605405,41
67	COOLING WATER	m3	54	97	174873600,00	1802820,62	97352313,40	0,56	97352313,40
68	FLY ASH	Tonnes	105	105	1310767,50	12483,50	1310767,50	1,00	1310767,50
69	FLY ASH	Tonnes	383	458	31616000,00	69030,57	26438707,42	0,84	21904469,10
81	CRUDE ATMOSPHERIC DISTILLATION WW	Tonnes	96	97	327200,00	3373,20	323826,80	0,99	323826,80
82	WOOD WASTE	Tonnes	48	143	5768400,00	40338,46	1936246,15	0,34	1936246,15
86	CARCASE	Tonnes	604	1037	3906899,00	3767,50	2275570,87	0,58	2275570,87
87	WOOD WASTE	Tonnes	86	143	5768400,00	40338,46	3469107,69	0,60	3469107,69
89	COOLING WATER	m3	21	143	272000000,00	1902097,90	39944055,94	0,15	39944055,94
95	SOLID WASTE FUEL FEEDSTOCK	Per T		266	5297000,00	19913,53	5297000,00	1,00	5297000,00
97	OIL		266	266	4475965,00	16826,94	4475965,00	1,00	4475965,00
98	BITUMEN				201286,00	756,71	201286,00	1,00	201286,00
100	GAS OIL				3739682,00	14058,95	3739682,00	1,00	3739682,00

For the 38 most impacting synergies, the total number of combinations in Europe is around 1 380 000. 21 501 opportunities are directly within a profitable radius and could led to around 1 500 synergies between the nearest emitting sites. In a viable radius avoided economic losses for industrial partners, the number of synergies between the nearest partners in the case of a wide implementation would be around **3 400** (with 200 000 opportunities). The total recoverable volume is about **327M Tons of material**.

This information was used to revise and refine the environmental and socio-economic assessments were in the previous tasks (T3.3 and T3.4).

A final assessment of the most impacting synergies was performed:

- By updating and unifying the right amount of resources involved and the right amount that could be finally recovered in the case of a valorisation
- By only counting the number of emitting sites that find a receiver within the maximum viability radius. Only resources in this shortlist can be valorise transported and valorised.
- By avoiding double counting of potential benefits because same resources can be involved in several synergies (e.g. BF slags can be used in cement, mineral wool production, etc.)

For both environmental and socio-economic assessment of the most impacting synergies, two key results are presented:

- The EU IS potential considering a widely implementation of the most impacting synergies
- The remaining potential not implemented that has yet to be implemented to date

The remaining potential was obtained by using several sources of information to assess the management scenario commonly used (current practices) for each specific resource. The Table 31 provide data and sources used to estimate the remaining potential quantification.

Final environmental assessment table is presented in the Table 32. Overall environmental benefits and remaining potential are respectively exposed in Table 33 and Table 34.

Table 31: Resource management scenario and confidence level (Source: Strane)

#	Resource	Remaining potential	Confidence level
1	COKE OVEN GAS	**All potential is counted on synergy n°2 due to higher benefits. 60% of COG volume is typically needed for internal processes.** There are two options for dealing with the large amount of generated coke oven gas: •in the first case, the coke oven gas is fully collected and further processed by the cleaning and recovery of by-products. The cleaned coke oven gas (after the removal of economically valuable by-products) is internally or externally used by other steelworks consumers as a fuel in coke oven batteries, hot blast stove (cowper), blast furnaces, for the heating of ignition furnaces in sinter plants, for pusher-type heating furnaces in rolling mills and for electric power generation in power plants •in the second case, the heat recovery process, the raw coke oven gas is burnt directly at its source in the coking reactor by a prudent air supply and no further recovery steps are necessary. The heat produced is partly used for the coking process. The excess energy is subsequently converted to steam and/or electricity. The heat recovery coking process has been operating successfully in the US since 1998. Another possibility is to use the cleaned coke oven gas as a raw material in the chemical synthesis of methanol or for hydrogen separation. In China approximately 10 methanol production installations with capacities of 70 – 200000 tonnes/year each are in use. An example is the installation in Shaanxi Hancheng Heimao Coking Company. Methanol synthesis from coke oven gas after deep desulphurisation in one step with a fixed bed reactor is a technique developed by Second Design Institute of Chemical Industry (SEDIN) which has been in operation since 2006. Remaining potential in EU is full.	HIGH
2	COKE OVEN GAS	**60% of COG volume is typically needed for internal processes.** There are two options for dealing with the large amount of generated coke oven gas: •in the first case, the coke oven gas is fully collected and further processed by the cleaning and recovery of by-products. The cleaned coke oven gas (after the removal of economically valuable by-products) is internally or externally used by other steelworks consumers as a fuel in coke oven batteries, hot blast stove (cowper), blast furnaces, for the heating of ignition furnaces in sinter plants, for pusher-type heating furnaces in rolling mills and for electric power generation in power plants •in the second case, the heat recovery process, the raw coke oven gas is burnt directly at its source in the coking reactor by a prudent air supply and no further recovery steps are necessary. The heat produced is partly used for the coking process. The excess energy is subsequently converted to steam and/or electricity. The heat recovery coking process has been operating successfully in the US since 1998. Another possibility is to use the cleaned coke oven gas as a raw material in the chemical synthesis of methanol or for hydrogen separation. In China approximately 10 methanol production installations with capacities of 70 – 200000 tonnes/yr each are in use. An example is the installation in Shaanxi Hancheng Heimao Coking Company. Methanol synthesis from coke oven gas after deep desulphurisation in one step with a fixed bed reactor is a technique developed by Second Design Institute of Chemical Industry (SEDIN) which has been in operation since 2006. Remaining potential in EU is full.	HIGH
3	PLF	**Ongoing implementation on a pilot site. Remaining potential: 100%.**	HIGH
4	COKE RESIDUES	Coke is directly burned on site. **Remaining potential 100%.**	HIGH
5	EAF DUSTS	**34% of EAF dusts are landfilled** [22] https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/IS_Adopted_03_2012.pdf	HIGH
6	BASIC OXYGEN FURNACE SLAG	14.1% of steel slags are landfilled, 8.6% are stored. 46% are used for road construction so it would be better to valorise them in cement or insulation production (e.g.23%) for their metal content. **The remaining potential is around 44.7%.** [23] https://www.euroslag.com/wp-content/uploads/2019/01/Statistics-2016.pdf	HIGH
8	GYPSUM	5% of FGD gypsum go to disposal, around 7% are stockpiled and only 10% are restored. The rest of FGD is used in construction industry: The FGD gypsum is utilised for the production of plasterboards and self-levelling floor screeds, as well as a retarder for cement and underground mining. **The remaining potential can be roughly assumed at 30%**. [24] https://eippcb.jrc.ec.europa.eu/sites/default/files/2020-03/superseded_lcp_bref_0706.pdf	HIGH
9	OFF-GAS	Only 15 refineries in EU. 55 procedures referenced in the word (oil refining, non-ferrous metals, petrochemicals, coke and viscos fibres industries) [25]. **The assumption made is that around 50% of EU installations are equipped for Sulphuric acid recovery**	LOW
10	SULPHURIC ACID	Chemical plants commonly buy conventional sulphuric acid. Same ratio used as Synergy 9	LOW
12	SALT FROM SALT SLAG	After iron, aluminium is the most widely used metal in the world. Nevertheless, its recycling process can generate salt slag, which is an increasingly serious environmental issue because it is not easy to dispose of. Indeed, their landfilling is no longer allowed in Europe and the Middle East. Despite this, due to high installation and operating costs, there are only nine very large capacity (around 100 000 t/y [26] https://www.alcircle.com/news/altek-successfully-installs-the-demonstration-unit-of-a-large-capacity-salt-slag-recycling-plant-28996) slag recycling facilities in the whole of Europe, serving more than 270 treatment plants. Aluminium oxide residues are most of the time sold to cement, ceramic and insulation sector. There are still some deposits to exploit in cement industries and glass industries. **Remaining potential = (9 (very large salt slag companies) * 100 000 (capacity t/y)) / 2 000 050 (total salt slag produced in EU)**	HIGH
17	OFF GAS	This practice exists but may not be widespread unlike direct on-site combustion because it is not economically viable. **Remaining potential assumption: 75%**	MEDIUM
19	PROCESS GASES	This practice exists but may not be widespread unlike direct on-site combustion because it is not economically viable. **Remaining potential assumption: 75%**	MEDIUM
22	REFRACTORY PRODUCTS	Technical NO GO. **Remaining potential is full but it is not count in the final calculation due to technical NOGO.**	HIGH
23	SLAG	Although the boiler slag could potentially be used for mineral wool production, the stability and presence of toxic compounds needs to be carefully evaluated. The potential is not counted in the final result. Combustion plants slags are commonly used in construction sector which involved underground mining operation, road construction and maybe cement. So, it could be a better use to provide insulations production companies instead of underground mining operations or road construction. **We assume that 20% could be used in this application but the benefit is not counted in the final result as there is a technical NOGO**. [27] https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/JRC_107769_LCPBref_2017.pdf	HIGH
24	SLAG	BF slags are used in cement and concrete industries (81,4%), in road construction (20,9%) and in others applications (2,5%). The use of the slag in mineral wool production for its intrinsic value (material content) would be better than a use in road construction. **The remaining potential is around 23.4%. Not to be double counted** [23] https://www.euroslag.com/wp-content/uploads/2019/01/Statistics-2016.pdf	HIGH

29	RED MUD	Current practice is to deposit red mud on or near the site in specially designed, sealed ponds. Some refineries use high-pressure filtration as a last step for red mud treatment. The output from this operation is a solid bauxite residue, which can be easily and safely transported over long distances and which can be used in various applications, such as in the cement industry for the production of clinker, in the ceramic industry as an alternative raw material, or in road construction [28]. The remaining potential is high and assumed at 85%	HIGH
30	SLAG	[23] https://www.euroslag.com/wp-content/uploads/2019/01/Statistics-2016.pdf	HIGH
31	ALUMINIUM OXIDES FROM SALT SLAG	After iron, aluminium is the most widely used metal in the world. Nevertheless, its recycling process can generate salt slag, which is an increasingly serious environmental issue because it is not easy to dispose of. Indeed, their landfilling is no longer allowed in Europe and the Middle East. Despite this, due to high installation and operating costs, there are only nine very large capacity (around 100 000 t/y: source: https://www.alcircle.com/news/altek-successfully-installs-the-demonstration-unit-of-a-large-capacity-salt-slag-recycling-plant-28996) slag recycling facilities in the whole of Europe, serving more than 270 treatment plants. Aluminium oxide residues are most of the time sold to cement, ceramic and insulation sector. There are still some deposits to exploit in cement industries and glass industries. **Remaining potential = (9 (very large salt slag companies) * 100 000 (capacity t/y)) / 2 000 050 (total salt slag produced in EU).** [26] https://www.alcircle.com/news/altek-successfully-installs-the-demonstration-unit-of-a-large-capacity-salt-slag-recycling-plant-28996)	HIGH
32	ALUMINIUM OXIDES FROM SALT SLAG	Same as synergy 31. Not to be double counted	HIGH
35	EAF SLAG	The most common practice for EAF slags management is landfilling and storing (**61.4% of total EAF slags produced**) by 57 plants. [22] https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/IS_Adopted_03_2012.pdf	HIGH
39	SULPHURIC ACID	**Potential already assessed with the synergy 10**	HIGH
47	COKE OVEN GAS	[22] 60% of COG volume is typically needed for internal processes; the remaining part can be used for power generation with GE's Jenbacher gas engines resulting in approximately 400kWh Per tonne of steel produced through the LD process approximately 50Nm3 of converter gas are released which can burn in GE's Jenbacher gas engines leading to approximately 50kWh electrical power. https://www.clarke-energy.com/steel-production-gas/	HIGH
48	BLAST FURNACE GAS	[22] On the 630MWH of BF gas generated energy content, 231 is directly returned to BF operations (remains 67%). The remaining part is enriched with BOF gas and provide several other operations. 60% of the enriched BOF-BF mix is send to a power plant (266,4MW) https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/IS_Adopted_03_2012.pdf	HIGH
49	BASIC OXYGEN FURNACE GAS	[22] On the 77,6MWH of BOF gas generated energy content, 25 is directly returned to BF operations (remains 68%). The remaining part enrich BF gas and provide several other operations. 60% of the final BOF-BF enriched mix is send to a power plant (266,4MW) https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/IS_Adopted_03_2012.pdf	HIGH
50	LIMESTONE FINES	Little information was found in the literature. One project of limestone recycling was found ([29] https://www.unido.org/sites/default/files/2012-05/12-50724_Factsheet_SASC_Ebook_0.pdf). It consists in the collection and reuse of limestone fines at the lime preparation unit for use in civil engineering works as filler material for roads, highways and cement manufacturing. Some mineral quarries explain that rich limestone fines are an ideal resource for farmers, for asphalt mix producers in summer (increased resistance of bitumen thanks to the specific qualities of the dust), and for public works professionals in winter and early spring. These dusts, once considered as waste, are now emerging as new resources ([30] https://www.unicem.fr/2017/11/16/valorisation-des-dechets-industriels-des-synergies-pour-une-economie-circulaire/). It seems that the remaining potential of this synergy seems to be full. **Remaining potential assumption 95%.**	HIGH
66	BLAST FURNACE AND CONVERTER SLAG	**Benefits already counted with synergy 30**	HIGH
67	COOLING WATER	No data were found	
68	FLY ASH	**Mainly used in construction industries. The synergy 69 data were used for this synergy.**	HIGH
69	FLY ASH	8% are landfilled, 1% are stored, around 50% are restored and the remaining part is used mainly in construction industries. **So, the remaining potential is around 10%.**	HIGH
81	CRUDE ATMOSPHERIC DISTILLATION WW	**No data were found so the remaining potential was assessed to 0%**	LOW
82	WOOD WASTE	Mainly used as fuel, in brickwork, biomass boiler and production of chip. So, this resource is already well exploited. **Remaining potential assumed: 20%**	MEDIUM
86	CARCASE	France produces approximately 850000 tonnes of MBM and approximately 150000 tonnes of tallow annually. Approximately 130000 tonnes of MBM and 40000 tonnes of tallow are from SRM and are co-incinerated by the cement industry. **The remaining potential in France is between 85 and 73 %. No data were found at EU level.**	MEDIUM at EU level
87	WOOD WASTE	Mainly used as fuel, in brickwork, biomass boiler and production of chip. So, this resource is already well exploited. **Remaining potential assumed: 20%.**	N/A
89	COOLING WATER	No data were found	N/A
95	SOLID WASTE FUEL FEEDSTOCK	**Core business and impossible to quantify remaining deposits**	N/A
97	OIL	**Core business**	N/A
98	BITUMEN	**Core business**	N/A
100	GAS OIL	**Core business**	N/A

Table 32: Final environmental assessment results and remaining potential (Source: Strane)

										Final LCA					Remaining Potential					
#	Resource	Unit	Number of emitting sites involved	Total number of installations in EU	Total waste stream quantity in Europe	Total waste stream quantity per site	Total quantity involved	Ratio	Final fraction recovered and valorised	Climate change (IPCC 2013) [kg CO2-eq]	Human health [DALY]	Ecosystem quality [PDF.m2.y]	Resources [MJ]	Freshwater withdrawal [m3]	Remaining potential factor	Climate change (IPCC 2013) [kg CO2-eq]	Human health [DALY]	Ecosystem quality [PDF.m2.y]	Resources [MJ]	Freshwater withdrawal [m3]
1	COKE OVEN GAS	Nm3	23	42	22099000000	526166666,67	12101833333,33	0,55	192350,41	-427978003,71	-177,46	-36799887,10	-15302364959,3	-30358575,84	0	0	0	0	0	0
2	COKE OVEN GAS	Nm3	23	42	22099000000	526166666,67	12101833333,33	0,55	3340740,74	-2239687048,57	-2070,36	-261984498,84	-121343414284,9	-101712701,67	1	-2239687048,57	-2070,36	-261984498,84	-121343414284,92	-101712701,67
3	PLF	Tons	7	7	16800	2400	16800	1	7182	-26242552,88	-11,88	-1758120,47	-259894729,50	-47141,59	1	-26242552,88	-11,88	-1758120,47	-259894729,50	-47141,59
4	COKE RESIDUES	Tons	44	44	17600	400	17600	1	17600	-11775922,40	-32,43	-2791209,92	-618886136	-195531,92	1	-11775922,40	-32,43	-2791209,92	-618886136	-195531,92
5	EAF DUSTS	Tons	180	180	1654600	9192,22	1654600	1	301334,44	-106158,07	-0,50	-426963,30	-1198626,81	-5338,11	0,34	-36093,75	-0,17	-145167,52	-407533,12	-1814,96
6	BASIC OXYGEN FURNACE SLAG	Tons	37	37	15360000	415135,14	15360000	1	14592000	-9510007300	-4863,52	-2863494180	-68476222300	-92979584,65	0,45	-4250973263,10	-2173,99	-1279981898,46	-30608871368,10	-41561874,34
8	GYPSUM	Tons	165	458	7850000	17139,74	2828056,77	0,36	2828056,77	-45672381,88	-230,82	-55293503,06	-917539277,29	-1256551,59	0,30	-13701714,56	-69,25	-16588050,92	-275261783,19	-376965,48
9	OFF-GAS	Tons	53	62	63116000	1018000	53954000	0,85	53954000	-1411737534,68	-10317,11	-1039201842,58	-96512796120,97	-930755123,2	0,50	-705868767,34	-5158,55	-519600921,29	-48256398060,48	-465377561,61
10	SULPHURIC ACID	Tons	5	5	500000	100000	500000	1	500000	-54075524,08	-395,19	-39805830,78	-3696848882,50	-35651861,24	0,50	-27037762,04	-197,59	-19902915,39	-1848424441,25	-17825930,62
12	SALT FROM SALT SLAG	Tons	48	161	2050000	12732,92	611180,12	0,30	229192,55	-398068715,62	-181,71	-64090497,90	-2064605854	-10131012,12	0,56	-223306840,47	-101,94	-35953206,14	-1158193527,85	-5683250,70
17	OFF_GAS	Tons	13	13	156000	12000	156000	1	124800	-13883945,77	-5,76	-1193817,58	-496420859,50	-984856,29	0,75	-10412959,33	-4,32	-895363,19	-372315644,63	-738642,22
19	PROCESS GASES	Tons	44	44	388027	8818,80	388027	1	310422	-690686250	-286,39	-59388980	-24695506000	-48993758	0,75	-518014687,50	-214,79	-44541735	-18521629500	-36745318,50
22	REFRACTORY PRODUCTS	Tons	180	180	1009315	5607,31	1009315	1	1009315	-336269680	-280,43	-62051898	-3269935800	-6369779	1	-336269680	-280,43	-62051898	-3269935800	-6369779
23	SLAG	Tons	363	458	1000000	2183,41	792576,42	0,79	792576,42	-1104725984,28	-1417,60	-316185823,89	-13564894689,96	-35964920,88	0,20	-220945196,86	-283,52	-63237164,78	-2712978937,99	-7192984,18
24	SLAG	Tons	18	37	1973340	53333,51	960003,24	0,49	960003,24	0	0	0	0	0	0	0	0	0	0	0
29	RED MUD	Tons	160	160	6510000	40687,50	6510000	1	6510000	-4297804,70	-139,95	-30942968	-82922322	-124140,43	0,85	-3653134	-118,96	-26301522,80	-70483973,70	-105519,37
30	SLAG	Tons	36	37	24600000	664864,86	23935135,14	0,97	23935135,14	-3874232455,13	-6364,47	-4206053205,83	-61998868675,26	-124827538,71	0,23	-906570394,50	-1489,29	-984216450,17	-14507735270,01	-29209644,06
31	ALUMINIUM OXIDES FROM SALT SLAG	Tons	160	160	2050000	12812,50	2050000	1	1168500	-1609625419,65	-2496,33	-650798122,15	-25368926889,46	-47116938,73	0,56	-902960601,27	-1400,38	-365081873,40	-14231349230,67	-26431453,44
32	ALUMINIUM OXIDES FROM SALT SLAG	Tons	158	160	2050000	12812,50	2024375	0,99	1153893,75	0	0	0	0	0	0	0	0	0	0	0
35	EAF SLAG	Tons	99	180	13650450	75835,83	7507747,50	0,55	7507747,50	-2772932745	-1645,06	-807340875	-22777208300	-32782945,80	0,61	-1702580705,43	-1010,07	-495707297,25	-13985205896,20	-20128728,72
39	SULPHURIC ACID	Tons	5	5	500000	100000	500000	1	500000	0	0	0	0	0	0	0	0	0	0	0
47	COKE OVEN GAS	Nm3	37	42	22099000000	526166666,67	19468166666,67	0,88	1063726,06	-4651981457,14	-5306,60	-1034864346,67	-22412759866,67	-67353024	0	0	0	0	0	0
48	BLAST FURNACE GAS	Nm3	37	37	186048000000	5028324324,32	186048000000	1	17414,90	-38748316,90	-16,07	-3331792,16	-1385447131,80	-2748607,87	0	0	0	0	0	0
49	BASIC OXYGEN FURNACE GAS	Nm3	37	37	5017209302,33	135600251,41	5017209302,33	1	14435,39	-32118746,14	-13,32	-2761745,39	-1148406657,60	-2278339,97	0	0	0	0	0	0
50	LIMESTONE FINES	Tons	16	17	1462500	86029,41	1376470,59	0,94	1376470,59	-11554759,53	-31,33	-21000816	-278231614,12	-680234,31	0,95	-10977021,55	-29,77	-19950775,20	-264320033,41	-646222,59
66	BLAST FURNACE AND CONVERTER SLAG	Tons	34	37	24600000	664864,86	22605405,41	0,92	22605405,41	0	0	0	0	0	0	0	0	0	0	0
67	COOLING WATER	m3	54	97	174873600	1802820,62	97352313,40	0,56	97352313,40	0	0	0	0	0						
68	FLY ASH	Tons	105	105	1310767,50	12483,50	1310767,50	1	1310767,50	-515750749,21	-772,37	-134977328,90	-7478529570,61	-14583536,32	0,10	-51575074,92	-77,24	-13497732,89	-747852957,06	-1458353,63
69	FLY ASH	Tons	383	458	31616000	69030,57	26438707,42	0,84	21904469,10	-10402900205,06	-15578,99	-2722546891,62	-150844944403,04	-294155781,28	0,10	-1040290020,51	-1557,90	-272254689,16	-15084494440,30	-29415578,13
81	CRUDE ATMOSPHERIC DISTILLATION WW	Tons	96	97	327200	3373,20	323826,80	0,99	323826,80	-154040966,60	-200,10	-85918594,64	-18155497237,11	-5459239,82	0	0	0	0	0	0
82	WOOD WASTE	Tons	48	143	5768400	40338,46	1936246,15	0,34	1936246,15	-326495476,36	-749,66	-620210483,92	-6099043132,87	-32177427,36	0,20	-65299095,27	-149,93	-124042096,78	-1219808626,57	-6435485,47
86	CARCASE	Tons	604	1037	3906899	3767,50	2275570,87	0,58	2275570,87	-373172208,95	-899,30	-740777634,72	-6839868405,01	-36416612,63	0,79	-294806045,07	-710,44	-585214331,43	-5403496039,96	-28769123,98
87	WOOD WASTE	Tons	86	143	5768400	40338,46	3469107,69	0,60	3469107,69	-525327199,16	-1177,84	-1064064889,51	-10238896587,41	-54609594,06	0,20	-105065439,83	-235,57	-212812977,90	-2047779317,48	-10921918,81
89	COOLING WATER	m3	21	143	272000000	1902097,90	39944055,94	0,15	39944055,94	0	0	0	0	0						
95	SOLID WASTE FUEL FEEDSTOCK	Per T		266	5297000	19913,53	5297000	1	5297000	-16531145098,50	-8529,78	-3137052268,36	-355894041450	-340434969,42	0	0	0	0	0	0
97	OIL		266	266	4475965	16826,94	4475965	1	4475965	-17850755000	-4620,03	-1526884300	-274610380000	-107598850	N.A	N.A	N.A	N.A	N.A	N.A
98	BITUMEN				201286	756,71	201286	1	201286	-847467290	-508,05	-100833340	-12877988000	-4469289,10	N.A	N.A	N.A	N.A	N.A	N.A
100	GAS OIL				3739682	14058,95	3739682	1	3739682	-14980281000	-29514,52	-2337009600	-229767160000	-101192520	N.A	N.A	N.A	N.A	N.A	N.A

Table 33: Final environmental assessment - Overall potential (Source: Strane)

Total Potential	Savings	Units	Benchmark
Climate change (IPCC 2013)	91 773 743 900	[kg CO2-eq]	22 Million cars/y not driven [1]
Human health	98 835	[DALY]	1 200 lives saved [6] 4.7 Billion of cigarettes not smoked [2]
Ecosystem quality	24 031 836 256	[PDF.m2.y]	2.4 Million ha of forest saved from conversion to concrete [3]
Resources	1 559 479 648 764	[MJ]	266 barrels of oil not extracted [4]
Freshwater withdrawal	2 564 416 326	[m3]	1 Million Olympic size swimming pools [5]

Table 34: Final environmental assessment - Remaining potential (Source: Strane)

Remaining Potential	Savings	Units	Benchmark
Climate change (IPCC 2013)	13 668 050 021	[kg CO2-eq]	3.3 Million cars/y not driven [1]
Human health	17 379	[DALY]	213 lives saved 800 Million of cigarettes not smoked [2]
Ecosystem quality	5 408 511 897	[PDF.m2.y]	540 000 ha of forest saved from conversion to concrete [3]
Resources	296 809 137 532	[MJ]	50 Million barrels of oil not extracted [4]
Freshwater withdrawal	837 351 525	[m3]	335 000 Olympic size swimming pools [5]

[1] *Assumption one car travels 20'000 km/year*
[2] *2.09E-05 DALY / cigarette*
[3] *10'000 PDF.m^2.y / ha forest converted to concrete*
[4] *5'858 MJ primary energy / barrel of oil*
[5] *2'500 m3 water/Olympic size swimming pool*
[6]*Average life expectancy in Europe* [31]*(Source: https://www.statista.com/statistics/274514/life-expectancy-in-europe/)*

Data coloured in blue refer to resources involved in several synergies in the shortlist of the most impacting. A specific analysis was carried out to avoid double counting of benefits. Data coloured in red refer to currently unviable synergies for which no technical solution was identified to recover and convert the flow in valuable resource. The associated benefits have been neglected.

The result clearly shows the potential of industrial symbiosis in Europe from an environmental and human health benefit perspective. Each year, a wide implementation of the most impacting synergies in EU could lead to:

- 91 Million tons of CO_2 saving corresponding to 22 Million of cars not driven
- Other environmental and human health benefits to be considered with caution due to the high level of uncertainty of the screening LCA:
    - 98 835 [DALY] → 4.7 Billion of cigarettes not smoked

- 24 031 836 256 [PDF.m2.y] →2.4 Million ha of forest saved from conversion to concrete 3
- 1 559 479 648 764 [MJ] → 266 Million barrels of oil not extracted
- 2 564 416 326 [m3] → 1 Million Olympic swimming pools

Some of the most impacting synergies selected are known and already partially or totally exploited. The remaining potential for this shortlist of the most impacting synergies is still significant and could be reached by a wide implementation for all pairs of installation in a viable radius. Benefits to reach are:

- Additional 13,5 Million tons of CO_2 avoided corresponding to 3.3 Million cars/y not driven
- Other additional environmental benefits to be considered with caution due to the high level of uncertainty of the screening LCA:
    - 17 379 [DALY] → 800 Million of cigarettes not smoked
    - 5 408 511 897 [PDF.m2.y] → 540 000 ha of forest saved from conversion to concrete
    - 296 809 137 532 [MJ] → 50 Million barrels of oil not extracted
    - 837 351 525 [m3] → 335 000 Olympic size swimming pools

The remaining potential is still high and could be reached with economically viable synergies. Full final socio-economic assessment results and remaining potential are respectively presented in the Table 35 and the Table 36 and main results are gathered in the Table 37.

The annual European greenhouse gas emissions directly from industrial processes and product use is 383 369 150 tons CO2-eq per year [32] (considering all type of pollutants emitted). The wide implementation of the 38 most impacting synergies CO2 savings is equivalent to **24% of annual greenhouse gas emissions from industrial process and product use**. **3.6%** of annual greenhouse gas emissions from industrial process and product use **could be achieved by implementing IS**.

Table 35: Final socio-economic assessment results (source: Strane)

		Final SEA																					
#	Resource	Waste stream price in Baseline scenario (€/Unit)	Waste stream volume (Unit/y)	Substituted material equivalent price (€/Unit)	Final volume recovered (Unit/y)	Operational costs (€/y)	VA	VAT	Labour Share (€/y)	Direct jobs (number)	Indirect jobs (min)	Indirect jobs (max)	CAPEX	Total investment in EU	€ Climate change	€ DALY	€ Ecosystem quality	€ Use of resources	Sum of external economic impacts (€)	Carbon tax evolution (€/y)	Waste tax balance	Waste treatment costs balance (€/y)	Number of equipment required
1	COKE OVEN GAS	0,1	4840733333,3	0,2	2139604133,3	Unknown	-149089163,4	-31994534,5	-68581015,2	-1556,1	-778,1	-4699,6	35 €/Nm/h		34238240,3	13131849,5	51519841,9	61209459,8	160099391,5	-17119120148,3	0,0	0,0	
2	COKE OVEN GAS	0,1	4840733333,3	372,0	3340740,7	941454148,1	-284266999,2	-61003698,0	-130762819,6	-2967,1	-1483,5	-8960,6			179174963,9	153206676,6	366778298,4	485373657,1	1184533596,0	-89587481942,9	-593473906666,7	0,0	
3	PLF	197,2	16800,0	2636,0	7182,0		15618942,2	3351825,0	7184713,4	163,0	81,5	492,3			2099404,2	878809,3	2461368,7	1039578,9	6479161,1	-1049702115,0	-1179166,8	-1923600,0	
4	COKE RESIDUES	41,9	17600,0	210,0	17600,0		2959088,0	635020,3	1361180,5	30,9	15,4	93,3	No CAPEX	No Investment	942073,8	2399585,5	3907693,9	2475544,5	9724897,7	-471036896,0	-2157760,0	-3520000,0	
5	EAF DUSTS	0,0	1654600,0	2315,0	301334,4	146989789,3	550599431,4	118158638,0	253275738,4	5747,0	2873,5	17355,9		262481766,7	8492,6	36660,0	597748,6	4794,5	647695,8	-4246323,0	-52533769,2	-71858401,4	21,0
6	BOF SLAG	0,0	15360000,0	370,5	14592000,0	2330588160,0	3075310080,0	659961543,2	1414642636,8	32099,2	16049,6	96939,5	9,6	146855140,8	760800584,0	359900660,2	4008891852,0	273904889,2	5403497985,4	-380400292000,0	-566461440,0	-774835200,0	153,6
8	GYPSUM	0,0	2828056,8	20,0	2828056,8		56561135,4	12138019,7	26018122,3	590,4	295,2	1782,9	No CAPEX	No Investment	3653790,6	17080712,7	77410904,3	3670157,1	101815564,6	-1826895275,1	-109785163,8	-150169814,4	
9	OFF-GAS	0,0		90,9	53954000,0		4904418600,0	1052488231,6	2256032556,0	51190,9	25595,4	154596,4	2900000,0	357229680,4	112939002,8	763465973,9	1454882579,6	386051184,5	2717338740,8	-56469501387,1			124,0
10	SULPHURIC ACID	0,0		90,9	500000,0		45450000,0	9753570,0	20907000,0	474,4	237,2	1432,7	2900000,0	3310502,3	4326041,9	29243978,4	55728163,1	14787395,5	104085578,9	-2163020963,3			2,0
12	SALT FROM SALT SLAG	0,0	611180,1	66,5	229192,5		15241304,3	3270783,9	7011000,0	159,1	79,5	480,4	No CAPEX	No Investment	31845497,2	13446848,4	89726697,1	8258423,4	143277466,1	-15922748624,8	-8897254,7	-12170124,2	
17	OFF_GAS	899,0	156000,0	2269,7	124800,0	Unknown	143013312,0	30690656,8	65786123,5	1492,7	746,4	4508,0	10 000 - 50 000€/Nm3/h	6086142,3	1110715,7	426007,6	1671344,6	1985683,4	5193751,3	-555357831,0	0,0	0,0	20,3
19	PROCESS GASES	899,0	388027,0	2269,7	310422,0	Low, except for the purchase of the adsorbent	425492331,2	91310654,3	195726472,3	4441,2	2220,6	13412,3	10 000 - 50 000 € /1000 Nm3/h	15138381,7	55254900,0	21192649,8	83144572,0	98782024,0	258374145,8	-27627450000,0	0,0	0,0	50,5
22	REFRACTORY PRODUCTS	0,0	1009315,0	322,0	1009315,0		324999430,0	69744877,7	149499737,8	3392,2	1696,1	10244,6	Not available		26901574,4	20751612,8	86872657,2	13079743,2	147605587,6	-13450787200,0	-39181608,3	-201863000,0	
23	SLAG	0,0	792576,4	86,0	792576,4		68161572,1	14627473,4	31354323,1	711,5	355,7	2148,6	Not available	Unknow	88378078,7	104902637,8	442660153,4	54259578,8	690200448,8	-44189039371,2	-30767816,6	-158515283,8	
24	SLAG	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
29	RED MUD	0,0	6510000,0	462,6	6510000,0		3011721300,0	646315391,0	1385391798,0	31435,5	15717,7	94935,1	No CAPEX	No Investment	343824,4	10356553,8	43320155,2	331689,3	54352222,7	-171912188,0	-252718200,0	-1302000000,0	
30	SLAG	0,0	23935135,1	86,0	23935135,1		2058421621,6	441737280,0	946873945,9	21485,2	10742,6	64885,3	No CAPEX	No Investment	309938596,4	470971076,6	5888474488,2	247995474,7	6917379635,9	-154969298205,3	-929161945,9	-4787027027,0	
31	ALUMINIUM OXIDES FROM SALT SLAG	0,0	2050000,0	341,1	1168500,0	221021307,6	177554042,4	38103097,5	81674859,5	1853,3	926,6	5596,8	HIGH	Unknown	128770033,6	184728536,3	911117371,0	101475707,6	1326091648,4	-64385016785,9	-45361170,0	-233700000,0	
32	ALUMINIUM OXIDES FROM SALT SLAG	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
35	EAF SLAG		7507747,5	16,5	7507747,5		123877833,8	26584183,1	56983803,5	1293,0	646,5	3904,9	No CAPEX	No Investment	221834619,6	121734501,8	1130277225,0	91108833,2	1564955179,6	-110917309800,0	-291450758,0	-1501549500,0	
39	SULPHURIC ACID	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
47	COKE OVEN GAS	0,0	8839600000,0	0,1	8839600000,0		1069298829,4	229471528,8	491877461,5	11161,0	5580,5	33706,3			372158516,6	392688262,6	1448810085,3	89651039,5	2303307903,9	-186079258285,7	NA	0,0	
48	BLAST FURNACE GAS	0,0	74791296000,0	0,0	74791296000,0		1594308868,8	342138683,2	733382079,6	16640,9	8320,5	50255,6			3099865,4	1188932,8	4664509,0	5541788,5	14495095,7	-1549932675,8	NA	0,0	
49	BASIC OXYGEN FURNACE GAS	0,0	2047021395,3	0,1	2047021395,3		116362359,1	24971362,3	53526685,2	1214,6	607,3	3668,0			2569499,7	985514,6	3866443,5	4593626,6	12015084,4	-1284749845,4	NA	0,0	
50	LIMESTONE FINES	0,0	1376470,6	151,2	1376470,6		208122352,9	44663056,9	95736282,4	2172,3	1086,2	6560,4			924380,8	2318670,9	29401142,4	1112926,5	33757120,5	-462190381,2	-53434588,2	-73090588,2	
66	BLAST FURNACE AND CONVERTER SLAG	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
67	COOLING WATER			0,9	97352313,4		87617082,1	18802625,8	40303857,7	914,5	457,3	2761,9			0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
68	FLY ASH	0,0	1310767,5	45,1	1310767,5		59128721,9	12689023,7	27199212,1	617,2	308,6	1863,8			41260059,9	57155305,4	188968260,5	29914118,3	317297744,1	-20630029968,3	-50883994,4	-69601754,3	
69	FLY ASH	0,0	26438707,4	45,1	21904469,1		988110601,1	212048535,0	454530876,5	10313,6	5156,8	31147,1			832232016,4	1152845538,1	3811565648,3	603379777,6	6400022980,4	-416116008202,5	-850331490,5	-1163127309,2	
81	CRUDE ATMOSPHERIC DISTILLATION WW	0,0	323826,8	286,4	323826,8		92742876,0	19902621,2	42661723,0	968,0	484,0	2923,4	NA	NA	12323277,3	14807106,7	120286032,5	72621988,9	220038405,5	-6161638663,9	NA	NA	
82	WOOD WASTE	0,0	1936246,2	23,6	1936246,2		45611224,6	9788168,8	20981163,3	476,1	238,0	1437,8	NA	NA	26119638,1	55474934,8	868294677,5	24396172,5	974285422,9	-13059819054,5	NA	-102814670,8	
86	CARCASE	0,0	2275570,9	24,5	2275570,9		55838057,0	11982847,0	25685506,2	582,8	291,4	1760,1	NA	NA	29853776,7	66548003,7	1037088688,6	27359473,6	1160849942,6	-14926888358,0	NA	-120832813,4	
87	WOOD WASTE	0,0	3469107,7	23,6	3469107,7		81720110,8	17537135,8	37591251,0	853,0	426,5	2576,0	NA	NA	42026175,9	87160106,8	1489690845,3	40955586,3	1659832714,4	-21013087966,4	NA	-184209618,5	
89	COOLING WATER			1,3	39944055,9		50329510,5	10800713,0	23151574,8	525,3	262,7	1586,5	NA	NA	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
95	SOLID WASTE FUEL FEEDSTOCK	29,4	5297000,0	384,0	8416933,0	143040820,0	2933117772,0	629447073,9	1349234175,1	30615,0	15307,5	92457,3	NA	NA	1322491607,9	631203898,1	4391873175,7	1423576165,8	7769144847,5	-661245803940,0		-649412200,0	
97	OIL																						
98	BITUMEN																			-33898691600,0			
100	GAS OIL																			-599211240000,0			

Table 36: Remaining socio-economic potential (Source: Strane)

												Remaining Potential									
#	**Resource**	**Remaning potential ratio**	**Waste stream volume (Unit/y)**	**Final volume recovered (Unit/y)**	**Operational costs (€/y)**	**VA**	**VAT**	**Labour Share (€/y)**	**Direct jobs (number)**	**Indirect jobs (min)**	**Indirect jobs (max)**	**Total investment in EU**	**€ Climate change**	**€ DALY**	**€ Ecosystem quality**	**€ Use of resources**	**Sum of external economic impacts (€)**	**Carbon tax evolution (€/y)**	**Waste tax balance**	**Waste treatment costs balance (€/y)**	**Number of equipment required**
1	COKE OVEN GAS	0,00	0,00	0,00		0,00	0,00	0,00	0,00	0,00	0,00		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0
2	COKE OVEN GAS	1,00	4840733333,33	3340740,74	941454148,15	-284266999,18	-61003698,02	-130762819,62	-2967,09	-1483,55	-8960,63		179174963,89	165,63	20958759,91	9707473142,79	9907607032,22	-89587481942,90	-593473906666,7	0,00	0
3	PLF	1,00	16800,00	7182,00	0,00	15618942,19	3351824,99	7184713,41	163,03	81,51	492,34	0,00	2099404,23	0,95	140649,64	20791578,36	23031633,18	-1049702115,00	-1179166,80	-1923600,00	0
4	COKE RESIDUES	1,00	17600,00	17600,00	0,00	2959088,00	635020,28	1361180,48	30,89	15,44	93,28	0,00	942073,79	2,59	223296,79	49510890,88	50676264,06	-471036896,00	-2157760,00	-3520000,00	0
5	EAF DUSTS	0,34	562564,00	102453,71	49976528,38	187203806,67	40173936,91	86113751,07	1953,98	976,99	5901,01		2887,50	0,01	11613,40	32602,65	47103,56	-1443749,81	-17861481,52	-24431856,48	8
6	BASIC OXYGEN FURNACE SLAG	0,45	6865920,00	6522624,00	1041772907,52	1374663605,76	295002809,80	632345258,65	14348,33	7174,17	43331,96	89243800,68	340077861,05	173,92	102398551,88	2448709709,45	2891186296,29	-170038930524,00	-253208263,68	-346351334,40	69
8	GYPSUM	0,30	848417,03	848417,03	0,00	16968340,61	3641405,90	7805436,68	177,11	88,56	534,87	65644247,93	1096137,17	5,54	1327044,07	22020942,66	24444129,43	-548068582,53	-32935549,13	-45050944,32	0
9	OFF-GAS	0,50	0,00	26977000,00	0,00	2452209300,00	526244115,78	1128016278,00	25595,43	12797,72	77298,20		56469501,39	412,68	41568073,70	3860511844,84	3958549832,61	-28234750693,55	0,00	0,00	62
10	SULPHURIC ACID	0,50	0,00	250000,00	0,00	22725000,00	4876785,00	10453500,00	237,20	118,60	716,33	178614840,18	2163020,96	15,81	1592233,23	147873955,30	151629225,30	-1081510481,66	0,00	0,00	1
12	SALT FROM SALT SLAG	0,56	342857,14	128571,43	0,00	8550000,00	1834830,00	3933000,00	89,24	44,62	269,51	1655251,14	17864547,24	8,15	2876256,49	92655482,23	113396294,11	-8932273618,80	-4991142,86	-6827142,86	0
17	OFF_GAS	0,75	117000,00	93600,00		107259984,00	23017992,57	49339592,64	1119,55	559,77	3381,03		833036,75	0,35	71629,05	29785251,57	30689917,72	-416518373,21	0,00	0,00	15,22
19	PROCESS GASES	0,75	291020,25	232816,50		319119248,39	68482990,70	146794854,26	3330,87	1665,44	10059,23	4564606,74	41441175,00	17,18	3563338,80	1481730360,00	1526734890,98	-20720587500,00	0,00	0,00	37,85
22	REFRACTORY PRODUCTS	1,00	1009315,00	1009315,00	0,00	324999430,00	69744877,68	149499737,80	3392,25	1696,12	10244,59	11353786,28	26901574,40	22,43	4964151,84	261594864,00	293460612,67	-13450787200,00	-39181608,30	-201863000,00	0
23	SLAG	0,20	158515,28	158515,28	0,00	13632314,41	2925494,67	6270864,63	142,29	71,15	429,72	0,00	17675615,75	22,68	5058973,18	217038315,04	239772926,65	-8837807874,24	-6153563,32	-31703056,77	0
24	SLAG	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0
29	RED MUD	0,85	5533500,00	5533500,00	0,00	2559963105,00	549368082,33	1177583028,30	26720,13	13360,07	80694,80	0,00	292250,72	9,52	2104121,82	5638717,90	8035099,96	-146125359,80	-214810470,00	-1106700000,0	0
30	SLAG	0,23	5600821,62	5600821,62	0,00	481670659,46	103366523,52	221568503,35	5027,54	2513,77	15183,16		72525631,56	119,14	78737316,01	1160618821,60	1311881888,32	-36262815780,05	-217423895,35	-1120164324,3	0
31	ALUMINIUM OXIDES FROM SALT SLAG	0,56	1150000,00	655500,00	123987562,80	99603487,20	21374908,35	45817604,11	1039,63	519,82	3139,69		72236848,10	112,03	29206549,87	1138507938,45	1239951448,46	-36118424050,61	-25446510,00	-131100000,00	0
32	ALUMINIUM OXIDES FROM SALT SLAG	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0
35	EAF SLAG	0,61	4609756,97	4609756,97	0,00	76060989,92	16322688,44	34988055,36	793,90	396,95	2397,58	0,00	136206456,43	80,81	39656583,78	1118816471,70	1294679592,72	-68103228217,20	-178950765,38	-921951393,00	0
39	SULPHURIC ACID	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0
47	COKE OVEN GAS	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	NA	0,00	0
48	BLAST FURNACE GAS	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	NA	0,00	0
49	BASIC OXYGEN FURNACE GAS	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	NA	0,00	0
50	LIMESTONE FINES	0,95	1307647,06	1307647,06	0,00	197716235,29	42429904,09	90949468,24	2063,70	1031,85	6232,38	0,00	878161,72	2,38	1596062,02	21145602,67	23619828,79	-439080862,12	-50762858,82	-69436058,82	0
66	BLAST FURNACE AND CONVERTER SLAG	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0
67	COOLING WATER	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0
68	FLY ASH	0,10	131076,75	131076,75	0,00	5912872,19	1268902,37	2719921,21	61,72	30,86	186,38	0,00	4126005,99	6,18	1079818,63	59828236,56	65034067,37	-2063002996,83	-5088399,44	-6960175,43	0
69	FLY ASH	0,10	2643870,74	2190446,91	0,00	98811060,11	21204853,50	45453087,65	1031,36	515,68	3114,71	0,00	83223201,64	124,63	21780375,13	1206759555,22	1311763256,63	-41611600820,25	-85033149,05	-116312730,92	0
81	CRUDE ATMOSPHERIC DISTILLATION WW	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	NA	NA	0
82	WOOD WASTE	0,20	387249,23	387249,23	0,00	9122244,92	1957633,76	4196232,66	95,22	47,61	287,55		5223927,62	11,99	9923367,74	97584690,13	112731997,48	-2611963810,91	NA	-20562934,15	0
86	CARCASE	0,79	1797700,99	1797700,99	0,00	44112065,06	9466449,16	20291549,93	460,43	230,21	1390,49		23584483,61	56,84	46817146,51	432279683,20	502681370,15	-11792241802,79	NA	-95457922,58	0
87	WOOD WASTE	0,20	693821,54	693821,54	0,00	16344022,15	3507427,15	7518250,19	170,59	85,30	515,19		8405235,19	18,85	17025038,23	163822345,40	189252637,66	-4202617593,29	NA	-36841923,69	0
89	COOLING WATER	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0
95	SOLID WASTE FUEL FEEDSTOCK	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0
97	OIL																				
98	BITUMEN											0,00									
100	GAS OIL											0,00									

Table 37: Final socio-economic assessment and remaining potential (source: Strane)

	Final socio-economic assessment	Remaining potential
Operational costs (€/y)	3 783 094 225 €	2 157 191 147 €
VA	21 948 352 228 €	8 150 958 802 €
VAT	4 710 116 388 €	1 749 195 759 €
Labour Share (€/y)	10 096 242 025 €	3 749 441 049 €
Direct jobs (number)	229 090	85 077
Indirect jobs (min)	114 545	42 539
Indirect jobs (max)	691 853	256 933
Total investment in EU	791 101 614 €	351 076 533 €
€ Climate change	4 647 619 249 €	1 093 444 002 €
€ DALY	4 750 231 605 €	1 390 €
€ Ecosystem quality	28 093 952 623 €	432 680 952 €
€ Use of resources	4 168 896 483 €	23 744 731 003 €
Sum of external economic impacts (€)	41 660 699 960 €	25 270 857 346 €
Carbon tax evolution (€/y)	-2 956 919 555 999 €	-546 722 000 846 €
Waste tax balance	-596 758 212 793 €	-594 609 091 250 €
Waste treatment costs balance (€/y)	-11 562 220 905 €	-4 287 158 398 €
Number of equipment required	371	193

As well as for the environmental assessment, red and blue coloured data refer respectively to technically unviable synergies and resources involved in several synergies. Double counting of benefits was avoided and technically unfeasible synergies were not counted in the final result.

The result clearly shows the potential of industrial symbiosis in Europe from a social and economic perspective. Each year, the full implementation of the shortlist of most impacting synergies (more than 90% of the 100 synergies list potential) could generate massive economic benefits due to the intrinsic value of waste resources and associated potential job creation related to the synergy's operational exploitation. It could generate around **22 Billion € of added value** and associated **5 Billion € of VAT** for governments. This figure is to be compared with the Gross value added and income in Europe Union (28 countries) generated by industries (except construction) in 2019: 2 748 646.7 M€ [33]. **The share of these most impacting synergies in the EU industries Gross Added value is around 1% (i.e. 0.8%).**

This additional activity could generate **10 Billion € of labour share** so **230 000 direct industrial jobs** and a minimum of **115 000 indirect jobs**. Around **600 Billion € of taxes** (incineration or landfilling) would be avoided due to the valorisation of waste and waste management costs would be reduced by **11,5 Billion €** of waste management costs would be avoided. For indirect synergies requiring technologies with available CAPEX and OPEX data (CAPEX for synergies 5, 6, 9, 10, 17, 19; OPEX for synergies 2, 5, 6, 31 and 95), total investment for a wide implementation is about **800 Million €** to deploy **371 technologies** with **3.8 Million €** of annual operating costs. External negative impact on environment or human health would be avoided and about **42 Billion €** equivalent damages costs would be spared to the society, human community and environment. The equivalent water volume that wouldn't be drawn upon is **2.5 Billion m3** with a **10 Billion €** monetary equivalent value.

Part of this potential is already exploited but remaining benefits are still to be reached:

- **8 Billion € of value added** and 1.7 Billion € of VAT corresponding to **0.3% to EU industries Gross Added value**
- **3.7 Billion € of labour** share to create employment with **85 000 direct jobs** and at least **42 000 indirect jobs**
- **4.3 Billion €** of waste treatment costs
- Around **800 Million m3** of water withdrawals (equivalent to 3.2 Billion € for the use of this resource)

To reach this potential, Europe still needs to invest at least **350 Million €** to deploy **193 technologies** (These figures only refer to the indirect synergies for which CAPEX and treatment capacities are available and known).

The remaining potential allow to earn the last 37% of the overall potential but it could allow to generate more significant external benefits: 60% of all external monetary impact.

All results enable to have a quantified overview of the IS potential. This potential is related to heavy process industries in particular large volume production installations. There is therefore a significant potential to quantify with other synergies with medium-sized and small sized installations. Moreover, most of the time, large companies have dedicated service for waste management, by-products sales and alternative raw materials identification and they benefit from the expertise and feedback from all operating sites. Medium companies and SME are therefore the actors who need technical support and research programs to implement industrial symbiosis at their scale.

Heat Recovery

An overview of the IS potential concerning waste heat recovery was performed in the D3.4 [3] for some type of industries with available data on waste heat energy emitted.

Table 38: Heat recovery potential for some EU sites (source: Strane)

SECTOR	PROCESS	PROCESSES IN EU	KWh/y	GJ/y
INORGANIC CHEMICALS	PYROGENIC SILICA MANUFACTURING	6	120 000 960	432 000
FOOD DRINK AND MILK INDUSTRIES	SALAMI AND SAUSAGE PRODUTION	200	16 383 600 000	58 980 960
SLAUGHTERHOUSES	CATTLE SLAUGHTER PROCESS	2420	227 578 590	819 283
SLAUGHTERHOUSES	PIG SLAUGHTER PROCESS	576	1 508 238 375	5 429 658
SLAUGHTERHOUSES	POULTRY SLAUGHTER PROCESS	191	429 759 000	1 547 132

PRODUCTION OF PULP PAPER AND BOARD	MECHANICAL PULPING AND CHEMIMECHANICAL PULPING	72	37 620 000 000	135 432 000
WASTE INCINERATION	RECOVERY OF ENERGY NH	467	87 485 292 050	314 947 051
ORGANIC CHEMICALS	EHTYLBENZENE MANUFACTURING	10	18 707 700 000	67 347 720
ORGANIC CHEMICALS	STYRENE MANUFACTURING BY DEHYDROGENATION	7	5 952 450 000	21 428 820
ORGANIC CHEMICALS	STYRENE CO-PRODUCTION WITH PROPYLENE OXIDE	4	3 401 400 000	12 245 040
ORGANIC CHEMICALS	HYDROGEN PEROXIDE MANUFACTURING	23	1 147 231 400	4 130 000
		Total number of processes	**Total KWh/y**	**Total GJ/y**
		3976	**172 983 250 375**	**622 739 665**

The total amount of energy is around 622 739 665 GJ per year (173 TWh/y). The price of energy produced by natural combustion in boilers is detailed in Table 39.

Table 39: MWh price produced by natural gas combustion with boilers (Source: Strane)

T (°C)	Cost_MWh_th €/MWh
70	26,057
80	26,147
90	26,239
100	26,330
110	26,451
120	26,571
130	26,692
140	26,814
150	26,937
160	27,061
170	27,187
180	27,313
190	27,441
200	27,570
210	27,700
220	27,831
230	27,964
240	28,098
250	28,233
260	28,369
270	28,507
280	28,646
290	28,787
300	28,928
310	29,072
320	29,216
330	29,363
340	29,510
350	29,659
360	29,810
370	29,962
380	30,116
390	30,271
400	30,428
410	30,587
420	30,747
430	30,909
440	31,072
450	31,238
460	31,405
470	31,574
480	31,745
490	31,917
500	32,092
510	32,268
520	32,446
530	32,627
540	32,809
550	32,994
560	33,180
570	33,369
580	33,560
590	33,753
600	33,948
610	34,145
620	34,345
630	34,547
640	34,752
650	34,959
660	35,168
670	35,380
680	35,595
690	35,812
700	36,032
710	36,254
720	36,480
730	36,708
740	36,939
750	37,173
760	37,410
770	37,650
780	37,893
790	38,139
800	38,388
810	38,641
820	38,897
830	39,157
840	39,420
850	39,686
860	39,956
870	40,230
880	40,508
890	40,789
900	41,075
910	41,364
920	41,658
930	41,955
940	42,257
950	42,564
960	42,875
970	43,190
980	43,510
990	43,835
1000	44,165
1010	44,500
1020	44,840
1027	45,081
Average	**33,850**

A GJ of heat recovered generate around 9 000€ of value added and 34€ of external costs benefits (environmental and social impacts). The heat recovery potential on selected industries in enormous. This synergy is widely used but many sites do not recover heat despite a significant potential. A lot of sites are currently implementing heat recovery for internal use or external supply (industries and district heating).

The total potential across Europe is:

- 5 000 M€ of value added corresponding to **0.2% to EU industries Gross Added value**
- 1 200 M€ of VAT
- 61 000 job created (probably overestimated)
- A major decrease of environmental impact particularly on ecosystems quality and climate change.

Apply heat recovery in all industrial sites in EU would be a major challenge with enormous benefits for sites and communities.

The EPOS project had estimated that the steel, refining, and cement sectors may produce 317 TWh/year of waste heat. Additional deposits quantified here (large volume chemicals, slaughterhouses, food and drink industries, incineration, and pulp and paper companies) represent 172 TWh/year. The current consumption of district heating of 225 TWh/year. 52 million inhabitants live at less than 8km from a site in the EPOS Sector, representing a theoretical heat demand of 346 TWh/year. [11]. In the case of SCALER, developing district heating could replace the consumption of fossil fuels, saving additional 60 MtCO2 per year (1.2% of EU emissions). A minimum of 260 MtCO2 or 5.2% of the EU emissions (Some SCALER sectors added to EPOS sectors). However, this theoretical potential cannot be fully grasped since installing district heating requires infrastructures, favourable topology, adapted climatic conditions justifying such a capital-intensive investment, and social acceptance.

Steam Recovery

An overview of the IS potential concerning steam use was performed in the D3.4 [3] for a few type of industries with available data on steam generated.

Table 40: Steam recovery potential for some processes in EU (source: Strane)

SECTOR	PROCESS	NUMBER OF units IN EU	KWh/y	GJ/y
SLAUGHTERHOUSES	INCINERATION MEAT AND BONE MEAL	12	1 319 268 750	432 000
REFINING MINERAL OIL AND GAS	CATALYTIC CRACKING FCC PROCESS	61	8 688 871 875	31 279 939
STEEL	BASIC OXYGEN STEELMAKING AND CASTING MANUFACTURING	101	2 200 610 873	28 292 760

Total number of processes	Total KWh/y	Total GJ/y
174	**20 897 623 373**	**91 284 638**

The steam potential to produce energy in the selected industries is large. :

- 707 M€ of value added corresponding to 0.025% to EU industries Gross Added value
- 151 M€ of VAT
- 7 000 job in Europe (probably overestimated)
- A major decrease of environmental impact particularly on eco-systems quality and climate change due to fossil energy use saving.

20 TWh of steam could be recovered and would potentially lead to 10 Mtonnes of CO_2 saving corresponding to 0.4% of EU CO_2 emissions.

4. Conclusions and recommendations

This study aimed to create 2 key results:

- A full methodology to identify synergies and quantify their environmental, social and economic benefits
- The assessment of the potential of industrial symbiosis (IS) for major heavy industries in Europe and support evidence-based policy-making

Historically, IS cases emerged through local, uncoordinated, voluntary initiatives. Synergies are diverse (valorisation, mutualisation, massification), using diverse resources (material, energy from combustion, waste heat, equipment, human resources, immaterial resources) and involving simple, direct logistics or complex treatment.

Very few studies quantified the full potential of industrial symbiosis in a systematic manner, looking at synergies individually. The EPOS project (2015-2019) had initiated a detailed quantified assessment of synergies involving the steel, cement, minerals and refining sectors. This study has built on it and extended the assessment to a number of other sectors and with a more comprehensive, systematic method.

The industrial sectors covered in this study are: agro-industry, fertilisers, cement, lime, ceramics, combustion plants, glass, inorganic and organic chemicals, livestock farming, non-ferrous metals, paper, pharmaceuticals, refineries, slaughterhouses, steel, textiles, waste incineration, wastewater treatment plants.

The EU counts 10 226 facilities in the scope of sectors covered in the study. A focus was put on 100 representative synergies involving 6 656 industrial facilities with the following statistics:

- The total number of combinations among these sites is around 43 million.
- The average and median distances between all couples of facilities are 1 000 and 1 050km.
- 4% (1.67 million) are below 200 km, 0.5% (200 000) below 50 km, 0.01% (5 700) below 10km, 0.006% (2 700) below 1 km.

Distances below a few kilometres may be exploited by pipeline transportation for very valuable gaseous and liquid resources. Distance up to 1 000 km can be exploited by road or rail transport.

Europe counts 4 major, dense hotspots: Benelux, Western Germany and North of France; Northern Italy; Valencia region & the industrial district of Castellon; UK midlands. The main one is the Benelux, Western Germany and North of France hotspot with 210,000 km2 and

14% of EU installations with a very well-balanced distribution per type of sector. Northern Italy has 6.7% of all EU industrial sites particularly represented by tanning plants, cement plants and secondary steel. UK midlands, already identified as a medium hotspot in EOPS project mainly represented by glass, non-ferrous metals and other petrochemical activities. A 30km large hotspot is identified, Valencia region & the industrial district of Castellon, with a weak variety of industrial activities. Other medium industrial hotspot are located near Paris, Lyon, Eastern Germany & Prague, Barcelona, Krakow, Lisbon, Madrid.

27% of all heat emitting installations are directly located within large cities, plus 19% (432 facilities) in Functional Urban Areas. 2 200 opportunities of district heating (distance between heat producer and the nearest city downtown) were assessed. 10% are below 2.8 km, a distance relevant for district heating. Most opportunities are in the range 5 – 10 km. The peak of opportunities is at 3 – 4 km (345).

SCALER project followed an ambitious methodology by modelling process industries, setting up databases, creating matching algorithms to identify cross-sectorial synergies. This methodology produced a list of 100 synergies that are representative of the diversity of cases in industrial symbiosis, and credible in terms of technical feasibility, economic viability and potential impact.

The 100 synergies were firstly assessed technically (feasibility and associated procedures and technologies), environmentally (by performing a LCA comparing baselines scenarios and synergy scenarios) and socio-economically (by performing a socio-economic assessment). All results were combined and a dedicated methodology was used to classify and score synergies by using benefits quartiles. The scoring and ranking led to focus on the 38 most impacting synergies, representing 90% of the total environmental and socio-economic impact of the 100 synergies.

For this sample of 38 synergies, the total number of combinations in Europe is around 1 380 000, of which 21 501 are below an economically viable distance. The total volume is about 327 million tonnes of material, some of it being already implemented.

Around 85% of this total potential is already implemented. The total implementation of the 38 most impacting synergies in EU would save 91 Million tons of CO_2 (24% of the direct emissions from industrial processes), 98 835 DALY, 24 031 836 256 PDF.m2.y, 1 559 479 649 GJ and 2 564 Million m3 of water. The volume not yet implemented represents 13,5 Million tons of CO_2 savings (3.6% of direct emissions from industrial processes), 17 379 DALY, 5 408 511 897 PDF.m2.y, 296 809 Million MJ and 837 Million m3 of water.

These 38 synergies were found to be profitable and generating socio-economic benefits: 22 Billion € of added value (0.8% of the European industry added value), 5 Billion € of value added tax, 230 000 new direct industrial jobs and 115 000 new indirect jobs, 11,5 Billion € of waste management costs savings, 42 Billion € equivalent damages costs avoided, 2.5

Billion m3 of water savings. The remaining part not yet implemented is equivalent to 8 Billion € of value added (0.3% of the European industry added value), 1.7 Billion € of VAT, 85 000 new direct jobs and 42 000 new indirect jobs, 4.3 Billion € of waste treatment cost savings, and around 800 Million m3 of water savings.

Indirect synergies require a total investment about 800 Million € to deploy 371 technologies with 3.8 Million € of annual operating costs. The remaining part not yet implemented would require an investment of at least 350 Million € to deploy 193 technologies.

Heavy industries produce around 489 TWh waste heat, which could save 260Mt of CO_2 emissions (5.2% of the EU annual emissions). However, this theoretical potential cannot be fully grasped since installing district heating requires infrastructures, favourable topology, adapted climatic conditions justifying such a capital-intensive investment, and social acceptance. 20TWh of waste steam could also be recovered, saving 10Mtonnes of CO_2 (0.4% of EU annual emissions).

Recommendation for future work

The methodology used was overall effective to successfully identify 100 credible representative synergies, of which 67 % were found to be technically feasible after in-depth assessment. It successfully provided a quantitative estimate of environmental, human health and socio-economic benefits from industrial symbiosis in Europe. Some improvements could anyway be envisaged.

Web scrapping could be used to populate automatically a database of existing synergies. Developing an optimal ontology would enable to add a larger set of wastes and resources and to better link processes, technologies and resources within different databases.

Developing a comprehensive technology database could help assess the feasible and unfeasible synergies automatically. Technical data on technology productivity and consumables is highly dependent on the scale used. Better approximations can be obtained by productivity range pre-definition. Innovative synergies were the most challenging as no significant background was available and further studies need to be engaged on that synergies. Technically unfeasible synergies with today's resources represent a sizable volume of resources. R&D would be needed to develop economically viable solutions.

Data availability was one of the main challenges of this work. Despite an in-depth and extensive search for data, the environment and socio-economic assessment was difficult and some synergies were difficult to model. Industrial data are required to perform a full and valid socio-economic study. A key action for the future is to work on non-sensitive industrial data collection especially on resources quality used in processes and wastes generated. The main challenge is the confidentiality and the data security with competitors.

A direct contact with industry would help collect relevant information:

- Refining baseline scenarios for a given synergy type taking into account the industrial context and location
- Quantifying the distribution of synergies already in place within a synergy type in order to distinguish the practices already in place vs potential future synergies. This would assist in linking the environmental results to key enablers, incentives or barriers, ultimately contributing to defining the boundary conditions needed to produce the savings potential of these untapped synergies.
- Including more detailed transport and technology procedure data
- Considering more operational factors/issues

Recommendation for IS implementation in EU

Based on this representative sample of 100 synergies, industrial symbiosis was surprisingly found to be overall profitable. An overall investment of 800 M€ in equipment would generate 22 bn€ of added value per year and 1.7 bn€ VAT per year. The bottlenecks concern rather:

- The difficulty to identify relevant synergies and partners: New startups emerge (including the one created out of SCALER, Seitiss) to offer matching services to industrial facilities. Support schemes for such solutions could foster the exploration of synergies and facilitate their emergence. This is especially important for SMEs who do not have the resources to have expert teams on waste management and alternative raw material sourcing, unlike large companies.
- Waste management is not core business for industrial facilities. An investment capacity will be targeted in priority on production lines. Revolving subsidies for waste management equipment would support industrial facilities in installing such equipment. Since most synergies were found to be profitable, subsidies could be recovered over time and reallocated. The total budget would be therefore limited.
- When synergies would not be profitable, indirect benefits with local job creation and environmental benefits should deserve a special attention by local authorities, in view of possibly providing subsidies justified by the benefits of general interest reached.

The extended waste producer responsibility encourages industrial managers in finding optimal outlets for their wastes. Industrial symbiosis also helps them creating a link between the potential use of a waste resource to replace their own supplies of resources. Industrial symbiosis could therefore be considered in the GEREP repositories as a specific waste treatment mean (besides the existing D1-15 R1-13 codes). This would provide a clear measure of its deployment for policy makers. Waste repositories like EPRTR could be completed with best practices and initiatives.

Synergies with proven economic and environmental viability should be encouraged, especially by updating the Best Reference Documents.

Overall, this work provided an in-depth review of a representative set of synergies. It was shown that industrial symbiosis is overall profitable and benefits to the society and the environment. These findings can hopefully support policy-making in order to widely deploy industrial symbiosis in Europe.

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