The European Commission's Knowledge Centre for Bioeconomy

Brief on algae biomass production[1]

Key messages

1. Macroalgae are harvested from wild stocks or produced in aquaculture systems, while microalgae are cultivated in open (e.g. raceway ponds) or closed (photobioreactors) systems (see section 1).
2. Annual macroalgae biomass production has increased worldwide since 1950, reaching 32.67 Mt in 2016 (see section 2). Global production is mainly based on aquaculture cultivation (97% in 2016).
3. Algae biomass production in the EU contributed only 0.28% to global production in 2016, whilst production in Norway and Iceland contributed an additional 0.57% (see section 2). In contrast with the global production pattern, the harvesting of wild stocks supplies most of the macroalgae biomass in Europe (98% in 2016).
4. Production plants of algae biomass in the EU are located in 15 of the Member States, in most of which both macro- and microalgae production units operate. Although the harvesting of wild stocks is the main biomass production method for macroalgae in terms of volume, the number of aquaculture plants has increased in recent years and already represents an important part of the macroalgae production units in Europe (see section 3).
5. The abundance of several commercially exploited species in Europe has already decreased in some regions due to multiple stressors such as global warming, herbivory, excessive harvesting, a decline in water quality and the introduction of non-native species (see section 4). Therefore, it is necessary to ensure that algae resources are exploited in a sustainable way.

[1] This brief is based on the JRC Science for Policy report "Biomass production, supply, uses and flows in the European Union. First results from an integrated assessment" (Camia et al., 2018), unless stated otherwise.

1. Which groups of algae are used for biomass production?

The term 'algae' comprises a wide range of taxa of photosynthetic organisms. Barsanti and Gualtieri (2014) estimate that there are approximately 72 500 algae species, with new species being discovered every year. About 80% of algae species are uni-cellular and are called microalgae, the other 20% are pluri-cellular and are called macroalgae or seaweeds. Macroalgae are macroscopic organisms that vary in size from millimetres to lengths of up to 70 m, as is the case for some kelp species.

Algae are structuring organisms in coastal ecosystems that provide habitat, food, reproductive areas and shelter to species from different levels of the food web (Bertocci et al., 2015; Reisewitz et al. 2006). Algae also contribute to important coastal ecosystem services such as carbon sequestration, removal of dissolved nutrients and coastal protection.

Algae biomass has been explored for centuries by coastal communities as a source of fertiliser, cattle feed and human food. It is currently mainly used by the food and chemical industries. However, over the past decades, the development of new algae-biomass-based applications (feed and food supplements, nutraceuticals, pharmaceuticals, third-generation biofuels, biomaterials and bioremediation services) has led to an increase and diversification in the market for these resources (Barbier et al., 2019).

Macroalgae biomass for commercial use is either harvested from wild stocks or produced by aquaculture. Techniques for collecting wild macroalgae include hand harvesting of storm-cast material from the shore at low tide (Figure 2), and diving and mechanical harvesting using boats and custom-built devices (Mac Monagail et al., 2017). The species commercially harvested in Europe are primarily *Laminaria hyperborea* and *Ascophyllum nodosum* (Mac Monagail et al., 2017). Macroalgae are cultivated in land-based tanks or ponds (Figure 3) or in sea-based (coastal and offshore) structures such as long-lines or rafts (Buschman et al., 2017). They can be cultivated as a monoculture or integrated multi-trophic aquaculture (IMTA), which is being promoted as a strategy to mitigate the potential negative impacts of marine aquaculture (Ellis et al., 2019; Nardelli et al., 2019). Examples of cultivated species in European waters are *Alaria esculenta*, *Palmaria palmata*, *Saccharina latissima* and *Ulva* sp. (Barbier et al., 2019).

Figure 1: Examples of macroalgae species present in European shores: (a) *Chondria coerulescens* (b) *Fucus serratus* (c) *Saccorhiza polischides*

Microalgae are cultivated in open or closed systems. In open systems, which generally have lower installation and operation costs, the growth medium is in direct contact with the atmosphere. They can take the form of rectangular or circular ponds that are stirred mechanically (see Figure 5), or of 'raceway ponds' which are stirred by a paddle wheel.

Closed systems can be photobioreactors (PBRs, Enzing et al., 2014) or fermenters. The PBRs are usually more expensive but generate higher volumetric productivity and more controlled conditions, including prevention of contamination, better control of the cultivation conditions (pH, temperature, nutrient supply, etc.), reduction of water use and CO_2 losses. PBRs consist either of horizontally or vertically arranged tubes, or vertically arranged panels (Figures 4 and 6). Fermenters take advantage of the ability of microalgae to grow in the dark on sugars (heterotrophic production), and represent a cost-effective method of large-scale production for some microalgae species (Xiong et al., 2008; Doucha & Lívanský, 2012).

Figure 2: Traditional harvest
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Figure 3: Integrated farm - fish ponds, macroalgae tanks and supporting buildings
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Figure 4: Photobioreactor microalgae production
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Figure 5: Open pond microalgae production
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Figure 6: Photobioreactor microalgae production
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Figure 7: Offshore macroalgae aquaculture - Harvesting macroalgae using a sea vessel © Seaweed Energy Solutions AS, 2019

2. How much algae biomass is produced?

Global macroalgae biomass production has gradually increased since 1950, driven by a growth in the aquaculture of macroalgae (see Figure 8). It reached 32.67 Mt (wet weight) in 2016. In the same year, EU production was 0.093 Mt, with another 0.187 Mt produced in Norway and Iceland, contributing only 0.28% and 0.57% respectively to global production. As available data on microalgae are very fragmented, this section deals only with macroalgae.

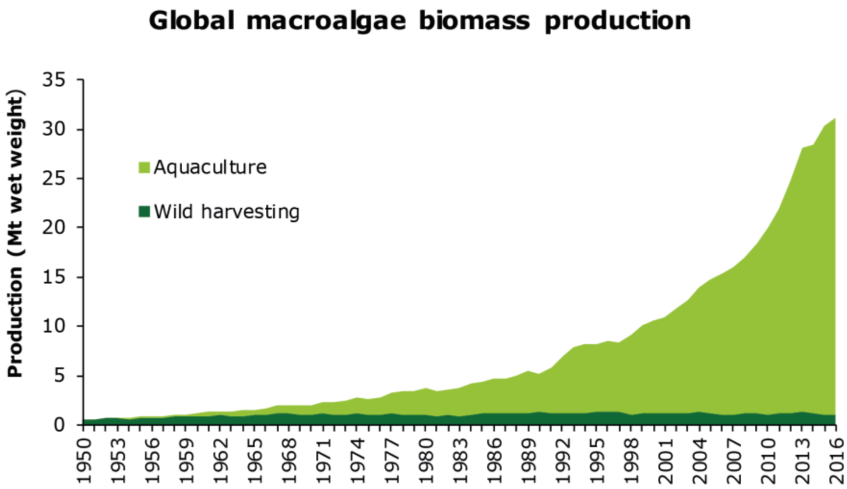

Figure 8: Annual production of macroalgae biomass at the global level

Global aquaculture production of macroalgae increased by approximately 20 Mt over the past 20 years (Figure 9). While China was the main aquaculture producer during this period, Indonesia showed the largest increase in production. In fact, based on average production in the years 2014 to 2016, all top seven aquaculture macroalgae-producing countries are in Asia (Figure 11, top chart). Over the same period, global wild harvesting remained stable at approximately 1.2 Mt (Figure 10), and by 2016 it contributed only 3.5% to total global macroalgae production. The top wild macroalgae harvesting countries were Chile, China and Norway (Figure 11, bottom chart).

Aquaculture production in the EU and Norway contributed only 0.002% to global aquaculture production in the years 2014 to 2016. France, Denmark and Ireland were the largest producers (Figure 12, top chart). In this part of the world, the aquaculture production system is still marginal. The same region contributed 18% to global wild harvesting, with Norway, France, Ireland and Iceland being the largest producers (Figure 12, bottom chart). In the EU plus Norway and Iceland, wild macroalgae harvesting remained stable over the past 20 years, at less than 0.4 Mt.

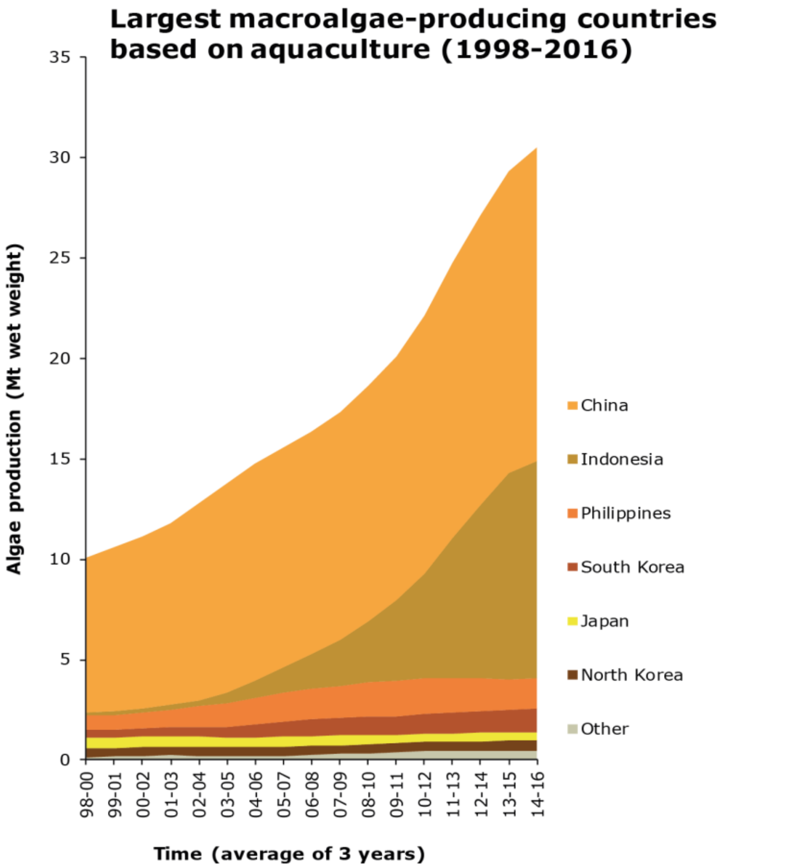

Figure 9: Global macroalgae production based on aquaculture - development over the period 1998 to 2016.

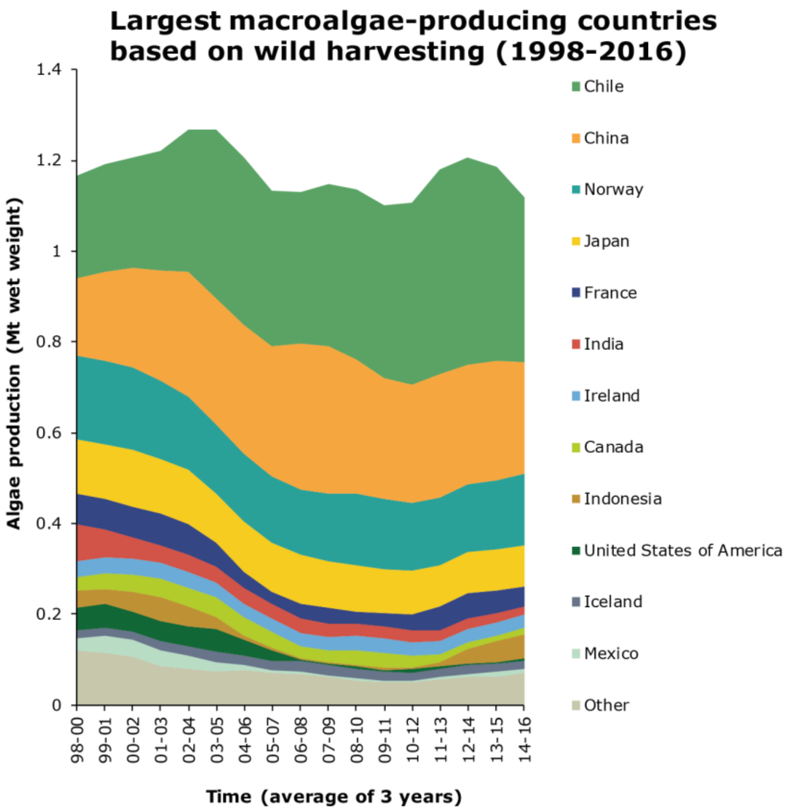

Figure 10: Global wild macroalgae harvesting - development over the period 1998 to 2016.

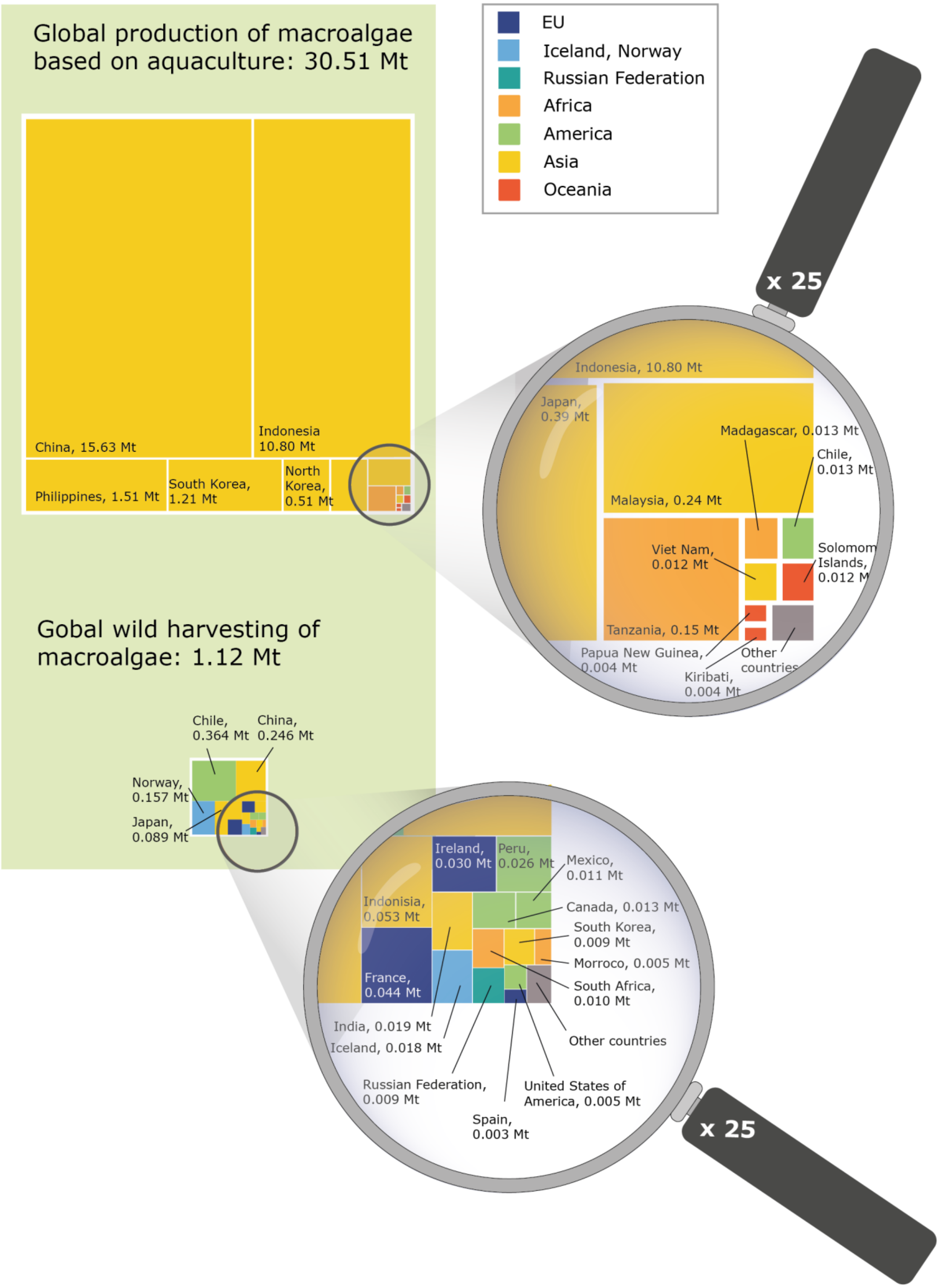

Figure 11: Largest countries in terms of average macroalgae production based on aquaculture (top chart) and on wild harvesting (bottom chart) globally, for the years 2014 to 2016.

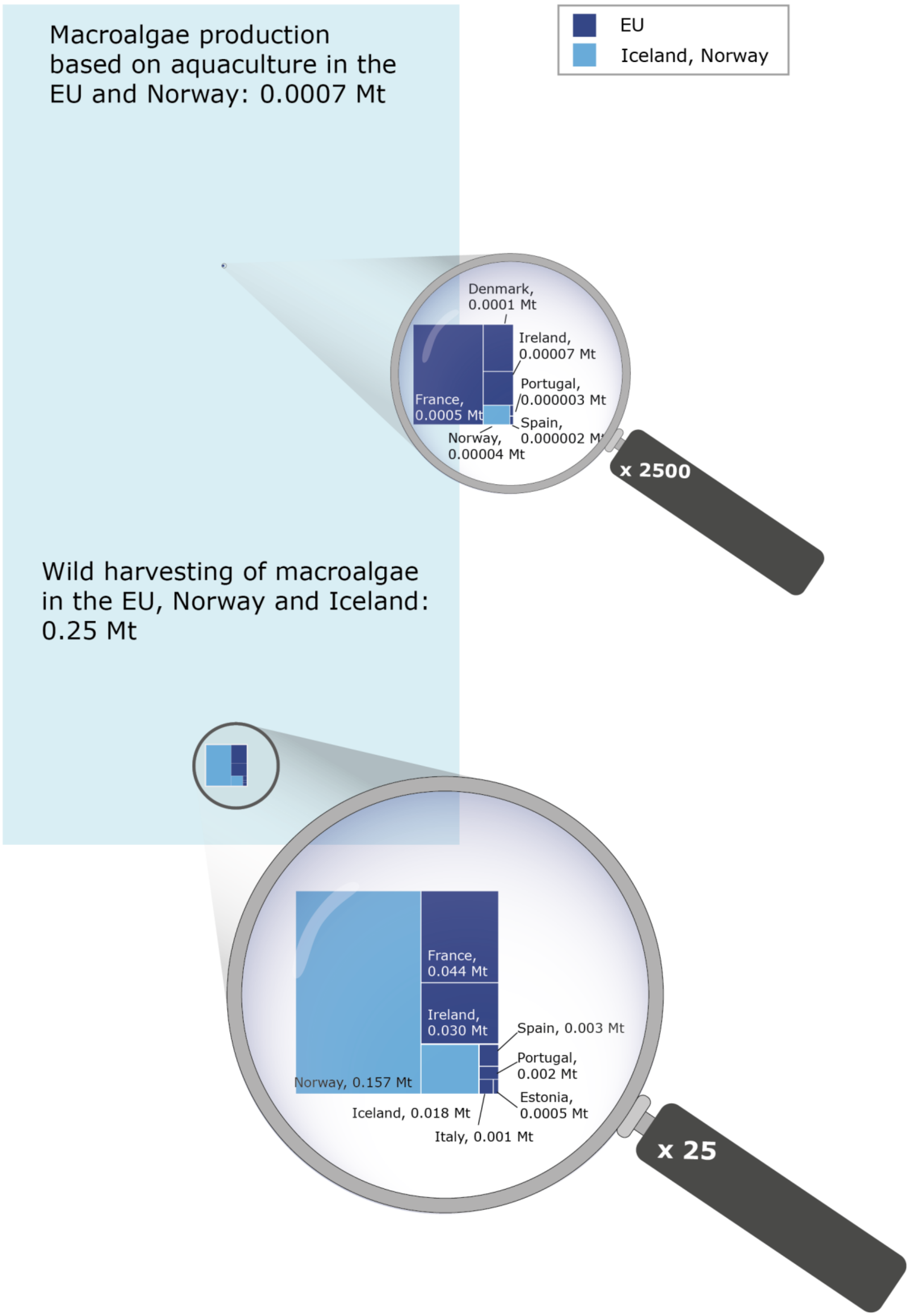

Figure 12: Largest countries in the EU plus Norway and Iceland in terms of average macroalgae production based on aquaculture (top chart) and on wild harvesting (bottom chart) for the years 2014 to 2016.

3. How are the algae biomass production plants distributed in Europe?

According to the latest available data (JRC algae database), there are 126 algae-producing companies in the EU (AT, BE, CZ, DK, EE, FR, DE, HU, IE, IT, NL, PT, ES, SE, UK) running a total of 144 production plants, and 15 producing companies outside the EU (Faroe Islands, Greenland, Iceland, and Norway) running one plant each. In total, 57% produce macroalgae, and 43% microalgae. The largest number of companies are based in France, followed by Spain, Ireland and Germany. In France, Spain, Portugal and the Netherlands, there are approximately equal numbers of macro- and microalgae producers. German, Italian and Austrian production is dominated by microalgae, and Irish, Danish and Norwegian production by macroalgae (Figure 13).

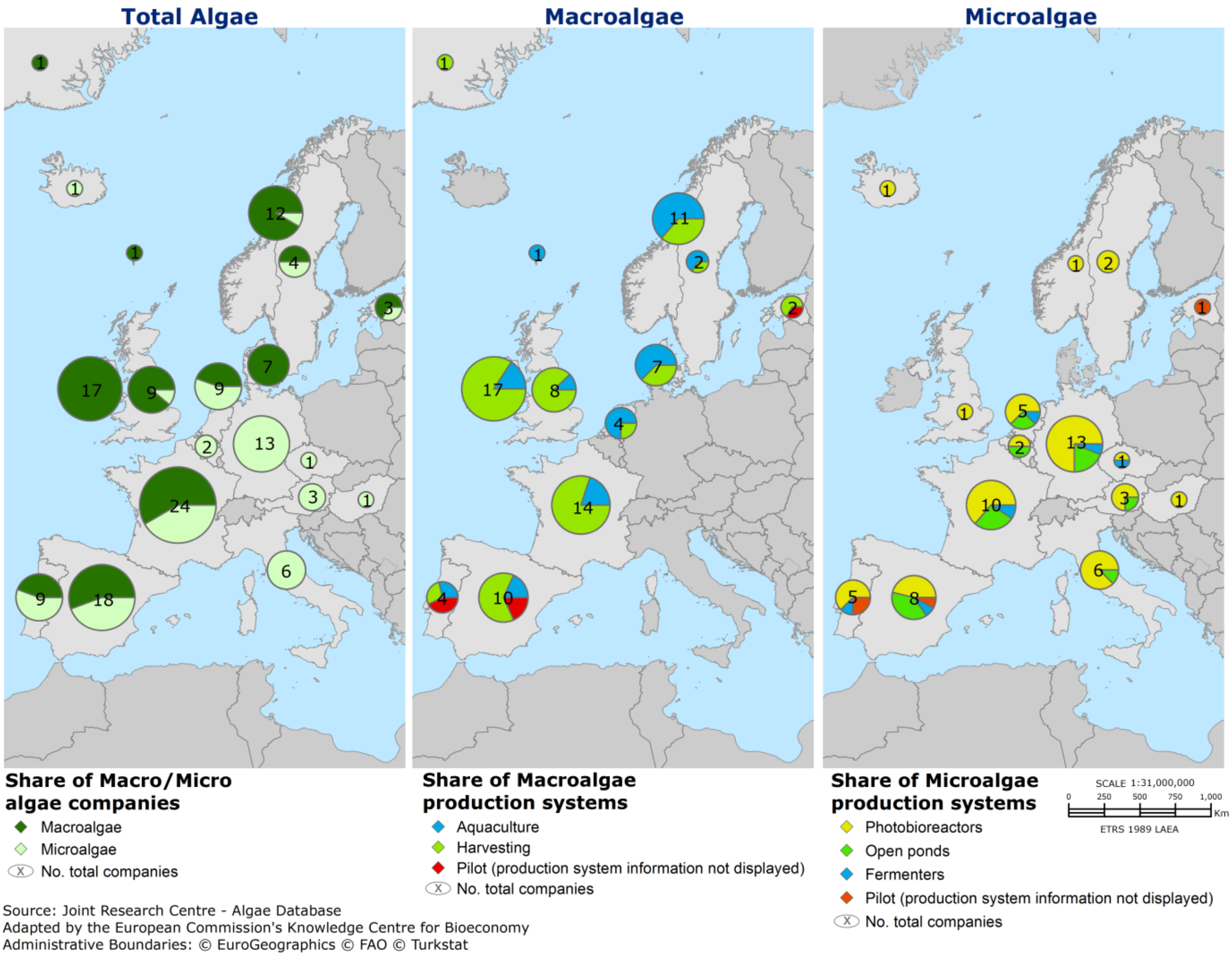

Figure 13: Number of companies producing algae biomass in Europe, (a) share between macroalgae and microalgae and production systems for (b) macroalgae and (c) microalgae, as of December 2019. Source: JRC - Algae Database.

The location of the production plants (Figure 14) shows that this sector represents opportunities especially for coastal and remote areas. Aquaculture systems for macroalgae are mainly being developed in the Atlantic. With currently only six land-based aquaculture plants, most are at-sea plants (offshore and coastal). Microalgae production is a completely different sector. The production plants are located both on inland and coastal sites. Yet, only 13 Member States have microalgae production plants. Some production plants combine different production systems, e.g. photobioreactors with fermenters or open ponds. Overall, photobioreactors are the most common systems used for microalgae production.

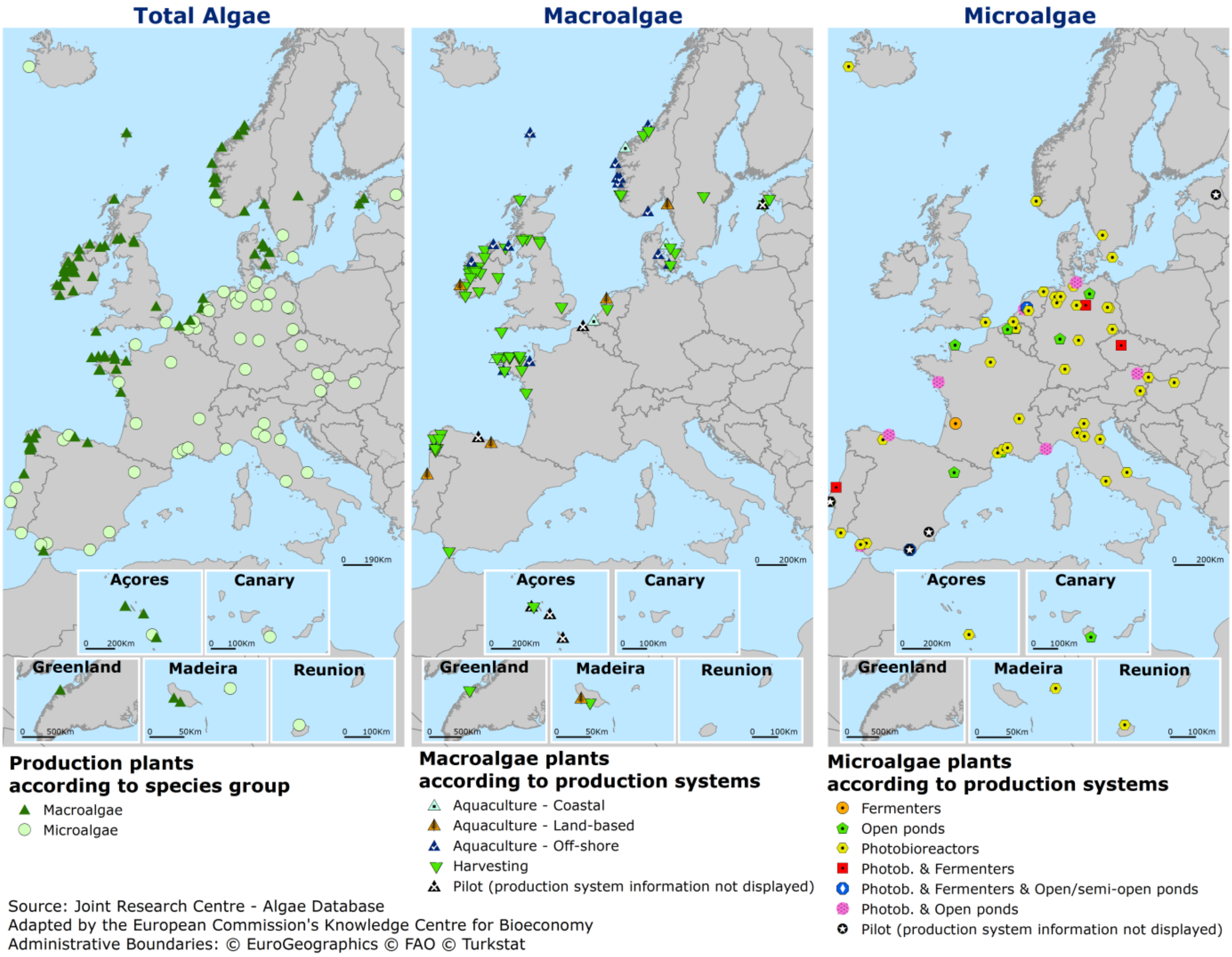

Figure 14: Location of production plants of algae biomass categorised (a) by species group (macroalgae/microalgae) and (b) and (c) production systems for macro- and microalgae respectively, as of December 2019. Source: JRC - Algae Database.

4. Why is environmental sustainability of algae exploitation important?

The abundance of several commercially exploited macroalgae species in Europe has already decreased in some regions, due to multiple stressors such as global warming, herbivory, a decline in water quality and the introduction of non-native species (Williams and Smith, 2007; Lorentsen et al., 2010; Wernberg et al., 2010; Moy & Christie, 2012; Delebecq et al., 2013). The excessive harvesting of wild stocks, either manually or mechanically, can further impact the structure of coastal communities. Examples of the negative effects of over-harvesting are well documented. Sustainable management plans for regulating the harvesting of some commercial macroalgae species are in force in some European countries (e.g. Norway and France) and include licenses, quotas and rotation systems. However, in other European countries, there are no management guidelines and the most appropriate techniques and frequencies for harvesting are unknown for some species and regions. Sustainable management plans for the harvesting of macroalgae that are consistent with EU environmental policies and based on robust scientific knowledge and ecosystem-based management models need to be widely implemented and closely monitored.

Macroalgae aquaculture, seen as a solution to meeting the increasing demand for macroalgae biomass while decreasing the pressure on wild stocks, has proven environmental benefits (e.g. the integrated multi-trophic aquaculture (IMTA) approach). However, more evidence is needed to properly evaluate the environmental impacts of macroalgae aquaculture as this production method can potentially change sedimentation rates, increase the risk of introduction of alien species and diseases, and change the structure of local communities

(Barbier et al., 2019). An ecosystem framework approach for macroalgae aquaculture should be promoted in line with the sustainable development of this sector (Brugère at al., 2018).

To ensure the environmental sustainability of microalgae production, the demand for water, energy and land use, as well as the potential pollution and the risks of releasing invasive species into the environment, need to be considered. The proper design of the production plant and adoption of best practices across the production cycle can reduce the environmental footprint of the production methods.

5. Methodology

The figures on macroalgae production presented in section 2 are based on the Global Fishery and Aquaculture Statistics of the Food and Agriculture Organization of the United Nations (FAO): datasets on global production by production source (species, country, production area, production source and year (1950-2015) downloaded from the FishStatJ workspace; FAO, 2019). These datasets are based on national statistics reported by countries and estimates of FAO experts. Section 2 only presents data on macroalgae, as microalgae statistics are only reported in a very incomplete form and so have not been included in the analysis.

In addition to measured values, the dataset includes many estimated and missing values. Therefore, data were presented in either aggregated form (Figure 8) or broken down at national level as the averages of three consecutive years (Figures 9 and 10). Rolling averages (arithmetic means of the previous, current and following year) were used in figures 11 and 12, resulting in smoother and more realistic curves.

An ongoing joint JRC - European Marine Observation and Data Network (EMODnet) initiative with the objective of mapping the algae production industries is resulting in a database that lists algae producing companies (EMODnet, 2019). These lists are elaborated based on the information provided by the European Algae Biomass Association (EABA) and complemented by data collected from individual stakeholders (researchers, managers, industry) from different countries.

In 2019, a total of 216 companies were mapped, relevant information was retrieved from the company webpages, and the companies were contacted to confirm the collected information. Information was collected on the location of the production units, the organisms produced and the production methods used. Based on the results of this exercise, the companies were categorised into 3 levels: Level 1: Companies that confirmed the information by email (74 companies); Level 2: Companies that did not confirm the information by email but had a webpage with information of sufficient quality to be included in the database (67 companies); Level 3: Companies that did not confirm the information by email and had a webpage with insufficient information to be included in the database (75 companies). The companies in Level 1 and Level 2 are included in the final database, which will be used to update the EMODnet portal and will be available for consultation and download.

Knowledge gaps

1. Data on microalgae biomass production are very fragmented and information is difficult to obtain.
2. Statistics from the FAO and Eurostat on macroalgae biomass production in Europe are incomplete and not detailed for some countries, species, years and production methods.
3. The database on the European algae producers resulting from a joint initiative between the JRC and EMODnet is not yet complete. The currently available results are included in a first effort to map the algae production units in Europe, which includes data on the location of production units, the organisms produced and the production methods used. This dataset is frequently updated with new entries and will soon include new categories of information.
4. More evidence is needed on the natural dynamics of wild resources, the impact of harvesting methods and the growth potential of aquaculture production to support the sustainable development of the algae sector in Europe.

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