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0	Diego Peñaloza, Selim Stahl	RISE	Production of the first draft of the document
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2	Diego Peñaloza, Selim Stahl, Heiko Keller, Patricia Harvey	RISE, IFEU, UG	Changes based on one last round of review before submission

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1. Executive Summary

The work presented in this deliverable aims to provide the necessary input concerning social sustainability for the integrated sustainability assessment of the D-Factory concept, which is the ultimate goal of work package 7. The work consists of two main components; a social risk assessment and a SWOT analysis. The social risk assessment aims to estimate the positive and negative social impacts of the implementation of D-Factory with a life cycle perspective. It measures the risk of negative social impacts as well as the avoided impacts from different scenarios where D-Factory is implemented. On the other hand, the SWOT analysis aims to identify strengths, weaknesses, opportunities and threats of the D-Factory technology, based on expert knowledge and feedback from stakeholders. This would provide a wide range of possibilities that may have positive or negative effects to the D-Factory concept and caused by D-Factory operations.

The results of both assessments are positive for the development of the technologies, and show a clear pathway for the D-Factory development. However, these outcomes are based on a certain set of assumptions and are conditioned by other issues identified in both the social risk assessment and the SWOT analysis. Therefore, it is recommended that these findings are taken into account and properly communicated to stakeholders, especially those in charge with the continuation of the work in D-Factory. Overall, the task was carried out successfully.

2. Introduction

Defining what Sustainable Development (SD) is may not be a simple task. Many attempts to define the concept have been carried out ever since the Brundtland Commission made a first attempt to do so (WCED, 1987). Different ways to define SD have been proposed through the years, but some common ground among these can be found on how each of these definitions see the goals, indicators, values and practice of SD (Kates et al., 2005). In that sense, many of these definitions agree on a well-known “Triple bottom line” definition: People, economy and society must be developed while sustaining nature, life support and community (USNRC, 1999). In order to assure that human development follows sustainable pathways, substantial efforts are needed to ensure that all technologies are able to achieve this equilibrium between economic, social and environmental demands.

This is why a sustainability assessment is necessary for the technology developed within the D-Factory project. In order to do so, the goal of WP7 is to carry out an integrated sustainability assessment where the impacts of the D-Factory technology are analysed with a life cycle perspective. For this integrated sustainability assessment (Keller et al., 2017), it is necessary to study the impacts of the technology to the aforementioned three pillars of sustainability.

Microalgae-based processes are increasingly being considered as a promising alternative to traditional high-impact technologies such as fossil fuels; and while much is discussed about the contrasting interests of achieving economic feasibility and decreasing their environmental impacts, social aspects are often ignored (Malcata, 2011). As part of recent research efforts, some publications are available where social issues of algae-based processes are discussed qualitatively, namely local work creation in low-employment areas, negative public opinion and competition with tourism (Montagne, 2013). However, more recent research projects may offer some further insights, but no publication with quantitative social assessments is available to date (Hingsamer, 2014). Therefore, it is clear that more knowledge is needed about the social impacts of algal-based products.

The aim of the work presented in this deliverable is to assess the overall impacts that the D-Factory technology could have for the social pillar of sustainability. For this, the positive and negative impacts from the D-Factory need to be estimated using two complementary tools: Social Life Cycle Assessment (S-LCA) and SWOT analysis. Social LCA will provide the life cycle perspective evaluating potential social hotspots through a supply chain model created specifically for this goal. Meanwhile, the SWOT analysis will provide a qualitative analysis of the potential positive and negative consequences of the D-Factory, using a stakeholder perspective. Together, these assessments will provide the necessary input to establish the overall impact that the D-Factory will have on the social pillar of sustainable development.

3. Methodology

This section describes the methodology adopted for the assessment in order to attain the aim described in the previous section. The first subsection focuses on the social LCA, the second subsection on the SWOT analysis and the third on the integration of both tools towards an integrated social assessment.

3.1. Social risk assessment

Social Life Cycle Assessment (S-LCA) is a somewhat novel assessment tool that can be used to measure the social impacts of a product or service with a life cycle perspective. Due to the multiple paradigms in social sciences, social phenomena have a “multi-layered” nature resulting in a wide variety of methodological approaches to Social LCA (Iofrida, 2016). This has become evident with the surfacing of multiple proposals for methodological approaches (Weidema, 2016; Smith & Barling, 2013), indicators (Iribarren *et al.*, 2016), ways to account for positive impacts (Di Cesare *et al.*, 2016), databases (Benoît-Norris, 2014) and even discussion about the relevance of certain chosen topics (Arvidsson *et al.*, 2015). Consequently, the diversity in possible approaches has made it more challenging to standardise S-LCA practice.

The closest to what can be referred to as a standard for S-LCA are the guidelines for S-LCA of products published by the Life Cycle Initiative (UNEP/SETAC, 2009). This document offers a “skeleton” with the key elements that should conform a S-LCA, and in spite of it not being mandatory, it is to this date the main reference for standardisation of S-LCA. More recently, the guidelines were further developed with the creation of a set of methodological sheets for subcategories of Social LCA, focusing on guidance for the inventory analysis phase of a S-LCA (Benoît-Norris *et al.*, 2011). The methodology applied to this assessment follows the UNEP/SETAC guidelines, and uses data from a database built based on the methodological sheets.

3.1.1. Goal

The goal of the work presented in this deliverable is to measure the risks of social negative and positive impacts of the D-Factory technology under different scenarios and to identify early potential social hot-spots in these scenarios. The results are meant to be used as guidance for further development of the D-Factory concept from research to a full-scale business model. In this sense, the intended users for these results are the stakeholders that will take on this further development, so they can make informed decisions where the social risks and hot-spots identified can be avoided. The study has used generic databases (see Appendix 1 and 2) and should not be used to make comparative assertions with other products from well-established supply chains, but rather to inform about social risks for D-Factory upscaling.

3.1.2. Scope

The scope of the assessment is cradle-to-grave, as it includes all the processes from raw material extraction until end-of-life of the product. Given that many of the downstream processing D-Factory technologies are still in an early stage of development (see Deliverable 7.4), there is not a complete supply chain for all intended products to model and evaluate. Therefore, a significant amount of assumptions have to be made, while mostly generic data had to be used to model the processes within the system boundaries. The activity variable used to measure the relative importance of each process is the amount of working hours, which are normalized in reference to the functional unit. The only processes modelled using specific data are those within a theoretical D-Factory pilot production plant. Still, the amount of work that occurs in upstream processes is relatively low in terms of working hours in relation to the downstream plant itself. A graphic description of the system studied for this assessment is displayed in Figure 1.

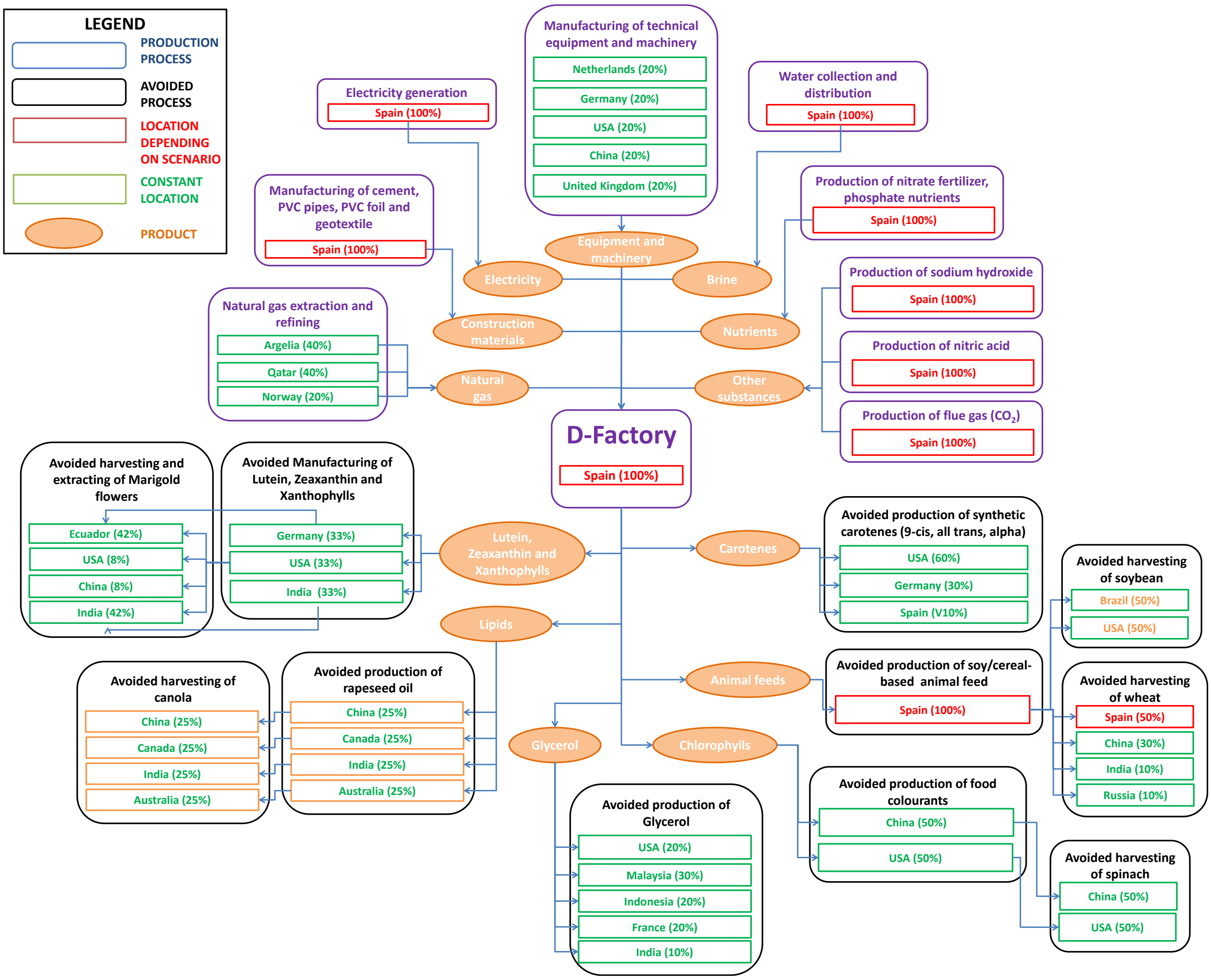


Figure 1 System studied in the social risk assessment. All the processes displayed in the figure are included within the scope.

Scenarios on material flows in the system are based on quantitative models that represent the fully-developed and up-scaled D-Factory product system in the year 2025, based on the technical scenarios described in Deliverable 7.3 (Harvey, 2017). However, the modelling of the market share of the upstream processes is based on historical data, meaning that for simplification it is assumed that the market of the inputs and outputs to and from D-Factory do not change over time. The baseline scenario of the assessment corresponds to a 20-hectares plant located in Monzón, Spain. However, the geographical boundaries of the system vary for the scenarios analysed (see section 3.1.5) since different locations for the D-Factory and therefore local processes (red and green in Figure 1) are explored. Still, the location configuration based on market shares presented is constant in all scenarios for the upstream processes (blue in Figure 1) and for the avoided products (orange in Figure 1).

3.1.3. Functional unit and multiple-product allocation

The functional unit (FU) used for this assessment is **kilograms of dry algae paste produced**. The D-Factory biorefinery by definition produces multiple products, posing a challenge for allocation of impacts. To solve this allocation problem, system expansion is applied to the social impacts of the D-Factory. This way, the impacts from the downstream processing plant operations are fully accounted for, while each of the co-products is assumed to displace an equivalent product and therefore avoid manufacturing processes in other locations globally. On the other hand, some upstream processes also require allocation, and for these the same allocation procedure used in the database sources is applied.

3.1.4. Inventory analysis: Model of the supply chain and working hours

The choice of working hours as the activity variable in the system model means that each process within the scope has a relative significance on the result depending on how many working hours are required to produce the quantity of its reference flow (functional unit). For example, the relative importance of the process "Electricity generation" corresponds to the working hours required to generate the amount of electricity needed per FU; in relation to the total amount of working hours per FU in the system. Therefore, an estimation of the working hours per unit of output for each of the processes (also for each potential location of these processes) within the studied system was required.

This estimation was calculated using country-level statistics for different industrial sectors. Data for total output and total expenditures in wages and salaries (in MUSD) was accessed from the United Nations Industrial Development Organisation - UNIDO databases MINSTAT and INDSTAT (UNIDO, 2017). These data are aggregated per year and per industrial sector based on the International Standard Industrial Classification of all Economic Activities - ISIC, an aggregation that varies for each country depending on data availability so the best data available was used for each process. A detailed account of the data sources and assumptions used in this part of the assessment can be found in Appendix 1. The amount of working hours per process was finally obtained using the approximate price of goods (unit of output from each process) and an estimation of the average hourly wages in the respective country. The data for average country hourly wages was extracted from the OECD statistics database for OECD countries (OECD, 2017) and from the International Labour Organisation – ILO statistics for non-OECD countries (ILO, 2017). The specifications regarding the data used for price of goods and average hourly wages can also be found in Appendix 1.

This approach was particularly sensitive to the choice of data for price of goods for high-value products; more specifically Lutein, Zeaxanthin, Xanthophylls, Carotenes and Chlorophyll. This is because of the uncertainty surrounding the relationship between the price of the goods and the costs from labour, amplified by the relatively high price of the goods per unit of mass. As a consequence, a different approach was used for these products, where data for wages or value created for employees in relation to total output was obtained from the specific manufacturer's sustainability or financial reports. Similarly for these products, more accurate data for the wages and salaries in the nutraceuticals and pharmaceuticals sectors was extracted from the web portal "Payscale" (Payscale, 2017).

The material and energy inputs and outputs required to model the D-Factory system as well as the benchmark products that are assumed to be substituted by the D-Factory co-products were obtained from within the D-Factory consortium. The data and scenarios are the same used by all partners in WP7 for their specific tasks. This way, it is ensured that the components for the sustainability assessment have comparable scope and scenarios, and can be integrated in the final task. Nevertheless, given that the D-Factory system analysed in this study, which is currently configured for multiple sites, corresponds to future scenarios, there is uncertainty about the staff required for it to operate and produce the expected co-products, a sensitivity analysis was carried out with different assumptions concerning staffing needs of the D-Factory.

3.1.5. Social risk data: Social hotspot database (SHDB)

The next step in the analysis is to obtain data for the associated social impacts of each of the processes in the studied system introduced in Figure 1. These processes, which can be raw material extraction, manufacturing of specific inputs or energy generation; also feature specifications concerning one or more countries where they occur. To obtain these data, the Social Hotspots Database (SHDB) has been used; a tool conceived for use in social life cycle assessments (SLCA) (SHDB, 2013a). The SHDB is a directory of social risks in 227 countries and 57 sectors, given in 22 social themes divided into 5 social categories. The SHDB features country and sector-specific data for social impact indicators. Its goal is to help identify hotspots in terms of countries and sectors of concern in supply chains, based on potential social impacts (SHDB, 2013b). These indicators can be used to measure the risk of a specific social issue, which could also be seen as the opportunity to improve it.

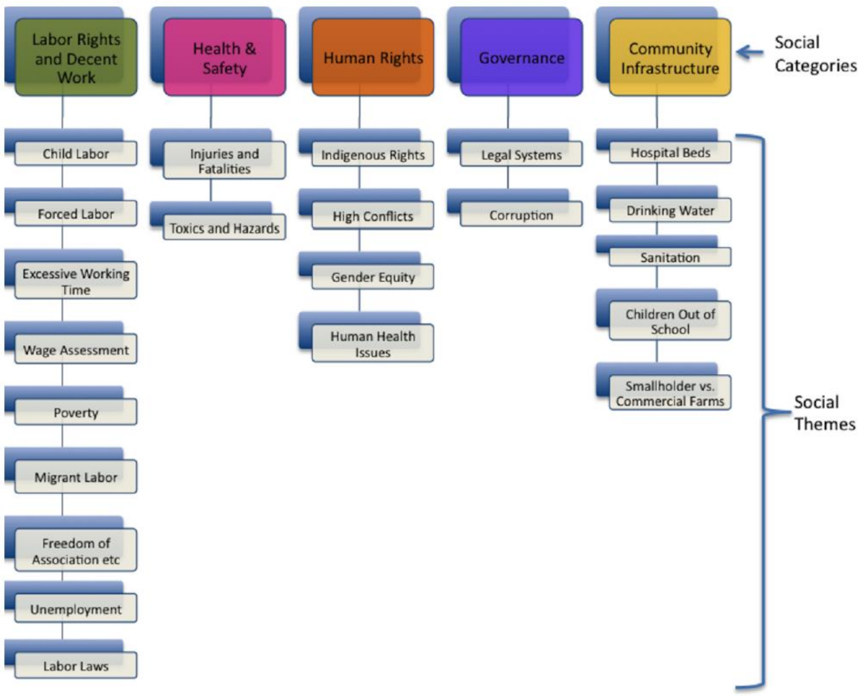


Figure 2 Social categories and themes in the Social Hotspot Database (SHDB, 2013b)

Figure 2 shows an outline of the social categories and themes evaluated in the SHDB, which were defined based on standards, policy frameworks and expert advisory (SHDB, 2013b). For each social theme, there are one or several indicators. These indicators correspond to either qualitative or quantitative issues related to each social theme. For each country and sector, a risk rating of 0 (low risk), 1 (medium risk), 2 (high risk) or 3 (very high risk) is given to each indicator, based on indicator-specific characterization rules. Then a risk rating between 1 and 4 is generated for each theme, by averaging over all indicators and giving extra weight to particularly important indicators. The risk ratings for all themes within a category are then summed, divided by the highest sum possible for that sector, and multiplied with 100 to generate a value between 0 and 100, which is the social hotspot index for a particular social category in a particular sector and country. The indices for the five social categories may then be further summed into a total social hotspot index for a particular sector in a particular country. The social hotspot index can be seen as "a total number of weighted risks to be aware of when working in that particular country and sector" (SHDB 2013b, p. 4). A short description of the social impact categories included in the SHDB and what they measure can be found in Table 1.

Table 1 Short description of each social impact category in the SHDB and what kind of impacts it measures.

Impact category	Short description
Labour rights and decent work	Risk of unfair conditions of work or labour accords violations in the value chain (child labour, low wages, forced labour, etc.)
Health and safety	Risk of high prevalence of occupational injuries and deaths and high exposure to workplace hazards
Human rights	Risk of human right violations (infringements of indigenous rights, weakness of gender equality, potential for high conflicts, etc.)
Governance	Risk of manufacturing processes located in countries or regions with weak legal systems, high risk of corruption or poor law enforcement.
Community infrastructure	Risk of negative impacts to the local community (school for children, drinking water, land ownership of small land holdings, etc.).

As mentioned before, the assessment of social sustainability is highly dependent on location because of the regional specificity of the social impacts. This regional dependency is caused by societal, political and cultural differences among countries. This is why the SHDB is built based in national and global statistics and other publicly available data sources. It is possible that sector-specific data is not available for all indicators, but it has been used in the database when available. The division in industrial sectors followed by the SHDB is based on the sectoral list established by the Global Trade Analysis Project – GTAP (GTAP, 2017). These data are complemented with qualitative data from similar sources. Finally, the data used in the SHDB are chosen based on a set of criteria including comprehensiveness, legitimacy, reliability of collection methods, relevance to the related theme and the possibility for quantification (SHDB, 2013b). Specific references to the social risk data used for each process can be found in Appendix 2. The database was last updated in 2016 using data for 2015, so the social risk scores for each process have been recently updated.

The SHDB and its data have two main limitations. First, the level of aggregation of the data in industrial sectors means that data for specific technologies or products cannot be differentiated, and only aggregated data can be used. Given that the goal of this assessment is of explorative character, aggregated data are deemed sufficient. Moreover, the D-Factory system is still in development, which means that the data obtained for inputs and outputs are still highly uncertain, as well as the setting of the supply chain and upstream processes, especially concerning location. This means that at this stage of development, multiple scenarios with acceptable uncertainty should be preferred over fewer scenarios with more specific settings. The second limitation is the fact that the SHDB does not include positive social impacts. To overcome this limitation, the positive impacts have been accounted for in this assessment by estimating the social risks avoided by substituting the benchmark products identified for each of the D-Factory co-products.

3.1.6. Social assessment based on working hours

The final step of the assessment is to calculate the social risks of the D-Factory system. Using the working hours per functional unit required from each process in Figure 1 and the social risks associated with this process obtained from the SHDB, this risk has been estimated. The working hours required from each process per functional unit are then multiplied by the social risk of each process for all the social themes and categories in the SHDB. The same is applied for the working hours required to produce the avoided production of the benchmark for all co-products, and their corresponding social risks. The final result of the assessment is the sum of the social risks from all the processes in the system, in working hours-risk per functional unit.

3.1.7. Description of studied scenarios

The baseline scenario of the assessment is the “base case scenario” under optimistic conditions as defined in deliverable 7.3, located in Monzón (Spain), assuming a staffing factor 4.3 employees per hectare for the site (upstream only). Additional scenarios were then evaluated under different conditions concerning e. g. conservative expert estimates productivity and other scenarios from deliverable 7.3. These additional scenarios are also common with the other sustainability components in the other tasks of WP7. The final result of each scenario shows then a comparison between the negative social risks (with positive values) and the avoided social risks (with negative value). The studied scenarios are summarized in Table 2.

Due to the importance of location for social impacts, additional scenarios were assessed in order to test the sensibility of the results to the country where D-Factory technology is implemented. For this sensitivity analysis, different locations for the “local” processes (in red) in Figure 1 were tested. These locations were selected based on internal knowledge and observations throughout the project concerning interest from external stakeholders. There are a number of countries in Europe with similar conditions to Spain where D-Factory could be located such as Portugal or Italy. However, due to the similarities in policy, culture and society among these countries, the social risks per process were very similar to those from Spain, which is why only Spain was considered in Europe. Israel was chosen due to the presence of NBT (partner in D-Factory), where significant parts of the research in the project were carried out. Saudi Arabia was named during project meetings as sources of interest by diverse external stakeholders. Chile was added as requested in one of the project meetings and to represent a context from another continent.

Finally, due to the uncertainty concerning staffing needs for the D-Factory site, a sensitivity analysis was included to assess how different assumptions concerning staffing needs would affect the outcome of the assessment. Two additional assessments were performed; one with a lower staffing factor (2.1 staff/hectare) and one with a higher factor (8.6 staff/hectare).

Table 2 Outline of the different scenarios modelled for the D-Factory system

Scenario from deliverable 7.3	Up-scaling productivity	Possible locations studied	Staff assumed for the plant (Nr/ha)
Base case	Optimistic	Spain	4.3
			2.1
			8.6
		Israel	4.3
		Saudi Arabia	4.3
		Chile	4.3
	Least expected	Spain	4.3
1c (Westfalia, membranes)	Optimistic	Spain	4.3
	Least expected	Spain	4.3
1d (With Westfalia, no pre-concentration)	Optimistic	Spain	4.3
	Least expected	Spain	4.3
1f (glycerol recovery)	Optimistic	Spain	4.3
	Least expected	Spain	4.3
1g (no purification of extract)	Optimistic	Spain	4.3
	Least expected	Spain	4.3
1h (no prep HPLC of carotenoids)	Optimistic	Spain	4.3
	Least expected	Spain	4.3

3.2. SWOT Analysis

The work to carry out a SWOT analysis can be divided in two sub-analysis. The first is an analysis of external factors to identify the opportunities and threats of the surrounding environment. These could be identified using strategic analysis models, Porter's five forces analysis or a scenario analysis. There can be the appearance of new competitors, a new technology, new rules related to the specific target market, new potential markets etc. By nature the results of the external analysis are the same for all the market competitors. The second is an internal analysis, which lists the strengths and weaknesses of the domain activity. These strengths and weaknesses can be identified using strategic analysis models like value chain analysis, benchmarking analysis or industrial cluster analysis. This can be done using the technology portfolio, the notoriety, the geographical presence, the partner's network or the organisational structure of the project. By nature, the results of the internal analysis are specific to the studied organisation. It is the confrontation between the two analyses established with the SWOT model (internal analysis and external analysis), which can fuel the next step of a strategic options proposal.

The SWOT model is relevant only if the questions asked are relevant ones, that there exist answers to them and that each of the fields involved in the project has been analysed in terms of both performance and importance. The likelihood of the SWOT results being right depends on correctness of the analysis on short, middle and long term perspectives and from the understanding that the internal or external environment can change quickly, which implies updates to the SWOT analysis on a regular basis. A typical mistake is to do a SWOT analysis for a whole organisation or company. Indeed, the SWOT model is only relevant for a strategic business unit. By nature, each strategic business unit is defined by a specific combination of key success factors, resources and competences, which implies that the external analysis and internal analysis vary from one strategic business unit to another. The summary of the SWOT analysis of each strategic business unit generally do not allow obtaining the global SWOT analysis of an organisation or a company.

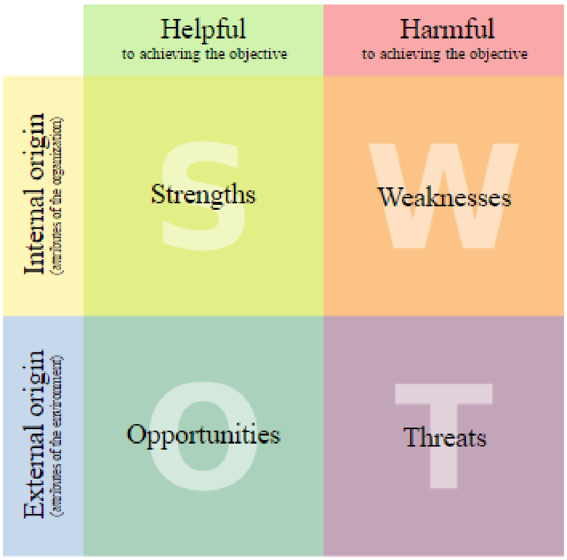


Figure 3: SWOT analysis with its four elements in a 2 x 2 matrix

The SWOT analysis results are presented as a matrix with four main cells, as illustrated in Figure 3. Vertically there are two columns. The left column gathers the list of elements having a positive or favourable impact on the studied strategic business unit of the organisation. The right column gathers the list of elements having a negative or unfavourable impact on the studied strategic business unit of the organisation. On the other hand, there are two horizontal rows. The top row gathers the list of elements which are due to internal reasons, specific to the studied strategic business unit. These elements – which are internal to the organisation – are supposed to be controllable by the organisation in case a change is needed. The bottom row lists the elements which are due to external reasons, generally occurring among all the market competitors. These elements – which are due to external reasons – are not controllable by the organisation. At the intersection of the columns and rows are four cells where the relevant information is displayed:

- Cell S (Strength): the Strengths or positive internal factors
- Cell W (Weaknesses): the Weaknesses or negative internal factors
- Cell O (Opportunities): the Opportunities or positive external factors
- Cell T (Threats): the Threats or negative external factors.

The list in each cell contains commonly about 3 to 5 elements. In addition, a hierarchy is usually achieved by listing the elements from highest to lowest in the Strength cell, the weakest elements first in the Weaknesses cell and same logic in the Opportunities and Threats cells. The work presented in this report presents a SWOT analysis performed to identify the strengths, weaknesses, opportunities and threats the D-Factory algae biorefinery has. A first list of strengths, weaknesses, opportunities and threats has been identified while interviewing the D-Factory project members. This preliminary list is available in Appendix 3. The list of elements has been rated from -1 to 3 (-1 being an element considered irrelevant and to be removed, then 1 to 3 with 3 being the strongest element) and then reviewed again by each D-Factory main value chain stakeholder (algae cultivation and reactors, extraction, purification, project owner) to become the list presented below. The list has then been enhanced by interviewing external stakeholders with a series of questions close to the SWOT analysis final list but sufficiently general so that no Non-Disclosure

Agreement had to be signed beforehand. These Q&A with external stakeholders are also available in Appendix 3.

3.2.1. Goal and Scope

The SWOT analysis in this report is part of an overall integrated assessment of sustainability (Keller et al., 2017). The goal is to identify the key internal and external factors for the success of the D-Factory pathways. It is based on available D-Factory reports and information (mostly from the overall integrated assessment WP) as well as references from literature and expert partners.

3.2.2. System boundaries: what is internal and external to D-Factory

For this study, every inherent property of D-Factory technologies and the performance under normal circumstances will be considered internal. In contrast, will be considered external all aspects which relate to success or failure in development of other technologies or the performance of the D-Factory biorefinery concept under other circumstances than those it was designed for. The analysis is based on the scenarios, expected products and processes established in Deliverable 7.3.

Since there are only minor differences regarding SWOT arguments between the extraction methods and the biomass state, there are no extra matrices for each scenario. If there are specific arguments regarding the extraction methods or biomass state that are necessary to mention, they will be specifically labelled in the matrix with the corresponding scenario reference.

4. Results

This section presents an outline of the most relevant results obtained for the social risk assessment and the SWOT analysis. The results presented here are summarized, while a more detailed account of the results is available in Appendix 4.

4.1. Social risk assessment

The results for the base case and the contribution from different processes are presented in Figure 4. Meanwhile, Figure 5**Error! Reference source not found.** presents a summary of the results obtained for all the remaining scenarios, including both negative risks and avoided risks of D-Factory.

4.1.1. Results for the base case

As can be observed in Figure 4, a significant share of the positive impacts from application of D-Factory technologies can be attributed to the substitution of high-value products, more specifically all-trans-ß-carotene, pure 9-cis-ß-carotene and α-carotene. This is due to the fact that these products have both a high value and significant social impacts. Their high value means that they require relatively higher amounts of working hours to produce small amounts of the end product. In addition, their associated social impacts are higher because their manufacturers and raw materials are mostly located in countries with relatively high social impacts in their agricultural and chemical sectors such as China, India and even USA. Given that the social risks of each process in our model is a product of the working hours per functional unit and the associated social impact of the unit process, the substitution of these high-value products have a significant influence in the result.

With regard to social hotspots, as illustrated by Figure 4 the main social impacts caused by the D-Factory production system are concentrated in the health and safety and governance impact categories. The high risk of negative impacts in health and safety are due to the fact that besides energy, most of the inputs required by the D-Factory are chemicals or related to this industrial sector, which is commonly associated with occupational hazards in Spain and Europe. On the other hand, the high score for governance are caused by the use of oil-based materials such as heptane, hexane, ethyl acetate, methanol and ethanol. The market of these products is dominated by high-risk countries such as Saudi Arabia, Iran and India. The processes that have the highest contribution to the negative social impacts of the D-Factory are the production of hexane and heptane, the production of ionic liquids and the production of bottled CO2.

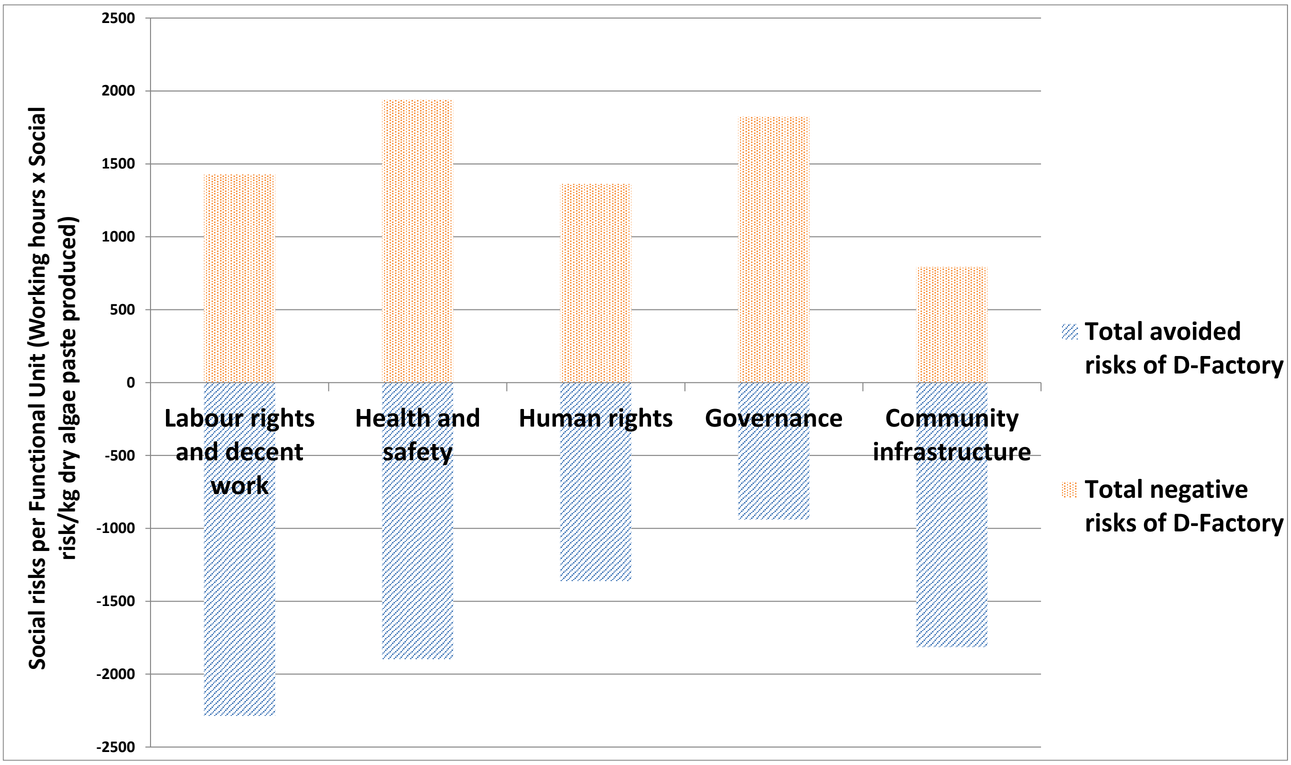


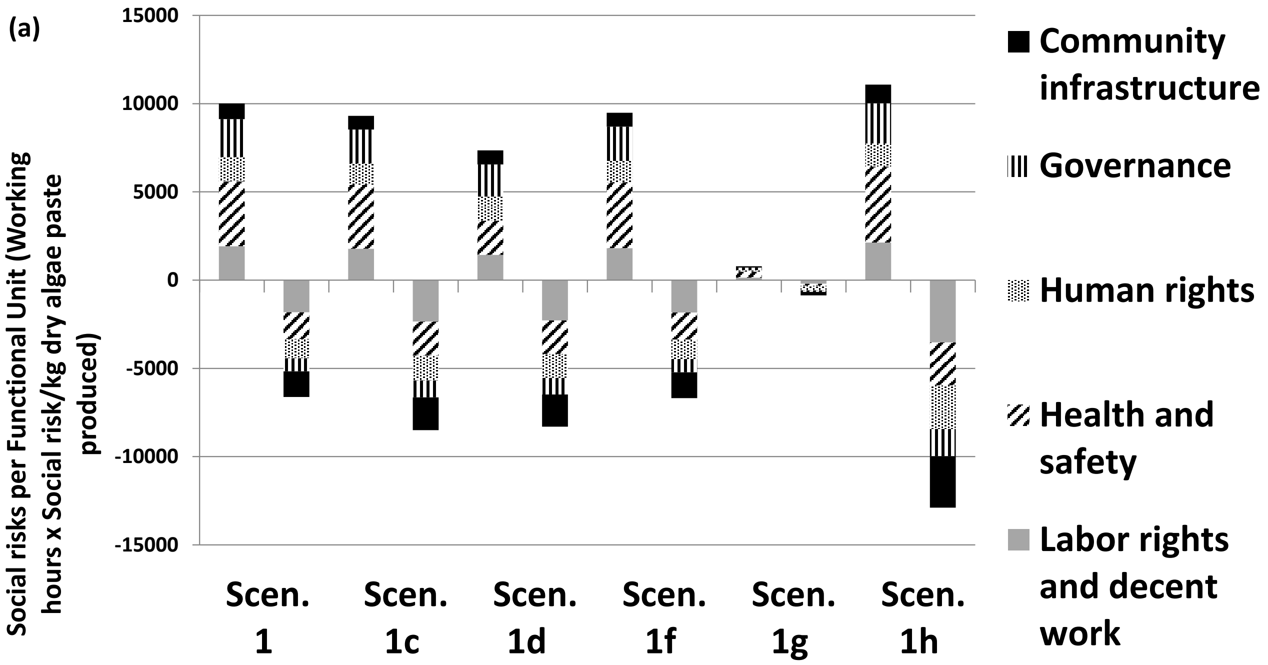
Figure 4 Social risk assessment results for the base case scenario (from the scenarios defined in deliverable 7.3), located in Spain, optimistic conditions.

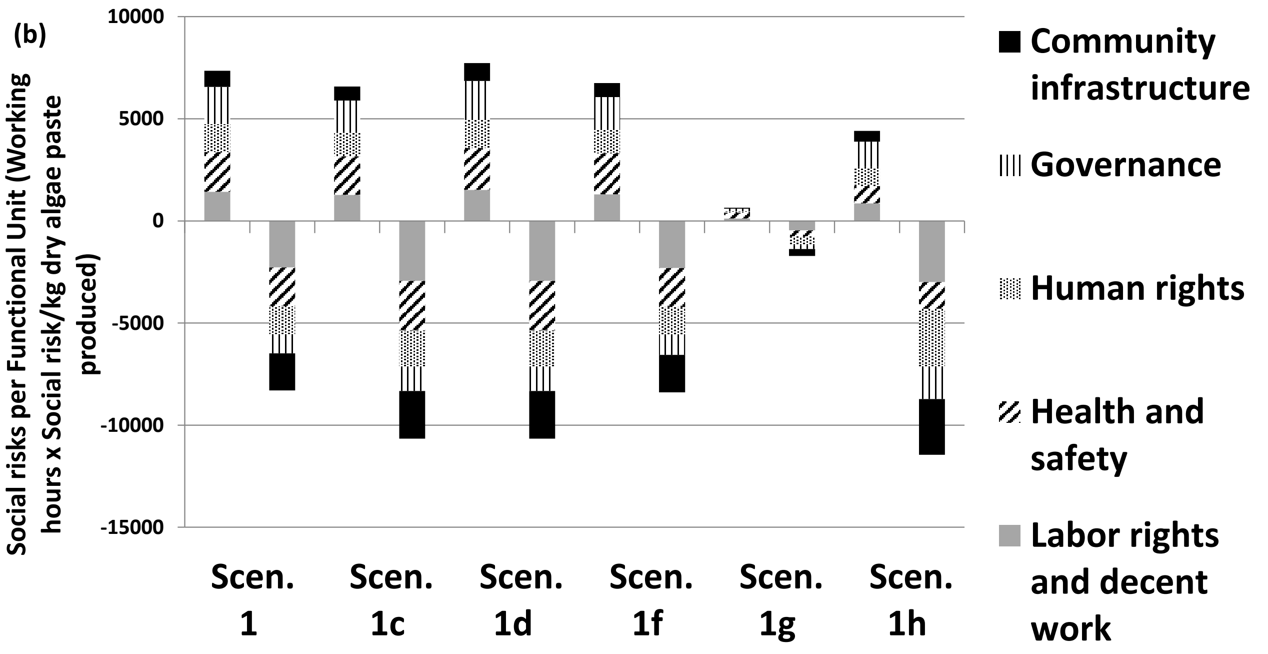
4.1.1. Sensitivity analysis: results for the other scenarios

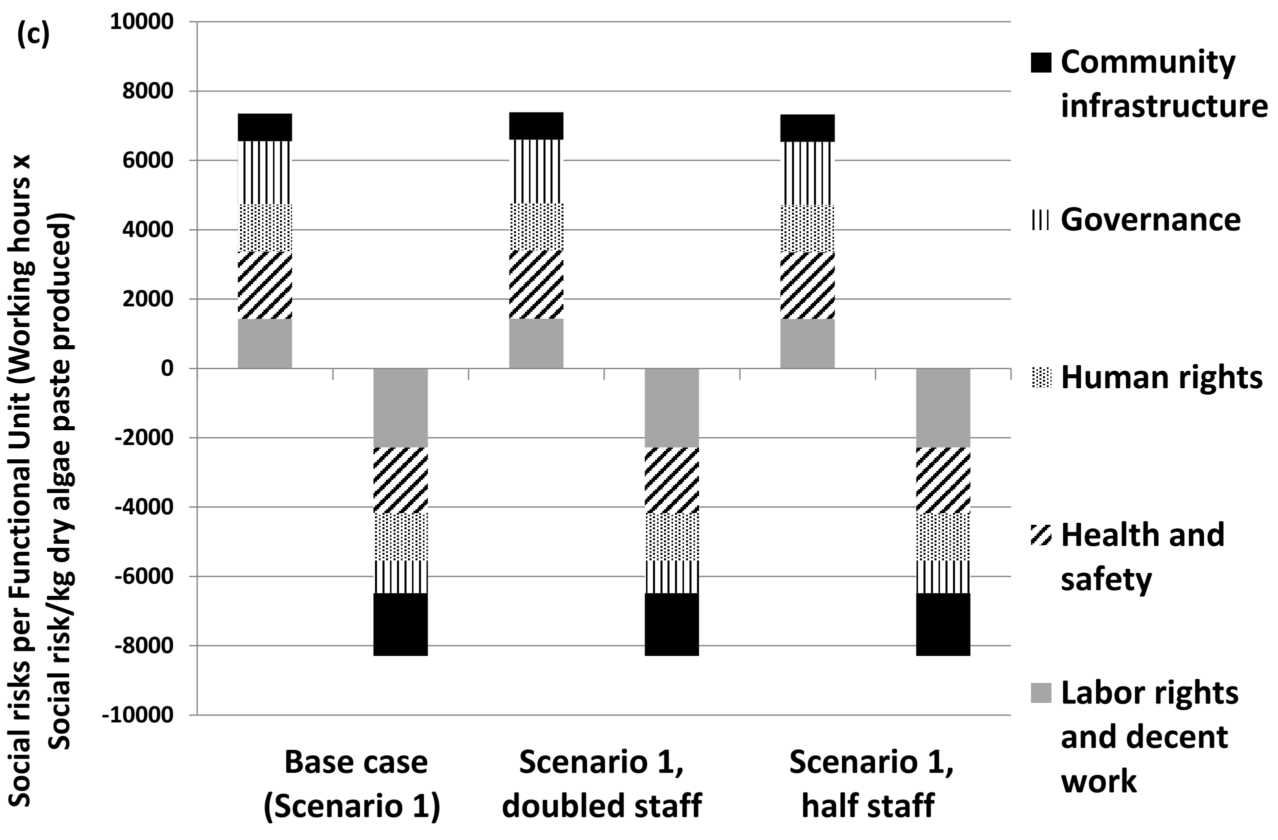
The results for the base case presented in the previous sub-section represent the most likely outcome of an up-scaled D-Factory system with regard to three key assumptions identified; located in southern Europe, base case scenario from deliverable 7.1 and optimistic performance with up-scaling. To test if the positive results of the based case remain with significant changes in these assumptions, sensitivity analysis has been carried out through a scenario analysis (see scenarios in Table 2). In this subsection, the results for this sensitivity analysis are presented in Figure 5 and discussed.

The results suggest that the outcome of the social risk assessment is not particularly sensitive to the choice of scenario setting in relation to the scenarios defined in deliverable 7.3. The results for all scenarios are quite similar to the result of the base case, with the particular exception of scenarios 1g and 1h. In the case of scenario 1g, the positive and negative impacts of D-Factory are significantly reduced due to the reduction in inputs and outputs achieved by omitting processing steps beyond the use of sCO_2. Scenario 1h omits preparative HPLC and HPCCC to separate carotene isomers and , its significant reductions of material inputs are achieved while keeping high product yield.

The results are significantly sensitive to the assumptions concerning the level of development of the up-scaled D-Factory system. While the potential of the D-Factory system to reduce social impacts remains if least expected productivity values are assumed, the difference between the impacts caused and the avoided impacts from product substitution decreases. This is specially the case for the risks associated with health and safety impact category, and for governance to a lesser extent. This reduction is not surprising since lower productivity would mean higher material inputs while producing lower amounts of co-products, thus reducing the avoided impacts. Therefore, it can be said that the potential benefit of D-Factory depends significantly on a successful scale-up of the system. The amount of staff personnel required for the plant does not have a significant influence on the outcome of the assessment either. This is because the avoided impacts are still significantly higher than the impacts from D-Factory, no matter the assumptions for staff requirements.




(b)
Social risks per Functional Unit (Working hours x Social risk/kg dry algae paste produced)
10000
5000
0
-5000
-10000
-15000
Scen. 1
Scen. 1c
Scen. 1d
Scen. 1f
Scen. 1g
Scen. 1h
Community infrastructure
Governance
Human rights
Health and safety
Labor rights and decent work


(c)
Social risks per Functional Unit (Working hours x Social risk/kg dry algae paste produced)
10000
8000
6000
4000
2000
0
-2000
-4000
-6000
-8000
-10000
Base case (Scenario 1)
Scenario 1, doubled staff
Scenario 1, half staff
Community infrastructure
Governance
Human rights
Health and safety
Labor rights and decent work

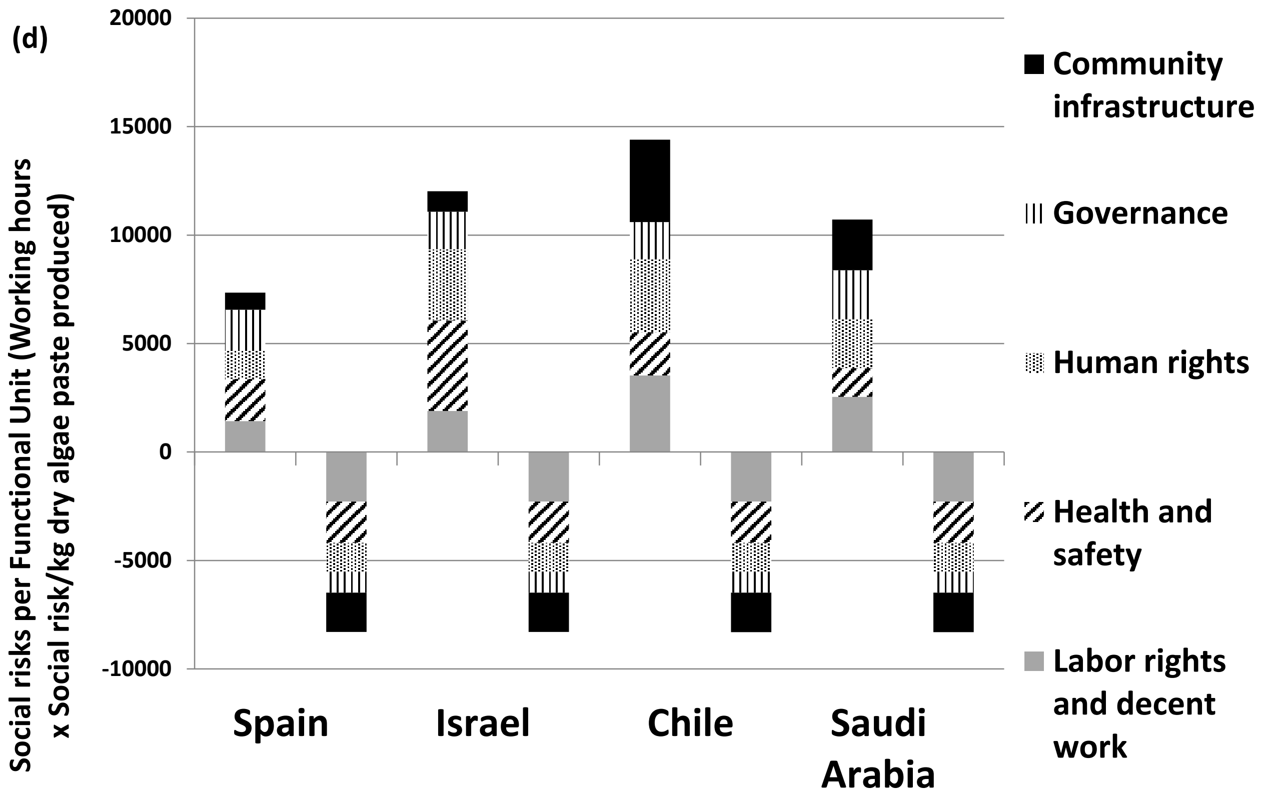


Figure 5 Social impact results for all the sets of scenarios analysed: (a) All scenarios from D7.3 with least expected performance (1 - Base case, 1c - Westfalia membranes, 1d - with Westfalia, no pre-concentration, 1f - glycerol recovery, 1g - no purification of extract, 1h - no prep HPLC and HPCCC of carotenoids), (b) All scenarios from D7.3 with optimistic performance, (c) sensitivity analysis for D-Factory staffing assumptions (base case assumptions, doubled staff, half the staff), (d) Sensitivity analysis for D-Factory location. Each scenario features two bars; one with positive values (risks of negative social impacts with D-Factory) and another with negative values (avoided impacts with D-Factory)

The results of the social assessment depend heavily on the country where the D-Factory is located. This is due to the assumption that most of the input materials (as well as some avoided products such as animal feed) for the D-Factory are easily sourced locally anywhere in the world, which is a base assumption for the assessment. Therefore, what is achieved with D-Factory is that processes that occur in high-risk countries and sectors are avoided for the most part(manufacturing of the benchmarks) and substituted by processes in one single country, that where D-Factory operations are located. If such a country is to be Spain, any other country in Europe or even Israel; the social impact mitigation potential of D-Factory remains. In contrast, if D-Factory is located in countries such as Saudi Arabia, this mitigation potential is substantially affected, causing risks that must be avoided with special measures. What is more, if D-Factory is located in a country outside the European Union and the up-scaling productivity turns lower than expected, it is highly likely that the risks of negative social impacts from the implementation of D-Factory could surpass its potential benefits. Finally, a trade-off between negative impacts to different impact categories can occur when different locations are assumed. If the system is implemented in Saudi Arabia, results show higher risks for human rights or community infrastructure, and if implemented in Israel human rights and health and safety would be the main concerns.

4.2. SWOT Analysis

The following sub-sections present the results of the SWOT analysis for the D-Factory. The D-Factory value chain has been divided into two “Strategic Business Units”, for which two separate SWOT analysis have been carried out: the algae biomass cultivation system and the algae bioprocessing (extraction, separation and purification) system. The main Strengths, Weaknesses, Opportunities and Threats of the D-Factory system are categorized as technical, financial, environmental and social. This SWOT analysis complements dedicated analyses of technical (Harvey, 2017b), environmental (Keller et al., 2017b) and financial (Mitchell & Goacher, 2017) sustainability aspects by adding stakeholders' inputs and views etc. on these aspects.

4.2.1. SWOT Analysis of algae biomass cultivation

This sub-section describes the final results of the SWOT analysis regarding the algae production. The results are summarized in Figure 6.

	Helpful to achieving the objective	**Harmful** to achieving the objective
Internal origin (attributes of the system)	*Strengths* • Salt & performant/resistant algal strain control and reduce contamination • Raceway ponds with CO_2 input are easier to build and with lower CAPEX • Industrial symbiosis with CO_2, salt and heat recycling from nearby industry	*Weaknesses* • Land use associated costs can be high • Brine and power plant/industries are not available everywhere • Mostly SMEs and not yet access to large cash amount or larger order-book • Corrosive hypersaline environment
External origin (attributes of the environment)	*Opportunities* • Better understanding of Dunaliella • Become a flagship for the algae industry • Export tech to ideal countries with sun/salt water/land • Strong demand for natural/bio product • Large production scale could help solve societal issues (ex: sustainable food from the ocean)	*Threats* • Using industrial flue-gases may need more control and cleaning to be food/drugs compliant • External factors threatening the scale-up from demo • Other use of land (ex: real estate or solar power) • Public perception of – marine – water usage for algae project • Competition from lower price/quality producers

Figure 6 Outline of the results for the SWOT analysis of the D-Factory cultivation system

STRENGTHS:

- **Technical Strengths of the D-Factory cultivation system**
  One of the main technical strengths of the D-Factory cultivation system is it potential for industrial symbiosis. Flue gas with CO_2 concentration of 6% or equivalent could be used directly to feed the algae. Pure CO_2 injection would be suboptimal since it will not all be absorbed nor used by the algae. When the CO_2 comes from the combustion of natural gas (as it is the case at the Monzón site in Spain) direct flue gas injection into the pond is possible, without the need of any flue-gas treatment. In addition, depending on the amount of CO_2 and heat needed (or other streams like nutrients, etc), an industrial symbiosis could be relevant with local industrial sites in the neighborhood of the D-Factory. One such

industrial site with potential symbiosis has already been identified in Spain[1]. Historically, many of the initial microalgae cultivation projects were related to waste water treatment via algae cultivation[2] and this symbiosis with waste water treatment plants is also possible. Another technical strength of the D-Factory cultivation system is its hypersalinity. The hypersalinity of the ponds (with salt concentration of 300 g/l compared to average seawater salinity of 35 g/l) and robust Dunaliella algae strains give an extra resistance argument against external contamination of the pond by bacteria and other contaminants (Hughton & Hendry, 1996) and helps control and reduce contamination.

- **Financial Strengths of the D-Factory cultivation system**
  One strength of the D-Factory cultivation system is that it uses raceway ponds. Raceway ponds with CO_2 input are easy to build and with a relative low CAPEX (Richardson *et al.*, 2014).

WEAKNESSES:

- **Financial Weaknesses of the D-Factory cultivation system**
  Though land-use per output for algae cultivation systems is usually smaller than conventional bio-pathways, the total land use necessary for significant output production may still be quite important, especially in sunny countries where sunny locations close to infrastructures are highly valued (cf. real estate, tourism, solar power, etc.). This will put weight on the CAPEX of the D-Factory cultivation system. Another weakness of the D-Factory cultivation system is that the salt water and corrosive environment is adding cost and specific requirements to the demo plant. In addition, brine is not available everywhere so in order to get to the right hypersalinity of 300 g/l, water and salt may have to be mixed locally. Finally, from a cash-flow perspective, the D-Factory consortium does not have any Fortune 500 "large" company as partner and may hence lack the global network and large order-book specific to big multinational corporations which is much needed for commercialization of new products.

OPPORTUNITIES:

- **Financial Opportunities of the D-Factory cultivation system**
  An opportunity for the D-Factory cultivation system is the high demand for bio-based and natural products from consumer brands. The D-Factory is ideally positioned to answer this demand. Another financial and social opportunity is the potential to export D-Factory technologies to ideal countries when it comes to sun, brine and land resources. This list of countries with ideal Dunaliella cultivation conditions availability is extensive and the D-Factory demo plant could be replicated and technology exported to a number of suitable locations. Following the drop in oil prices, the micro algae cultivation business is in a downward spiral, with many biofuel or petrochemical from algae projects and startups going bankrupt. Therefore, the D-Factory with focus on nutrition and pharmaceutical could boost the whole interest in this field by becoming a flagship for the algae industry. Higher margin products (compared to biofuels) have been saving the algae industry for decades and could, one more time, present interesting financial opportunities. These more advanced products (cf. animal feed, food/feed additives, pharmaceutical products, etc.) add to the virtuous cycle of helping the development of new technologies for algae production. These algae new technologies help in their turn to make possible larger size algae production which in turns help decrease the cost of algae production and is now helping target commodities. The same lessons learnt from large scale agriculture production can be nowadays learnt from algae production.

[1] From personal communication with Carlos Casanovas (Monzón)
[2] http://algaesystems.com/technology-2/process/

- **Social Opportunities of the D-Factory cultivation system**
  From a social and financial perspective, large scale production of algae could solve societal issues like sustainable food production. In addition, a better scientific understanding of Dunaliella could benefit the global society. A better dissemination of knowledge through publications and shared best practice would give a better understanding of Dunaliella to the stakeholders and constitutes a social opportunity for the D-Factory project.

THREATS:

- **Technical Threats of the D-Factory cultivation system**
  External factors influencing the late technology development for specific parts of the D-Factory biorefinery demo could threaten the scale-up of the demonstration plant.
- **Financial Threats of the D-Factory cultivation system**
  The CO_2 requirement and flue gas sources are not a real technical threat since the flue gas source does not impact the FDA or regulatory approval. Therefore, "dirtier" flue gas sources than natural gas combustion would need more expensive cleaning systems to achieve such purity requirement. This will still add operational expenditures to the process and could be considered a financial threat. In addition, other biotechnologies than Dunaliella algae-based with lower price or quality products could reach the market and compete with the D-Factory demo.
- **Social Threats of the D-Factory cultivation system**
  In touristic areas, the access to land and the real estate boom may be a threat to the implementation of the D-Factory. In addition, since solar PV costs have plumbed electricity production may also be competing with algae production, especially in countries where electrification is still lacking.
- **Environmental Threats of the D-Factory cultivation system**
  Water usage and sustainability issues need to be addressed and clarified in order to promote the D-Factory as a sustainable alternative. The public perception of marine water usage and energy used to pump, circulate and filter this water for algae is usually negative (Howell, 2010) and could be considered an environmental threat.

4.2.2. SWOT Analysis on algae bioprocessing system

This sub-section describes the results of the SWOT analysis regarding the bioprocessing system. The results are summarized in Figure 7.

STRENGTHS:

- **Technical Strengths of the D-Factory extraction system**
  The four processes based on use of the Evodos centrifuge for harvesting cells intact; use of supercritical CO_2 for carotenoid extraction and production of defatted powder, and use of the High Performance Countercurrent Chromatography for separating carotenoids coupled with membrane separation to remove solvents together present new opportunities for separation processes for algae compound extraction. Indeed, since the Evodos centrifugation technique does not destroy the cell structures of the Dunaliella there are many possible extraction scenarios and much optimization potential. This is one of the technical strengths of the D-Factory. In addition the D-Factory has a strong knowledge network covering all the parts of the algae production and chemical extraction value chains, both timewise and geographically.

- **Financial Strengths of the D-Factory extraction system**
  The carotenoid market is a high-value products market and in addition to this, the D-Factory intends to be able to produce these directly from the demo plant. There is no competitor on the market for such carotenoids purity. Nobody has done pharmaceutical production from algae before. D-Factory has a first mover advantage on a high margin market here. This is one of the main advantage and differentiator of this algae-based project. The same is true for defatted powder, which presents opportunities as a feed additive.
- **Environmental Strengths of the D-Factory extraction system**
  One of the strengths of the D-Factory algae biorefinery concept is that it is minimizing waste and all streams are optimized for the production of the final products (see environmental assessment report for further aspects, Keller et al., 2017b).

	Helpful to achieving the objective	**Harmful** to achieving the objective
Internal origin (attributes of the system)	*Strengths* • Unique combination of spiral-plate centrifuge+ScCO2+HPCCC + membrane extraction • Potential high value products • Waste stream minimization	*Weaknesses* • Clinical trials need to be put into place • Some of the flagship products have not been quantitatively assessed in production yet • Some techniques are still in R&D level
External origin (attributes of the environment)	*Opportunities* • Extraction processes of the D-Factory applied to other carotenoid content biomass • International development of the D-Factory biorefinery concept • Mathematical modeling optimization of the extraction process	*Threats* • Market demand side (nutraceutical/pharmaceutical) is not structured • It may be harder than thought to comply with products legislation • Availability of Dunaliella algae feedstock

Figure 7 Outline of the results for the SWOT analysis of the D-Factory algae bioprocessing system

WEAKNESSES:

- **Technical Weaknesses of the D-Factory extraction system**
  Some techniques used in the D-Factory processes are still at the R&D level (ex: isomer separation) and may need more funding or different approaches for upscaling the production. High Performance Counter Current Chromatography (HPCCC) is still an expensive and custom-made process (choice of appropriate two-phase solvent (Wozniak and Garrard, 2014) which may need to be cost optimized for the D-Factory biorefinery process. The HPCCC with liquid/liquid extraction technology, which allows much higher purity grade with 70-100% efficiency, is not yet ready for the D-Factory concept. For production sake, today solid substrate chromatography is used to separate carotenoids. In addition, supercritical CO_2 extraction is for the moment using freeze-dried material since spray drying does not work yet because of particulate size. For the supercritical CO_2 extraction process, cost of extraction is usually following a polynomial curve (Rocha-Uribe *et al.*, 2014) hence favoring large volume extracted

which is not the case today, leading to suboptimal separation. One last technical weakness of the D-Factory is that some of the flagship products namely individual isomers of carotenes and pure lutein and zeaxanthin, have not been quantitatively assessed in production. Therefore, it is harder to make plans for future scaling-up or address new potential markets.

- **Financial Weaknesses of the D-Factory extraction system**
  One of the weaknesses of the D-Factory is the absence of clinical trials for some of the products it focuses on. These trials are essential to establish, prices, volumes and address new market. They are expensive and were not included in the scope of the D-Factory project from the start. They may need to be implemented and will definitely add costs to the final product's commercialization.

OPPORTUNITIES:

- **Technical Opportunities of the D-Factory extraction system**
  The four separation processes with the Evodos centrifuge to separate (harvest) intact cells from brine, the supercritical CO_2 extraction of carotenoids from dry biomass, the High Performance Countercurrent Chromatography for separating carotenes, xanthophylls, chlorophyll and lipids, and the membrane separation combination could be optimized for best ROI. Potential new algae projects and further research could use and enhance the mathematical optimization modelling of such D-Factory biorefinery for the production of a specific range of compounds. Another technical opportunity of the D-Factory is that extraction processes could be applied to other carotenoid content biomass, helping to decrease the cost of extraction and enhancing the quality of the final products.
- **Financial Opportunities of the D-Factory extraction system**
  One of the main financial opportunities for the D-Factory bioprocessing system is that it may open new possibilities for international development of the D-Factory biorefinery or some specific extraction or purification technologies. This would help the international development and deployment of the D-Factory biorefinery concept.

THREATS:

- **Financial Threats of the D-Factory extraction system**

  One financial threat to the D-Factory extraction system is that product legislation may be harder to comply with than initially assessed. This may add extra costs related to enhancing the separation and purification technologies used in the D-Factory biorefinery. Another financial threat to the D-Factory extraction system is that the market demand side for the nutrition and pharmaceutical sectors is not structured. Because the carotenoids extracted are from a natural product, the composition will change depending on natural condition. Being a first mover here is challenging. Buyers will indeed have to deal with one production source at the beginning and that could be perceived as a threat (in case production is disrupted for any reasons). These issues could be solved but need to be solved carefully in order for the D-factory biorefinery concept to thrive. Part of this issue is more related to being able to reproduce the D-Factory production lines somewhere else with the same quality output. From a buyer perspective this could translate into a lock-in agreement, which is not always possible. To be able to have a lock-in situation, there is a need to be able to replicate the production. In addition to these issues, one has to keep in mind that the D-Factory is dealing with a basket of natural products with a multi-market target ranging from pharmaceuticals to colorant or food products. This increases the complexity and makes it harder to predict how the D-Factory could adapt to the market's demand.

- **Social Threats of the D-Factory extraction system**

Today the D-Factory extraction system and the algae cultivation systems are not located in the same place. Production takes place in southern countries (Spain, Israel), whereas extraction and purification takes place in northern countries (Germany, UK). From a social perspective, it is beneficial to a country or local community to create new jobs in the primary sector (algae cultivation is considered agriculture in most countries). However, most developing countries want to move to more of secondary or tertiary activities and having the algae cultivation separated from the carotenoid extraction process could be seen as hindering for the shift to secondary and tertiary activities.

5. Conclusions

5.1. Social risk assessment

The main conclusion of the social risk assessment is that the D-Factory concept shows a significant potential for mitigation of negative social impacts. This outcome holds for every scenario analysed, which means that the net potential to reduce negative social impacts does not change with different location, D-Factory setting (in relation to the scenarios in deliverable 7.3) or future performance at scale-up. Still, the magnitude of this potential can be affected by some of these variables, and some clarifications concerning this conclusion need to be made:

- The social impact mitigation potential of D-Factory depends heavily on the assumption that the aimed high-value products can be substituted, and any change in that regard would affect significantly the outcome of this assessment.
- If D-Factory fails to substitute these high-value products, the substitution of lesser value products such as glycerol, animal feed, chlorophyll or rapeseed oil would not be enough to offset the social impacts caused by the D-Factory system and its upstream processes. The outcome of the assessment would depend then on which products are successfully produced and which are not, as well as in each quantity. Still, it is necessary that at least some of the high-value products aimed are obtain in the range of the quantities estimated.
- The results of the social assessment depend heavily on the country where the D-Factory is located. If D-Factory is implemented in any country outside the European Union, special measures need to be implemented in order to avoid risks of negative social impacts.
- The study presented in this deliverable has weaknesses and limitations inherent to the status of the D-Factory concept. The D-Factory scenarios evaluated in this deliverable do not exist, mainly because they occur in the future and they do not represent an established value chain, which is needed to analyse real social impacts. This is why the assessment focuses on risks rather than impacts, a method in accordance with the goal of the study, which is to identify risks early in order to be able to avoid them. Nevertheless, it is important that the recommendations section is read carefully if the results are to be used by stakeholders for decision-making.
- Another limitation worth mentioning is the lack of data available for some countries and for recent years, mainly for the estimation of working hours (see appendix 1). Chile is a good example, but also some processes for the baseline scenario are affected by this limitation. This may affect the accuracy of the result, but not the main conclusions. What is more, the data used for social impact risk (appendix 2, from the social hotspot database) does not have this kind of limitation, as the Social Hotspots Database was updated in 2016 using data for 2015.

5.2. SWOT analysis

The main strength of D-Factory lies in its name itself. The “D” of the D-Factory refers to halotolerant algae *Dunaliella salina*. As its name says, *Dunaliella salina* is growing in hypersaline environment and high salt concentration is used to control the potential. In addition the ways of extracting the carotenoids are unique and should be pursued further along the D-Factory value chain. Though the yield is higher than cultivation of many other crops, the main weaknesses of the D-Factory are the relatively large amount of land used for the cultivation (because competition with other uses and costs) and the implementation of clinical trials for the active compounds extracted. These will not hinder the development of the D-Factory but could be used by competitors as counter arguments. The main opportunities for the D-Factory lie in the fundamental understanding of *Dunaliella salina* and how to exploit its value as the richest source of carotenoids. The carotenoid market could be targeted even with other feedstocks, but this is unlikely since Dunaliella is the richest source of carotenoids known. Finally the threats coming from food/drug compliance as well as the ever-changing market structure could add some uncertainty to the project. Overall the SWOT analysis does not show any special conflicts between economy, society and the environment and mostly highlights synergy potentials between different industries and benefits to society and the local communities.

5.3. Recommendations for further development

- The dependency on location for the social impact mitigation potential of D-Factory does not mean that the system should not be implemented in the above mentioned countries. It rather means that if that was the case, the implementation should be closely followed so negative social impacts are avoided, especially concerning the impact categories mentioned for each of the countries used as example. In other words, practices that do not cause negative social impacts for labour rights and decent work, health and safety and governance should be applied in whatever country D-Factory is implemented.
- The outcome of this assessment should not be interpreted as a red or green light for the D-Factory concept. Rather than that, it should be used as a roadmap for future developments of the technology. The main recommendation for the stakeholders that take up on advancing with the D-Factory is to keep in mind that its social sustainability depends substantially on three key variables; the successful substitution of the aimed high-value products, the productivity of the system after upscaling and the location of the plant. Keeping this in mind, measures should be adopted when implementing the D-Factory and establishing its value chain towards preventing social impacts related to the hot-spots identified (health and safety in the case of Spain). And in case another country is chosen as location, additional measures may be required depending on the circumstances.
- The results of this assessment indicate risk of negative social impacts, but not actual social impacts. Therefore, a high score does not mean that D-Factory will have negative social impact when implemented. There are many strategies to avoid these risks, thus making D-Factory a source of positive social change in any location. Such strategies should be aimed towards ensuring and monitoring that the working conditions and quality of life of the stakeholder community around the D-Factory does not cause deviation from labour rights standards and human rights global accords. One of these strategies could be to have reporting of social indicators (labour, health and safety, etc.) as one selection criterion for suppliers of a scaled-up system. Examples of criteria for suppliers are the willingness to deliver manufacturer-specific social reporting, openness concerning working conditions at their sites, suppliers that include social indicators in sustainability reports, or the

possibility to carry out sustainability audits to the suppliers. These indicators, reports and audits should be focused on the hot-spots identified for each country concerning social impact category and process. For example, for the base case scenario with the D-Factory plant located in Spain, health and safety impacts from heptane and hexane, ionic liquids and bottled CO_2 for supercritical CO_2 extraction should be prioritized.

- In a similar way, the results from the SWOT analysis should be taken into account when planning the following steps of the D-Factory implementation. The purpose of such exercise is always to use expert knowledge to try and foresee possible ramifications of the technology, either positive or negative. Therefore, it is recommended that the results of the SWOT analysis are passed through to stakeholders responsible to take D-Factory to the next level.

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7. Appendix 1: Estimation of working hours

This appendix shows the data references used for the estimation of working hours from each life cycle process per functional unit.

Life cycle process	Country	Industrial sector	Database	Period	Cost of working hour
Natural gas extraction and transport	Argelia (Egypt as proxy)	11 Extraction of crude oil and natural gas, etc.	MINSTAT 2016 Rev 3	2002-2006	ILO statistics, mean nominal monthly earnings (local currency)
	Qatar	11 Extraction of crude oil and natural gas, etc.	MINSTAT 2016 Rev 3	2009-2013	ILO statistics, mean nominal monthly earnings (local currency)
	Chile (Peru as proxy)	40 Electricity, gas, steam and hot water supply	MINSTAT 2016 Rev 3	2003-2005	ILO statistics, Mean nominal hourly earnings of employees
	Norway	06 Extraction of crude petroleum & natural gas	MINSTAT 2016 Rev 4	2011-2013	OECD Database, Avg wages (country)
Oil extraction for naphtha	Iran	0B Mining and quarrying	MINSTAT 2016 Rev 4	2012-2013	Statistical Center of Iran
	Sudan	0B Mining and quarrying	MINSTAT 2016 Rev 4	2008-2010	ILO statistics, Avg monthly earnings
	Russia	111 Extraction of crude oil and natural gas	MINSTAT 2016 Rev 3	2009-2013	ILO statistics, Avg monthly earnings
	Norway	06 Extraction of crude petroleum & natural gas	MINSTAT 2016 Rev 4	2011-2013	OECD Database, Avg wages (country)
	Canada	089 Mining and quarrying n.e.c.	MINSTAT 2016 Rev 4	2009-2012	OECD Database, Avg wages (country)
Production of naphtha for hexane and heptane	Iran	2320 Refined petroleum products	INDSTAT 4 Rev 3	2008-2012	Statistical Center of Iran
	Sudan	2320 Refined petroleum products	INDSTAT 4 Rev 3	2006-2007	ILO statistics, Avg monthly earnings
	Russia	2320 Refined petroleum products	INDSTAT 4 Rev 3	2009-2013	ILO statistics, Avg monthly earnings
	Norway	1910 Coke oven products	INDSTAT 4 Rev 4	2010-2013	OECD Database, Avg wages (country)
	Canada	1920 Refined petroleum products	INDSTAT 4 Rev 4	2009-2012	OECD Database, Avg wages (country)
Production of heptane	India	2011 Basic chemicals	INDSTAT 4 Rev 4	2008-2012	ILO statistics, Avg monthly earnings (local currency)
	Japan	2011 Basic chemicals	INDSTAT 4 Rev 4	2008-2010	OECD Database, Avg wages (country)
	Germany	2011 Basic chemicals	INDSTAT 4 Rev 4	2009-2013	OECD Database, Avg wages (country)
	USA	241 Basic chemicals	INDSTAT 4 Rev 3	2006-2008	OECD Database, Avg wages (country)
Oil extraction for ethylene	Saudi Arabia	11Extraction of crude oil and gas, etc.	MINSTAT Rev 3	2006-2009	ILO statistics, Avg monthly earnings (local currency)
	South Africa	1C Total mining and quarrying	MINSTAT Rev 3	2008-2010	ILO statistics, Avg monthly earnings (local currency)
	Canada	089 Mining and quarrying n.e.c.	MINSTAT 2016 Rev 4	2009-2012	OECD Database, Avg wages (country)
	USA	061 Extraction of crude petroleum	MINSTAT 2016 Rev 4	2012	OECD Database, Avg wages (country)

Life cycle process	Country	Industrial sector	Database	Period	Cost of working hour
Synthesis of ethylene for ethanol	Saudi Arabia	2320 Refined petroleum products	INDSTAT 4 Rev 3	2006-2008	ILO statistics, Avg monthly earnings (local currency)
	South Africa	2320 Refined petroleum products	INDSTAT 4 Rev 3	2006-2008	ILO statistics, Avg monthly earnings (local currency)
	Canada	1920 Refined petroleum products	INDSTAT 4 Rev 4	2009-2012	OECD Database, Avg wages (country)
	USA	2320 Refined petroleum products	INDSTAT 4 Rev 3	2006-2008	OECD Database, Avg wages (country)
Production of starchy feedstock for bioethanol	USA	1532 Starches and starch products	INDSTAT 4 Rev 4	2006-2008	OECD Database, Avg wages (country)
	Brazil	106 Grain mill products, starches and starch products	INDSTAT 4 Rev 4	2009-2013	ILO statistics, Avg monthly earnings (local currency)
Production of ethanol	Saudi Arabia	2320 Refined petroleum products	INDSTAT 4 Rev 3	2006-2008	ILO statistics, Avg monthly earnings (local currency)
	South Africa	2320 Refined petroleum products	INDSTAT 4 Rev 3	2006-2008	ILO statistics, Avg monthly earnings (local currency)
	USA (Petroleum ethanol)	2320 Refined petroleum products	INDSTAT 4 Rev 3	2006-2008	OECD Database, Avg wages (country)
	USA (Bioethanol)	1040 Vegetable and animal oils and fats	INDSTAT 4 Rev 3	2008	OECD Database, Avg wages (country)
	Brazil (bioethanol)	1040 Vegetable oils and fats	INDSTAT 4 Rev 4	2009-2013	ILO statistics, Avg monthly earnings (local currency)
Production of ionic liquid	Germany	202 Other chemical products	INDSTAT 4 Rev 4	2009-2013	Payscale pharmaceuticals median salary
Production of nitric acid	Spain	2412 Fertilizers and nitrogen compounds	INDSTAT 4 Rev 3	2004-2008	OECD Database, Avg wages (country)
	Israel	2411 Basic Chemicals, except fertilizers	INDSTAT 4 Rev 3	2006-2010	OECD Database, Avg wages (country)
	Chile	241 Basic Chemicals	INDSTAT 4 Rev 3	2004-2008	ILO statistics, Mean nominal hourly earnings of employees
	Saudi Arabia	241 Basic Chemicals	INDSTAT 4 Rev 3	2006-2009	ILO statistics, Avg monthly earnings (local currency)
Production of sodium hydroxide	Spain	2412 Fertilizers and nitrogen compounds	INDSTAT 4 Rev 3	2004-2008	OECD Database, Avg wages (country)
	Israel	2411 Basic Chemicals, except fertilizers	INDSTAT 4 Rev 3	2006-2010	OECD Database, Avg wages (country)
	Chile	241 Basic Chemicals	INDSTAT 4 Rev 3	2004-2008	ILO statistics, Mean nominal hourly earnings of employees
	Saudi Arabia	241 Basic Chemicals	INDSTAT 4 Rev 3	2006-2009	ILO statistics, Avg monthly earnings (local currency)
Bottled CO_2	Spain	2011 Basic chemicals	INDSTAT 4 Rev 4	2009-2013	OECD Database, Avg wages (country)
	Israel	2411 Basic Chemicals, except fertilizers	INDSTAT 4 Rev 3	2006-2010	OECD Database, Avg wages (country)
	Chile	241 Basic Chemicals	INDSTAT 4 Rev 3	2004-2008	ILO statistics, Mean nominal hourly earnings of employees
	Saudi Arabia	241 Basic Chemicals	INDSTAT 4 Rev 3	2006-2009	ILO statistics, Avg monthly earnings (local currency)
Production	Spain	2412 Fertilizers and nitrogen compounds	INDSTAT 4 Rev 3	2004-2008	OECD Database, Avg wages (country)

Life cycle process	Country	Industrial sector	Database	Period	Cost of working hour
of Nitrogen fertilizers	Israel	2411 Basic Chemicals, except fertilizers	INDSTAT 4 Rev 3	2006-2010	OECD Database, Avg wages (country)
	Chile	241 Basic Chemicals	INDSTAT 4 Rev 3	2004-2008	ILO statistics, Mean nominal hourly earnings of employees
	Saudi Arabia	241 Basic Chemicals	INDSTAT 4 Rev 3	2006-2009	ILO statistics, Avg monthly earnings (local currency)
Water transport	Spain	360 Water collection, treatment and supply	MINSTAT 2016, Rev 4	2009-2013	OECD Database, Avg wages (country)
	Israel	4E Total electricity, gas and water supply	MINSTAT 2016, Rev 3	2008-2010	OECD Database, Avg wages (country)
	Chile (Peru as proxy)	40 Electricity, gas, steam and hot water supply	MINSTAT 2016 Rev 3	2003-2005	ILO statistics, Mean nominal hourly earnings of employees
	Saudi Arabia	4E Total electricity, gas and water supply	MINSTAT 2016, Rev 3	2006-2009	ILO statistics, Avg monthly earnings (local currency)
Electricity generation	Spain	351 Electric power generation, transmission	MINSTAT 2016, Rev 4	2009-2013	OECD Database, Avg wages (country)
	Israel	4E Total electricity, gas and water supply	MINSTAT 2016, Rev 3	2008-2010	OECD Database, Avg wages (country)
	Chile (Peru as proxy)	40 Electricity, gas, steam and hot water supply	MINSTAT 2016 Rev 3	2003-2005	ILO statistics, Mean nominal hourly earnings of employees
	Saudi Arabia	4E Total electricity, gas and water supply	MINSTAT 2016, Rev 3	2006-2009	ILO statistics, Avg monthly earnings (local currency)
Heat generation	Spain	353 Steam and air conditioning supply	MINSTAT 2016, Rev 4	2009-2013	OECD Database, Avg wages (country)
	Israel	4E Total electricity, gas and water supply	MINSTAT 2016, Rev 3	2008-2010	OECD Database, Avg wages (country)
	Saudi Arabia	4E Total electricity, gas and water supply	MINSTAT 2016, Rev 3	2006-2009	ILO statistics, Avg monthly earnings (local currency)
Waste water treatment	Spain	382 Waste treatment and disposal	MINSTAT 2016, Rev 4	2009-2013	OECD Database, Avg wages (country)
	Israel	4E Total electricity, gas and water supply	MINSTAT 2016, Rev 3	2008-2010	OECD Database, Avg wages (country)
	Chile (Peru as proxy)	40 Electricity, gas, steam and hot water supply	MINSTAT 2016 Rev 3	2003-2005	ILO statistics, Mean nominal hourly earnings of employees
	Saudi Arabia	4E Total electricity, gas and water supply	MINSTAT 2016, Rev 3	2006-2009	ILO statistics, Avg monthly earnings (local currency)
Construction materials	Spain	239 Non-metallic mineral products n. e. c.	INDSTAT 4 Rev 4	2009-2013	OECD Database, Avg wages (country)
	Israel	239 Non-metallic mineral products n. e. c.	INDSTAT 4 Rev 4	2011-2012	OECD Database, Avg wages (country)
	Chile	239 Non-metallic mineral products n. e. c.	INDSTAT 4 Rev 3	2004-2008	ILO statistics, Mean nominal hourly earnings of employees
	Saudi Arabia	2610 Glass and glass products	INDSTAT 4 Rev 3	2006-2009	ILO statistics, Avg monthly earnings (local currency)
Manufacturing of membranes	Spain	2520 Plastic products	INDSTAT 4 Rev 3	2004-2008	OECD Database, Avg wages (country)
	Israel	2520 Plastic products	INDSTAT 4 Rev 3	2006-2010	OECD Database, Avg wages (country)

Life cycle process	Country	Industrial sector	Database	Period	Cost of working hour
(fossil-based polymeric hollow fibre)	Chile	2520 Plastic products	INDSTAT 4 Rev 3	2004-2008	ILO statistics, Mean nominal hourly earnings of employees
	Saudi Arabia	251 Rubber products	INDSTAT 4 Rev 3	2006-2009	ILO statistics, Avg monthly earnings (local currency)
scCO2 extraction plant (stainless steel)	Spain	2811 Structural metal products	INDSTAT 4 Rev 3	2004-2008	OECD Database, Avg wages (country)
	Israel	273 Casting of metals	INDSTAT 4 Rev 3	2006-2010	OECD Database, Avg wages (country)
	Chile	289 Other metal products; metal working services	INDSTAT 4 Rev 3	2004-2008	ILO statistics, Mean nominal hourly earnings of employees
	Saudi Arabia	2710 Basic iron and steel	INDSTAT 4 Rev 3	2006-2009	ILO statistics, Avg monthly earnings (local currency)
Manufacturing of machinery and equipment	Spain	282 Special-purpose machinery	INDSTAT 4 Rev 4	2009-2013	OECD Database, Avg wages (country)
	Israel	281 General-purpose machinery	INDSTAT 4 Rev 4	2011-2012	OECD Database, Avg wages (country)
	Chile	291 General purpose machinery	INDSTAT 4 Rev 3	2004-2008	ILO statistics, Mean nominal hourly earnings of employees
	Saudi Arabia	291 General purpose machinery	INDSTAT 4 Rev 3	2006-2009	ILO statistics, Avg monthly earnings (local currency)
Manufacturing of glycerol, polar lipids and free fatty acids	USA	1514 Vegetable and animal oils and fats	INDSTAT 4 Rev 3	2004-2008	OECD Database, Avg wages (country)
	Malaysia	1514 Vegetable and animal oils and fats	INDSTAT 4 Rev 3	2004-2008	ILO statistics, Avg monthly earnings (local currency)
	Indonesia	1514 Vegetable and animal oils and fats	INDSTAT 4 Rev 3	2005-2009	ILO statistics, Avg monthly earnings (local currency)
	France	2320 Refined petroleum products	INDSTAT 4 Rev 3	2004-2008	OECD Database, Avg wages (country)
	India	1514 Vegetable and animal oils and fats	INDSTAT 4 Rev 3	2004-2007	ILO statistics, Avg monthly earnings (local currency)
Growing and harvesting of Marigold flowers	India	1549 Other food products n. e. c.	INDSTAT 4 Rev 3	2003-2007	ILO statistics, Avg monthly earnings (local currency)
	USA	1549 Other food products n. e. c.	INDSTAT 4 Rev 3	2004-2008	OECD Database, Avg wages (country)
	Ecuador	1549 Other food products n. e. c.	INDSTAT 4 Rev 3	2004-2008	ILO statistics avg monthly earnings (local currency)
	China	1549 Other food products n. e. c.	INDSTAT 4 Rev 3	2007-2011	ILO statistics avg monthly earnings (local currency)
Manufacturing of Lutein and Zeaxanthin	USA	2423 Pharmaceuticals, medicinal chemicals, etc	INDSTAT 4 Rev 3	2004-2008	Payscale Nutraceuticals median salary
	India	2100 Pharmaceuticals, medicinal chemicals, etc.	INDSTAT 4 Rev 4	2008-2012	Payscale laboratory employees
	Germany	2100 Pharmaceuticals, medicinal chemicals, etc	INDSTAT 4 Rev 4	2009-2013	Payscale pharmaceuticals median salary
Manufacturing of synthetic Carotenes	USA	2423 Pharmaceuticals, medicinal chemicals, etc	INDSTAT 4 Rev 3	2004-2008	Payscale Nutraceuticals median salary
	Germany	2100 Pharmaceuticals, medicinal chemicals, etc	INDSTAT 4 Rev 4	2009-2013	Payscale pharmaceuticals median salary
	Spain	2100 Pharmaceuticals, medicinal chemicals, etc	INDSTAT 4 Rev 4	2009-2013	Payscale pharmaceuticals median salary
Growing and	Brazil	106 Grain mill products, starches and starch	INDSTAT 4 Rev 4	2009-2013	ILO statistics, Avg monthly earnings (local currency)

Life cycle process	Country	Industrial sector	Database	Period	Cost of working hour
harvesting of soy		products			
	USA	1532 Starches and starch products	INDSTAT 4 Rev 4	2006-2008	OECD Database, Avg wages (country)
Growing and harvesting of wheat	Spain	1531 Grain mill products	INDSTAT 4 Rev 3	2004-2008	OECD Database, Avg wages (country)
	China	1531 Grain mill products	INDSTAT 4 Rev 3	2006-2011	ILO statistics avg monthly earnings (local currency)
	India	1531 Grain mill products	INDSTAT 4 Rev 3	2003-2007	ILO statistics, Avg monthly earnings (local currency)
	Russia	153 Grain mill products; starches; animal feeds	INDSTAT 4 Rev 3	2009-2013	ILO statistics, Avg monthly earnings
Manufacturing of animal feed	Spain	1080 Prepared animal feeds	INDSTAT 4 Rev 4	2009-2013	OECD Database, Avg wages (country)
	Israel	1075 Prepared meals and dishes	INDSTAT 4 Rev 4	2011-2012	OECD Database, Avg wages (country)
	Chile	153 Grain mill products; starches; animal feeds	INDSTAT 4 Rev 3	2004-2008	ILO statistics, Mean nominal hourly earnings of employees
	Saudi Arabia	515 Processed meat, fish, fruit, vegetables, fats	INDSTAT 4 Rev 3	2006-2009	ILO statistics, Avg monthly earnings (local currency)
Growing and harversting of canola	Canada	1514 Vegetable and animal oils and fats	INDSTAT 4 Rev 3	2000-2004	OECD Database, Avg wages (country)
	China	1514 Vegetable and animal oils and fats	INDSTAT 4 Rev 3	2007-2011	ILO statistics avg monthly earnings (local currency)
	India	1514 Vegetable and animal oils and fats	INDSTAT 4 Rev 3	2003-2007	ILO statistics, Avg monthly earnings (local currency)
	Australia	1514 Vegetable and animal oils and fats	INDSTAT 4 Rev 3	2007-2010	ILO statistics, Avg monthly earnings (local currency)
Manufacturing of rapeseed oil	Canada	1514 Vegetable and animal oils and fats	INDSTAT 4 Rev 3	2000-2004	OECD Database, Avg wages (country)
	China	1514 Vegetable and animal oils and fats	INDSTAT 4 Rev 3	2007-2011	ILO statistics avg monthly earnings (local currency)
	India	1514 Vegetable and animal oils and fats	INDSTAT 4 Rev 3	2003-2007	ILO statistics, Avg monthly earnings (local currency)
	Australia	1514 Vegetable and animal oils and fats	INDSTAT 4 Rev 3	2007-2010	ILO statistics, Avg monthly earnings (local currency)
Growing and harvesting of spinach	USA	1513 Processing/preserving of fruits & vegetables	INDSTAT 4 Rev 3	2004-2008	OECD Database, Avg wages (country)
	China	1513 Processing/preserving of fruits & vegetables	INDSTAT 4 Rev 3	2006-2010	ILO statistics avg monthly earnings (local currency)
Manufacturing of spinach-based food colouring	USA	1513 Processing/preserving of fruits & vegetables	INDSTAT 4 Rev 3	2004-2008	OECD Database, Avg wages (country)
	China	1513 Processing/preserving of fruits & vegetables	INDSTAT 4 Rev 3	2006-2010	ILO statistics avg monthly earnings (local currency)

8. Appendix 2: Data for social impact

This appendix shows the data references used to obtain process data for social impact, in terms of risk of negative impact from the Social Hotspot Database. All the datasets were updated in 2016 with data collected in 2015.

Life cycle stage	Life cycle process	Country	Industrial activity category
Production of natural gas	Natural gas extraction and transport	Argelia (Egypt as proxy)	Gas manufacture, distribution
		Qatar	Gas manufacture, distribution
		Norway	Gas manufacture, distribution
Heptane production	Oil extraction	Iran	Oil
		Sudan	Oil
		Russia	Oil
		Norway	Oil
		Canada	Oil
	Production of Naphtha	Iran	Petroleum, coal products
		Sudan	Petroleum, coal products
		Russia	Petroleum, coal products
		Norway	Petroleum, coal products
		Canada	Petroleum, coal products
	Synthesis of Heptane	India	Petroleum, coal products
		Japan	Petroleum, coal products
		Germany	Petroleum, coal products
		USA	Petroleum, coal products
Ethanol production	Oil extraction	Saudi Arabia	Oil
		South Africa	Oil
		Canada	Oil
		USA	Oil
	Synthesis of ethylene	Saudi Arabia	Petroleum, coal products
		South Africa	Petroleum, coal products
		Canada	Petroleum, coal products

Life cycle stage	Life cycle process	Country	Industrial activity category
		USA	Petroleum, coal products
	Production of starchy feedstock	USA	Other grains
		Brazil	Sugarcane and sugarbeet
	Production of Ethanol	Saudi Arabia	Petroleum, coal products
		South Africa	Petroleum, coal products
		USA (Petroleum ethanol)	Petroleum, coal products
		USA (Bioethanol)	Vegetable oils and fats
		Brazil (bioethanol)	Vegetable oils and fats
Production of nitric acid	Production of nitric acid	Spain	Chemical, rubber, plastic products
		Israel	Chemical, rubber, plastic products
		Kenya	Chemical, rubber, plastic products
		Chile	Chemical, rubber, plastic products
		Saudi Arabia	Chemical, rubber, plastic products
Production of sodium hydroxide	Production of sodium hydroxide	Spain	Chemical, rubber, plastic products
		Israel	Chemical, rubber, plastic products
		Kenya	Chemical, rubber, plastic products
		Chile	Chemical, rubber, plastic products
		Saudi Arabia	Chemical, rubber, plastic products
Production of flue gas	Bottled CO2	Spain	Chemical, rubber, plastic products
		Israel	Chemical, rubber, plastic products
		Kenya	Chemical, rubber, plastic products
		Chile	Chemical, rubber, plastic products
		Saudi Arabia	Chemical, rubber, plastic products
Production of nutrients	Production of Nitrogen fertilizers	Spain	Chemical, rubber, plastic products
		Israel	Chemical, rubber, plastic products
		Kenya	Chemical, rubber, plastic products
		Chile	Chemical, rubber, plastic products
		Saudi Arabia	Chemical, rubber, plastic products

Life cycle stage	Life cycle process	Country	Industrial activity category
D-Factory	Water transport	Spain	Water
		Israel	Water
		Kenya	Water
		Chile	Water
		Saudi Arabia	Water
	Electricity generation	Spain	Electricity
		Israel	Electricity
		Kenya	Oil & Gas (equal)
		Kenya	Electricity & Coal (equal)
		Kenya	Oil
		Chile	Electricity
		Chile	Coal
		Saudi Arabia	Oil
		Saudi Arabia	Gas
		Saudi Arabia	Electricity
	Heat generation	Spain	Electricity
		Israel	Electricity
		Chile	Electricity
		Saudi Arabia	Electricity
	Waste water treatment	Spain	Water
		Israel	Water
		Chile	Water
		Saudi Arabia	Water
	Construction materials	Spain	Construction
		Israel	Construction
		Chile	Construction
		Saudi Arabia	Construction
	scCO2 extraction plant (stainless steel)	Spain	Ferrous metals
		Israel	Ferrous metals

Life cycle stage	Life cycle process	Country	Industrial activity category
		Chile	Ferrous metals
		Saudi Arabia	Ferrous metals
	Manufacturing of membranes (fossil-based polymeric hollow fibre)	Spain	Chemical, rubber, plastic products
		Israel	Chemical, rubber, plastic products
		Chile	Chemical, rubber, plastic products
		Saudi Arabia	Chemical, rubber, plastic products
	Manufacturing of machinery and equipment	Spain	Machinery and equipment nec
		Israel	Machinery and equipment nec
		Chile	Machinery and equipment nec
		Saudi Arabia	Machinery and equipment nec
Avoided risks	Manufacturing of glycerol, polar lipids and free fatty acids	USA	Petroleum, coal products
		Malaysia	Petroleum, coal products
		Indonesia	Petroleum, coal products
		France	Petroleum, coal products
		India	Petroleum, coal products
	Manufacturing of propylene glycol	Spain	Chemical, rubber, plastic products
		Israel	Chemical, rubber, plastic products
		Chile	Chemical, rubber, plastic products
		Saudi Arabia	Chemical, rubber, plastic products
	Growing and harvesting of Marigold flowers	India (OmniActive & Kemin)	Crops nec
		USA (Kemin)	Crops nec
		Ecuador (Cognis & Kemin)	Crops nec
		China (Kemin)	Crops nec
	Manufacturing of Lutein and Zeaxanthin	USA (Kemin Foods)	Chemical, rubber, plastic products
		India (OmniActive)	Chemical, rubber, plastic products
		Germany (Cognis)	Chemical, rubber, plastic products
	Manufacturing of Xanthophylls	USA (Kemin Foods)	Chemical, rubber, plastic products
		India (OmniActive)	Chemical, rubber, plastic products
		Germany (Cognis)	Chemical, rubber, plastic products

Life cycle stage	Life cycle process	Country	Industrial activity category
	Manufacturing of synthetic Carotenes	USA (DSM)	Chemical, rubber, plastic products
		Germany (BASF)	Chemical, rubber, plastic products
		Spain (Vitatene)	Chemical, rubber, plastic products
	Growing and harvesting of soy	Brazil	Crops nec
		USA	Crops nec
	Growing and harvesting of wheat	Spain	Wheat
		China	Wheat
		India	Wheat
		Russia	Wheat
	Manufacturing of animal feed	Spain	Animal products nec
		Israel	Animal products nec
		Chile	Animal products nec
		Saudi Arabia	Animal products nec
	Growing and harvesting of canola	Canada	Oil seeds
		China	Oil seeds
		India	Oil seeds
		Australia	Oil seeds
	Manufacturing of rapeseed oil	Canada	Vegetable oils and fats
		China	Vegetable oils and fats
		India	Vegetable oils and fats
		Australia	Vegetable oils and fats
	Growing and harvesting of spinach	USA	Vegetable, fruits, nuts
		China	Vegetable s, fruits, nuts
	Manufacturing of food colouring	USA	Food products nec
		China	Food products nec

9. Appendix 3: Expanded SWOT analysis

The results of the SWOT analysis in the main report correspond to a summary of the strengths, weaknesses, opportunities and threats that were identified as the most important by means of interviews and feedback with internal and external stakeholders. However, there are several that were identified but were not regarded as important by stakeholders. This appendix present a complete list of all the strengths, weaknesses, opportunities and threats identified throughout the work for this task.

SWOT analysis for algae production

	Helpful to achieving the objective	**Harmful** to achieving the objective
Internal origin (attributes of the system)	*Strengths* • Potential industrial symbiosis with CO2 and heat exchange from neighboring industry • Not tapping into fresh water resources but into brine sources • Salt & performant/resistant algal strains reduce contamination • Raceway ponds with CO2 input are commercially available • PBR inoculation increases productivity • Direct CO2 recycling of flue gas • Israeli reputation in raceways and track records • Promising alternative to oil based products • Multi-national partners • SME involvement (hands-on) • Investment partner (Hafren) for ”investor ready” project • No extra light or heating needed • Help diversify agriculture	*Weaknesses* • Brine is not available everywhere. • Nutrients are costly and can lead to “intensive” algae based cultivation • Land use and associated cost can be high • Raceway & PBT (worst or best of 2 worlds?), unclear. Maybe no PBR needed • A demo plant is always High CAPEX and OPEX • The algae sector has not deliver all its promises • 13 objectives • First stage Demo D-Factory (hardest point in product development cycle) • Salt/corrosive environment • Multi-national partners (harder to communicate) • No large multinational corporation only SME: lack of global network and access to cash • Harder for landlocked countries • Adaptation to climate change (since algae production is agriculture)

External origin (attributes of the environment)	Opportunities	Threats
	• Algae could make a significant contribution to sustainable development • A D-Factory could bring together different social background: farmers+blue-collar+white-collar • Strong demand from brands for natural/bio products • CO2 from flue gas are a waste today (eligible for gov support schemes) • Export tech to ideal countries with sun/salt water/land • Technology transfer to other algae clusters • One-algae-fits-all (new oil) • Scalability • Better understanding of Dunaliella • Development of PBRs for Dunaliella • Become a flagship for the algae industry • No waste stream left behind • Fish food/animal food by products	• Economic change and volatility of oil prices • Fast implementation of other biotech feeding the market requests • Changing policies on algae/bio economy • Questioning of water usage and sustainability • Algae produced by using industrial flue-gases may not be food/drugs compliant • Inability to scale up from demo • No flue gas/CO2 nearby • Contaminated flue gas • If demo in unstable countries • Other use of land (ex: tourism) • Geopolitical risk in some countries

SWOT Analysis on algae bioprocessing system

	Helpful to achieving the objective	Harmful to achieving the objective
	Strengths	*Weaknesses*
Internal origin (attributes of the system)	• Maximizing algae production efficiency minimizing waste • 9-cis beta carotene cannot be synthetically produced. No competitor • ScCO2 extraction is flexible • Membrane separation knowledge • Unique combination of centrifuge+ScCO2+HPCCC extraction • Production of multi-product/market output • Strong knowledge network • Biorefinery is a robust and proven concept (cf. forestry, agrifood, etc) • Potential high value product • 3 out of the 7 outputs of D-Factory have established market • Flexible biorefinery concept with steps that could be geographically distributed. • Target compounds and BAT extraction systems • Help reach UN Sust. Dev. Goals • Waste stream minimization	• Need of involvement of stakeholders for different market sector: too many markets addressed. • Most promising algae scenario, including current/future market volumes/prices not clear • No product's end-user/marketer in the consortium • Most promising extraction system not clear • LCA does not show a significant improvement over synthetic beta carotene? • Cost of extraction still to be identified • Bioprocessing/harvesting/extraction is still the bottleneck? • The highest growing carotenoid product (beta-apo-8-carotenal) is not addressed • Running late on production • Customized HPCCC not ready • Extraction can become the bottleneck • D-Factory extraction system not optimized • Flagship products have not been steadily been produced yet. • ScCO2 extraction is a heavy process

External origin (attributes of the environment)	*Opportunities*	*Threats*
	• International development of D-Factory biorefinery concept • Relaunch interest in algae bioeconomy • Stronger focus on nutraceutical for better market positioning • Optimization of the extraction processes • Could promote R&D investments in southern countries • RP/standards for carotenoids HPCCC solvents • Not yet any market with theses purity/specs, blank page for contracting and partnerships • Synthetic carotenoids are expensive • HPCCC with dedicated environmentally friendly solvent • Extraction processes of the D-Factory applied to other carotenoid content biomass	• Availability and contractability of Dunaliella algae feedstock • Goal of end users often focused on single product • Market demand side (nutraceutical/pharmaceutical) is not structured • Could end up with the “chocolate paradigm” i.e. low value production in poor countries and high value extraction/purification in developed countries • Upcoming cheaper extraction processes

External stakeholders Q&A interviews:

1. **David Savary**

Economic & Environmental Evaluations at SOLVAY Research and Innovation Center Lyon, France.

Interviewed (telecom) on the 06/07/2017

https://www.linkedin.com/in/david-savary-ba84519/

2. **Christophe Lombard, PhD.**

Industrial integration manager at AlgoSource S.A.S.)

Interviewed (telecom) on the 07/07/2017

https://www.linkedin.com/in/christophelombard2/

3. **Dr. Sghaier Noury**

PhD in economics Engineer in electronics. Founder or co-founder of several start-ups, including one in the field of spirulina production and conditioning in Tunisia (see: https://www.facebook.com/Spiruline-bio-gatrana-366730713360371)

Do you agree that using CO2 emissions from industries to feed the algae is a big advantage to society?

yes, if we find an efficient way for recycling CO2 to algae production units, considering that the two activities today require different production environment and are often far away. And if the algae production becomes a big industry to absorb the huge CO2 emissions

Do you think that fresh water should preferably not be used to cultivate the algae?

Yes if there is better alternative, otherwise algae production doesn’t require a lot of water, even one of the less water consuming for proteins production.

Do you have a preference for algae cultivation systems? Open ponds? Or Photobioreactors?

Open ponds, because it's closer to the natural process of the algae reproduction; and should require less energy and control, thus more inclusive.

Do you think salt water use in algae cultivation systems can be an issue with corrosion?

No corrosion technical issue. But saline waste water should be handled properly and can be recycled of other purposes.

Do you believe the area and land where you live should first be dedicated to specific purposes (like agriculture or tourism) ?

Yes, organic agriculture and environmental tourism (PV for eco-tourisme)

Do you think the geographical location of the algae cultivation should be based on nearby infrastructure/industries?

In open ponds, no. In photo-reactors, yes.

Do you think more fundamental research about algae species is necessary?

Yes, especially if we want to invent an efficient recycling system including industry and agriculture and use massively algae to combat malnutrition and diseases.

Do you think Europe should (or could) export its algae technology abroad?

Yes, for the production of algae; may be not in transformation and extraction (IP security).

Do you think the algae industry in general needs a rebirth/booster/flagship project?

Definitely, to make the algae become a real CO2 killer for our planet, and to promote the use, boost the production, create new technologies and processes for more efficient production, transformation and extraction and conservation.

Do you think the share of algae production for food and products should increase in the future?

Yes, it should drive wide move towards social and solidarity economy

Do you think flue gas cleaning is an issue when coupling an industry to algae production?

Definitely yes. I will not use dirty flue gas as a source of CO2 whatever the cleaning process.

Do you think the high value of carotenoids would be an advantage to D-Factory/algae biorefineries?

No because it is not compatible neither at cost level or priority

Do you think waste minimization/circularity should be at the core of any new industrial process?

Yes, if this doesn't create more exclusion than environment protection (and algae could be a solution creating foods and jobs and absorbing CO2 and saving water for instance)

Do you think decreasing the cost of extracting products from algae should be a priority?

Yes, it's an efficient way to boost this industry and make it an added value segment, profitable

Do you think algae production should focus on one product output only?

No, because algae are of different nature/content and the industry needs are different. But specialization may be required for efficiency and environment requirements.

Do you think that high purity carotenoids could be produced from other sources than algae?

Yes (fruits, vegetables, synthesis), but less efficiently

Do you believe in the biorefinery concept? https://en.wikipedia.org/wiki/Biorefinery

Yes, as this production process could be better than the petroleum one and more sustainable

Do you think one sector is more promising than other when it comes to cultivating and extracting products from algae? (ex: food, cosmetics, pharmaceutical etc)?

Yes, I think food and health will have a fast growth

Do you know if regulation could hinder algae cultivation and extraction?

Yes, for instance certification specifications creation or health authorization for distribution in UE or the USA

Have you ever bought algae or algae products in a shop or online?

Yes, I'm a spirulina producer in Tunisia for the local and European market.

4. **Diana Arroyo (interviewed as a Monzón citizen).**

Do you agree that using CO2 emissions from industries to feed the algae is a big advantage to society? Yes, of course

Do you think that fresh water should preferably not be used to cultivate the algae? It´s preferably use marine water because fresh water is a limited resource.

Do you have a preference for algae cultivation systems? Open ponds? Or Photobioreactors? The two systems have advantages and disadvantages and both are interesting to culture different species of algae.

Do you think salt water use in algae cultivation systems can be an issue with corrosion? It could be a problem in halophyte species like Dunaliella, in other species could affect but depends of the medium molarity.

Do you believe the area and land where you live should first be dedicated to specific purposes (like agriculture or tourism) ? yes

Do you think the geographical location of the algae cultivation should be based on nearby infrastructure/industries? I think it would be very important to facility the cultivation and provide the material necessary.

Do you think more fundamental research about algae species is necessary?yes I think research is very important about microalgae and dissemination as well.

Do you think Europe should (or could) export its algae technology abroad? I think it would be interesting to expand microalgae market to other countries.

Do you think the algae industry in general needs a rebirth/booster/flagship project? I think algae needs more booster projects to have more information about them, because the population needs more solid information.

Do you think the share of algae production for food and products should increase in the future?i think algae production will be an important market in the future and it will be included in a lot of food and animal food.

Do you think flue gas cleaning is an issue when coupling an industry to algae production?Flue gas can be collected to culture the algae, so it can be used in the growth process.

Do you think scaling up algae production is a technical issue? Scaling up is a step necessary to get a good cell density. If the technology is adequate do not have to present a problem.

Do you think the public has a positive image of algae and algae cultivation? I think the public is not informed enough about microalgae

Do you see algae production competing with other agriculture branches?this question is difficult to answer because the people knows very good agriculture but microalgae production is relatively new market, especially in occident.

Do you think using centrifuges, Super critical CO2 extraction and High Performance Chromatography altogether is unique? For now, are unique and very good methods but the technology advances very fast and there are many things to discover in this area

Do you think the high value of carotenoids would be an advantage to D-Factory/algae biorefineries? I think yes, because the quality of the carotenoids is very high.

Do you think waste minimization/circularity should be at the core of any new industrial process? Of course yes. I think all the new industries could be based in circular economy or waste reductions and the old industries should adapt to this way of work.

Do you think decreasing the cost of extracting products from algae should be a priority? I think that reducing costs is very important because those expenses can be reversed in making other improvements

Do you think algae production should focus on one product output only? Algae can provide several byproducts of interest so focusing on one can be profitable but they would be wasting others that may also be interesting

Do you think that high purity carotenoids could be produced from other sources than algae? Other sources exists but algae biomass is very interesting to get a good quality of carotenoids

Do you believe in the biorefinery concept? Yes but I think its necessary to improve technologies.

Do you think one sector is more promising than other when it comes to cultivating and extracting products from algae? (ex: food, cosmetics, pharmaceutical etc)? I think some by products are more interesting to some sectors, but it can change in the future because it need more research in the field of microalgae.

Do you know if regulation could hinder algae cultivation and extraction? My opinion is there are some restrictions currently by the ignorance about this field

Have you ever bought algae or algae products in a shop or online? yes I bought Spirulina and Chlorella in a shop.