Sustainable Jet Fuel from Flexible Waste Biomass

Deliverable D6.4:

Map of scenarios for alternative use of feedstocks

for:
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PRO	Technical/economic progress report (internal work package reports indicating work status)	
DEL	Technical reports identified as deliverables in the Description of Work	**X**
MoM	Minutes of Meeting	
MAN	Procedures and user manuals	
WOR	Working document, issued as preparatory documents to a Technical report	
INF	Information and Notes	

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PU	Public	**X**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	
CON	Confidential, only for members of the Consortium	

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1 EXECUTIVE SUMMARY

Life Cycle Assessment (LCA) is a method for analysing and evaluating the environmental performance of processes, products or services throughout their entire life cycle and it is a crucial tool to direct new products and innovative processes towards sustainability. The 'Life Cycle Inventory' (LCI) phase aims at realizing an inventory of input/output data with regard to the system being studied. It involves the collection of the necessary data to meet the goals of the defined study. The process of conducting an inventory analysis is iterative. As data are collected and more is learned about the system, new data requirements or limitations may be identified that require a change in the data collection procedures so that the goal of the study will still be met.

1.1 Description of the deliverable content and purpose

This deliverable D6.4 aims to map and describe the processes included in the system boundaries of the alternative scenarios, which will be compared to the SABR-TCR integrated system in order to evaluate their environmental sustainability.
The report is divided into four main chapters: the first chapter is this executive summary, the second one is an introduction to the deliverable where the aims and methods of the report are briefly described; the third one is the main part of the report where the description of the processes of the alternative scenarios system are defined; the fourth chapter includes the annexes in which detailed information of selected datasets is reported.
As mentioned, the third chapter is the main part of this deliverable. It reports a detailed description of the processes included in the system boundaries for each alternative scenario. Seven alternative scenarios are identified: 1) UCO / biodiesel production, 2) UCO / bio-lubricants production; 3) DW / agricultural amendment, 4) WW / gasification; 5) WW / incineration; 6) WW / activated carbon production; 7) fossil-based jet fuel production.
Some further investigation and additional datasets are needed to complete the inventory for all the alternative scenarios, and they will be collected over the coming months.

1.2 Introduction

The introduction reports the goal of the deliverable and a brief introduction to the LCA methodology. This second part aims at contextualizing the collection of the data necessary to meet the goals of the WP6, so a focus on the "Life Cycle Inventory" phase is reported since it is the LCA phase to which this deliverable refers.

1.3 Goal of this deliverable

The goal of task 6.3 is twofold. The first goal is to collect data from the integrated SABR-TCR plant design (WP2) to quantify all relevant energy and material inputs and outputs of the system and create an inventory referring to the functional unit. A second goal is to create scenarios of alternative uses of the feedstocks. As a consequence, this task foresees two deliverables:

- D6.3 – which is dedicated to the SABR-TCR system;
- **D6.4 – the present document, is dedicated to the alternative uses of the feedstocks and to the production of jet fuel from fossil raw materials.**

1.4 Introductory overview of Life Cycle Assessment

Life Cycle Assessment (LCA) methodology is standardized by EN ISO 14040:2006 (ISO, 2006a; ISO 2006b). There are four phases in the LCA study (Figure 1):

a. goal and scope definition;
b. inventory analysis;
c. impact assessment;
d. interpretation.

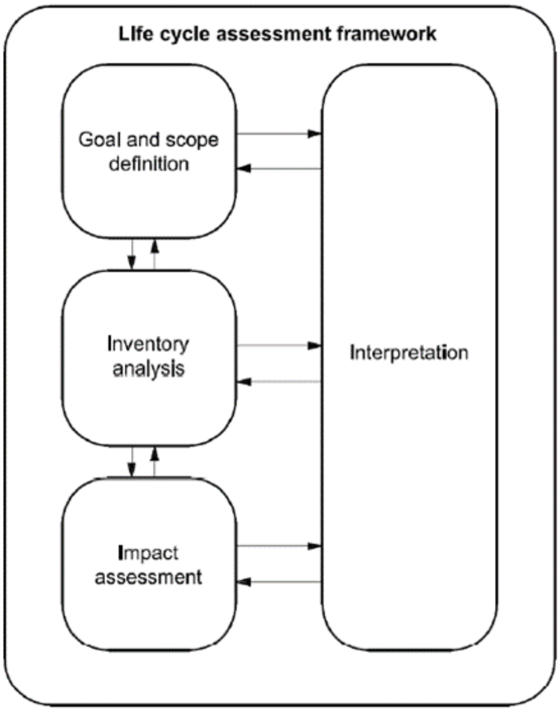

Figure 1. Stages of an LCA.

The goal definition identifies the specific purpose of the LCA analysis. The scope of an LCA analysis, including system boundaries and level of detail, depends on the subject and the intended use of the study. The depth and the breadth of an LCA analysis can differ considerably depending on the goal.
The Life Cycle Inventory analysis (LCI) phase is an inventory of input and output data with regard to the system being studied. It involves the collection of the necessary data to meet the goals of the defined study.

The Life Cycle Impact Assessment phase (LCIA) is the third phase of the LCA. It is aimed at evaluating the significance of potential environmental impacts using the LCI results.
Life cycle interpretation is the final phase of the LCA procedure, in which the results of an LCI or an LCIA, or both, are summarized and discussed as a basis for conclusions, recommendations and decision-making in accordance with the goal and scope definition.

1.4.1 Life Cycle Inventory analysis

Life Cycle Inventory analysis involves data collection from various sources (real working systems, process design documents, literature, databases, etc.) and calculation procedures to quantify relevant inputs and outputs of a product system.
The process of conducting an inventory analysis is iterative. As data are collected and more is learned about the system, new data requirements or limitations may be identified that require a change in the data collection procedures so that the goal of the study will still be met. Data for each unit process within the system's boundary can be classified under major headings, including:

- energy inputs, raw material inputs, other physical ancillary inputs;
- products, by-products and waste;
- emissions to air, discharges to water and soil;
- other environmental aspects.

Data collection can be a resource-intensive process. Practical constraints on data collection should be considered in the scope and documented in the study report.

2 INVENTORY ANALYSIS OF LCA APPLIED TO GreenFlexJET PROJECT FOR THE ALTERNATIVE USE OF FEEDSTOCKS

This chapter describes the following issues:

- the assumptions made during the Life Cycle Inventory analysis;
- the allocation methods adopted to address the multifunctionality of the analysed systems;
- the processes and their related data collected.

All these issues are referred to both the alternative uses of the feedstocks and the production of jet fuel from fossil raw materials.
As already discussed in Deliverable 6.2, the goal of the GreenFlexJET project is twofold: the SABR-TCR system can be considered both a new sustainable and effective solution to manage digestate waste and waste wood and a suitable system to produce Sustainable Aviation Fuel (SAF), potentially able to replace the conventional jet fuels. Therefore, we decided to put a dual purpose in our LCA analysis and to adopt both the process- and the product-oriented approach:

- the first purpose is to assess the environmental benefits of the SABR-TCR technology as a new alternative for "end-of-life" treatment of both used cooking oils (UCO), digestate waste (DW) and waste wood (WW), following the so-called "process-oriented" approach;
- the second one is to assess the environmental performance of the SABR-TCR technology as a new alternative potentially replacing current jet fuel production technology; this is the so-called "product-oriented" approach.

The adoption of both approaches will allow us to quantify the environmental sustainability of the integrated SABR-TCR technology, and to compare the results with those of alternative jet fuel production technologies and those of alternative feedstock valorisation routes in support of future commercialisation, in compliance with the requirements set by the EU revised Renewable Energy Directive.
The intended audience to which the LCA analysis is addressed consists of a wide variety of subjects:

- internal members of the project (GreenFlexJET partners);
- external members involved in the project (the European Commission and the stakeholders);
- a more general public, including the scientific community.

The results are intended to be used in comparative assertions which will be disclosed to the general public.

Table 1 shows the seven identified alternative scenarios for both feedstocks' management (*process-oriented*) and jet fuel production (*product-oriented*), their functional units and selected allocation methods. Two alternative used cooking oils (UCO) management treatments were selected: biodiesel production and bio-lubricants production; so, the scenarios "UCO / biodiesel production" and "UCO / bio-lubricants production" aim to evaluate the environmental performances due to the management of 1 tonne of UCO. In the EU, an estimated 180 million tons of anaerobic digestate are produced per year, most of which is used as organic fertilizer (Corden et al., 2019). For this reason, one alternative digestate waste (DW) management treatment was selected: spreading on agricultural soils as fertilizers. Scenarios "DW / agriculture amendment" aims to evaluate the environmental performances due to the management of 1 tonne of DW as a soil amendment. In order to evaluate the environmental performances of waste wood management, three alternatives have been selected: its gasification for producing heat and power, its incineration for producing heat and power, and its exploitation for producing activated carbon. Finally, one alternative jet fuel production process was selected; the scenario "fossil-based jet fuel" aim to evaluate the environmental performances concerning the production and the combustion of 1 MJ of high heating value (HHV) of conventional jet fuel.

Table 1. Alternative scenarios.

Approach	Function	Scenario	Functional unit	Allocation
Process-oriented	Used cooking oil management	Biodiesel	1 tonne of waste vegetable oil ready to be treated	System expansion
		Bio-lubricants	1 tonne of waste vegetable oil ready to be treated	System expansion
	Digestate waste management	Agricultural amendment	1 tonne of digestate waste ready to be treated	System expansion
	Wood waste	Gasification for heat and power	1 tonne of wood waste ready to be treated	System expansion
		Incineration for heat and power	1 tonne of wood waste ready to be treated	System expansion
		Activated carbon production	1 tonne of wood waste ready to be treated	System expansion
Product-oriented	Jet fuel production	Fossil-based jet fuel	1 MJ of HHV in the produced fuel	System expansion

2.1 Data collection

The inventory phase related to the alternative scenarios was focused on the choice of the methods and tools (datasets) to be used according to the choices done during the "goal and scope definition" phase. While the LCA Standard ISO14040 encourages practitioners to collect primary data for the systems being studied, we rejected the option of using primary data provided by companies because they would have been representative only of specific data suppliers. Therefore, we preferred to use secondary data, as they are much more representative of an average European situation. Subsequently, we compared different types of secondary data, such as GaBi datasets and technical specific literature, by considering temporal, geographical and technological representativeness. We concluded that technical specific literature data would have been limiting again due to excessive specificity. Conversely, the use of a European dataset allowed the best quality of data for both: i) geographical representativeness and ii) technology sector representativeness. Moreover, selected datasets have excellent time-related representativeness.
Finally, the chosen datasets underwent a check to assure that their adoption allows us to model scenarios that fit the system boundaries set in Deliverable 6.2, in order to be perfectly comparable with the SABR-TCR system boundaries. In particular, the following cut-off rules and assumptions were adopted:

1) start-up, shut-down and hot idle operating modes, together with maintenance operations, were omitted; only the main operating mode was considered;
2) emergency flows and fugitive emissions were omitted;

3) capital goods (e.g., construction of factory buildings, vehicles, machines and auxiliary equipment) were not included; this is a relatively usual practice in LCA studies, as in literature is found that for technical systems with long life, the environmental impact deriving from construction is often small in relation to impact caused by operations (Geisler et al., 2004; Hischier at al., 2005);
4) material transport, waste production and waste disposal were included in the system boundaries for each scenario.

2.1.1 Process-oriented scenarios – UCO management

As previously mentioned, the modelling of the process-oriented scenarios is based on secondary data. The starting point for both alternative UCO management scenarios is the collection of waste vegetable oil from households and from commercial and industrial facilities.

Biodiesel production

The biodiesel production scenario aims to assess the environmental performance of the use of waste vegetable oils to produce biodiesel. The system boundaries must include every process, starting from the UCO collection, then their purification and treatment through the transesterification process to produce methyl esters, and finally the esters refining to obtain biodiesel and glycerol.
This scenario will be modelled using the following datasets:

- 'EU-28 / Transport, small truck (up to 14 t total cap., 9.3 t payload) (A4)' [Sphera]
- 'GLO / Treatment of waste cooking oil, purified, esterification' [ecoinvent]

The following links report the documentation and the description of the first dataset:
http://gabi-documentation-2019.gabi-software.com/xml-data/processes/a0f72fc8-bac8-4f8b-aa4a-2e489c20677d.xml
Please note that documentation of datasets provided by ecoinvent is not downloadable for free.

Bio-lubricants production

The bio-lubricants production scenario aims to assess the environmental performance of the use of the waste vegetable oils to produce bio-lubricating oils. The system boundaries must include every process, starting from the UCO collection, then their purification and treatment in a refining process to produce the lubricating oils.
This scenario will be modelled using the following datasets:

- 'EU-28 / Transport, small truck (up to 14 t total cap., 9.3 t payload) (A4)' [Sphera]

As for the refining step, although extensive research was done in several databases, it was not possible to identify any lubricant production process starting from vegetable oil. However, a dataset was identified in the GaBi database which foresees the use of fossil resources:

- 'EU-28 / Lubricants at refinery' [Sphera]

The following link reports the documentation and the description of the dataset:
http://gabi-documentation-2021.gabi-software.com/xml-data/processes/bdfac21c-7415-46af-acbc-8916cb95b9b8.xml
A possible solution is to build this dataset by acquiring the above mentioned and tailor it to find a common point with the production process starting from the used cooking oils. Any missing step could then be modelled using technical specific literature or other datasets. An alternative solution that we are currently examining is to carry out a dedicated study to have primary data from a company producing bio-lubricants starting from waste vegetable oils, but in this case, the geographical representativeness will be lost.

2.1.2 Process-oriented scenarios – Digestate waste management

The modelling of the digestate waste (DW) management scenario is also based on secondary data. The starting point for the alternative management scenario is the anaerobic digestion and the consequent production of digestate as a co-product of biogas.

Agricultural amendment

The agricultural amendment scenario aims to assess the environmental performances of the agriculture uses of anaerobic digestate. The system boundaries must include the transport of digestate to agricultural fields and the substitution of chemical fertilizers with digestate.
This scenario will be modelled with the following datasets:

- 'EU-28 / Transport, small truck (up to 14 t total cap., 9.3 t payload) (A4)' [Sphera],
- 'CH / Digested matter, application in agriculture' [ecoinvent].

Please, note that documentation of datasets provided by ecoinvent is not downloadable for free.

2.1.3 Process-oriented scenarios – Waste wood management

The modelling of the waste wood (WW) management scenarios is also based on secondary data. The starting point for the alternative management scenarios is the presence of wood waste ready to be treated.

Gasification

The gasification scenario aims to assess the environmental performance of the gasification of WW. The system boundaries must include WW pre-treatment and its gasification in a waste-to-energy (WtE) plant.
This scenario will be modelled with the following datasets:

- 'EU-28 / Transport, small truck (up to 14 t total cap., 9.3 t payload) (A4)' [Sphera]
- 'CH / synthetic gas, from wood, at fixed bed gasifier' [ecoinvent]
- 'RER: industrial furnace production, natural gas' [ecoinvent]

Please, note that documentation of datasets provided by ecoinvent is not downloadable for free.

Incineration

The incineration scenario aims to assess the environmental performance of the incineration of WW. The system boundaries must include WW pre-treatment and its thermal treatment in a waste-to-energy (WtE) plant.
This scenario will be modelled with the following datasets:

- 'EU-28 / Transport, small truck (up to 14 t total cap., 9.3 t payload) (A4)' [Sphera]
- 'EU-28 / Wood (natural) in municipal waste incineration plant waste-to-energy plant with dry flue gas treatment' [Sphera]

The following link reports the documentation and the description of the latter dataset:
http://gabi-documentation-2021.gabi-software.com/xml-data/processes/9a8854e3-a953-44a7-9d7a-134c701ea57e.xml

Activated carbon production

The activated carbon production scenario aims to assess the environmental performances of the production of activated carbon starting from WW.
This scenario will be modelled with the following dataset:

- GLO / charcoal production from wood [ecoinvent]
- 'DE / Activated carbon technology mix; production mix, at the plant' [Sphera]

Please note that documentation of datasets provided by ecoinvent is not downloadable for free.
The following link reports the documentation and the description of the latter dataset:
http://gabi-documentation-2021.gabi-software.com/xml-data/processes/f763690d-1a10-4a6d-8f6d-fec5c46d8088.xml

2.1.4 Product-oriented scenarios – Jet fuel production

Fossil-based jet fuel

The fossil-based jet fuel production scenario aims to assess the environmental performances of conventional jet fuel production and use. Also, the modelling of this scenario is based on secondary data. The system boundaries must include every process from the extraction of fossil resources to the combustion of the produced fuel in a jet engine.
This scenario will be modelled with the following datasets:

- 'EU-28 / Kerosene/jet A1 at refinery' [Sphera]

The following link reports the documentation and the description of the latter dataset:
http://gabi-documentation-2019.gabi-software.com/xml-data/processes/701f8775-bd15-4b91-b3d0-43e7ee04044a.xml
In the Annex is reported an excerpt of the dataset documentation provided by Sphera, containing the description of the processes included in the system boundary, the temporal, geographical and sectoral representativeness.
As for the combustion step, although extensive research was done in several databases, it was not possible to identify any combustion process of jet fuel. This missing step shall then be modelled using technical specific literature.

3 CONCLUSIONS

The deliverable reports the alternative uses of the feedstocks exploited in the project to feed the SABR-TCR, which will be considered as comparison scenarios in the subsequent phases of the project. The said scenarios are the production of biodiesel and biolubricants in the case of UCO, use as an agricultural soil amendment in the case of digestate and gasification, incineration, and production of activated carbon in the case of wood waste. Suitable LCA datasets have been identified for each alternative use of each feedstock. In most cases, these are representative datasets of the European situation. Furthermore, this deliverable shows the alternative scenario for the product-oriented approach LCA analysis; it is a fossil-based jet fuel dataset designed for the European situation.

All the selected datasets, for process- and product-oriented approaches, have good or excellent technological, temporal and geographical representativeness.

The environmental performance of the SABR-TCR technology, the related GHG emissions and the comparison with alternative scenarios will be reported in the following deliverables, D6.5 and D6.6.

GHG emissions of SABR-TCR technology will be compared to the fossil-based jet fuel and the fossil fuel comparator reported in the Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources, RED II. The aim will be to verify the 65% GHG emission reduction of the SABR-TCR technology compared to the fossil reference, as required by article 29, point 10, letter c of the Directive.

The evaluation of the environmental impacts of the SABR-TCR technology will be submitted to a sensitivity analysis, considering the decrease of fossil energy sources and the increase of renewable energy sources, as envisaged by the EU target of 55% net emissions reduction by 2030 and climate-neutrality by 2050. An analysis of the different environmental performances of SABR-TCR technology, based on the different energy mixes (representative of different energy situations in the EU Countries) will be carried out, too.

4 ANNEXES

Hereunder, the main feature of datasets of Sphera that will be used in the Life Cycle Assessment of the alternative scenarios of GreenFlexJET will be reported. Information is from GaBi LCA Databases. Documentation related to datasets from ecoinvent is not reported since it is not public.

Transport services

Name of the dataset: **Transport, small truck (up to 14 t total cap., 9.3 t payload) (A4); diesel driven, Euro 4, cargo; consumption mix; 12-14 t gross weight / 9,3t payload capacity** (by Sphera 2021).
This dataset is modelled according to the European Standard EN 15804 for Sustainable Construction. Results are declared in modules, which allows the structured expression of results throughout the life cycle. A4: The construction stage, contains the following module: Transport to the construction site. The dataset refers to the transport of 1,000 kg cargo at a distance of 1 km by truck (EURO 3) with up to 14t total capacity and 9.3 t payload in external haulier service with a utilisation ratio of 85%. The extraction and processing of the fuel are included. The production of the vehicle is not included in the balancing. The average fuel consumption is 2,6 l/100 tkm.
Data quality indicators: Technological representativeness: Good. Time representativeness: Very good. Geographical representativeness: Good.

Lubricants

Name of the dataset: **Lubricants at a refinery; from crude oil; production mix, at a refinery; 38 MJ/kg net calorific value** (by Sphera 2021).
The data set covers the entire supply chain of the refinery products. Allocation among the different products is based on the net calorific value. The reference flow is 1 kg of lubricating oil. The inventory is mainly based on industry data and is completed, where necessary, by secondary data.
The model reflects the average situation in Europe. The reference year is 2017.
Data quality indicators: Technological representativeness: Good. Time representativeness: Very good. Geographical representativeness: Good.

Wood in a municipal waste incineration plant

Name of the dataset: **Wood (natural) in municipal waste incineration plant; waste-to-energy plant with dry flue gas treatment, without collection, transport and pre-treatment; production mix (region-specific plants), at a plant; 18.0 MJ/kg net calorific value** (by Sphera 2021).
The data set represents an end-of-life inventory for the thermal treatment of waste wood in an average Waste-to-Energy (WtE) plant with dry flue gas cleaning. The data set includes the emissions and resource consumption for the thermal treatment of waste. The behaviour of bottom ash and air pollution control residues on a landfill is considered. Electricity and steam flows have to be connected in order to take into account these credits.
The energy balance of the incineration model reflects the average situation in Europe and is extrapolated to the heat input of the specific waste. The emissions are either calculated based on scientific sound transfer coefficients and the elementary composition of the waste, or represent European plant and BAT data. The reference year is 2020.
Data quality indicators: Technological representativeness: Good. Time representativeness: Very good. Geographical representativeness: Good.

Activated carbon production

Name of the dataset: **Activated carbon; technology mix; production mix, at a plant; porous carbon structure, 35.2 MJ/kg net calorific value** (by Sphera 2021).
The process of producing activated coal can be operated with various carbon carriers as a precursor. The quantity of input (coal, wood, other C-carriers) has to be scaled according to the carbon content. The

production process of activated carbon described here is based on a hard coal input ready for use in air purification as well as wastewater processing. The preparation of activated carbon involves two main steps: carbonization of the raw material in the absence of oxygen, and activation of the carbonized product with water vapour.
The data set represents the German situation, focusing on the main technologies, the region-specific characteristics and/or import statistics.
The reference year is 2020.
Data quality indicators: Technological representativeness: Good. Time representativeness: Very good. Geographical representativeness: Good.

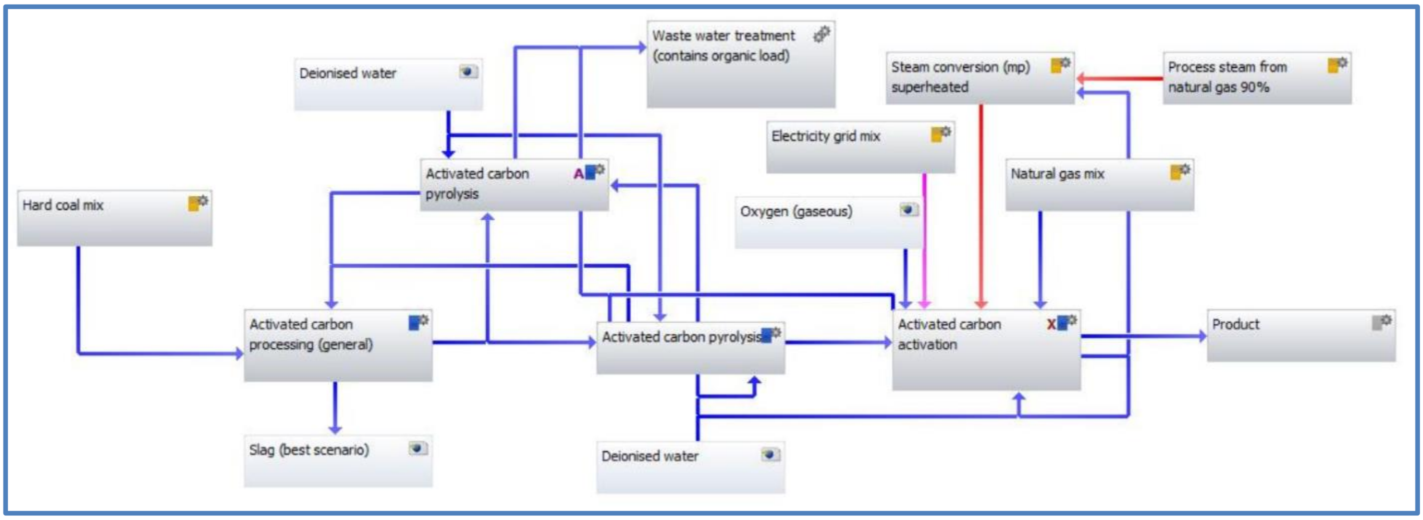

Figure 2. Flow chart model of activated carbon production.

Fossil-based jet fuel scenario

Name of the dataset: **Kerosene / Jet A1 at a refinery; from crude oil; production mix, at a refinery; 480 ppm sulphur** (by Sphera 2021).
The dataset represents the production of jet fuel A1 from crude oil et A1 for air transportation, residential heating and other consumers. The dataset covers the entire supply chain of the refinery products. This includes well drilling, crude oil production and processing as well as transportation of crude oil via pipeline resp. vessel to the refinery. Main technologies such as conventional (primary, secondary, tertiary) and unconventional production (oil sands, in-situ), both including parameters like energy consumption, transport distances, crude oil processing technologies are individually considered for each crude oil production. Also considered are country/region-specific downstream (refining) technologies, feedstock (crude oil) and product (diesel fuel, etc.) properties, like sulphur contents, as well as the output spectrum of the refineries. The biogenic components blended into the fossil fuel are also modelled individually. The inventory is mainly based on industry data and is completed, where necessary, by secondary data.
Petroleum refineries are complex plants. The combination and sequence of many processes are usually very specific to the characteristics of the crude oil and the products to be produced. Additional influencing factors are the market demand for the type of products, the available crude oil quality and certain requirements set by authorities, the configuration and complexity of a refinery. Simple hydro-skimming refineries can process only a few crude oil qualities and produce a few high-quality products. Complex refineries with many conversion plants can process different crude oil types. Petroleum refinery activities start with the reception of crude oil. After desalting, the crude oil is fed to the distilling column of the atmospheric distillation (fractionation of the crude oil by separation according to density/ boiling/ condensation areas). The light ends (gases) go up to the head of the column and are employed in the liquid/gas system to recover methane and ethane for use as a refinery fuel and LPG (propane and butane) as saleable products. This light product separation is done in almost every refinery. These gases can also be used in a steam-reforming process to produce hydrogen, which is needed for the desulphurisation processes, the hydrocracking and, to a lesser

extent, for the isomerisation unit. The straight-run naphtha of the atmospheric distillation, which is taken in the upper trays of the column is spitted and fed to three different processes. The light naphtha fraction is introduced to the chemical sweetening process. Some sweetened naphtha is directly blended in the gasoline pool, the main fraction is sent to the isomerisation unit where the aliphatic paraffins are converted into iso-paraffins with a high-octane value. Often there is a de-isopentaniser (distillation) downstream to increase the gain of iso-components. These iso-paraffins are very valuable components for the gasoline production with high RON content. After desulphurisation, the heavy naphtha fractions are sent to the reformer for catalytic transformation from aliphatic paraffins to iso-paraffins and from cyclo-paraffins to aromatic compounds, with a reduction of the net calorific value. The specific feature of this process is the production of hydrogen (the only hydrogen producer besides additional plants, like steam-reforming). The outputs of the isomerisation (often including a de-isopentaniser) and catalytic reforming go to the gasoline blending system and premium or regular gasoline follow as products. Kerosene is directly obtained from the atmospheric distillation and is separately treated from the rest of the middle distillates fraction. The main part of the middle distillates produced in the atmospheric distillation is employed in the hydrofiner (for desulphurisation). The desulphurised product is fed to the middle distillate blender. The residue from the atmospheric distillation is, mainly, introduced to the vacuum distillation. Here, there is a distillation in light vacuum gas oil, vacuum gas oil (wax distillate) and vacuum residue. A part of the atmospheric residue is fed into the visbreaker (mild thermal cracking). Small amounts are introduced directly into the heating oil blending system and the asphalt-blowing process. The light gas oil, as a product of the vacuum distillation, goes to the hydrofiner, is desulphurised, and is employed in the middle distillate blender. Some of the vacuum distillate, which has been taken from the middle trays of the vacuum distillation, is introduced to the base oil production of lubricants and waxes. Most of it is fed either to a catalytic cracker (first desulphurised) or a hydrocracker, where the feeds are converted into shorter chains by molecule restructuring. The products are gases, gasoline, middle distillates and heavy cycle gas oils (components of the heavy fuel oil). The gases of the catalytic cracking are treated in an alkylation and polymerisation unit to manufacture additional valuable gasoline components. These processes are used to combine small petroleum molecules into larger ones. Butylene of the catalytic cracker is further used to produce Methyl-Tertiary- Butyl- Ether (MTBE), a product used as an octane booster. Sometimes, external purchased bio-ethanol is used instead. The naphtha of the FCC has to be treated in a special desulphurisation process to reduce the high sulphur content. The vacuum residues go into the coking process, which produces gases, gasoline, middle distillates and heating oil. A further product is petroleum coke, which is then purified. The vacuum residue, like some of the atmospheric residue, is also used as feed for the visbreaking, which also produces gases, naphtha, middle distillates and heating oil. The extracted hydrogen sulphides of all desulphurisation processes are fed to a sulphur recovery unit (Claus plant) to recover elemental sulphur. Energy generation (heat, steam and electricity) requires a large amount of fuels. The fuel burned in refineries power plants and incinerators may be refinery gas, heating oil (residual oil), petrol coke and sometimes middle distillates and LPG. Besides, purchasing natural gas and electricity is employed. All-important material and energy flows (input-output) are shown in the following graph system boundary of the refinery model. Furthermore, a simplified flow chart is shown below. The arrangement of these processes varies among refineries, and few, if any, employ all these processes. The dataset describes a mass-weighted average refinery for the respective country/region. The dataset considers the whole supply chain from crude oil exploration/well installation, production, transport to refining operation. If indicated in the process name, some fuels have certain shares of bio-components. The supply of these bio-components (bio-ethanol and bio-diesel) is modelled according to the national/regional situation).

For all products of the refinery, allocation by mass and net calorific value is applied. The feedstock (crude oil) is allocated by energy, the refinery efforts (emissions) by mass to each product. The production route of every refinery product is modelled in detail, and therefore, it is possible to track the energy efforts for operating each single unit process of the refinery. These energy demands and the corresponding emissions can be allocated causer-oriented to each refinery product. The feedstock of the respective unit process, which is necessary for the production of a product or an intermediate product, is allocated by energy (i.e., mass of the product * net calorific value of the product). In this way, products with high caloric values, e.g., gasoline or gases, are assigned to higher feedstock consumption and hence higher environmental upstream

impacts compared with low caloric value products (e.g., asphalt, residual oil). The energy demand (thermal energy, steam, electricity) of a process, e.g., atmospheric distillation, being required to create a product or an intermediate product, is allocated according to the share of the throughput of the unit process (mass allocation). In general, products that are more complex to produce and therefore pass a lot of refinery facilities e.g., gasoline, are assigned with higher energy consumption values (and hence higher emissions) compared with e.g., straight-run products. For the combined crude oil, natural gas and natural gas liquids (NGL) production allocation by net calorific value is applied.
Data quality indicators: Technological representativeness: Good. Time representativeness: Very good. Geographical representativeness: Good

Figure 3 shows the flow chart model of the supply chain of the kerosene production created by Sphera.

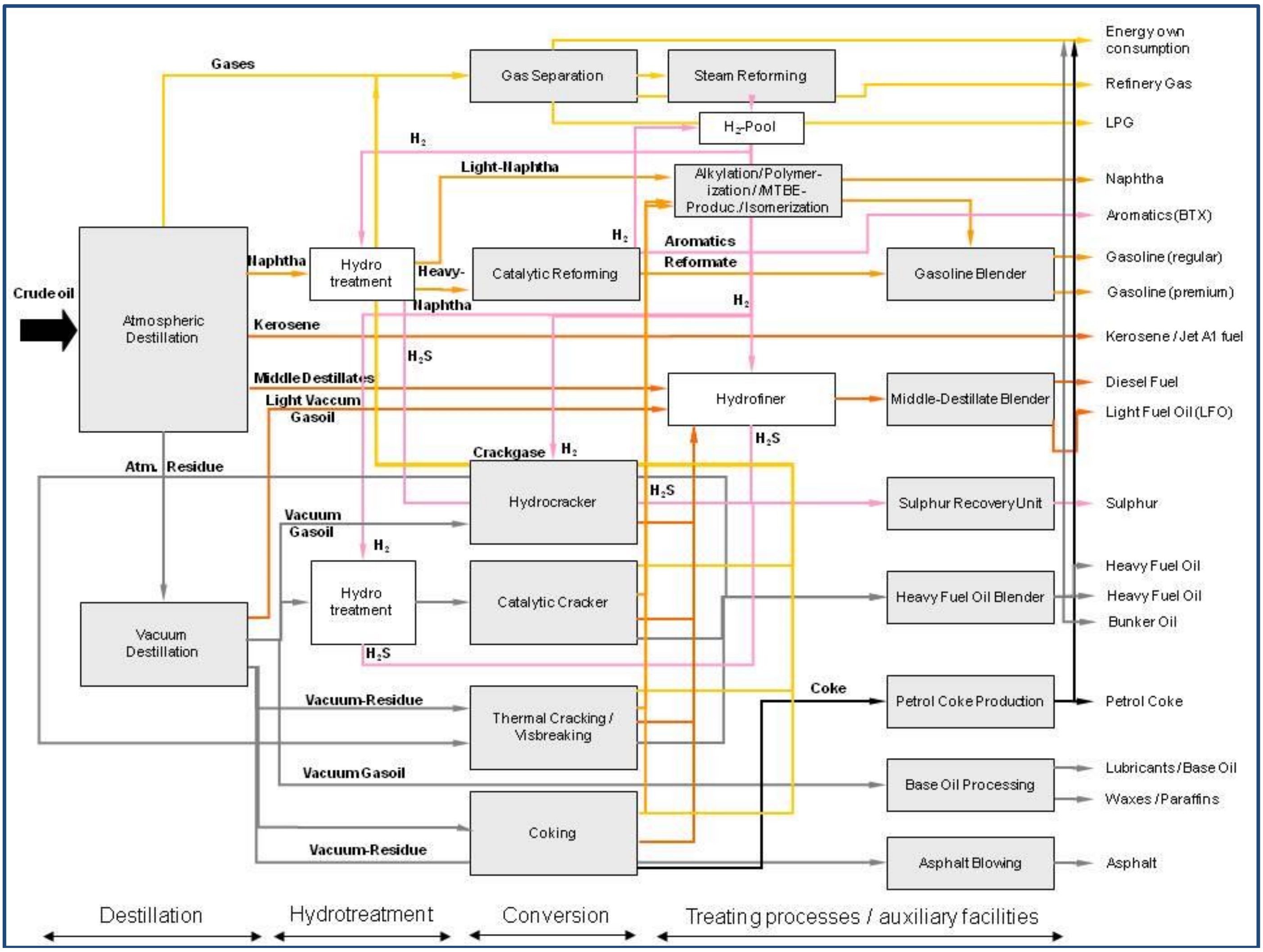

Figure 3. Flow chart model of kerosene production.

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