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LCA scope and analysed system boundaries

Definition of limits and functional units: LCA preparation

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Summary

The overall aim of FFW project is to obtain liquid (diesel) and gas (synthetic natural gas) fuels starting from olive and olive oil residues via synthetic processes, namely Fischer Tropsch and methanation, both via gasification. In order to do so, a complex process needs to be undergone, and Work Package 6 is focused on the assessment of the environmental feasibility of that process.

This Deliverable is the first step taken towards the production of a life cycle assessment of the FFW process and aims to define the system and the working conditions of it in order to enable the beginning of work and, when the assessment is finished, also the comparability of the final report.

In this state of things, the main objectives of this Deliverable are the following:

- Show an introduction to the concept of life cycle assessment and define the reasons why its application in this particular project is required,
- Define the concept of system boundary, the different possible scenarios for those and the proposed solution for this process,
- Define the different steps included in the production of the previously proposed fuels and the inclusion of those in the coming life cycle assessment,
- Introduce the idea of allocation system and present the different possibilities. As happens in many studies, not a single allocation option will be selected, but we will need to distribute the environmental burden of different steps and the most appropriate option will be taken in each case, noting it specifically in the final report,
- List the possible impact categories to work on and point out those which will be considered more specifically within the study,
- Explain the importance of a good selection of functional units and select the most appropriate option for this particular system. Even when a solid proposal is made, space is left for other partners within the consortium to propose other options when the system is more specifically defined.

Obtaining appropriate data is also a very important issue when it comes to producing an appropriate life cycle assessment. As will be discussed through the Deliverable, apart from using available life cycle databases, self produced information will be included in the assessment as well, being of especial importance in those cases when newly developed technology is applied.

In these cases, the output from research Work Packages and from the demonstration will be taken as references, but assumptions will be required in order to take into account scale ussues. It is of vital importance to list these assumptions and dully justify them in the final reports in order to produce a quality work that can be compared to others.

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1 Introduction to Life Cycle Assessment

The main objective of Work Package 6 is, together with the Environmental Technology Verification, to run the Life Cycle Assessment of the process of fuel production apart from agricultural residues aiming to provide quantitative information on the sustainability of the new technologies over their whole life cycle.

ISO 14040 defines LCA as: "a technique for assessing the environmental aspects and potential impacts associated with a product, by:

- compiling an inventory of relevant inputs and outputs of a product system;
- evaluating the potential environmental impacts associated with those inputs and outputs;
- interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.

LCA studies the environmental aspects and potential impacts throughout a product's life (i.e. cradle-to-grave) from raw material acquisition through production, use and disposal. The general categories of environmental impacts needing consideration include resource use, human health, and ecological consequences."(1)

In this particular case, the process will include as raw materials, olive pruning and olive oil solid residues and the final products will be the ready fuels. The Life Cycle Assessment (LCA) will take into account the whole process from residue to synthetic natural gas and diesel via gasification and methanation or Fischer Tropsch reaction respectively.

The importance of conducting an LCA in this case can be explained by the importance of ensuring the sustainability of the newly produced fuels. LCA aims to evaluate the sustainability of a process or product. The process is formalised by the International Standards Organisation (ISO) and focused on the evaluation of the environmental burden of the studied process or product according to different parameters such as waste produced or energy and materials consumed: according to ISO 14040:97, the definition of LCA is a "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle". This facilitates the comparison between different processes which have been studied according to the same parameters with the same methodology.(1)

The full assessment can study the whole life cycle of the studied product, process or activity starting from the extraction and process of raw materials and following with their manufacture, commercialisation, transportation, distribution, use, re-use, maintenance, recycling and final disposal(2). The environmental impact of those is obtained based on the outputs: energy and emissions, together with the requirements. It is shown schematically on Figure 1.

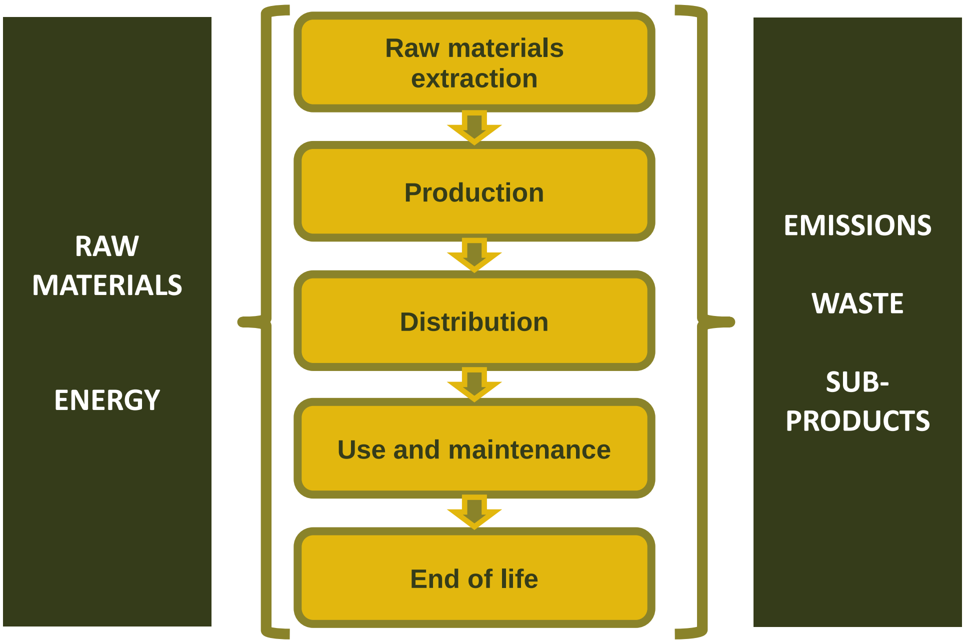

Figure 1 General schematics of inputs, outputs and steps considered on an LCA

The difference between LCA and other environmental management tools is that it analysies the entire life cycle instead of focusing on one single stage of the process. It can even include impacts outside the immediate factory gates. This allows to place the burden in the very step where it belongs, which leads to being able to actually identify those processes which produce greater impacts thus making it possible to work on strategies to reduce the burden of those with a more effective impact to the overall process or product.

There are specific objectives of LCA that can be summarised in these four:

– Supplying objective information about the interactions of the product, process or activity with the environment;
– Improving the understanding of the consequences of human activities in the environment;
– Foreseeing negative consequences in decision taking and identifying improvement opportunities;
– Easing communication between different social sectors concerned about environmental quality.

In order to attain these objectives, information on inputs and outputs of the whole process need to be gathered and processed. A full methodology has been developed in order to do this obtaining comparable results, and the application of LCA methodology encompasses four phases, Illustrated in Figure 2, below.

– Goal and scope definition: this first step defines the functional system to be studied within the LCA, this is the process D.6.1 will cover, setting the boundaries, the level of detail and the functional basis for comparison. With this, we will describe the system to be studied, its functions and functional unit. The functional unit will be compared as the basis for comparison together with the stages to cover, the environmental impacts to investigates, the methods to apply, interpretation approaches to use. The assumptions made about data will be included in the work as soon as data arrives from the previous research partners, including information on the quality of data, method issues and value choices (3).

- Inventory Analysis: once the first step is covered, data needs to be compiled from the actual system to be studied including inputs and outputs (specifying their units): emissions, energy and raw materials for each process will be presented in an inventory board. The inventory is based on resource use and emissions for the previous steps (from raw material) and the specific modelling of the analysed system (fuel production). The first validation will be carried out within this phase (3).
- Impact Assessment: this is the technical process through which the effects of resource use and those of emissions are quantified into environmental impact categories. Specialised software will be used for this purpose. LCI results will be assigned to the impact categories and potential environmental impacts will be calculated in each category (climate change, aquatic eco-toxicity, land use, acidification, material resource depletion or human health) (3).
- Interpretation: once the system has been uploaded to the software tool and the impact has been quantified, the results need to be gathered, a report is produced, and the evaluation process begins.In principle the interpretation will provide the information on the impact, in the desired format (Carbon footprint, effect on water or soil, among others). The required output needs to be defined as a part of the definition of boundaries. First of all, significant issues need to be identified (main process contributing most to the results). The interpretation requires consistency checks, ensuring that there is complete information. Sensitivity checks should also be run. The uncertainty and accuracy of results is also addressed here (3).

These steps are clearly ordered, but LCA studies are iterative, which means that the most relevant processes, resources and emissions may receive the focus of attention. Which are the most relevant processes may be known based on the first run of the assessment, based on initially available data. The accuracy of this should be studied and then corrections may be made. It is typical to carry out one to three iterations before obtaining the final results (3).

Once the four main steps have been completed, there is a possible fifth: gathering the results from impact assessment, the person interpreting may not only read them and produce an informative report but also revise the whole process, determining which are the heaviest processes and commenting on possible modifications, getting back to the experts working on the optimisation of those in order to reduce the overall weight of the system(3).

This fifth step will be carried out within the work of FFW, and the results of the LCA will be taken into account as much as possible in the design of the final system.

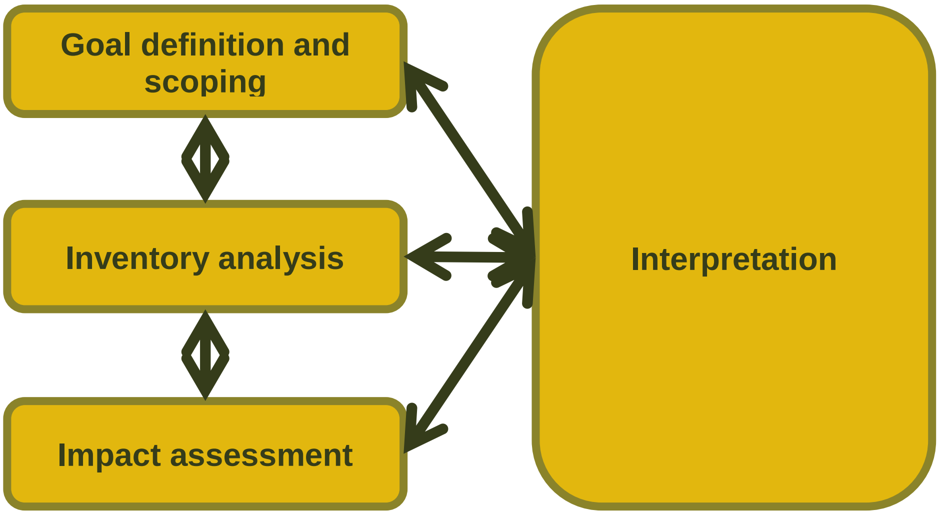

Figure 2 The analytical stages in Life Cycle Assessment

In any case, and even when life cycle assessment is getting more and more common, there are some limitations of the application of such a tool.

In the first place, it is highly dependent on the data used for running the assessment, which needs to be accurate and is not accessible (or does not even exist) for many of the processes and materials. In the case of FFW, we will work in order to solve this problem through the use of self-produced data, but this results in additional requirements.

LCA is very complex a tool when used on a young industry: it is difficult to give a holistic view of the sustainability of the whole system in a first analysis, before the process has been completely set and there is enough information on its consequences. However, it is important for this kind of analysis to run in line with the development of the process in order for it to be sustainable since the beginning instead of attempting to implement the modifications on an already established process.

Apart from that, life cycle assessment is intrinsically subjective: the very idea of proposing the system to be studied, defining its boundaries and its functional units, chosing the data sources, the weighing and the allocation of impacts is based on the subjectivity of the person or team running the analysis.

The analysis cannot take into account the possible rebound effects such as greater consumption which reduces or even eliminates the improvements of environmental and cost efficiency.

System boundaries, allocation strategies and impact assessment, in particular, merit further discussion.

In general biofuel sustainability is a broad subject of study, and there is a need to establish general rules in order to make the different analyses fully comparable. In any case, even when taking into account different LCAs already performed on similar systems, the way to make sure that the outputs from this work are well understood will be to fully define the boundaries of the system and the assumptions accepted during the work. This Deliverable will be the first document to try and inform of this particularities, but full account will be taken of the peculiarities of the work during the life of the project and included in Deliverables to come.

2 System definition

2.1 System Boundaries

The system boundaries for a life cycle assessment determine which processes and activities includes the overall LCA. This kind of analysis needs to take into account the material and energy flows of primary processes, together with extraction of raw materials, and whenever possible, the production of intermediate feedstocks or the manufacture of equipment, which could potentially be included. the end of life is also another factor to take into account: how to dispose of products, by-products, waste and process materials is another important factor to include within the life cycle boundary. The inclusion or exclusion of any step can affect importantly the outcome.

The boundaries are the way to define the system of study for our life cycle analysis: the system will include everything within the boundaries, including processes, materials and intermediate feedstocks, that can be better understood by checking Figure 3.

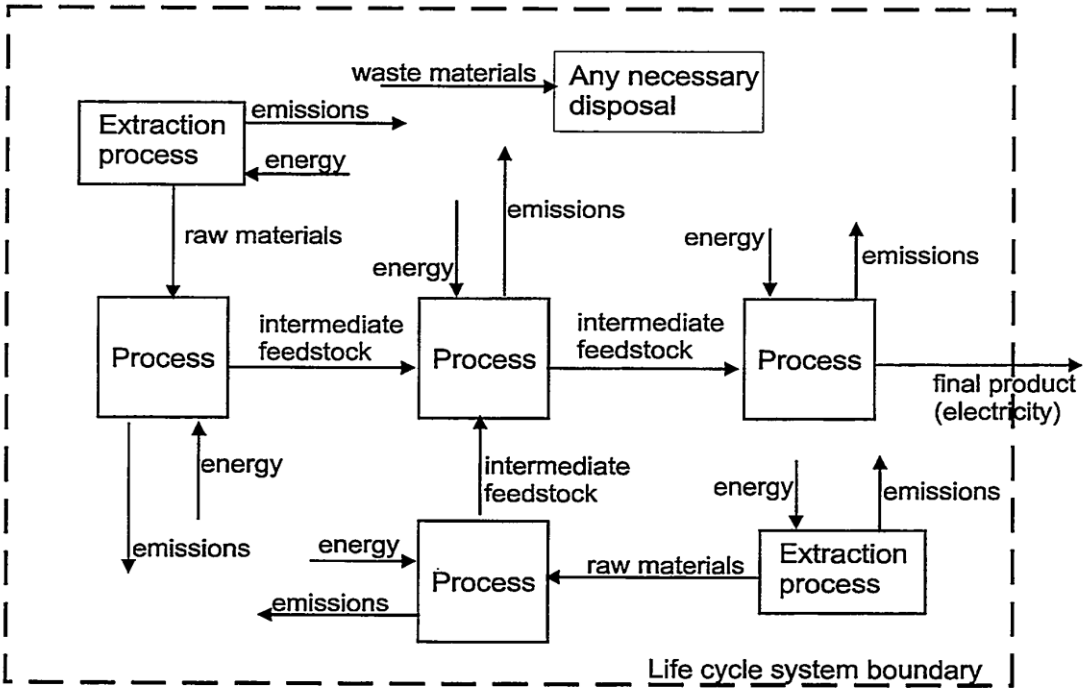

Figure 3 System concept in life cycle assessment(1)

However, it is really important to define where to stop tracking energy and material uses of upstream processes: otherwise the analysis would be infinite and the impacts to the environment would be diluted in those of the several processes studied.

In general, the impact of upstream processes are diminished just as the process gets further away from the process of interest, and it is thought that after the third level the impact is only apparent. In order to make an LCA effective, it is really important to define efficient system boundaries taking into account the available data and the possibilities of producing new information (2).

Taking this into account, we will consider within the system the production of our raw materials only based on data from databases: nearly all of the major processes required to produce the energy and biomass will be taken into account. On the other hand, the principal processes regarding biofuel production will include self-produced information that will lead to specific results regarding the newly developed system for liquid and gas fuel production based on olive and olive oil residues: the FFW process.

In order to define how the system will be determined, it is of main importance to fix the boundaries of it.The system boundaries are selected in order to define the spatial, temporal and production chain limits (start and end points) selected for the process subject of analysis. In order to give an example, the GHG balance of a crop will depend on its size and the location of the cultivation area (space boundary), the number of seasons that are taken into account (time boundary), and which treatments are considered (fertilizer, pesticides, means to collect) and post harvest transport are considered (start- and end point boundaries). We define boundaries as the limits of what is and is not included in the process from the point of view of LCA, and those are the main definition of that system.

There are different overall approaches that may be taken into account from the simplest to the most complex. Figure 4 shows graphically the core idea of those approaches which are further defined here as well:

– Gate to gate: it is the simplest option and includes the analysis only from reception of the raw materials, ready to use, to the end of production, when the product, service or activity is ready to be used or received by the final user, but without considering distribution or further. This is usually applied to specialised unit process studies that need to be studied specifically. It is common to pay specific attention to a gate to gate
– Cradle to gate: this option includes more information. In this case the production process is considered, but so are the previous stages from raw material including which type of resource is selected as raw material, the way to exploit them, the possible transformations that are required for the process to take place and also the transportation steps that are needed in between.
– Cradle to grave: this approach goes one step further and includes within the scope of the assessment the life and end of life of the product: its distribution, the use given by the client and even the possible scenarios for its end of life management. This is a usual procedure to be applied on commodities.
– Gate to grave: the idea in this case is to study what happens since the product is finished (after production) till its end of life. This is a useful idea when applied to market studies of products since it allows the assessment of the distribution, use and end of life treatment separately.
– Cradle to cradle: this option is the most complex one and it includes everything taken into account by the previous one but also the recirculation of what could be considered as waste into the process itself: solid residues or parts of those are converted into by-products and reused or treated in order to make their reuse possible within the very process, recyrcling them into the first step, as raw materials, or directly to the transformation step.

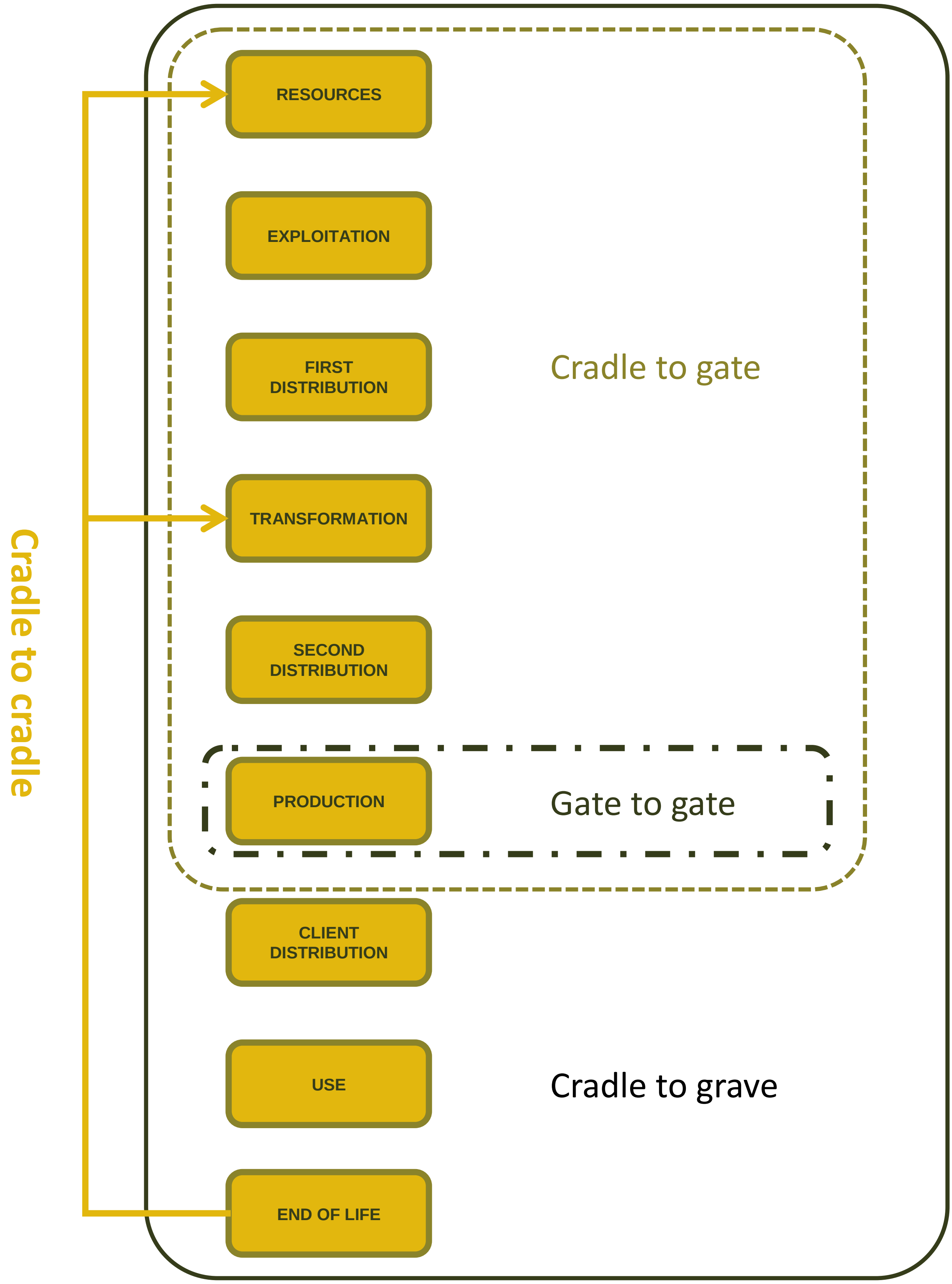

Figure 4 Different LCA approaches

Each step of biofuel production involves energy and GHG uptake, energy use and GHG emissions: taking this into account, the smallest possible system boundary would include the biofuel crop yield, having GHG inputs considering the CO_2 for photosynthesis and outputs such as CO_2 from autotrophic and heterotrophic respiration, nitrogen oxide and methane fluxes from the soil. All this will be considered as a part of the cultivation process, which will be obtained from databases in this case.

On the other hand, there is also olive oil residues as an input to the project. There are different options for olive oil production that lead to different inputs, outputs and ecological burdens. A survey has been carried out within FFW project and the answers of the olive oil producers will be taken into account in order to define the average installations that would yield the most appropriate results.

In any case, the allocation of environmental burdens will be of the greatest importance taking into account that the raw materials to the process are in both cases residues from other industries, which means that most of the impact should be allocated to the main product, our inputs receiving only a small part of the overall impact. This will be considered under Allocations.

One of the main applications of LCA is the comparison of the obtained results to those of the products or processe the object of study is competing with, and in order to be able to do that appropriately, system boundaries need to be fully defined. These are usually decided by the particular research question for bioenergy systems, which are commonly compared to fossil fuel distribution and combustion. Fossil fuels are usually assessed from fuel acquisition to combustion, and that may be compared to biofuel production.

However, the comparison is not necessarily fair: when the LCA for biofuels includes a cradle-to-grave perspective considering upstream costs for growing the crop (including fertilisers or crop establishment, for example), a fair comparison would include for fossil fuels the cost of their whole production (taking exploration or drilling into consideration as well). This means that even when the LCA for biofuels may be holistic, it is not usually compared to an equally holistic approach for fossil fuels. This is the reason why clearly stating the boundaries for the system is basic, in order to facilitate the comparison.

In this context, regarding to system boundaries, it was defined that the LCA analysis will consider the process involve in the production of SNG and Diesel (gasification, syngas cleaning, fischer-tropsch synthesis methanation) proposed in the project. Then, a gate to gate approach will take into account.

2.1.1 Steps to be considered within the LCA for FFW

All the steps of the overall process should be taken into account for LCA, and not only those that will be carried out as subject of study throughout the work of the FFW consortium, but also previous processes and the treatment of the produced waste.

In each case when a solid product is obtained and regarded as a waste product of the activity carried out for fuel production, the waste scenario will be designed, considering the available options and if there is not the chance to reuse it to another step of the very process.

The overall FFW system is shown on Figure 5, and all the steps shown in the diagram will be taken into account as part of the LCA study.

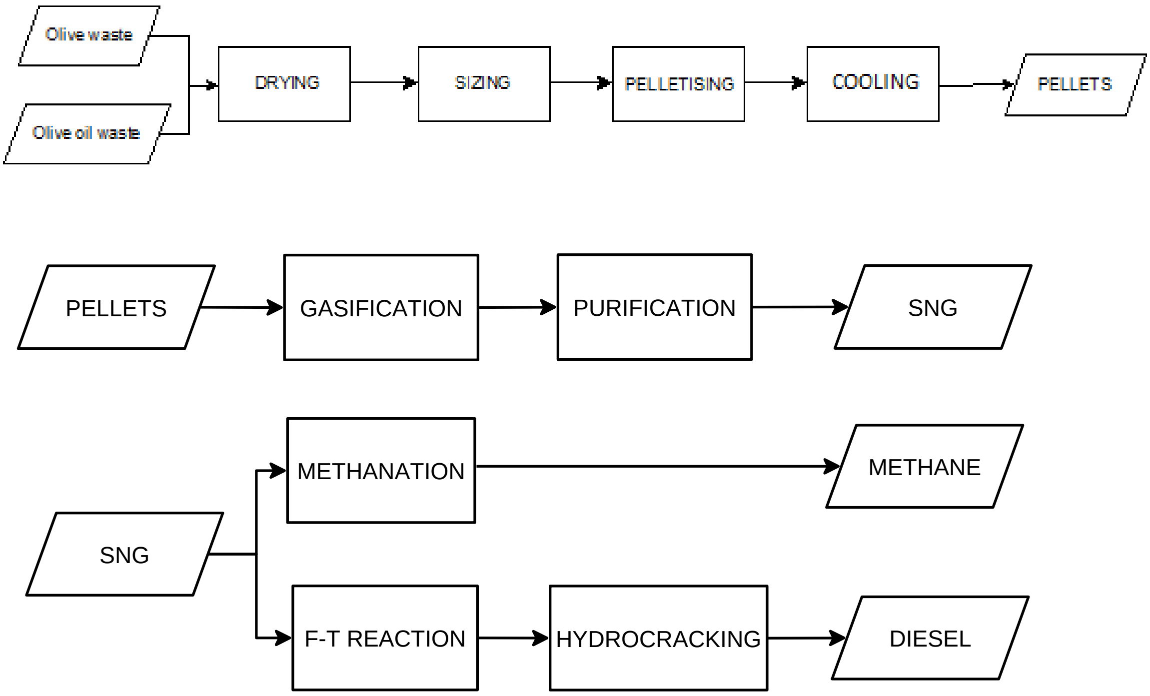

Figure 5 FFW process

- Raw material collection: The raw materials considered in this case are residues from the olive farming industry and the olive oil industry. Those will be considered directly as inputs, not conducting research on the production processes and accepting average information on the production conditions in the locations to be included within the scope of the project. Considering that only raw materials will be used as raw materials, a small part of the overall impact of olive and olive oil production will be considered as acceptable to be allocated to the final fuel.In this context, the production methods will be taken from available databases.
- Drying: Raw materials are collected with high levels of humidity that need to be homogeneously reduced in order to make them ready for pelletising. This process will be carried out via natural drying, which does not have important energy requirements and yet achieves good performance.
- Sizing: pruning residues are received as gathered in site. This means that the size needs to be reduced and homogeneised in order for the raw material to successfully undergo further processes. The sizing process will be optimized according to the pelletising requirements, but a most common particle size for pelletising is around 2 mm for pelletising.
- Pelletising: the pellets are 6 mm according to the EU standard requiring pellets in cylindrical shape no longer than 25 mm. Pelletisers use large electric motors to extrude the matter based on high pressure (about 300 MPa) and temperature (around 90ºC), and this needs to be taken into account, together with the possible lubricant and water required by the process (6). Specific information will be gathered from Work Package 2 and the demonstration once it is carried out.
- Transport: the way to bag the pellets and transport them will be taken into account, with means of transport and average distances considered on the basis of the optimisation carried out within WP2.

- Gasification: the gasification process will be taken into account based on the laboratory data and the simulation obtained from Work Package 3. The confirmation from demonstration will also be considered. In this case, the gasifier will be designed and optimised based on the previously commented laboratory information. This gasification step will also consider the required purification processes for using the syngas on the synthetic steps and also the water gas shift reaction, which will take place within the gasifier. The purification step will be designed according to catalyst requirements, including laboratory results from Molten Salt Reactor testing as well as available literature data for SNG utilization.
- Methanation: this heterogeneously catalised reaction can be optimised for a selectivity close to 100 %. Being exothermic, it requires a cooling system to maintain the appropriate temperature during operation, and the layout needs to be optimised but the most usual is to use adiabatic fixed reactors in series with cooling in between, although fluidised bed methanators can also be used (7). The most appropriate option for this case will be discussed and the conclusions from Work Package 5 will be included in the life cycle analysis. This step will include all purification required to produced the synthetic natural gas (SNG) obtained as an output, meeting the desired specifications.
- Fischer-Tropsch reaction: it is also heterogeneously catalised, and it requires to optimise the conditions in order to produce primarily waxes. This may be accomplished by running in a low temperature range (220, 240 ºC). Those waxes will afterwards be hydrocracked into a diesel fraction. The whole process will be considered within this step, including also the purification which is required to meet the desired specifications for the liquid fuel(8).

The SNG/diesel ratio depends on the requirements of the system, and it has been calculated within Work Package 4 as 0.142 kg diesel/Nm^3

2.2 Allocation

The impacts of the different stages of a process need to be parted according to the importance of each of the outputs. This may be done through allocation, although the ISO recommends avoiding it as much as possible, dividing whenever it is feasible the unit process into sub-processes in order to include the function of the co-products instead of using this system. This is due to the fact that the system to allocate the burdens is not easy to standardise and it might be considered as a source of subjectivity.

Every time that allocation is applied, it should reflect a justified relationship between the different products or co-products such as the physical relationship or the economic value of each and not necessarily in proportion to the mass flow.

There are different specific cases when allocation may be used:

- Direct substitution: the by-product from a process is directly used somewhere else. This happens in most of the cases with heat: a stream which comes out from a process with excess heat is used to warm up another one which needs to increase its temperature thus replacing the system that could have used otherwise.

- By-product seen as a waste: allocation on an arbitrary basis. The allocation may be selected by the analyser (it should be dully justified) or based on economic, calorific value or mass criteria. These criteria can be found appropriate but have advantages and disadvantages: using mass as a basis does not gather all of the complexity that allocation should imply, but market value is highly variable and also sometimes is not a good solution, when the difference between the economic weight of one of the products is much higher than the other one.

In general, no assessment deals exclusively with one form of allocation: in each particular case the system needs to be justified and explained in order to make the assessment comparable. Allocation calculations are really important on the final outcome of biofuel assessments. In fact in this case biofuels could be considered a by-product of the industries that create the waste instead of a separate business. In this case we will take into account that the inputs are waste products but will not strongly relate our calculations to the industries leading to the production of the waste.

There is the need, in any case, to be actively conscious of the possible co-products to consider due to the fact that those have a major impact on the final GHG emissions and energetic of the system.

2.3 Impact Assessment

Numerous potential environmental impact (PEI) categories can be assessed. The most common ones selected are:

- Greenhouse gas emissions;
- Energy use: any energy recovered from waste is given as the higher heating value (HHV) of the burned materials. It may be expressed as cumulative non-renewable energy demand;
- Water use: impact on water, including:
  - Water consumed during process;
  - Waterborne emissions: discharges into receiving waters after treatment, measured as a value of the biological oxygen demand (BOD), chemical oxygen demand (COD), or suspended/dissolved solids;
  - Acidification or eutrophication;
- Solid waste: any waste sent to landfills;
- Land use;
- Global Warming (GWP);
- Ozone layer depletion.

In this particular case different PEI will be considered, taking as basic GHG emissions, energy use and water use. Other categories will be commented when found if it is considered necessary but will not be considered of leading importance.

2.4 Functional unit

The functional unit is the specific quantitative description of the function or functions that the selected system provides. It gathers what it does, how much of that it may provide, how well it is done and for how long. The correct definition of the functional unit is basic for comparison: if it is not fully defined, a product delivering fewer or worse functions tha a competitor may appear after comparison as better from the environmental point of view simply because fewer issues were being taken into consideration (3).

The choice of functional unit may not be that important for an individual study, as it is only used to assess a given aspect of a life cycle. However, it is important to set it clearlyin order to facilitate comparison between studies. A common functional unit is CO_2 emission per gallon of biodiesel. The energetic balance may be assessed considering the energy produced per unit of energy consumed through the whole process and then the environmental balance would be considered as GHG emissions per unit of energy consumed.

Other possibilities are using simply units of power (electricity), fuel consumed, mass of biomass used per year and some others.

All of those have been used in different assessments for biofuel production, and all could be applicable to our case. However, considering that we have a complex system with two different outputs and that starts from two different types of raw material. In order to coordinate all of this, a common functional unit needs to be defined that covers the whole output and considers both main inputs.

The proposed solution is to consider the final energy produced (MJ produced) per unit of biomass consumed (kg biomass), which gathers all inputs and outputs. In this sense, 1 MJ of energy released by combustion of produced biofuels was considered for this anlysis. Although this will be left open for discussion from the partners providing the technical information and can be modified in case it is considered important. The modification on such a basic factor for the assessment would be dully specified in the final report which, in any case, will include a summary with the functional unit, boundaries, allocation systems and assumptions made through the whole analysis.

It is of great importance to correctly define the functional unit due to the fact that facilitating comparisons of the performance of different options from the environmental performance point of view is one of the principles of life cycle assessment, and this comparison needs to be held on an equal basis, thus helping identify the possibilities for improvement. The comparison of alternative options based on their functional unit is basic for assessing the technical performance/equivalence.

2.5 Sources of data

There are different options when it comes to obtaining data for the studies. In our case, we will have access to laboratory data and the demonstration system will also yield information at a higher scale, but those still will need scaling up to estimate the values produced by a full size system. Apart from that, the study will be backed up by the EcoInvent databases and other LCI databases.

It is of main importance to be transparent when it comes to the source of data. This, together with the explaination of assumptions, makes the study more creditable. In order to ensure the trazability of the information, data sources and assumptions will be specifically identified in the final report.

In order to have all of the possible steps of the process covered, the experts will be asked for information and assessment for defining the LCA system. This way not only the data but also the definition of the process will be appropriate. This is one of the issues when it comes to LCA: many times the authors are LCA experts but not experts in the field of synfuel production. In order to reduce the problems derived from this situation, the whole FFW consortium will be involved in the LCA.

Clearly, arguments about the values used are bound to happen, and until an actual system is created in full size, basing the work on pilot systems with critical thinking of the effects of scaling up is the best that studies can do.

2.6 Lessons learned from existing LCA studies

The review of existing LCA supports the following conclusions:

- Many studies on biofuel production techniques consider a wide range of conceptual designs, but they usually provide partial descriptions of the production systems. Then some of the studies only consider the production stage, and those will naturally provide a more positive energy balance than studies that include subsequent processing steps.
- Comparison is also hindered by the use of inconsistent boundaries and functional units.
- The studies use a range of allocation methods.
- In many cases there is little primary data upon which process assumptions can be based. The production processes analysed appear to be assembled from component parts, rather than designed as integrated systems.

3 Conclusions

Work Package 6 will be eminently focused on the life cycle assessment of the full FFW system. The impact of diesel and synthetic natural gas will then be addressed using a life cycle assessment approach in order to identify their production bottlenecks and ease them as much as possible in order to facilitate the development of this kind of fuel production based on agricultural residues and more specifically on olive and olive oil waste.

One of the strength of LCA is that it provides quantitative results, and combined with financial modelling it can lead to complete information on how feasible from all points of view the studied technology is.

In order to make sure that the LCA meets this objective, it is important to make sure that the concept is clearly attained and the inputs to assessment are coherent and well designed processes, not only from the point of view of the laboratory work but also for the study itself, taking into account the assumptions that need to be taken.

Due to the fact that some of the data will need to be extrapolated to production scale, it is really important to be transparent with the assumptions made in this respect: one of the most important issues for the reports regarding LCA is to take account of all assumptions, considering definition issues but also allocation issues and others.

The main conclusion from this report is that the definition of the overall system is basic for the production of an understandable and comparable assessment in the end. System boundaries, allocation options and functional units are the ways to describe a system and those have been treated within the Deliverable in order to estructure the first ideas on which the whole LCA will build. Even though some of the questions have been left open for discussion with other members of the consortium, all of them have been pointed out and treated, and all of them will be dully specified for the final report, being an important part of it, crucial for the comparability of the final result.

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