

Report on the state of algae related research and industrial activities in North-West Europe

Report WP2A9.08



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1 Introduction

In 2012-2014 an inventory of North-West European algae initiatives was carried out to provide an impression of research and commercial activities connected to algae production and utilization. The collected data has been reviewed in country specific reports and collated and summarised in this overview report covering the whole North-West-Europe region (including Great Britain, Ireland, Germany, Belgium, France, Switzerland, Luxemburg and the Netherlands).

Data was obtained via a comprehensive questionnaire which was distributed among stakeholders identified in a preliminary scoping exercise. Although not unexpected, unfortunately not all questionnaires were returned. In these cases, publically available information was used for the landscaping study and some additional information was collected through personal interviews with the respective stakeholders. The questionnaire aimed to gather more information on focus, expertise and applied technology of the addressed institutions. It was also designed in a way that it allows its use as an information sheet in EnAlgae's web-based information portal.

This report summarises the results of the analysis of data collected in the sample region. It must be emphasized that this report cannot claim to reflect an exhaustive list of all stakeholders active in algae research and business. Various reasons account for this problem:

To begin with, the "algae sector" is rather extensive (including the whole value chain from cultivation, harvesting, processing to marketing of algae products as well as respective research to further develop and improve these activities and underpinning measures like bioprospecting or life-cycle assessments) and in some cases only very limited information is publically available. In addition, there is lots of movement in this sector with regard to new start-ups and the closing down of business operations, making it difficult to give an up-to-date overview. If too little information could be found about certain institutions they were not included in this survey at all.

However, this study nevertheless represents the most important institutions active in this area, allowing conclusions to be drawn about the main fields of interests, technology and market opportunities for algal research in North-West Europe. It summarises the country specific reports that have been produced at an earlier stage and which are also based on the data of the survey. Aim of the present report is to give an impression of the algae related activities in the entire considered region (North-West Europe).

2 Algae stakeholders

In total 284 institutions working with algae could be identified in North-West Europe. The majority of these stakeholders (60%) are academic stakeholders, which mainly carry out research activities. The other stakeholders are from commercial institutions. It needs to be noted, though, that most commercial algae stakeholders are also carrying out algae research. The separation into the different types was mainly done in order to evaluate the foci of the work of scientific and commercial stakeholders and to which extent they match to each other.

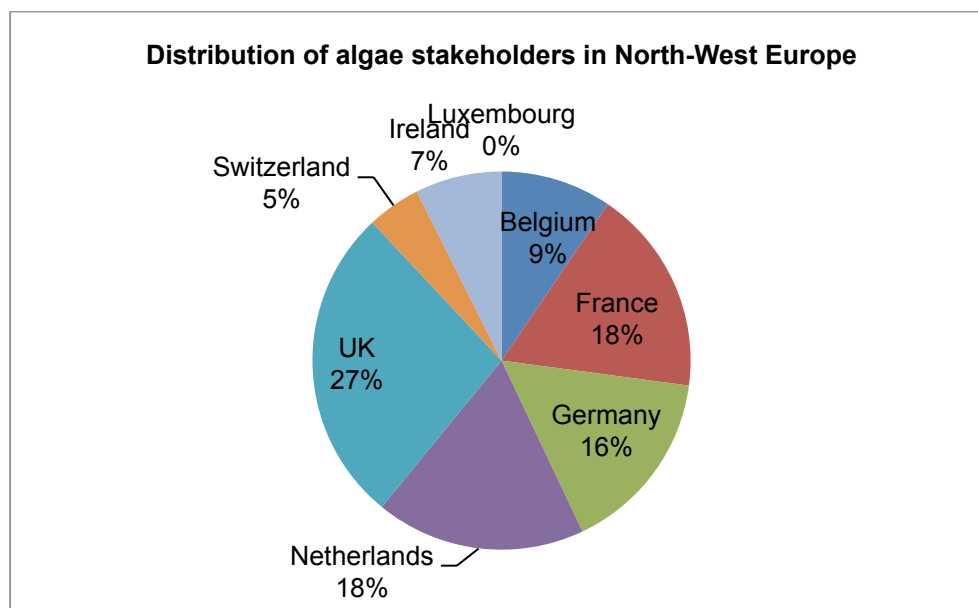


Figure 1: Distribution of algae stakeholders in NW-Europe.

The number of stakeholders in the different countries varies significantly from no algae stakeholders being identified in Luxembourg to over 77 stakeholders identified in the UK. The United Kingdom consequently has the highest representation of stakeholders working with algae in North-West Europe followed by the Netherlands and France. 27% of all identified algae stakeholders in NW-Europe work in the UK and 18% in France and the Netherlands respectively (figure 1).

Looking at the respective break down into scientific and commercially oriented stakeholders it can be noted that the UK is also the country with the most unequal distribution of these 2 groups. 78% of the identified UK-stakeholders are research institutions. In most of the countries that were included in the survey the ratio differs between these two groups differ not so strongly. Nevertheless the scientific stakeholders account for the majority in the algae sector. Only in France, the collected data gave a different picture: 64%, hence a significant majority, of the French stakeholders represent commercially driven algae businesses. In Ireland, the ratio of scientific and commercial stakeholders is the most equal one (figure 2).

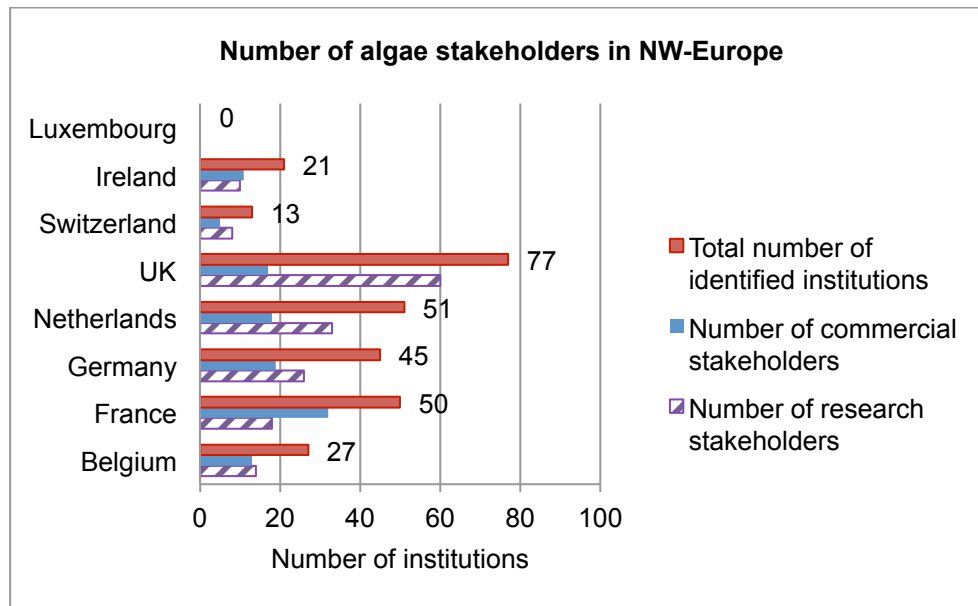


Figure 2: Number of algae stakeholders in NW-Europe.

As to which extent the specific algae related research efforts in NW-Europe match with the actual focus of algae production or processing companies will be further discussed in chapter 7 (“Markets – scientific vs commercial focus”).

3 Algal strains

There are three primary algae strain categories: microalgae, cyanobacteria and macroalgae (Sikes, Van Walwijk, McGill, 2011). Quite different attributes characterise these strains. Consequently most of the identified algae stakeholders focus their work on just one of these main categories which again is dependent on their location (e.g. accessibility to the sea) and their targeted market. For simplification cyanobacteria were included in the microalgae categories in this survey.

The main characteristics of micro and macroalgae are listed in following table (table 1; Sikes, Van Walwijk, McGill, 2011).

The majority of the stakeholders in NW-Europe are predominantly working with microalgae (figure 3). Only in Ireland does the use of macroalgae (48% vs 14%) exceed that of microalgae, whereas in France cultivation and use of these two algae groups are rather well-balanced (21 stakeholders working with microalgae versus 18 stakeholders focusing on macroalgae). Ireland and France are consequently the countries showing the highest rates of macroalgae growth and usage. The Swiss and Belgian stakeholders in contrast almost exclusively concentrate their activities on microalgae. Besides, all countries have a small group of stakeholders working on both, macro and micro types.

Table 1: Summary of characteristics of the primary algae strain categories (Sikes et al., 2011).

	Microalgae	Macroalgae
General description	Microalgae include a diverse group of unicellular, eukaryotic organisms adapted to freshwater or marine environments. Cyanobacteria are also microscopic organisms that efficiently use photosynthesis. In contrast to microalgae they lack a nucleus and membrane-bound organelles and conduct photosynthesis in its cytoplasm. They are therefore categorised as prokaryotes like bacteria although they are traditionally referred to as “blue-green algae” because of their similarities to microalgae.	Macroalgae, commonly referred to as seaweeds, are a diverse group of multicellular marine organisms that have a ranging in length from a few millimetres to tens of meters. They are classified in three categories that refer to their respective pigments: brown, red and green seaweeds.
Strength	Microalgae have high replication rates, high energy content and higher lipid yields than cyanobacteria and macroalgae Cyanobacteria can store large quantities of carbohydrates and are better positioned for genetic manipulation. Compared with microalgae they have higher light conversion rates.	Macroalgae have rapid growth rates, are abundant in oceans and coastal waters, can store large quantities of carbohydrates, are easier to cultivate and harvest than microalgae and cyanobacteria. They have been grown on commercial scale for food for many years.
Weaknesses	Cultivation and harvesting of microalgae is relatively difficult and costly.	Lipid yields are generally low. Research for use in biofuels and energy industry is less advanced than for microalgae.

Having extensive coast lines Ireland, France and the UK are certainly naturally predestined for using macroalgae. This could also explain the almost none existent role of macroalgae in Switzerland and Belgium (8% of the stakeholders in each country work on both algae groups; figure 3).

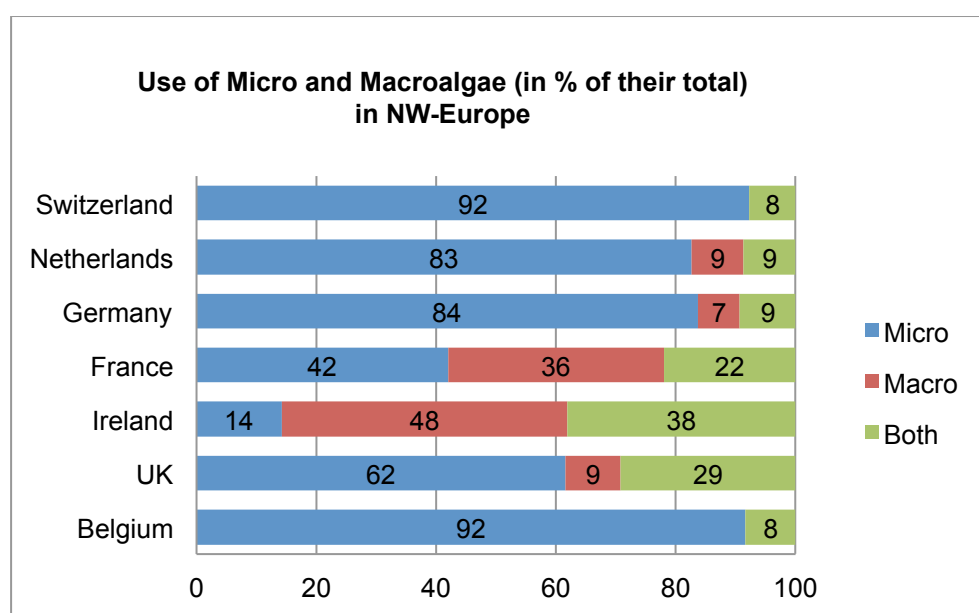


Figure 3: Use of Micro and Macroalgae in NW-Europe in % (combined research- and commercial activities).

As for the usage of these primary algae strains, the survey has shown that macroalgae are not solely used for human consumption as has been the case for a very long time, predominantly in Asia (Sikes, Van Walwijk, McGill, 2011), but that macroalgae are also increasingly considered for bioenergy purposes. In France and Ireland, for instance, “Energy” is the mostly targeted market of the algae stakeholders, followed by “Speciality chemicals” and “Food & Feed”. In general these are also the main three market sections that algae stakeholders from countries with predominantly microalgae usage, are targeting (refer to chapter 6 “Targeted markets” for further information). This leads to the assumption that apart from the algal biomass characteristics, political frameworks and a respective focus of funding programmes considerably influence the utilisation of algae – micro as well as macroalgae.

4 Cultivation facilities

Over the last decade, constant and innovative research and development has been taking place in the area of algae cultivation technology. The mainly used cultivation approaches can be subdivided into following systems:

Table 2: Cultivation systems.

Open/ Half-open production systems
<ul style="list-style-type: none"> • Open-Ponds/ Race-Way-Ponds • Longlines
Closed photobioreactor systems (PBR)
<ul style="list-style-type: none"> • Flat bed/ Plate/ Flat panel reactor • Tubular reactor • Bag/ Flexible tube reactor • Rain creating stack system („Horizon“) • Fermentation vessel (heterotrophic cultivation)

Closed cultivation systems have the advantage of better controlling the cultivation conditions and, consequently, to guarantee the best temperature and light regime under almost sterile conditions. According to the survey these cultivation systems are exclusively used for microalgae.

Many stakeholders run more than just one type of PBR. This circumstance needs to be kept in mind when seeing the results of this survey.

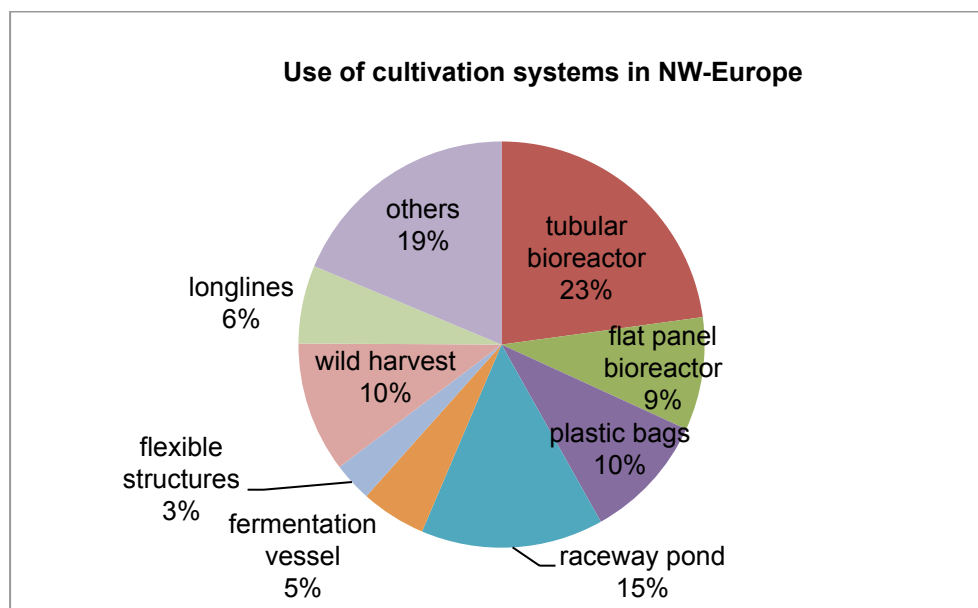


Figure 4: Use of cultivation systems in NW-Europe.

Tubular photobioreactors proved to be the most favoured cultivation systems for **microalgae** in NW-Europe. Only the Netherlands, where over 83% of the algae stakeholders use microalgae, raceway ponds are more often used than tubular photobioreactors (32% vs 24%; figure 5). Raceway ponds are actually the second mostly used cultivation system for microalgae in NW-Europe (15% of the cultivation systems in NW-Europe, figure 4). Apart from the Netherlands, these systems can be found more often in France (7 stakeholders) and Germany (5 stakeholders). In regard to other closed photobioreactor systems, beside tubular ones, plastic bags and flat panel reactors are relatively well established with an almost equal occurrence (10% and 9% of the NW-European cultivation systems respectively, figure 4)). In total numbers most of the plastic bag systems can be found in the Netherlands (10 stakeholders), Germany (8 stakeholders) and the UK (6 stakeholders). As for the flat panel systems, they are most frequently used in Germany (13 stakeholders) and the Netherlands (6 stakeholders). Very few of the stakeholders in NW-Europe have focused on heterotrophic growth of algae and therefore cultivation systems that include a fermentation vessel (5% of the cultivation systems in NW-Europe, figure 4). Only 15 of all the stakeholders pursue this kind of algae growth. Most of them can be found in the UK and Germany (4 stakeholders each).

The stakeholders specialising in the use of **macroalgae**, i.e. especially in Ireland and France, mostly harvest naturally grown (wild) seaweeds. However, in order to reach a larger scale in seaweed production a more controlled cultivation is required. For this purpose usually long line systems are used (6% of all identified algae stakeholders in NWE; figure 4), which consist of vertical strings suspended from a horizontal string held up by a series of buoys (NNFCC, Crop Factsheet Macroalgae, 2011). More recently, also other flexible seaborne structures have been used for macroalgae cultivation (3% of all algae stakeholders in NWE; figure 4).

Many of the NW-European algae stakeholders (especially the scientifically working ones) have mentioned that they use “other” algae cultivation facilities (19%; figure 4). Those “other” algae cultivation facilities are often mentioned to be LED photobioreactors or small scale laboratory flasks. New developments like the “Rain creating stack system (“Horizon”)” were also included in this category.

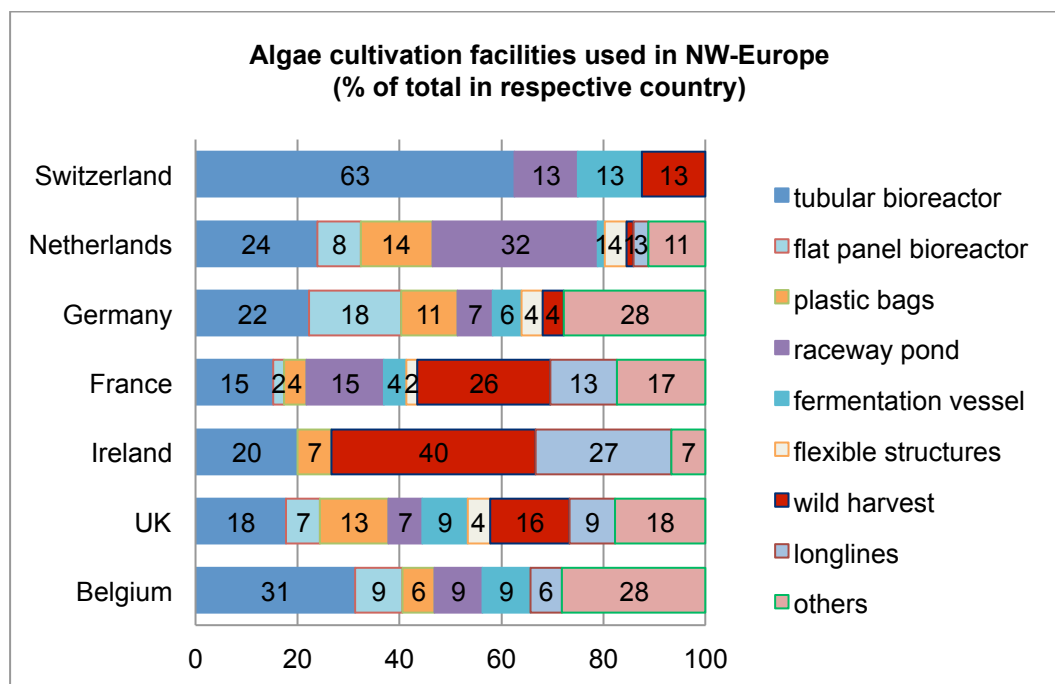


Figure 5: Algae cultivation facilities used in NW-Europe.

It also needs to be pointed out that not all stakeholders have provided information (either personally or through respective websites) about their used cultivation system. Particularly data collection for UK, Switzerland and Ireland could not be fully completed in that regard.

In terms of size of the facilities there are big differences between the different stakeholders. Some of the industrially used algae growth facilities (i.e. closed photobioreactors) comprise a volume of over 2500 m³, whereas some of the research institutions use facilities with less than 1 m³ capacity. As expected it can be noted that generally the commercial algae producers have the bigger algae production facilities.

5 Growth conditions

In average, only about 2/3rd to half of the questioned stakeholders (according to country) provided information about the conditions in their respective algae growth facilities (either personally or through respective websites). Information supply actually differed quite significantly among the considered countries (figures 6-8). In respect to growth conditions, the survey did not go into too much detail, but rather concentrated on the origin of the three main substances: water, light and carbon dioxide. Multiple answers were possible. The following graphs show the situation for the specific countries in NW-Europe.

In regard to the **growth medium**, most of the stakeholders do not concentrate solely on either salt or fresh water species, but use both, fresh and salt water for the cultivation (figure 6). Switzerland seems to be an exception: according to the collected information (from only 54% of the Swiss stakeholders), Swiss algae stakeholders exclusively use either fresh or waste water. When looking at the entire NW-European region, the use of salt water slightly seems to predominate (figure 6). On average 19% of the algae stakeholders use salt water versus 17% using fresh and 16% waste water. Again, it must be kept in mind though that on average 37% of the identified stakeholders did not supply respective information.

The waste water sources are quite different and comprise effluents from biogas plants, industrial and municipal wastewaters and residual or recirculation water from aquacultures.

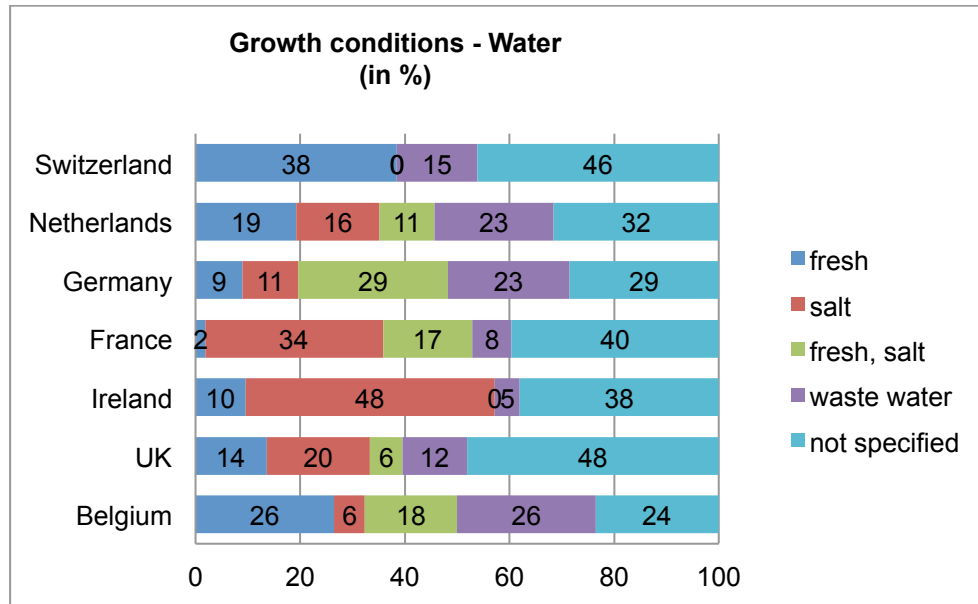


Figure 6: Growth conditions – Water.

In terms of the **light regime**, the majority of the stakeholders, who provided information (60% of all stakeholders), use natural light for growing algae: on average 32% solely rely on the natural radiation (figure 7). Most of them can be found in Germany (26 stakeholders), the Netherlands (24 stakeholders) and France (20 stakeholders). Only 15% of the stakeholders use artificial light when necessary and 13% supply continuous artificial lighting for their algae cultures (figure 7). In total numbers most of the stakeholders using an artificial light regime can be found in Germany (17 optional, 9 continuous), the Netherlands (12 optional, 7 continuous) and the UK (10 optional, 8 continuous). Only 2% of the stakeholders have (also) focused on heterotrophic microalgae production and do not need any light (equal number of stakeholders in the UK, France, Germany, the Netherlands and Switzerland).

Again, it must be highlighted that numerous of stakeholders particularly in UK (60%), France (50%) and Ireland (43%) haven't provided information about this aspect in their algae cultivation.

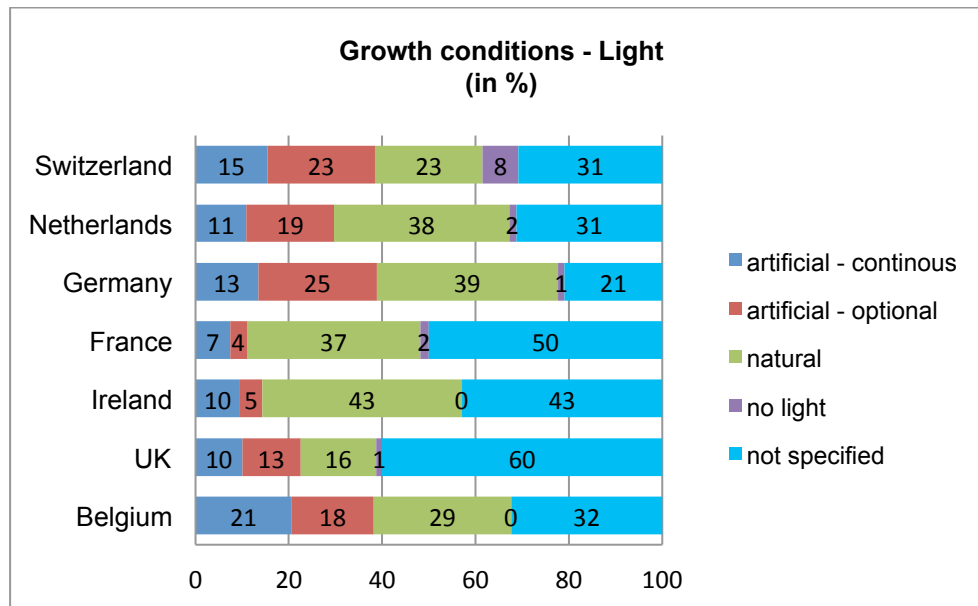


Figure 7: Growth conditions – Light.

As for the **carbon dioxide supply**, only half of the stakeholders provided information. Especially for France (79%), Switzerland (77%) and the UK (70%) very little information was supplied (figure 8). Concentrating only on stakeholders, where respective information was available, 39% of them used carbon dioxide from renewable or natural sources respectively. Renewable carbon dioxide is mostly used when algae production is combined with a biogas plant in which CO₂ is produced as side product. A “natural CO₂” source plays a particular role for the macroalgae production in the algae’s natural environment. Especially stakeholders in Ireland (13) and in Germany (10) rely on this carbon dioxide source. Since France and the UK are also big macroalgae producers it can be expected that naturally available carbon dioxide is of significant importance for those stakeholders as well.

Almost as many NW-European stakeholders, 36%, use industrially bottled CO₂. Only in Belgium does this source of CO₂ seem not to play a role. The remaining 25% of the stakeholders rely on fossil based carbon dioxide for their algae production. Most of these stakeholders, predominantly situated in Germany and the Netherlands (figure 8), focus on carbon sequestration and have installed their algae cultivation facilities close to heat or combined heat and power plants (CHP) using the fossil based flue gas for algae production.

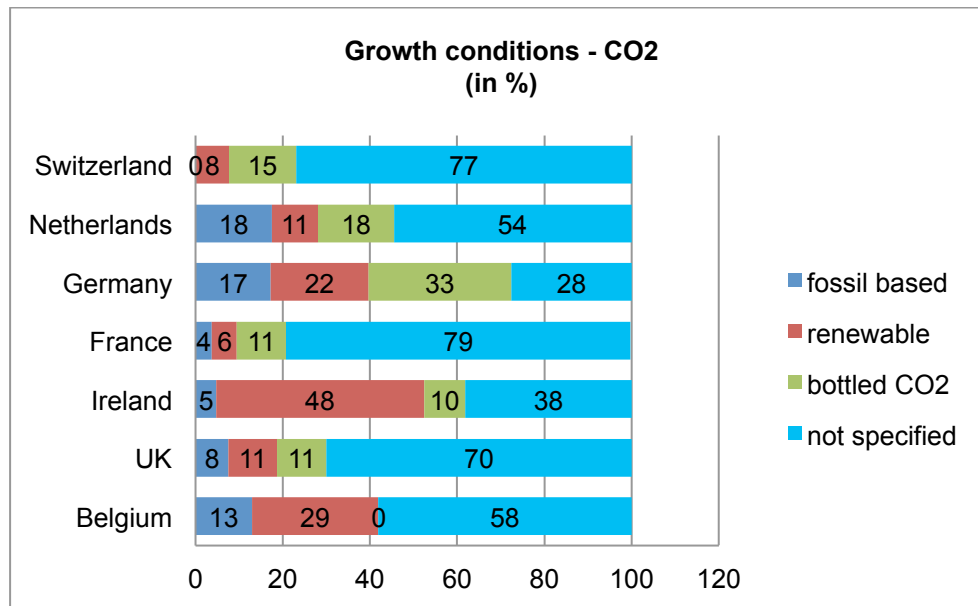


Figure 8: Growth conditions – Carbon dioxide.

6 Targeted Markets

As in the section on algal cultivation conditions, it needs to be emphasized that multiple answers were permitted since most algae stakeholders aim for more than one single product respectively market sector. The results have been summarized in figure 9.

In order to determine the most promising market sectors for algae, the targeted products have been grouped accordingly. The listed market sectors include the following algae based products (table 3):

Table 3: Algae market sector and their respective products.

Algae market sector	Included products (from micro as well as macroalgae)
Energy	Hydrogen, biogas, oil (for biofuel), bioethanol, biodiesel, not specified “other” products
Other Commodity products	Biopolymers, bioplastics, fermentation products, not specified “other” products
Speciality chemicals	Nutraceuticals, cosmeceuticals, pharmaceuticals, not specified “other” products
Feed & Food	Feed for aquaculture, feed for livestock and pets, not specified “other” feed products, food
Design & production of PBRs	Research on PBR design, PBR production and/ or sale of respective facilities
Bioremediation	Bioremediation using waste water, flue gas or not specified “other” mediums

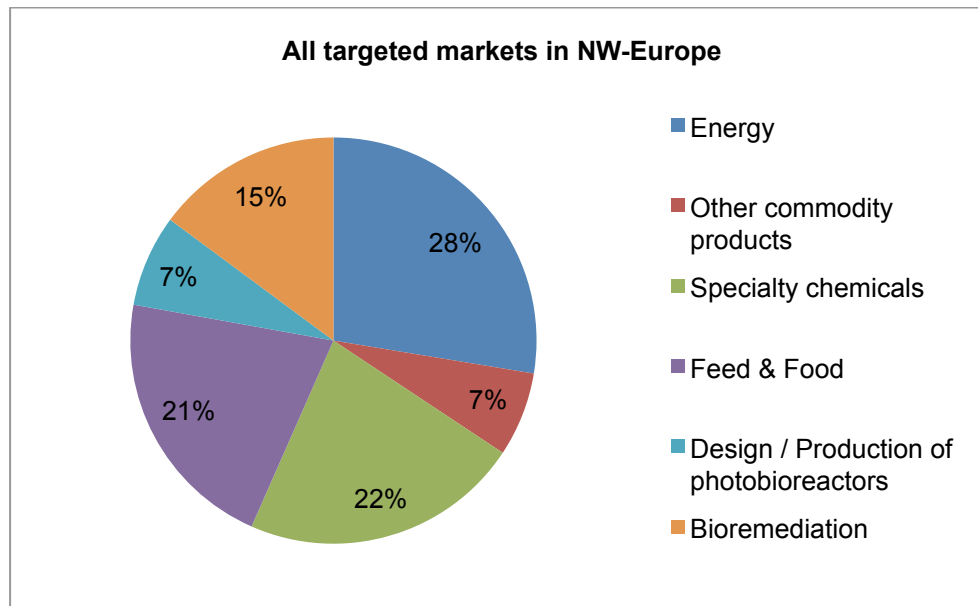


Figure 9: Targeted algae markets in NW-Europe.

The majority of the cultivated algae in NW-Europe are used for **material purposes** (50% of the stakeholders, figure 9), like specialty chemicals (cosmeceuticals, nutraceuticals, and pharmaceuticals), food and feed and other commodity products (e.g. bio-plastics and fermentation products). Algae-based **bioenergy** is a very important field of interest as well, especially when looking at the country specific foci (table 4). Almost 1/3rd of the NW-European algae stakeholders focus their research, development and demonstration activities on this market sector (figure 9). A reason for this is among others surely the current focus of respective funding policies in NW-Europe. Algae use for bioenergy products is, however, currently not practiced commercially. A considerable barrier for this market approach is the fact that algae production is still too expensive to successfully enter low cost and high tonnage markets like the one for bioenergy.

Table 4: Targeted algae markets in NW-Europe.

Algae markets (number of stakeholders per country)						
Country	Energy	Other commodity products	Specialty chemicals	Feed & Food	Design/ Production of photobioreactors	Bioremediation
Belgium	14	3	24	19	8	17
UK	59	8	44	30	10	21
Ireland	27	11	27	22	1	12
France	34	5	28	19	7	21
Germany	62	12	39	40	19	27
Netherlands	28	18	21	45	12	26
Switzerland	10	0	6	5	5	2
Total	234	57	189	180	62	126

Beside typical biofuel products like biogas, oil, bioethanol, biodiesel and – to a very small extend - kerosene, some research institutions further examine alternative energy products like hydrogen, propane or products derived through hydrothermal processing. This offers promising approaches, but seems currently to be still too far away from the market. Consequently, these pathways are mainly further developed in the context of research projects and are not yet pursued by commercial stakeholders.

Table 5: Targeted energy products per country.

Energy (in % of all algae stakeholders in respective country)						
Country	Hydrogen	Biogas	Biofuels: oils	Biofuels: bioethanol	Biofuels: biodiesel	Others
Belgium	14	36	29	0	14	7
UK	5	20	27	10	15	22
Ireland	7	15	22	22	15	19
France	21	21	26	6	26	0
Germany	0	34	27	19	13	6
Netherlands	4	18	21	11	21	25
<i>% of all stakeholders</i>	7	24	26	13	17	13

According to the observed frequency of targeted algae based energy products, oil for biofuel production (26%) and biogas (24%) appear to be the most favoured ones in NW-Europe (table 5).

Having a look at the country specific foci, it can be pointed out that algae based energy products play a particular role in Germany (62 stakeholder) and the UK (59 stakeholder, figure 10). However, the smaller number of stakeholders in the other countries might be slightly misleading. Even though the total number of stakeholders concentrating on energy products in the other countries appear much smaller, in proportion to their respective total number of stakeholders energy products are quite important (table 4). It is actually also the main market sector for Switzerland (36% of the Swiss stakeholders), France (30% of the French stakeholders) and Ireland (27% of the Irish stakeholders - beside “Speciality chemicals”). That means only Belgian and Dutch algae stakeholders do not aim for the energy market sector as first priority.

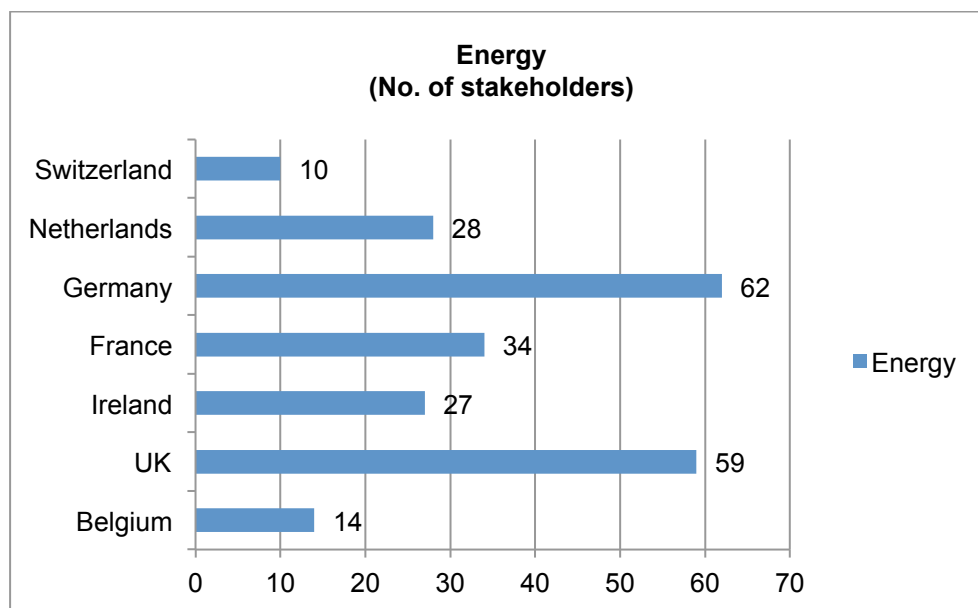


Figure 10: Targeted market – Energy.

Algae based **bioremediation**¹ is also often combined with energy production. Bioremediation has a share of 15% of the targeted algae markets in NW-Europe (figure 9). Stakeholders concentrating on bioremediation frequently cooperate with either big power plants or biogas plants, in order to use the CO₂ of the plants' exhaust gas and the produced waste heat for algae cultivation. Algae produced under these circumstances can usually not be used as component for material products, like for instance food/ feed additives or cosmeceuticals, but are further used for producing bioenergy. Thereby production of biogas is still the cheapest option. According to the total number of stakeholders in the considered countries, algae are mostly used for bioremediation purposes in Germany and the Netherlands (figure 11). However, having a look at the specific countries themselves it can be noted that, in proportion, bioremediation plays even a bigger role for the Swiss (20%) and the French (18%) algae stakeholders (table 4).

¹ Bioremediation refers to applications where algae are used for removing pollutants e.g. from power plant flue gas or from waste waters.

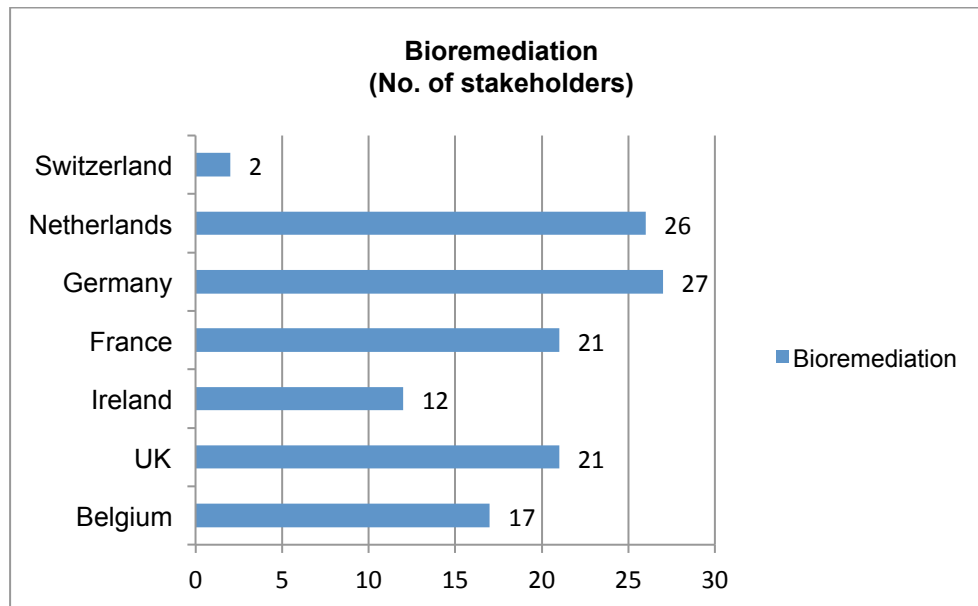


Figure 11: Targeted markets – Bioremediation.

The use of algae for other **commodity products** like bio-plastics and fermentation products account for only a minor share (7%; figure 9) in the total targeted markets for algae. The Swiss stakeholders are not interested in this kind of algae market at all. The most attention to this group of products is given in the Netherlands, Germany and Ireland (figure 12). However, generally speaking this algae market currently does not play a significant role in North-West Europe.

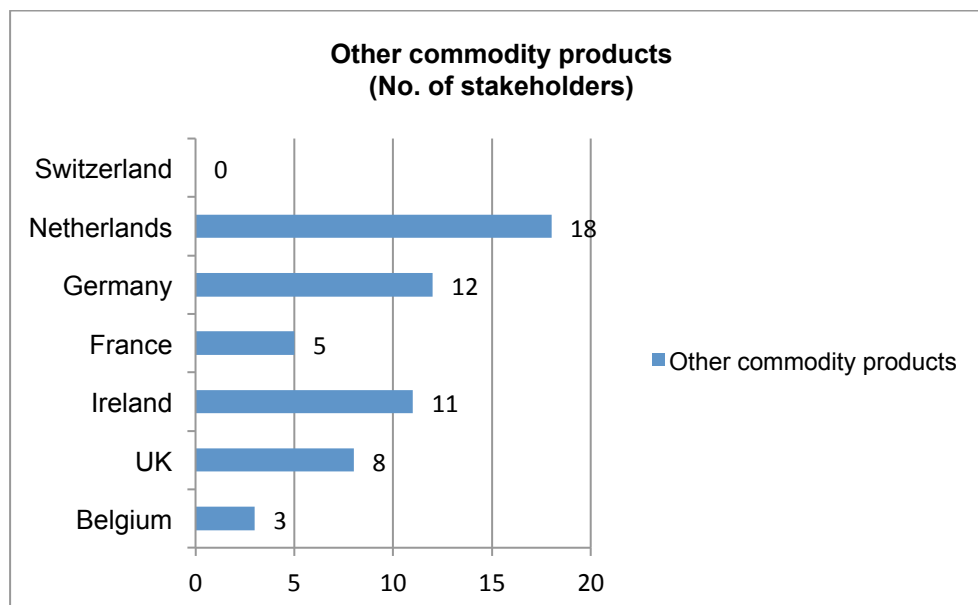


Figure 12: Targeted market – Other commodity products.

Another important market for algae is the one for “**specialty chemicals**”, i.e. specific components and ingredients that can be used in the production of cosmeceuticals, nutraceuticals and pharmaceuticals (22% of market share; figure 9). According to the country specific total number of stakeholders targeting this market sector, the UK and Germany are leading (figure 13). However the graph might be a bit misleading since the product group of “specialty chemicals” is actually the main algae market for Belgium (28%) and, besides bioenergy, the second most important market for Ireland (27%) and France (25%) and Switzerland (21%) (table 4).

There are attempts to further develop this market potential by looking for even more useful, algae-derived substances.

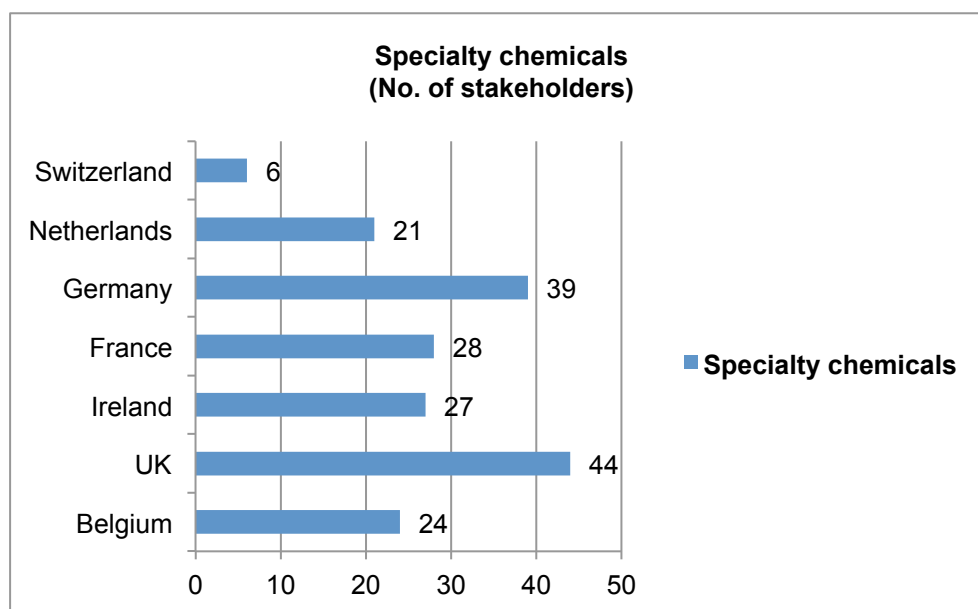


Figure 13: Targeted markets – Specialty chemicals.

An equally significant share of the algae market is the food and feed sector. 21% of the NW-European algae stakeholders use their algae (micro and macro) for the production of food or feed for pets, livestock or aquaculture (figure 9). It is actually the main market for the Dutch algae stakeholders. Almost 1/3rd of the Dutch algae stakeholders target this market. Germany shows the second highest number of stakeholders focusing on this algae market; figure 14 (equates to 20% of the German stakeholders; table 4). Looking at the country specific market targets, though, this sector also plays a quite important role for Belgium and Ireland (22% for each nation)

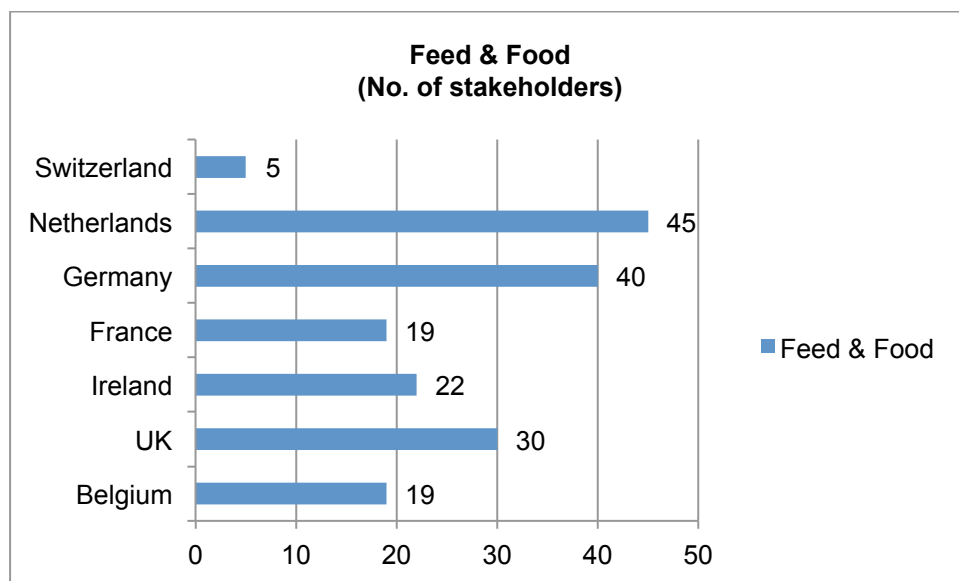


Figure 14: Targeted markets – Feed & Food.

One market branch inevitably connected with the cultivation and use of algae is the development and production of **photo-bioreactors** (PBRs). Nevertheless, its overall share in the total targeted market sectors accounts for only 7% (figure 9). As figure 15 clearly shows, most of the stakeholders doing research on PBR design or even selling respective facilities can be found in Germany. Again, when looking at country specific proportional market focus it can additionally be pointed out that this sector is actually also important for Switzerland (18% of the Swiss stakeholders; table 4).

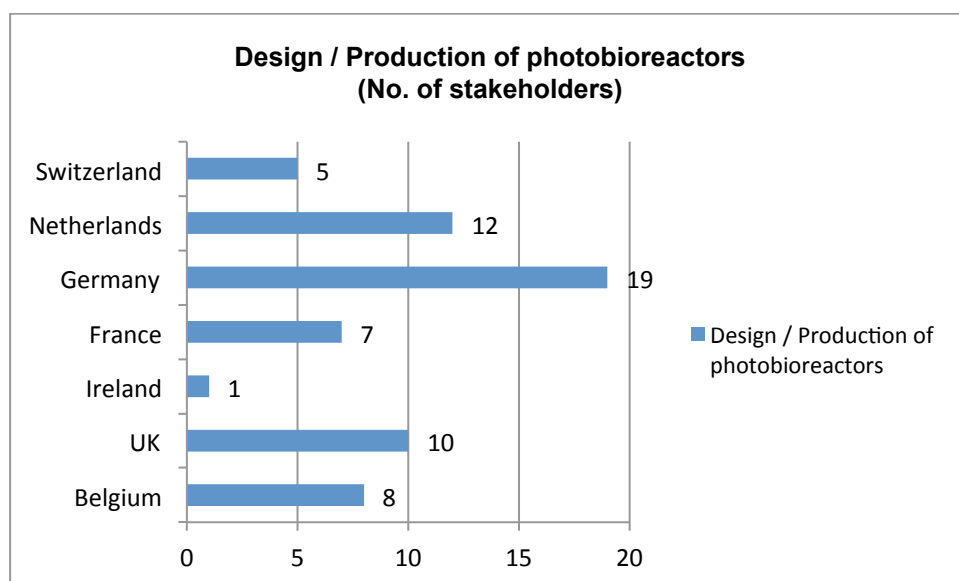


Figure 15: Targeted markets – Design/ production of photobioreactors.

7 Markets – Scientific vs Commercial focus

The last chapter analysed the data of the survey concerning the general market focus of algae stakeholders in NW-Europe. Another interesting perspective is the comparison of respective interests of research institutions and industry. Does the commercially driven focus actually match with the scientific one? This aspect will be further examined in the present chapter.

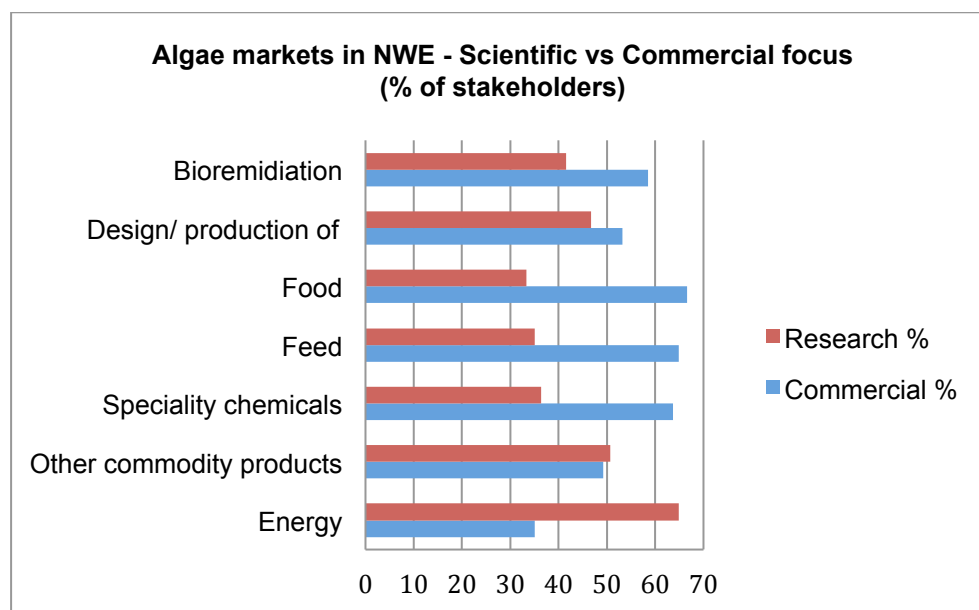


Figure 16: Algae markets in NW-Europe – Scientific vs Commercial focus (in %).

In general it can be stated that research institutions address a wider variety of aspects connected with algae cultivation and downstream processing and do more fundamental research compared to the stakeholders from industry. However, quite frequently, a close collaboration between industrial and scientific stakeholders can be found.

For some market categories the focus of scientific and industrial stakeholders differs quite significantly. Commercial activities in the fields of algae based food, feed and speciality chemicals are much higher than respective scientific ones (33%, 30% and 27% of difference respectively) (figure 16). In contrast, scientific activities targeting the bioenergy market are much more frequent (30% more than among commercial stakeholders; figure 16). A possible explanation for this circumstance could be the easier market entrance for low volume, high profit products. In contrast, bioenergy products generate much lower total revenues for the same volume of product. Consequently the production costs (including harvesting and processing of algae) must be adequately low in order to build up an economical viable business. This is currently not the case. However, there are enough incentives to further investigate this market approach – including respective funding policies – to do intensive research on that topic. Altogether 159 stakeholders are doing research on this kind of algae usage in NW-Europe. Consequently this topic is – by far - the most important research field for scientific algae stakeholders.

Table 6: Targeted markets – number of stakeholders.

	Commercial (115 stakeholders in total)	Research (169 stakeholders in total)
Energy	86	159
Other commodity products	35	36
Speciality chemicals	140	80
Feed	74	40
Food	58	29
Design/ production of photobioreactors	33	29
Bioremediation	62	44

Hence, bioenergy, with exception of biogas, is currently a less important product for industrial stakeholders. This might however change, if more efficient production, harvesting and/ or processing methods will be established.

According to the country specific findings, it can be pointed out that the strongest commercial activities in this market category can be found in Germany and Ireland (30 and 20 stakeholders respectively, figure 17). Germany nevertheless even shows a stronger interest in respective research (43 stakeholders) whereas in Ireland the commercial activities are by far predominant. In contrast, the opposite form of imbalance between industrial and research focus can be found in the UK, where much more scientific activities are focused on algal bioenergy (57 scientific vs 2 commercial algae stakeholders, figure 17).

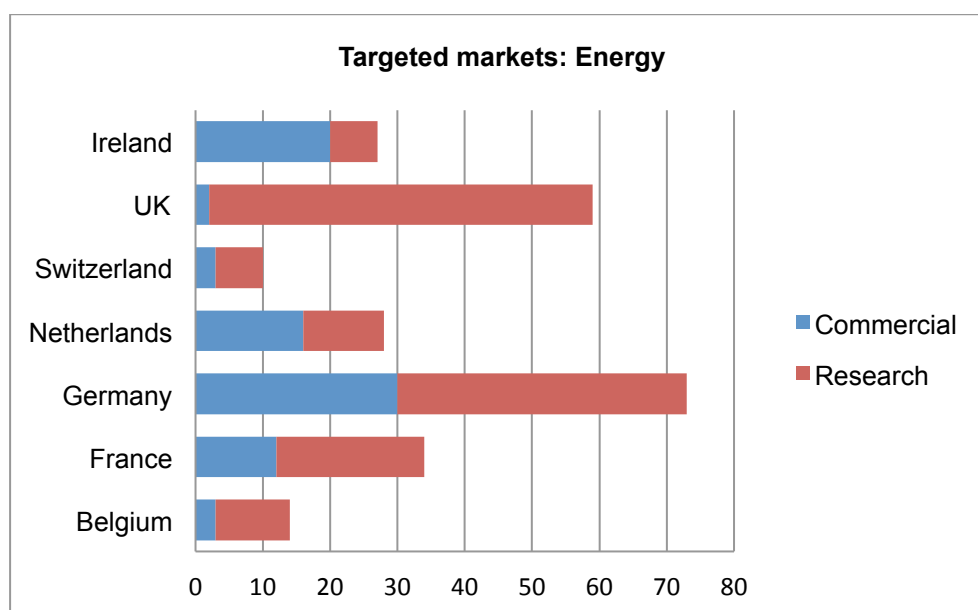


Figure 17: Algae markets in NW-Europe – Energy; Scientific vs Commercial focus (no. of stakeholders).

As already described in the previous chapter, algae based **commodity products** like bioplastics or fermentation products currently do not play a significant role. In comparison of the concerned countries, most of the stakeholders targeting this market can be found in the Netherlands, France and Germany (figure 18). None of the Swiss algae stakeholders show an interest in these kinds of algal products.

Besides Ireland, the Netherlands is the only other NW-European country where there are more commercial stakeholders focused on algal energy products than scientific ones. Compared to Ireland, the difference is only minor, though.

Although on a low level, the share of commercial and scientific activities in this market sector is very well balanced.

It can be assumed that the market of commodity products will be further developed for algae when its cultivation, harvesting and processing will be realisable at a lower cost. It is to be expected that algae based bioplastics and fermentation products are not (monetary) valuable enough to generate an acceptable and economically viable outcome for the stakeholders yet.

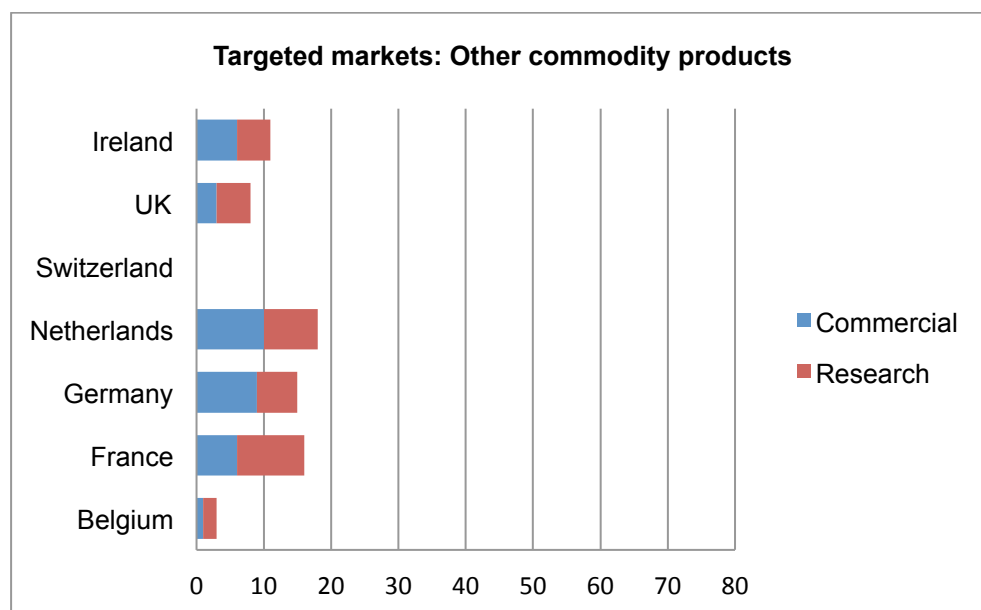


Figure 18: Algae markets in NW-Europe – Commodity products; Scientific vs Commercial focus (no. of stakeholders).

It is a different scenario for another algae based product market: “**specialty chemicals**”, i.e. specific components and ingredients that can be used in the production of cosmeceuticals, nutraceuticals and pharmaceuticals. These products account for 22% of the total algae market in NW-Europe (figure 9) and are quite interesting for the industry. It could be explained by a higher value of this product group. In contrast to the energy market this is a “low volume, high price” market, which has the potential to cover the considerable costs associated with algae production and use. Therefore it can be pointed out that particularly the commercial algae stakeholders show a high interest in this market sector. In almost all NW-European countries, except in the UK, the number of commercial stakeholders outweighs the share of

scientific stakeholders. According to the survey, there are 140 commercial, and 80 scientific algae stakeholders targeting this market sector in the whole NW-European region (table 6).

Having a look at the country specific distribution the highest share of commercial stakeholders focusing on the market of special chemicals was found in Switzerland, the Netherlands, France and Ireland (83% - 74%). In contrast, in the UK the number of algae stakeholders doing research on these kinds of algae based products is slightly outweighing the one of the commercially active stakeholders (25 vs. 19 stakeholders).

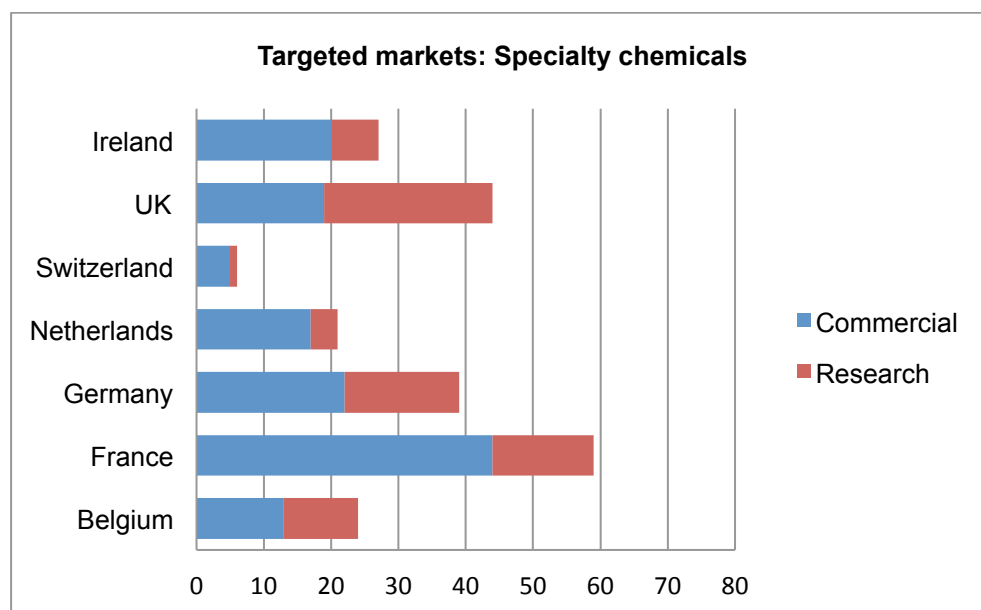


Figure 19: Algae markets in NW-Europe – Specialty Chemicals; Scientific vs Commercial focus (no. of stakeholders).

Another important market for the algae stakeholders is the market for **food and feed** with a share of 21 % of the total NW-European algae market (figure 9). Complete algae as well as specifically extracted components and ingredients are used for this market. Especially for the production of high valuable dietary supplements and colorants is economically seen quite interesting. This also explains why this is again a market sector particularly commercial algae stakeholders are active in, similar to the market of algae based specialty chemicals. Comparing the food and feed market, slightly more stakeholders focus on the feed market (114 vs. 87 stakeholders, table 6). However, the proportional distribution of commercial and scientific stakeholders on these 2 product markets is about the same (e.g. 67% of the stakeholders focusing on food and 65% of the ones focusing on feed are commercial stakeholders). Regardless of country it can be pointed out that the share of commercially active stakeholders is predominant in the food and feed market sector.

The majority of stakeholders targeting the algae food market also include algae based feed in their portfolio. Hence many stakeholders in the two categories “food” and “feed” might be double counted when adding the respective stakeholder numbers.

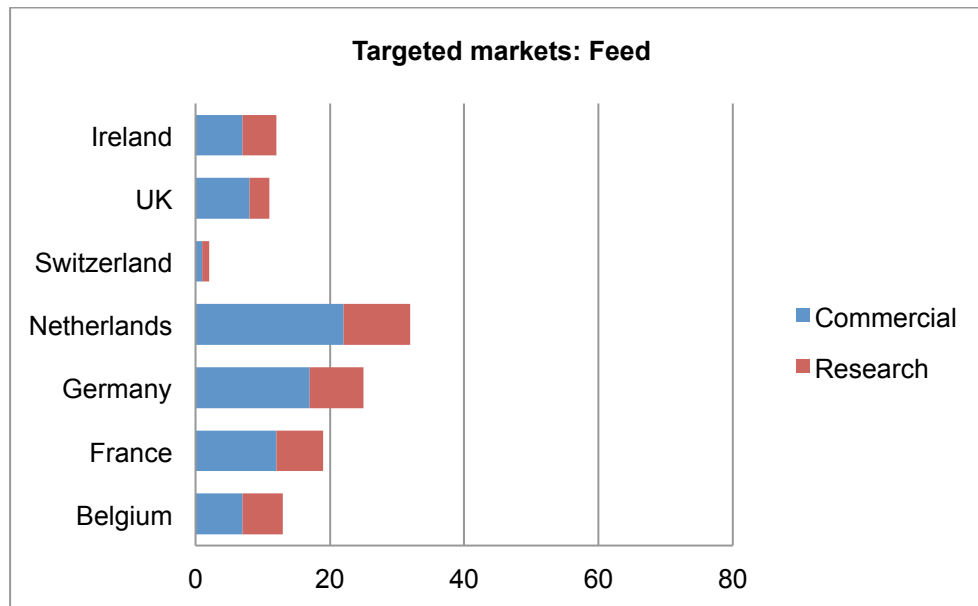


Figure 20: Algae markets in NW-Europe – Feed; Scientific vs Commercial focus (No. of stakeholders).

Analysing the country specific findings, it can be stated that the highest number of algae stakeholders targeting the food market can be found in France (21, table 6, figure 21) followed by the UK (19, table 6, figure 21). As for the feed market particularly the Dutch (32, table 6, figure 20) and German stakeholders (25, table 6, figure 20) are active.

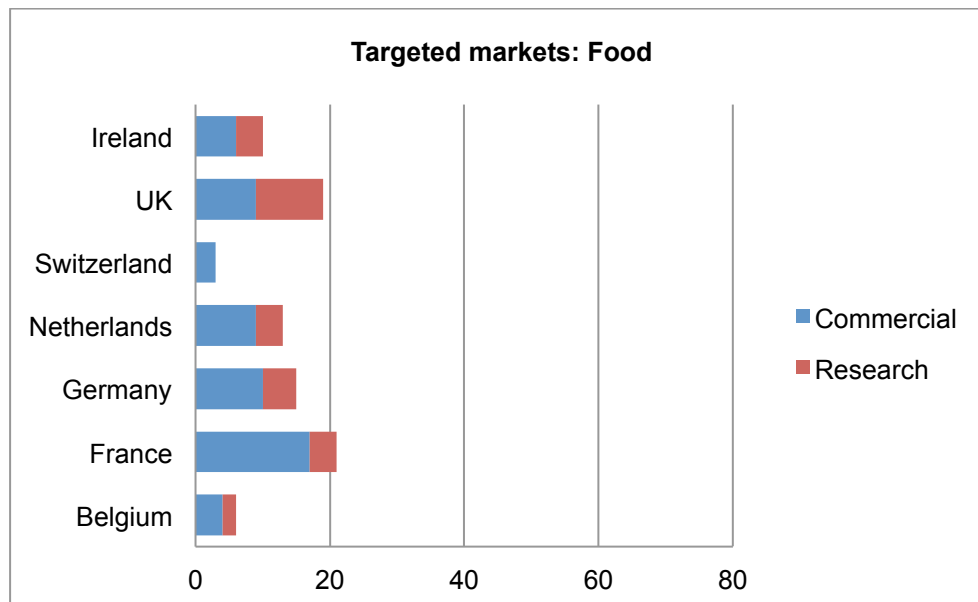


Figure 21: Algae markets in NW-Europe – Food; Scientific vs Commercial focus (no. of stakeholders).

A considerable barrier of this market is the legally defined requirements on food and feed quality. Only a few macro and microalgae have been officially accepted by the European Novel Food Regulation. According to the recent JRC report “Microalgae-based products for the food and feed sector: an outlook for Europe” (Enzing, Ploeg, Barbosa, Sijtsma, 2014) algae stakeholders face more constraints in this

market sector besides the complex regulations of novel foods and that includes for instance the still low European demand. Nevertheless they came to the conclusion that the EU has the potential to become the market leader in micro-algae based food and feed products in the coming decade. However, to achieve this it might be necessary to also include foreign (non-EU) markets for new microalgae based products.

One market branch inevitably connected with the cultivation and use of algae is the development and production of **photo-bioreactors** (PBRs). Its overall share in the total targeted market sectors accounts for 7% (figure 9). In Ireland only one scientific stakeholder is doing research on this kind of topic. In all other NW-European countries also a small percentage of commercial algae stakeholders is targeting this market. In France and the Netherlands there is a higher ratio of commercially active stakeholders in this market sector whereas in the remaining countries research and commerce is actually quite well balanced (figure 22). Most algae stakeholders targeting this market sector can be found in Germany (figure 22).

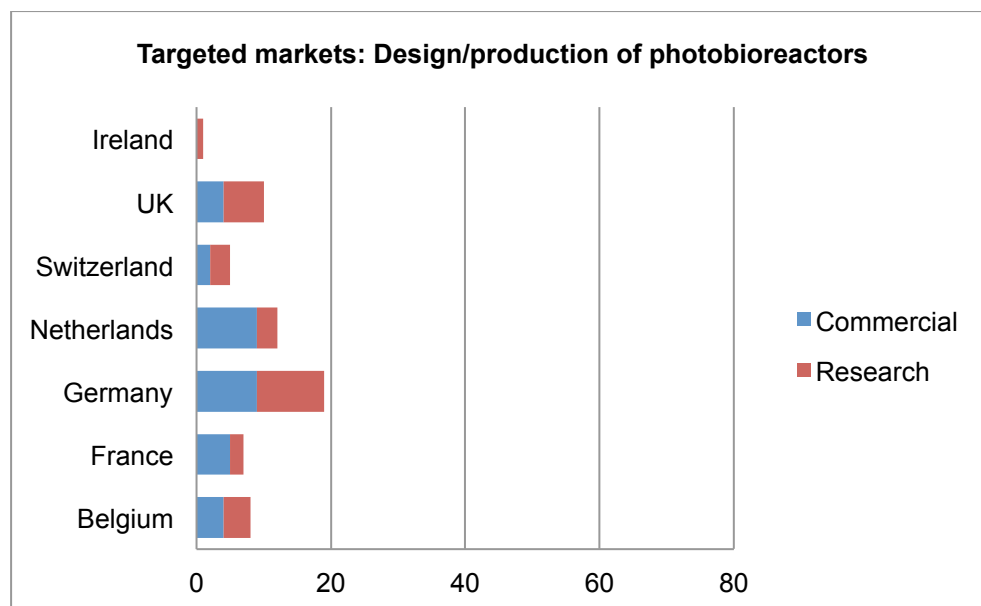


Figure 22: Algae markets in NW-Europe – Photobioreactors; Scientific vs Commercial focus (no. of stakeholders).

Different kinds of **Bioremediation** also account for a considerable market share (15 % of the total algae market). Microalgae are used to recover nutrients, bind toxic metals and/ or remove or neutralize pollutants from contaminated water or air. Since algae have a high absorption capacity their use is a very promising, cost-effective alternative to existing water treatment systems using physicochemical treatments.

According to the survey, 58% of the algae stakeholders focusing on this kind of algae utilisation work commercially (table 6). In Switzerland there seems no particular interest in this approach by commercial algae stakeholders. Only 2 Swiss stakeholders were found, who are doing research on this topic. With the exception of Switzerland and Belgium, the country specific share of commercial stakeholders active in this field is higher than the one of scientific stakeholders. Particular interest in bioremediation with the aid of algae could be found in Germany (27 stakeholders, figure 23) and the Netherlands (26 stakeholders, figure 23).

One important topic for the scientific stakeholders in this field is the question of end-use of these algae. Currently, algae biomass that has been used for bioremediation is almost entirely used for bioenergy. Economically this is obviously not the most favourable approach. The harvesting of the algae biomass that has been used for bioremediation is still a costly process in most cases. This could be balanced if the accumulated algae biomass could, at least partly, be used for other applications, like feed for aquaculture or fertilizer. Strict EU-regulations concerning biomass that had contact with waste water or flue gas are still preventing this approach, though. Further research and maybe also an adaption of regulations seems to be necessary to find a solution to this problem.

In the U.S.A. it is apparently not unusual to harvest the algal biomass that has been used for bioremediation and process it into “marketable commodities such as soil-enhancing compost, energy products or livestock feed. [...] nutrients are continuously recovered and removed from the treatment unit” (Fakhooorian, T. 2010)

The further use of the algae biomass certainly also depends on the medium that has been treated by the algae.

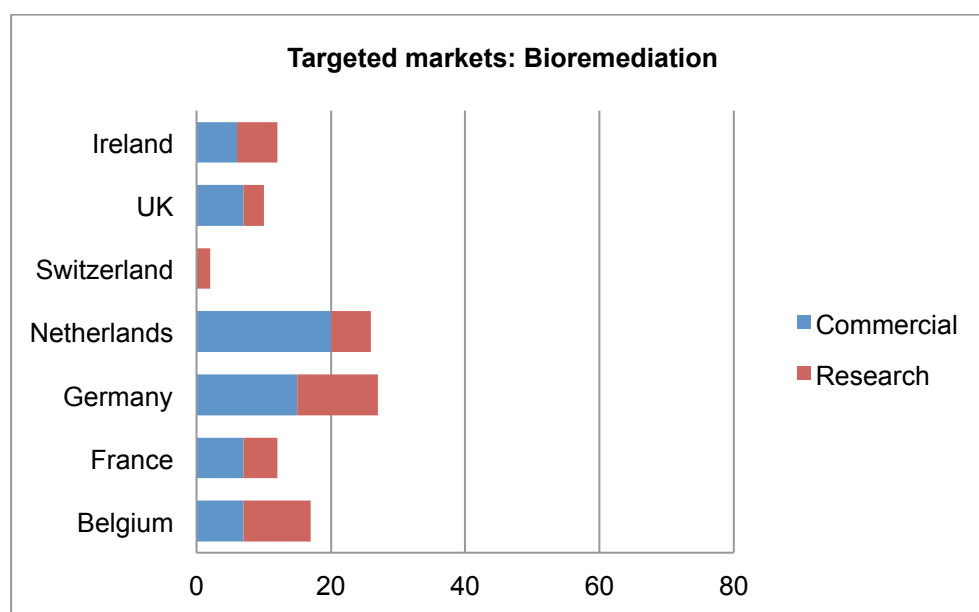


Figure 23: Algae markets in NW-Europe – Bioremediation; Scientific vs Commercial focus (no. of stakeholders).

8 Underpinning Research & Activities

Many NW-European stakeholders are also involved in some further research and underpinning activities concerning their field of (algae) interest. Even if it is not the main focus of these stakeholders, it was considered to be important enough to include it into the questionnaires that had been distributed among the algae stakeholders in the course of this survey. As the previous chapter has shown there is actually a high percentage of scientific and also commercial stakeholders, who are doing research beside their core business, in the field of algae cultivation and use.

Through the questionnaires and analyses of what the main interests of the NW-European algae stakeholders are in terms of underpinning activities. Again it must be pointed out that not all of the identified algae stakeholders have completed the questionnaire and publically available information particularly on underpinning activities are rare. Hence, the obtained results can only serve for showing trends in that regard.

Concerning the area of research on environmental impacts the analysis has shown a particular interest in the topic of life-cycle-assessments (LCA) (figure 24). According to the survey, 65 stakeholders in NW-Europe are doing research related to this sustainability criterion. Most of them can be found in the Netherlands and Ireland. Research on other, more specific topics concerning the environmental impact like abiotic and biotic interactions and modelling of environmental impacts can only be found to a lesser extent in the observed region (36 – 39 stakeholders for each of the named research areas). Research on marine spatial planning, algal diseases and competitors or other research topics concerning environmental impacts do not play an obvious role either. However, as already mentioned it can be assumed that the number of stakeholders doing respective research is much higher than what could be reflected by the survey.

Looking at the country specific distribution in North-West Europe it can be stated that most of these activities were found in the Netherlands and the UK (figure 24).

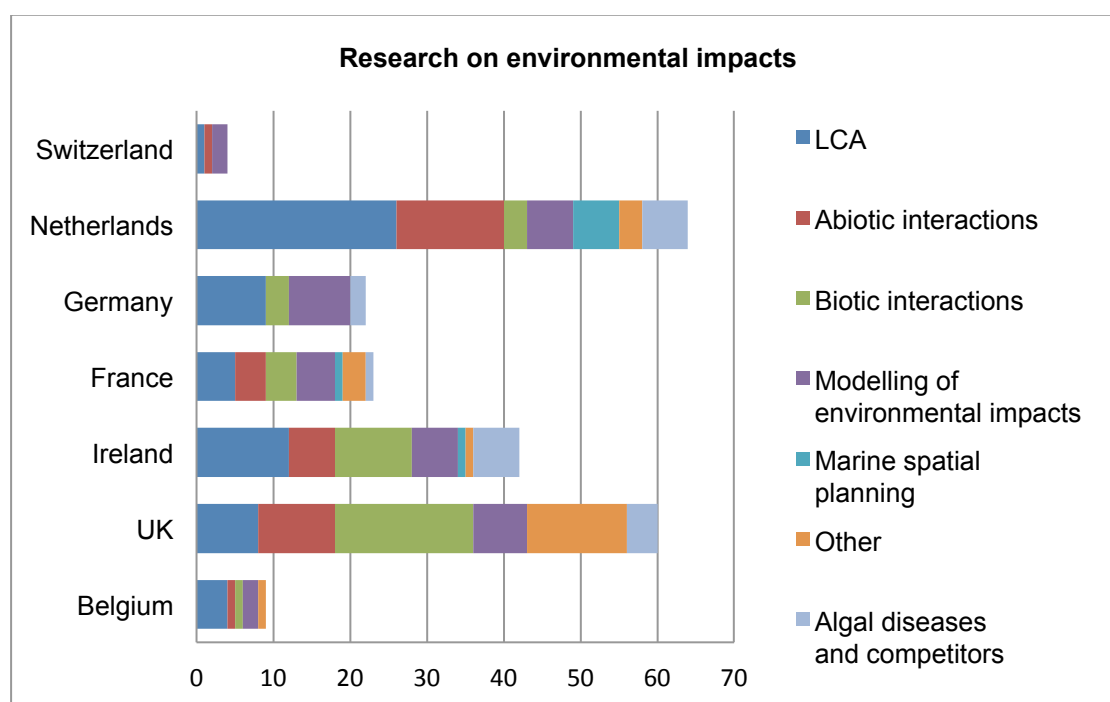


Figure 24: Research on environmental impacts (no. of stakeholders).

Apart from the environmental impacts, other research topics obviously need to be addressed. A particular high interest was found in the field of R&D on processing technology and, to a slightly lesser extent, on harvesting technology (altogether 91 and 59 stakeholders respectively) (figures 25). This leads to the conclusion that the first step in the algae value chain, which concerns the cultivation of specific algae species and which involves activities like culture collection, taxonomy and bioprospecting are still

important, but the current focus seems to be already one step further concerning the harvesting process and especially the processing of the algal biomass into marketable products. Again this can only show a trend and can certainly not be generalised. Depending on location and individual focus of the stakeholders the main interests in underpinning research activities might differ quite significantly.

Synthetic biology does not seem to be a very important topic among the algae stakeholder in NW-Europe at present. Major reasons for this are certainly respective, restricting European laws and regulations. In other countries like the United States it already plays quite an important role in the algae scene, though, and it is well imaginable that it will become more important in Europe for mainly economic reasons as well.

According to the survey a considerable amount of algae stakeholders are also involved in other “underpinning activities”, which have not been specified though.

Figure 25 shows the country specific distribution of underpinning research. The UK algae stakeholders seem to be the most active in that regard.

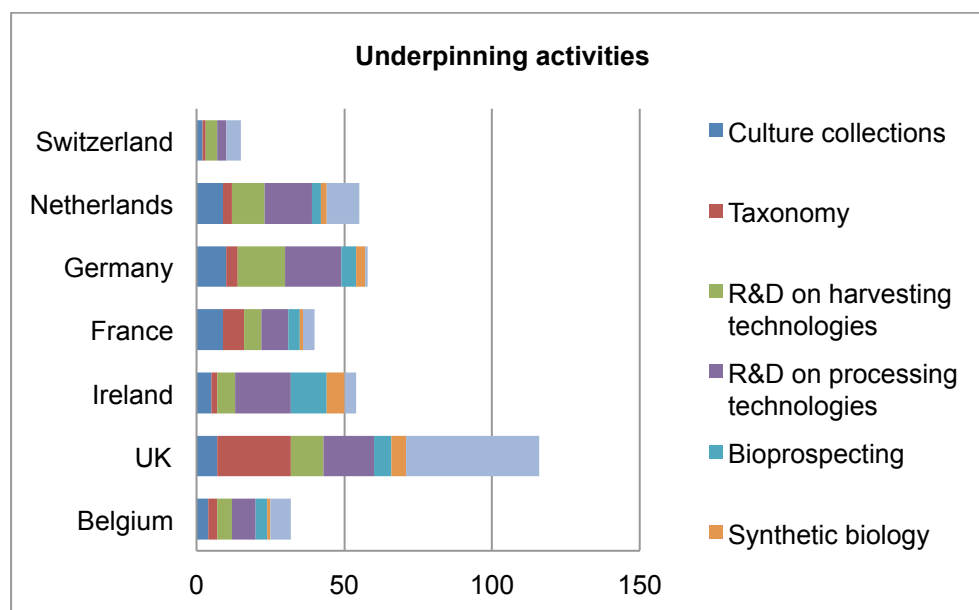


Figure 25: Underpinning activities (no. of stakeholders).

9 Further Reading

Further and more specific information, including the names and work profiles of the algae stakeholders in NW-Europe, can be obtained in the country specific reports that are based on this survey. The present report analyses the collected data for the whole region (North-West Europe) and consequently summarises the country specific findings.

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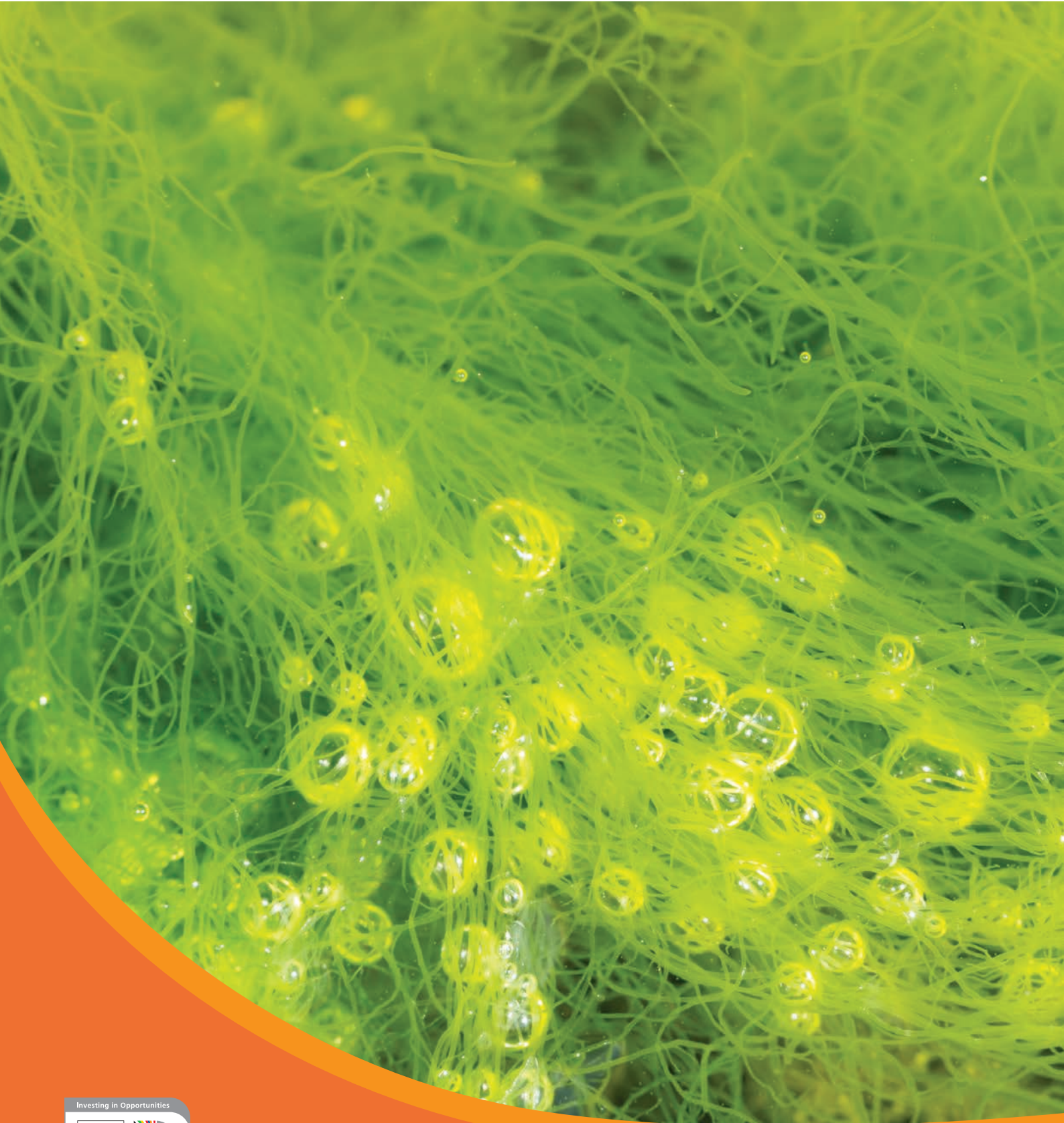
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EnAlgae is a four-year Strategic Initiative of the INTERREG IVB North West Europe programme. It brings together 19 partners and 14 observers across 7 EU Member States with the aim of developing sustainable technologies for algal biomass production.

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