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“Carbon4PUR - Turning industrial waste gases (mixed CO/CO_2 streams) into intermediates for polyurethane plastics for rigid foams/building insulation and coatings”

Research and Innovation Action

Topic: [SPIRE-08-2017] Carbon dioxide utilisation to produce added value chemicals

Deliverable 7.1:
Mapping of CO_2/CO (CO/CO_2) mixed and pure sources in Europe

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The Carbon4PUR Consortium

#	Participant Legal Name	Short Name	Country
1.	Covestro Deutschland AG *(Project Coordinator)*	COV	Germany
2.	Recticel N.V.	Recticel	Belgium
3.	Viomichania Ritinon Megaron Anastasios Fanis Anonymos Etairia	Megara	Greece
4.	Universiteit Gent	UGent	Belgium
5.	Universiteit Leiden	UL	Netherlands
6.	Dechema Gesellschaft für chemische Technik und Biotechnologie e.V.	Dechema	Germany
7.	Technische Universität Berlin	TUB	Germany
8.	Commissariat à l'énergie atomique et aux énergies alternatives	CEA	France
9.	ArcelorMittal Maizières Research SA	AMMR	France
10.	South Pole Carbon Asset Management Ltd.	SPG	Switzerland
11.	Grand Port Maritime de Marseille	MFPA	France
12.	Rheinisch-westfälische technische Hochschule Aachen*	RWTH	Germany
13.	PNO Consultants BV	PNO	Netherlands
14.	Imperial College of Science Technology and Medicine	ICL	UK

* At the RWTH two departments are involved: RWTH-AVT (Aachener Verfahrenstechnik) and RWTH-CAT (Catalytic Center)

Acronyms and Definitions

Acronym	Defined as
CCU	Carbon Capture and Utilisation
E-PRTR	European Pollutant Release and Transfer Register
LCA	Life Cycle Assessment

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1. The Carbon4PUR project

Carbon4PUR aims at turning industrial waste gases (byproduct exhaust gas streams and flue gas streams of steel industry/mixed CO/CO_2 streams) into intermediates for polyurethane plastics for rigid foams/building insulation and coatings.

The industrially driven, multidisciplinary consortium will develop and demonstrate a novel process based on direct chemical steel mill gas mixture conversion. The interdisciplinary consortium consists of 14 partners from seven European countries and across sectors: four industries (COV, Recticel, Megara, AMMR), five universities (UGent, UL, TUB, RWTH, ICL), one association (Dechema), one research organization (CEA), two service providers (PNO, SPG) and the Grand Port Maritime de Marseille-Fos.

Both the consortium and the work are organized along the full value chain starting with the provision and conditioning of industrial emissions from a steel (AMMR, UGent) to a chemical company (COV) in line with the concept of industrial symbiosis exemplarily at Marseille Fos, going through the transformation into chemical building blocks (CEA, RWTH and COV), which will be further transformed into polymer intermediates (RWTH, COV) and flow into desired sustainable polyurethane applications of rigid foams and coatings (Recticel, Megara). LCA and technology evaluation will be done (UL, RWTH, TUB, SPG) and replication strategies to transfer the technology to other applications will be elaborated (Dechema, PNO, ICL).

The distinctive feature of the developed process is avoiding resource-intense separation of the gas components before the synthesis, and developing a chemo-catalytic process to deal directly with the gas mixture. The challenge and innovation is coming up with an adjustable process in terms of on-purpose and demand tailor-made production of required products, taking into account all variables at the same time: the available steel mill gases characteristic from the steel plant, material and process parameters, and the market requirements for the end product, thus flexibly involving the whole value chain with best results and possibly lower the prices.

2. Objectives and Overview

The mapping of sources and replication potential aims to identify and locate relevant CO and CO_2 sources, chemical production sites in Europe and relevant for the deployment of Carbon4PUR processes in industrial symbiosis settings. The level of information and functionality of the mapping are based on publicly available data sets and interaction with relevant industry companies and industrial associations. The main data elements reported to the user include location, emission volumes, concentration and purity levels of CO and CO_2 mixed sources.

The mapping team comprised of ICL and DECHEMA helped identify suitable sources combining literature review on compatibility of sources with discussions with catalysis specialists and product process engineers. The mapping reflects availability of suitable sources, after considering the level of potential impurities, showing how their scale and location can be conducive to deploying the Carbon4PUR process.

The mapping tool is designed to illustrate the potential from the demand or uptake side of the symbiosis. The mapping will also help to focus attention on large and medium sized stationary industrial installations.

In practice, the tool is meant to enable users to evaluate the potential to use CO and CO_2 accessible for demand sites by identifying locations with favourable conditions. The interactive visualization is integrated in the Carbon4PUR website and available to the public. It will ultimately enable all users to make a first assessment of potential for polyurethane production using industrial gases in Europe.

3. Procedure and data resources used

To visualize the potential of CO/CO_2 sources and demand sites, installations with emissions compatible with the Carbon4PUR process have been identified and displayed as suitable sources. Information on their location and emission amounts has been extracted from the European Pollutant Release and Transfer Register (E-PRTR) database. Also, a list of possible "consumers" that could convert the CO/CO_2 to polyols has been compiled.

3.1 Emissions from industrial sources

3.1.1 Processes compatible with Carbon4PUR

Carbon4PUR investigates two possible cleaning steps: a catalytic process and a chemical looping. With the help of consortium partners involved in those cleaning steps, the gas input requirements were identified. From a list of industrial process emissions, those fulfilling the requirements were matched as shown in Table 1.

Table 1: *Requirements and suitable processes for Carbon4PUR cleaning steps*

Conversion route	Requirements	Suitable processes
Catalytic process	• Needs approx. 90% CO/CO_2 • CH_4 can be tolerated • Tolerates impurities, but inerts will end up in output stream • More CO_2 than CO is better	• Acheson • Steel gases
Chemical looping	• Needs at least 30-40% CO_2. Can be lowered a bit if CO is present • No CO needed • Reductant (CH_4, H_2, CO) needs to be at least equal to CO_2 (1 H_2 can reduce 1 CO_2, CH_4 can reduce 3) • Flushing introduces currently 50% of N_2, might be lowered	• Acheson • Biogas (before and after combustion) • Pyrolysis gas (after partial combustion) (maybe mixed with CO_2) • Refineries (after partial combustion) • Steam crackers (after partial combustion) • Steel gases • *Cement/lime kiln could be used when mixed with natural gas and O_2 removed* • *Note: ammonia plants contain only pure CO_2 (no reductant) and are thus not suitable unless mixed*

3.1.2 E-PRTR database

The European Pollutant Release and Transfer Register (E-PRTR) is the Europe-wide database that provides easily accessible key environmental data from industrial facilities in European Union Member States and in Iceland, Liechtenstein, Norway, Serbia and Switzerland. It replaced and improved upon the previous European Pollutant Emission Register (EPER).

Among others, it contains all CO/CO_2 emissions from industrial facilities in Europe above a certain threshold (100 kt/y CO_2 and 500 t/y CO), which corresponds to our goal to analyse the replication potential for large and medium sized industrial installations.

To classify the emissions, E-PRTR contains information on the NACE category of each facility. Each NACE category code (from "nomenclature statistique des activités économiques dans la Communauté européenne") is a “Statistical Classification of Economic Activities in the European Community”. This work included identifying and representing all NACE codes of the sources deemed suitable according to literature review and project technical discussions.

3.1.3 Combination and presentation

- We created a list of compatible processes and their corresponding NACE category.
- We then downloaded the emissions data from E-PRTR for all identified NACE categories. The NACE category from the database allows us to filter the database to only include those NACE categories containing the suitable processes from Table 1. This procedure allows us to narrow down the emissions, but does not ensure that only, or all, suitable process emissions are displayed.
- We created filters for each cleaning step.
- IMPORTANT: within a NACE category, there are more than just the processes we identified. This approach will therefore yield processes that do not necessarily fit all criteria. Once promising sites have been identified, it is up to the expert or project developer to check if the processes emitting CO/CO_2 are compatible with the cleaning steps. For the NACE category “production of electricity”, this is especially important as it is the biggest CO_2 producer in this tool.

- IMPORTANT: CO emissions from the E-PRTR are only emissions to air. Most processes involving CO like steel mills handle approximately 15 times more CO than what they finally emit, with the rest being burnt in a power plant. Therefore, CO availability might be orders of magnitude higher than what is shown in the tool.

3.2 Chemical parks and polyol plants

3.2.1 List of chemical parks in Europe

- This list has been compiled by DECHEMA for CarbonNext from different sources, but mainly from www.chemicalparks.eu.
- It is not an exhaustive list but contains all the important chemical parks known to us.
- The list can be found in Table 2.

3.2.2 List of polyol plants in Europe

- The list has been compiled through desk research from various sources
- The list can be found in Table 3.

3.2.3 Ethylene (oxide) and propylene (oxide) sources and pipelines

To make a meaningful decision regarding potential pilot and replication sites, the educts supply must be guaranteed and mapped. Besides CO/CO_2, ethylene and/or propylene are required for the preparation of the novel Carbon4PUR polyols. Therefore, a preliminary desk research has been conducted to determine, which of the above mentioned chemical parks and polyol plants are connected to at least one pipeline providing ethylene or propylene supply or have a local availability of one of these alkenes. Although the availability alone does not qualify a potential site it is a necessary prerequisite for the first assessment, as the actually required oxides, i.e., ethylene oxide and propylene oxide, must be prepared directly on site.

The used sources have been found by a thorough desk research following an iterative strategy of:

First, determining the ethylene and propylene pipelines throughout Europe using available pipeline maps published by the main pipeline infrastructure providers, *e.g.*, ARG[1], RC2[1], ISH[2], ISG[3], EPS[4], Sabic[5] as well as public reports[6] and a regularly updated interactive maps and databases provided by the GTAI[7] and the ECSPP[8,9,10,11] (European Chemical Site Promotion Platform).

Second, determining the local availability of ethylene and/or propylene at sites which are not connected to the pipeline system. Therefore, the regularly updated database at chemietechnik.de[12] has been used.

The results can be found in Table 2 and Table 3.

[1] ARGmbH & Co. KG; formerly Aethylen-Rohrleitungsgesellschaft; https://argkg.com/

[2] Infraserv GmbH & Co. Höchst KG; https://www.infraserv.com/en/standortbetrieb/energien_1/technische_gase_und_medien/ethylen_transport/ethylen_transp_grbild.html

[3] InfraServ GmbH & Co. Gendorf KG; https://www.infraserv.gendorf.de/en/CP%20-%20Nachhaltiges%20Wachstum%20am%20Chemiepark%20GENDORF/B-501%20Versorgung%20mit%20Strom%20Erdgas%20und%20Medien?id=E-528

[4] Ethylen-Pipeline-Süd; https://www.eps-pipeline.de/pipeline/verbund.html

[5] https://www.sabic.com/en/about/ehss/sabic-uk-pipelines

[6] “An Overview of the Pipeline Networks of Europe”, ECSPP (European Chemical Site Promotion Platform), https://chemicalparks.eu/attachments/14/download, publication date not available.

[7] German Trade and Invest; https://www.gtai.de/GTAI/Navigation/EN/Invest/Industries/Chemicals-materials/Chemicals/chemical-parks-in-germany.html

[8] Sites with ethylene grid connection: https://chemicalparks.eu/substances/74-85-1

[9] Sites with propylene grid connection: https://chemicalparks.eu/substances/115-07-1

[10] Sites with ethylene oxide grid connection: https://chemicalparks.eu/substances/75-56-9

[11] Sites with propylene oxide grid connection: https://chemicalparks.eu/substances/75-56-9

[12] Marktübersicht Industrieparks Chemie, Pharma, Biotech; https://marktuebersichten.chemietechnik.de/mu-industrieparks-chemie-pharma-biotech

Table 2: *List of chemical parks in Europe known to us*

Country	Facility Name	Longitude	Latitude	Has Ethylene pipeline	Has Ethylene	Has Ethylene oxide	Has propylene pipeline	Has propylene	Has propylene oxide
Austria	Chemiepark Linz	14.332	48.289	0	0	0	0	0	0
Austria	Schwechat	16.476	48.141	1	1		1	1	
Belgium	INEOS Antwerp site	4.286	51.325	1	1		1	1	
Belgium	Port Of Antwerp	4.394	51.244	1	1		1	1	
Belgium	Tessenderloo	5.088	51.064	1	1			1	
Estonia	Kohtla-Järve	27.224	59.389						
Finland	Kokkola Industrial Park	21.672	63.111						
Finland	Porvoo	25.665	60.393						
France	Chemparc. Aquitaine	-0.637	43.417						
France	Fos-Lavera-Berre	4.863	43.445						
France	Port Jérôme	0.534	49.482						
France	Port of Le Havre	0.147	49.472	1	1		1	1	
France	Port of Rouen	1.073	49.445						
Germany	Agro-Chemie Park Piesteritz	12.583	51.873						
Germany	BASF Schwarzheide GmbH	13.877	51.479	0	1	1	0	1	1
Germany	BASF SE. Ludwigshafen	8.434	49.495	1	1	1	1	1	1
Germany	Castrop-Rauxel	7.315	51.563	0	1	0	0	0	0
Germany	ChemCoast Park Brunsbüttel	9.165	53.908	1	1	0	0	0	0
Germany	ChemiePark Bitterfeld Wolfen	12.306	51.625	0	0	0	0	0	0
Germany	Chemiepark Knapsack	6.853	50.860	1	1	0	1	1	0
Germany	Chemie- und Industriepark Zeitz	12.194	51.068	0	0	0	0	0	0
Germany	Chempark Dormagen	6.829	51.078	1	1	1	1	1	1
Germany	Chempark Leverkusen Currenta	6.992	51.013	0	0		0	0	
Germany	GENDORF Chemical Park	12.722	48.178	1	1	1	0	1	1
Germany	Industrial Park Dorsten-Marl	7.087	51.686	1	1		1	1	

Table 2 - continued: *List of chemical parks in Europe known to us*

Country	Facility Name	Longitude	Latitude	Has Ethylene pipeline	Has Ethylene	Has Ethylene oxide	Has propylene pipeline	Has propylene	Has propylene oxide
Germany	Industriepark Höchst	8.537	50.086	1	1		1	1	
Germany	IndustriePark Lingen	7.308	52.486	0	0		0	0	
Germany	Industriepark Premnitz	12.352	52.534	0	0		0	0	
Germany	Industriepark Schwarze Pumpe	14.371	51.523	0	0		0	0	
Germany	Industriepark Solvay Rheinberg	6.579	51.565	1	1				
Germany	industriepark walsrode	9.658	52.905	0	0		0	0	
Germany	InfraLeuna GmbH	12.004	51.325	1	1	0			
Germany	Krefeld-Uerdingen Currenta	6.664	51.375	1	1		1	1	
Germany	Marl Chemical Park	7.082	51.682	1	1		1	1	
Germany	NUON Industriepark Oberbruch	6.141	51.059	0	0		0	0	
Germany	Schkopau	11.985	51.390	1	1		1	1	
Germany	Schwedt/Oder PCK Raffinerie GmbH	14.231	53.093	0	0		1	1	
Germany	Stade	9.471	53.593	1	1				
Germany	Wolfgang Industrial Park	8.965	50.119	0	0		0	0	
Germany	Vynova Wilhelmshaven	8.059	53.623	0	1	0	0	0	0
Germany	Henkel AG & Co. KGaA	6.838	51.181		1	1		1	1
Germany	BIZZPARK Oberbruch - Der Standort 3.0	6.143	51.058	0	0		0	0	
Germany	Chemical Park Knapsack	6.850	50.860	1	1	0	1	1	
Germany	Evonik Site Lülsdorf	7.003	50.827	1	1	0	0	0	
Germany	Industriepark Köln - Merkenich	6.939	51.018	1	1	0	0	0	
Germany	Solvay's Industrial Park in Bernburg	11.754	51.799	0	0		0	0	
Germany	Industrial Park Bayer Bitterfeld	12.288	51.660	0	0		0	0	
Germany	Evonik Site Darmstadt/Weiterstadt	8.617	49.885	0	0		0	0	

Table 2 - continued: *List of chemical parks in Europe known to us*

Country	Facility Name	Longitude	Latitude	Has Ethylene pipeline	Has Ethylene	Has Ethylene oxide	Has propylene pipeline	Has propylene	Has propylene oxide
Germany	Kalle-Albert Industrial Park	8.246	50.037	0	0		0	0	
Germany	Allessa GmbH	8.767	50.129	0	0		0	0	
Germany	Industry Centre Obernburg Mainsite GmbH	9.152	49.829	0	0		0	0	
Germany	BASF Lampertheim GmbH	8.439	49.618	0	0		0	0	
Germany	SOLVAY Acetow GmbH	7.844	48.020	0	0		0	0	
Germany	Industrial Park Gersthofen	10.879	48.444	0	0		0	0	
Germany	Chemiepark Trostberg	12.552	48.021	0	0		0	0	
Germany	DOW Olefinverbund Böhlen	51.188	12.360	1	1				
Germany	Basell Polyolefine	48.758	11.709	1	1				
Hungary	Pétfürdö	18.122	47.171						
Iceland	Hellisheiði ON-Power	-21.403	64.037						
Ireland	Monksland	-7.992	53.420						
Italy	Porto Marghera	12.267	45.463						
Poland	Środa Śląska	16.613	51.166						
Poland	Turek	18.501	52.015						
Portugal	ZILS - Sines Industrial and Logistics Zone	-8.833	37.983						
Slovakia	Strážske Chemko	21.809	48.875						
Spain	AEQT - Tarragona Chemical Cluster	1.246	41.120	1	1	1	1	1	1
Spain	Huelva	-6.945	37.261						
Sweden	Stenungsund	11.829	58.068						
Switzerland	Infrapark Baselland	7.665	47.533						
Switzerland	Solvay Ind.park	8.312	47.577						
The Netherlands	Chemelot	5.793	50.974	1	1	0	1	1	0
The Netherlands	Chemical Cluster Delfzijl	6.948	53.317						

Table 2 - continued: *List of chemical parks in Europe known to us*

Country	Facility Name	Longitude	Latitude	Has Ethylene pipeline	Has Ethylene	Has Ethylene oxide	Has propylene pipeline	Has propylene	Has propylene oxide
The Netherlands	EMMTEC Industry & Business Park	6.907	52.775						
The Netherlands	Port of Amsterdam	4.915	52.378	1	1		1	1	
The Netherlands	Port of Rotterdam	4.145	51.950	1	1				
The Netherlands	Valuepark Terneuzen	3.823	51.334	1	1		1	1	
United Kingdom	AkzoNobel R&D center Felling UK	-1.560	54.958						
United Kingdom	Grangemouth	-3.723	56.010	1	1				
United Kingdom	Saltend Chemicals Parks	-0.240	53.736	1	1		0	0	
United Kingdom	Wilton International	-1.095	54.580	1	1	1			

Table 3: *List of polyol plants in Europe known to us*

Country	Facility Name	Longitude	Latitude	Has Ethylene pipeline	Has Ethylene	Has Ethylene oxide	Has propylene pipeline	Has propylene	Has propylene oxide
Belgium	BASF Antwerpen N.V.	51.365	4.271	1	1		1	1	
Belgium	Covestro Tielt N.V.	51.290	4.325	1	1		1	1	
Belgium	Polyol Belgium N.V.	50.479	3.793						
France	CovestroFrance SNC	43.424	4.845						
Germany	BASF/Schwarzheide GmbH	51.478	13.875						
Germany	Covestro Deutschland AG	51.083	6.842	1	1		1	1	
Hungary	MOL Petrochemicals Plc.	47.918	21.027						
Hungary	BorsodChem	48.246	20.646						
Lithuania	NEO Group	55.674	21.224						
Netherlands	Dow Benelux N.V.	51.335	3.789	1	1		1	1	
Netherlands	Huntsman Holland B.V.	51.885	4.255	1	1		1	1	
Netherlands	Shell Nederland Chemie B.V.	51.880	4.341	1	1		1	1	
Poland	PCC Rokita S.A.	51.270	16.734						
Romania	Oltchim	45.041	24.298						
Slovakia	Fortischem	48.706	18.533						
Slowakia	MOL Petrochemicals Plc.	48.125	17.177e						
Spain	Dow Chemical Iberica S.A.	41.102	1.190						
Spain	Repsol Quinica S.A.	41.187	1.222						
Spain	Repsol Quinica S.A.	38.679	-4.056						

4. Overview of the tool

4.1 General presentation

A central objective of Carbon4PUR is to enable industrial symbiosis in Europe. The project harnesses the information potential of industrial emissions data in the European Pollutant Release and Transfer Register (E-PRTR). The visualization concept uses a gradual, logical sequence to select and present data to enable emitters and potential emission receivers to identify or plan resources for a symbiosis scheme or a regional strategy. Users select and deselect data to gain an overview of the potential across Europe relevant to their situation. The self-contained visualization tool is accessible from the project website at:

- https://www.carbon4pur.eu/outcomes/mapping-tool/

The stand-alone version of the tool can be found at:

- https://carbon4pur.github.io/mapping/

In addition, all data results and source code underlying the visualization are accessible at:

- https://github.com/Carbon4PUR/mapping/

The landing page displays default settings for chemical routes and availability of sources across a feasible radius as shown in Figure 1. Tabs on this page provide additional information on resources and guide the process of identifying first sources and then receiving sites including filtering and customization options. A tutorial following this logic is included in the landing page to increase user accessibility.

The funding from the EU is mentioned on the landing page, the disclaimer is included in the "Data, Licences, Privacy" page.

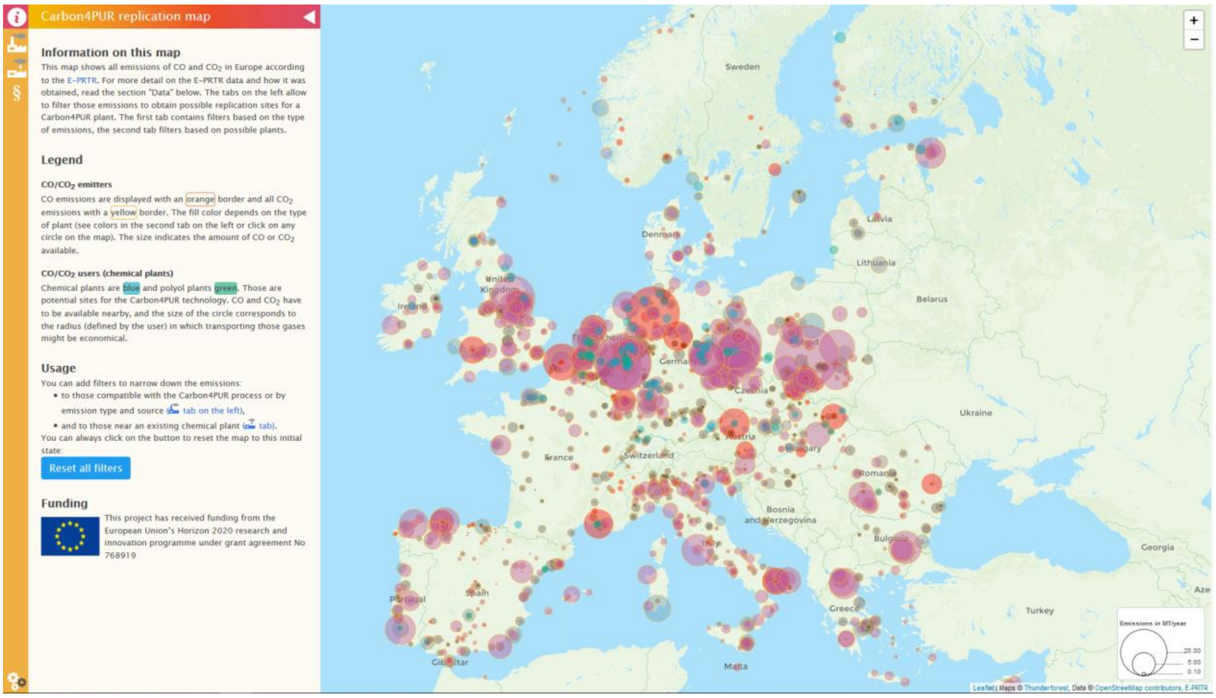

Figure 1: *Presentation on mapping tool landing page.*

4.2 Filtering possibilities

Users that have either followed the tutorial or read the information tab can start configuring visualizations for their own purposes. The first step is to select or deselect industrial processes that can act as sources of CO/CO_2 streams according to their suitability for each of the chemical routes. Each route, be it chemical looping or catalytic cleaning, requires different auxiliary inputs and therefore could work under symbiosis schemes involving different partners. Users can manually select processes relevant to their business or policy objectives.

Public and private sector users as well as researchers have particular needs. The tool is adaptable to all initial scoping situations. Selection and filtering capabilities help public sector users to investigate medium-term infrastructure needs and opportunities. By contrast, private sector users such as investors, project developers or industrial park managers can identify opportunities for by-product use, utility optimization and new, purpose-built symbiosis planning. Finally, researchers can develop early-stage scientific scenario analysis for technical and economic viability of multiple symbioses for regional resource efficiency. This can help to further investigate compatibility characteristics and formulate symbiosis specification guidelines.

Simple and intuitive filtering options are prominent on the customization panel on the left of the screen as shown on Figure 2. Users have the option to manually select and deselect their preferred chemical route or to manually include or exclude individual industrial process types. Subsequently, then can decide whether to evaluate availability of CO or CO_2 or both. In case of choosing manual selection of processes they can combine identifying for example only CO sources from one or very few relevant processes. The tool provides an interactive statistics panel underneath the selection buttons showing the total emissions resulting from the settings chosen both as aggregated as well as total from all relevant sites with combined CO/CO_2 emissions.

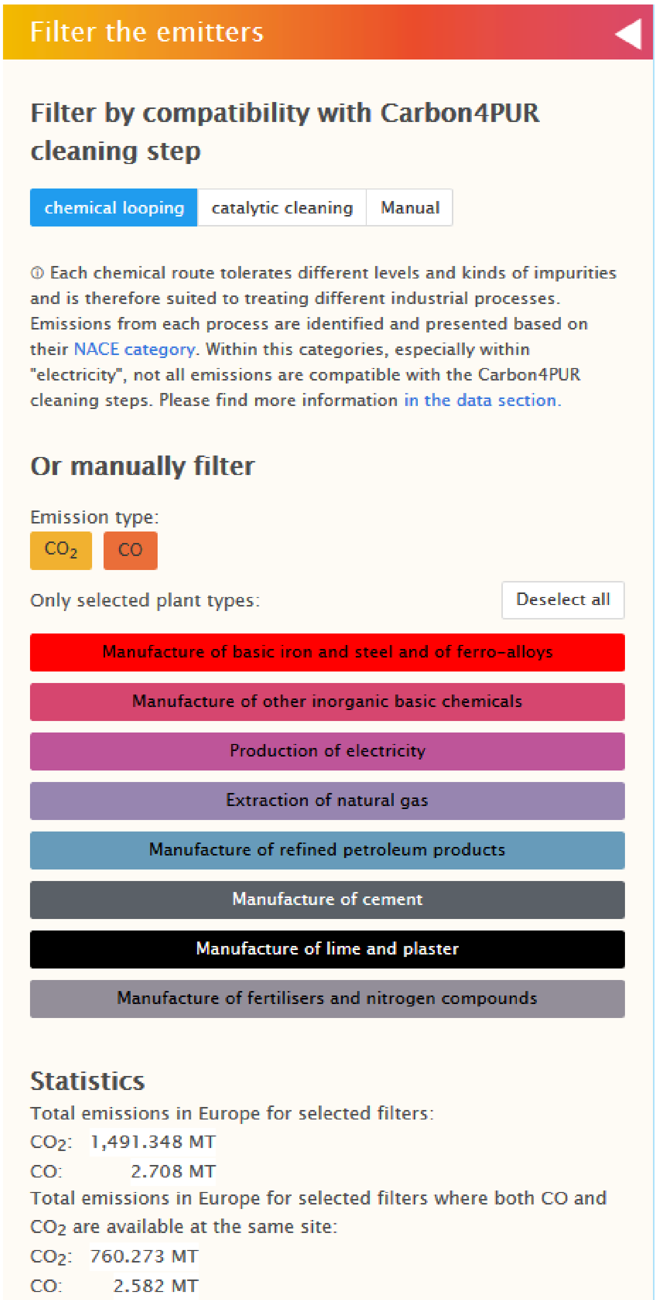

Figure 2: *Emission identification by properties and resulting statistics.*

Apart from identifying emissions, planning a symbiosis for polyol production can start with analyses of receiving plants where the synthesis can happen. Users have the ability to locate potential receiving plants according to current activity either by focusing on polyol plants or more generally targeting chemical production sites.

The tool can highlight the availability of suitable sources within a feasible radius based on expertise on logistics for industrial parks. In addition, the users can adjust the distance or radius within which they are prepared to look for potential partners using the green slide bar labelled “Search radius around plants”. Users also have the option to change the target plant size along the black and white slide bar labelled “Filter by possible Carbon4PUR plant size” according to their level of investment or regional development interest as shown on Figure 3.

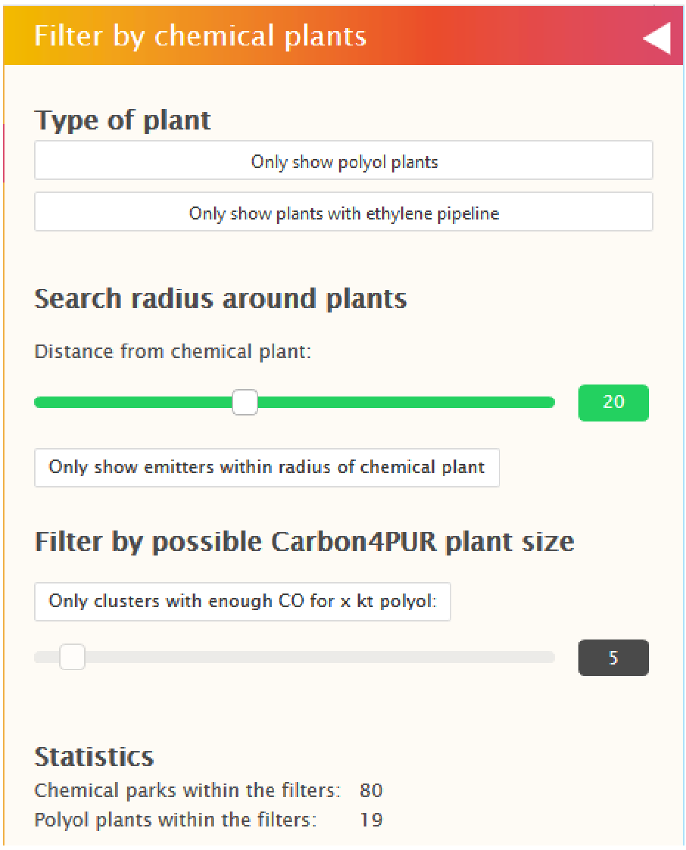

Figure 3: *Filtering chemical parks by type, identifying emissions by distance to chemical parks and filtering by uptake plant size.*

4.3 Analytics

At the same time of selecting type of chemical plant, uptake plant size and distance of emissions from plant, users can hover over a selected emission point to visualize interactive data specific to that site including trading name of the installation, explanation of activity based on NACE code, e.g. manufacture of steel and the annual emissions in million metric tonnes per year. Figure 4 shows interactive data of an emission plant as well as two highlighted radiuses around two potential receiving plants, namely a polyol plant and a chemical park.

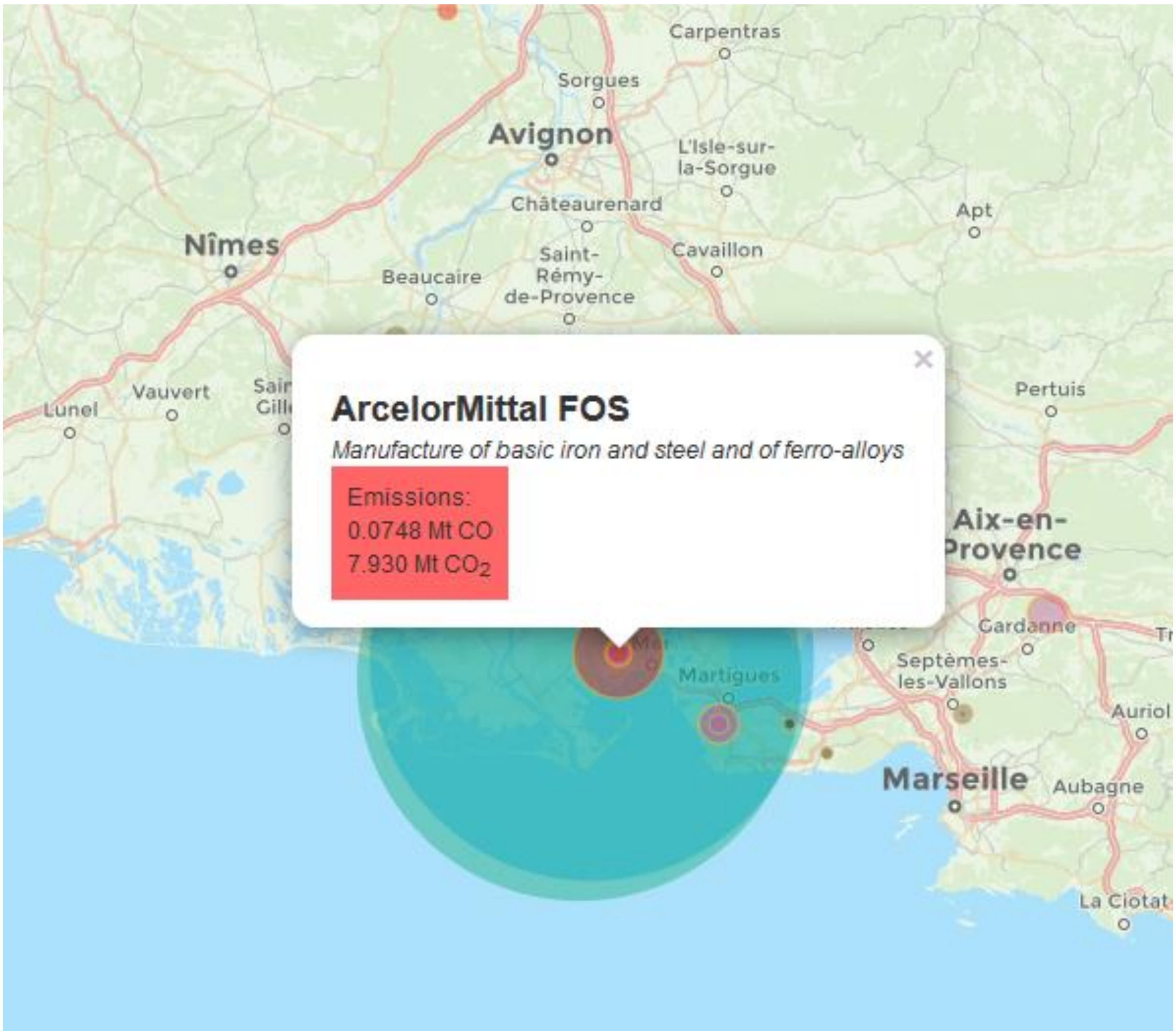

Figure 4: *Popup information on CO/CO_2 emitting plant.*

In a similar way, users can hover over a selected polyol production or chemical plant to visualize interactive data including trading name of the installation, explanation of activity based on NACE code and the annual emissions in million metric tonnes per year available in a radius determined by the user as shown in Figure 5.

Figure 5: *Popup information on a polyol plant with interactive statistics on available emissions within selected radius.*

Industrial users evaluating possibilities for symbiosis across Europe will benefit from the functionality to identify emissions that are suitable for their process in a radius they can determine according to their logistical capabilities or to their strategy constraints. Figure 6 presents the example of polyol plants across Europe highlighting available suitable emissions in a practicable radius set as 10 km from the plant.

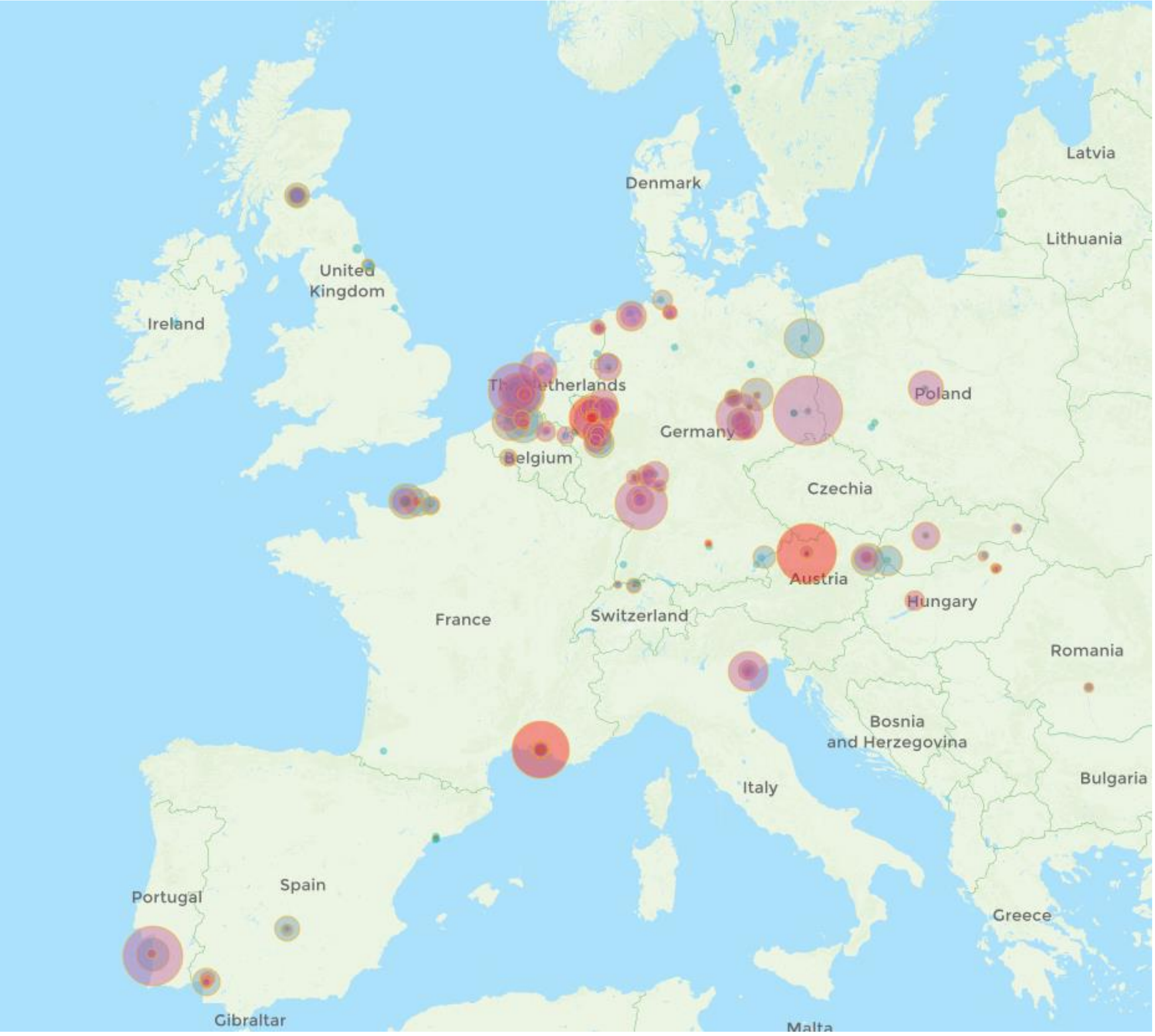

Figure 6: *View limited to emissions within 10 km of a chemical park or polyol plant.*

To refine the analysis even further, users can filter their results with additional detail to see industrial areas that meet important criteria to be able to host at least one polyol plant with an annual capacity set by the user. The example in Figure 7 presents the result of selecting type, radius and size to identify sites that can host a 50 kT per year polyol plant using the already qualified emissions within a 10 km radius.

Figure 7: *View of Figure 6 limited to chemical parks or polyol plants that could host at least a 50 kT Carbon4PUR plant.*

A final aspect for analysis to assess market opportunities, or saturation, is to restrict all the selections already made to display only areas that contain existing polyol plants as shown in Figure 8.

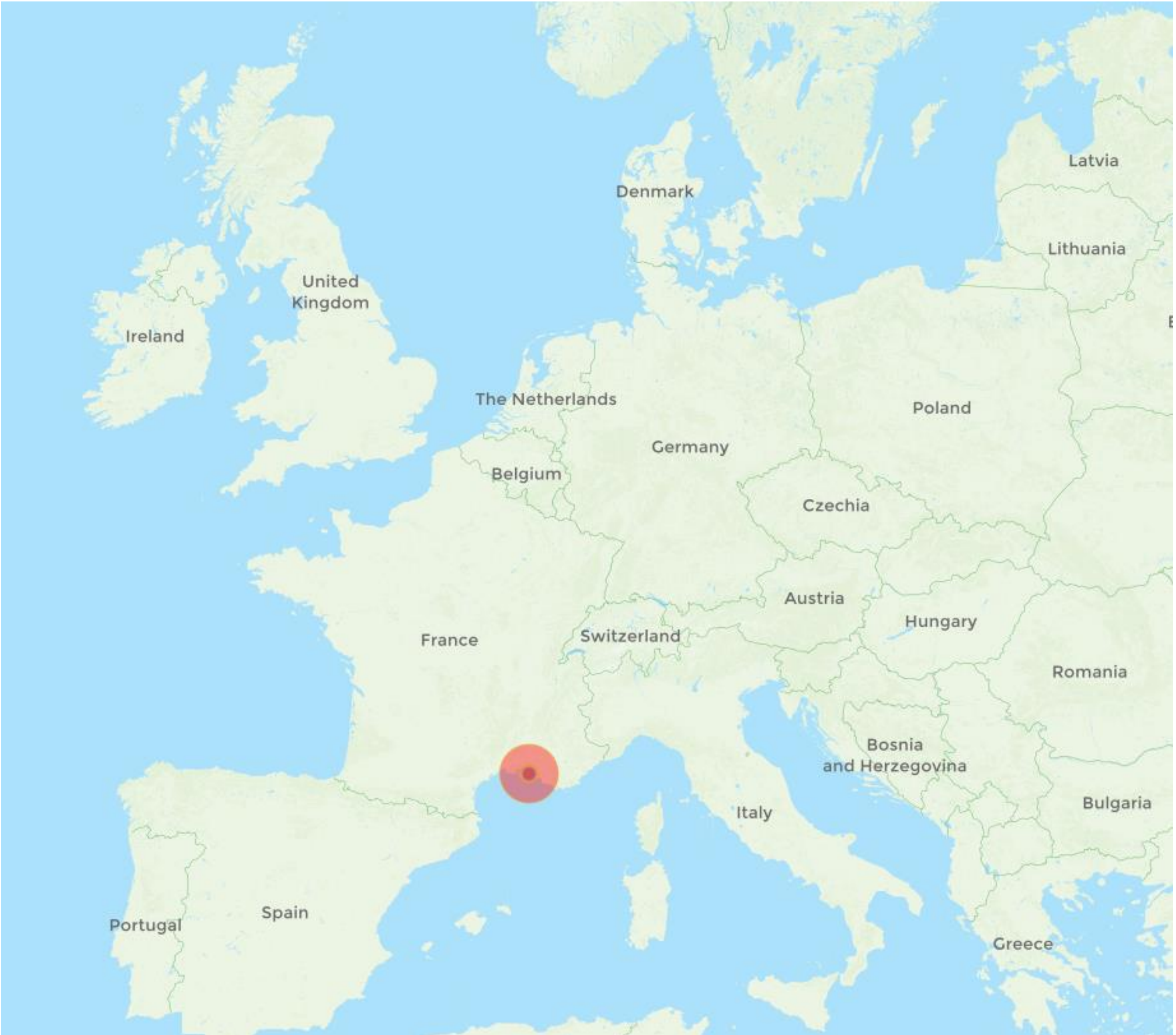

Figure 8: *View of Figure 7 limited to already existing polyol plants.*

4.4 User experience

To achieve maximum benefit, the tool has been designed as a user-friendly interface with the requirements of the target audiences in mind. Specific features to enable users to fully exploit the information include the following.

An introductory tour explains the layout that can be paused, repeated or skipped and explains the layout but also the key function behind each part of the tool covering all tabs and slide bars.

 The first tab with the information "*i*" icon explains how to use the tool and provides background information to the underlying data for emission sources; it explains the logic of

the legend and colour coding to distinguish between CO and CO_2 sources as well as between chemical and polyol plants; and finally it shows how to navigate the site using the icons for emission sources and for receiving plants.

The tab with the factory icon denotes the emissions and it enables users to select the chemical route as well as the industrial processes that are suitable for each route or that they want to explore explicitly. This tab also provides statistics of all the emissions across Europe for the selected industrial processes.

The tab with the factory icon receiving gas emissions helps users configure their search for symbiosis partnerships starting from the demand side. Slide bars help increase or decrease the distance from a chemical plant within which relevant emissions can be identified. In this tab users can also highlight areas that could host a polyol plant of a particular size. The final distinction they can make in this tab is whether to display only clusters that can host a polyol plant of a manually set size using a slide bar. The tab also contains statistics on how many chemical sites are suitable for hosting a Carbon4PUR plant of the defined size.

§ The tab with the “legal paragraph” sign has a section on data, which gives background information on the data sources for all kinds of emitters and provides a link to the query sequence used to obtain the results. In this section users can follow the “contact us” link to fill out the project contact form. The second section on the tab on NACE categories and plant types explains the logic of how the emissions of specific industrial processes are more suitable for symbiosis with either the chemical looping or the chemical cleaning routes.

Users who wish to produce further information materials based on tool results can refer to the licence terms under the MIT modality, whereby they are free to use the results and data as they wish as long as they cite the Carbon4PUR consortium and guarantee the use of a similarly permissive licence.

Finally, the section provides the EU disclaimer for the project and software used.

The settings tab with the cogwheel icon enables users to personalize their search and the appearance of the map providing two colour scheme contrast options such as the grey scale displayed in Figure 9. An important function of this tab is giving users the option to upload details of their own receiving plant(s).

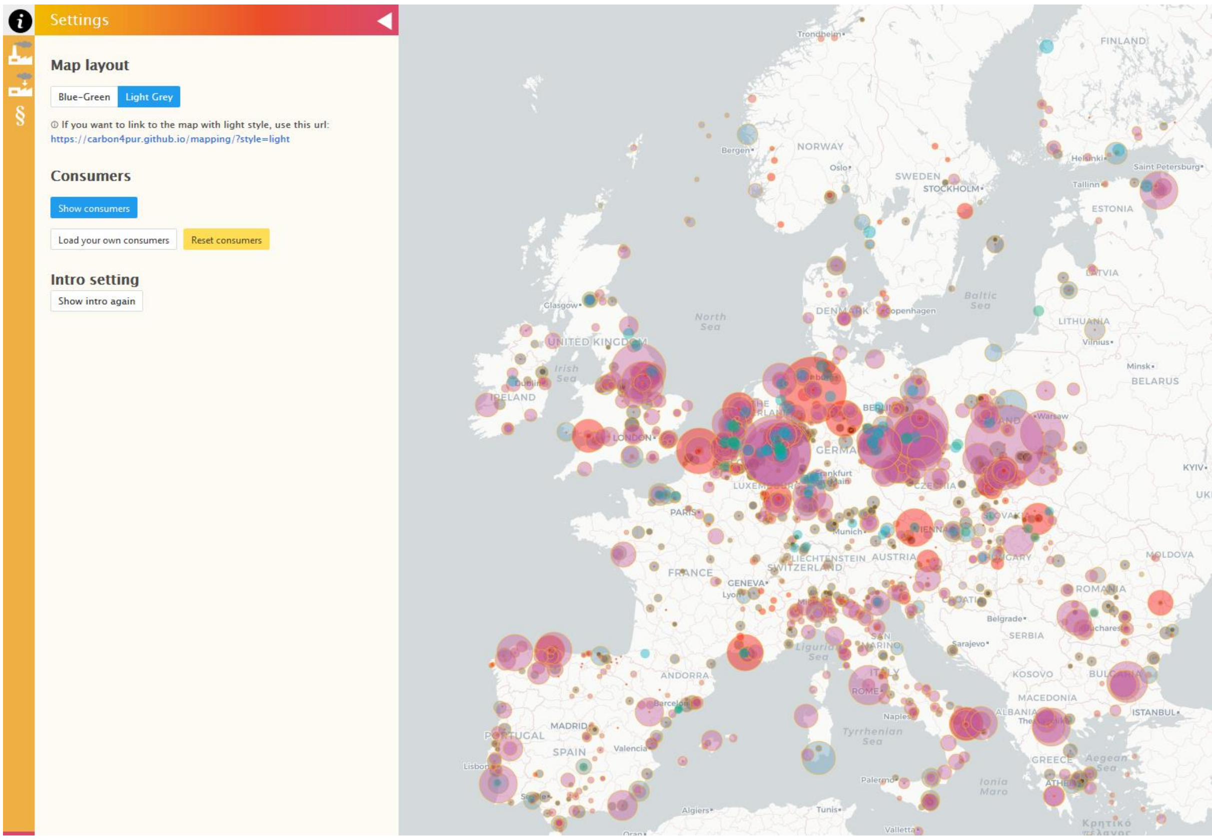

Figure 9: *Light grey version for better contrast.*

This section offers the option to start the tutorial again, if users return after some time.

Overall, the guiding principle was to offer an interactive experience with a gradual logical progression when searching for the components of symbiosis schemes. Since the chemical routes will only work in conjunction with specific sources, the first step is almost always to establish what sources will be suitable for what routes within the region of interest to the user.

Addressing the demand side, and after providing the locations of polyol or chemical plants, the next task is to identify suitable available sources in the radius determined by the size of the plant that exists or is likely to be built and the expected logistical constraints within the regions of interest.

The desired result is that by manipulating the filters along the sequence of the tabs, the users can come to her own conclusions, and narrow down the information to her needs whether they relate to the private sector or a regional development agency perspective.

4.5 Overall purpose and legacy

The tool will be used within the project to perform the replication analysis (Deliverable D7.2), which will combine the explanatory potential of the data respecting the technical viability constraints with the insights gathered from other work packages and from consultation with consortium partners.

Already within the "live" project duration, the tool will be an integral part of the website for coherence and convenience, as the user will not have to leave the website to use the tool as shown in Figure 10.

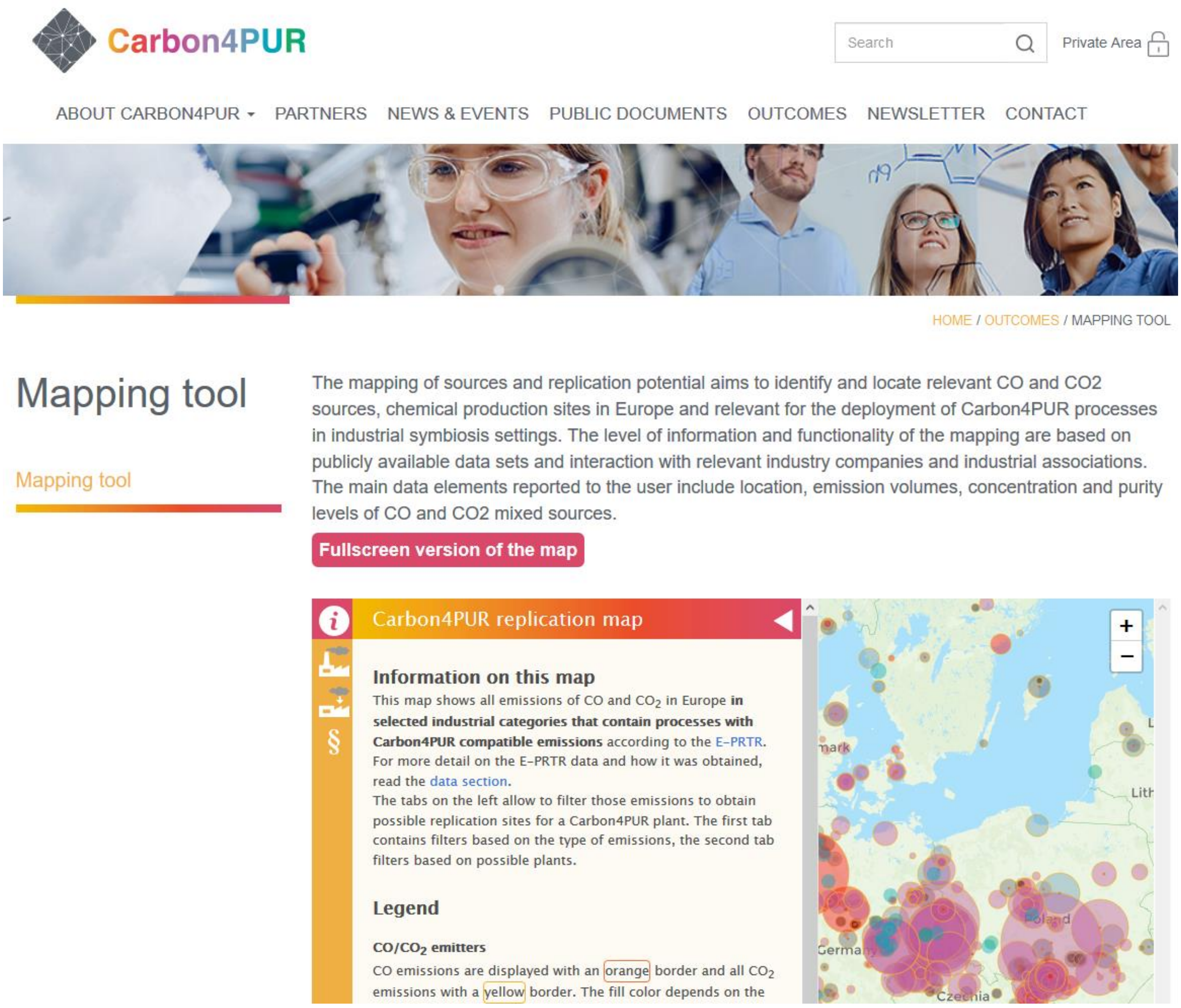

Figure 10: *Integration into Carbon4PUR website.*

The project, the visualization and the underlying data can be enriched to be more useful depending on specific needs of users. For example, the scripts that transform csv files or the E-PRTR data from a SPARQL endpoint to the needed json format can be modified to add other data such as emissions for different years or other emitted gases.

5. Conclusions

Carbon4PUR set out to provide a visualization and symbiosis data provision tool. The current product allows users to interactively adjust criteria to find sites where the principle of CO/CO_2 reuse can be applied. It would be relatively straightforward to adapt the tool for the use of other filters or more NACE categories.

The tool is general enough to be useful for other CCU applications and is helpful for stakeholders in the supply as well as the demand side. But it can be particularly useful for stakeholders in charge of regional infrastructure and economic development strategies. They can be investors, business development managers, port or industrial park managers and regional development agencies.

The relevance of the tool for the entire European chemical sector is valid both under present conditions and for the strategic planning into the medium and long term.