# Seaweed for Packaging Roadmap

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# Executive summary

**Reducing fossil plastics through seaweed based solutions.** Consequences of climate change and plastic pollution are becoming increasingly severe. Plastic packaging is a major contributor to these issues due to its non-renewable origins and low recycling rates. In response, the EU has introduced policies such as the Green Deal and the Packaging and Packaging Waste Regulation (PPWR), as well as the Single-Use Plastics Directive (SUPD) to counteract crises. The roadmap is intended to spark a discussion and pave a path for seaweed to play a significant role in solving these crises. The roadmap offers insights by analysing three dimensions: technology, market and regulatory. These insights were acquired through desk research and interviews. They offer direction and points of attention for the future of seaweed-based packaging.

**Leveraging USP's is critical for a cost-effective transition.** Like many other new materials, seaweed is relatively costly. For seaweed to compete with low-cost alternatives such as plastic, it helps to find the right application where seaweed outperforms plastic and where only a small amount of material is required. Biodegradability, renewability, barrier properties and overall low carbon emissions of seaweed make it an emerging and inspiring alternative to traditional plastics. Solutions such as plastic-free seaweed coatings on paper prove promising to replace single use plastics. Flexible plastic is often used for (food) packaging as it is lightweight and cheap. Replacing flexible plastics with edible coatings for fruit and vegetables to extend shelf life, and water-soluble films for dissolvable packaging such as detergent pods seems to have potential. More research should ***identify high potential market segments*** in which the combination of seaweed properties stands out from alternative biobased feedstock.

**The supply of seaweed from the EU** remains limited for the foreseeable future and the price of the feedstock will remain high. Currently, alginate extracted from brown seaweed is the most used material, along with agar-agar and sometimes carrageenan extracted from red seaweeds. In preparation for scale-up on the road to a marketable advantage, a good ***understanding of quality and composition requirements*** for seaweed cultivation needs attention.

**Mismatch with EU regulation.** Although seaweed supports Green Deal objectives, current regulations fall short on promoting the use of renewable and biodegradable resources, limiting water use, and reducing CO2 emissions. Compliance with regulations for the broad use of seaweed is needed to guarantee success. To bridge this gap, ***evaluations of legislation must be monitored:*** SUPD evaluation as well as evolving PPWR standards for recyclability and composting might bring opportunities for future seaweed-based packaging on the EU market (2027 onwards).

This roadmap formulates an ambition to **replace 10% of plastic coatings on paper and 10% of single-use films with seaweed-based materials by 2050 in Europe**, potentially cutting millions of kilograms of plastic waste. For seaweed to reach maturity in packaging, and to achieve this objective, further innovation, pilot projects, strengthening supply chains, policy alignment, and standardization will be required.

# 1 Introduction

## 1.1 Background

So far, human activities have caused significant environmental challenges, including rising greenhouse gas (GHG) levels, increased global temperatures, widespread plastic pollution, unsustainable extraction of finite fossil fuels and the consequences thereof.

Packaging contributes significantly to these issues. The production of packaging materials, particularly plastic, releases GHGs and relies heavily on fossil fuels. Improper disposal can lead to environmental pollution, including the release of microplastics into the environment. Despite these concerns, packaging is essential for protecting products, extending their shelf life, and preventing contamination. However, current packaging materials often outlast the products they contain, are derived primarily from non-renewable resources, and are not always recycled. Furthermore, those not recycled lead to persistent pollution, and those recycled may pose health risks[26].

To minimise the negative consequences of packaging, governments are introducing regulations to encourage the use of sustainable packaging and to discourage the use of harmful packaging. In the European Union (EU), multiple regulations and directives have been implemented and proposed to address these issues. One such measure is the European 'Green Deal'. The Green Deal's main objective is to make the EU climate-neutral by 2050 by promoting a circular economy. Included in the Green Deal are the Packaging and Packaging Waste Regulation (PPWR) and the Single-Use Plastics Directive (SUPD). These policies will have a significant impact on the packaging industry, encouraging the recycling and reuse of materials to minimise the environmental impact of packaging, and banning the use of plastics in certain applications.

Seaweed is a relatively new material used in the packaging industry. The properties of seaweed-based materials could make them useful for packaging purposes and help address environmental challenges. Packaging containing seaweed can be renewable and resistant to lipids and oxygen, which extends the shelf life of fresh produce. It can also be biodegradable, edible and plastic-free. These properties reduce dependence on fossil fuels, protect valuable products and limit the negative environmental impact of packaging. The question then remains:

**Can seaweed play a significant role in the transition to more sustainable packaging?**

To explore the current and future potential of seaweed, North Sea Farmers is developing multiple strategic roadmaps targeting the most promising markets. One key area of focus is the packaging sector, for which North Sea Farmers is creating, in collaboration with its members, a dedicated roadmap tailored to the European market. This document sets out a clear vision for 2050 and details the steps required to achieve it. However, it is important to recognise that the seaweed packaging landscape is highly dynamic and subject to change, requiring ongoing adaptability. Accordingly, this roadmap is intended to be a living document designed to evolve in response to emerging developments and changing market conditions.

## 1.2 Central question and sub questions

➔ Can seaweed play a significant role in the transition to more sustainable packaging and if so, how?
- What applications are already on the packaging market that use seaweed?
- What characteristics should seaweed packaging have to encourage adoption by potential users?
- What is the current regulatory and policy landscape for seaweed-based packaging in Europe, and how does it fit in?
- What are the strengths, weaknesses, opportunities and threats of using seaweed for more sustainable packaging?
- What is a feasible ambition for the European seaweed industry regarding more sustainable packaging by 2050?

- What actions are necessary among stakeholders to achieve this ambition?

## 1.3 Scope

To clarify the scope of this report, the figure below outlines several key definitions. 'Raw materials' refers to natural substances, such as minerals or crops, as well as chemical or synthetic components, such as additives, pigments, and resins, that are used to produce or modify other materials. 'Materials' refers to processed substances derived from raw materials and prepared for use in manufacturing finished products. Some materials are also used for packaging. 'Finished products' are fully functional end items that are ready for use or sale, and packaging itself is often considered a finished product.
This roadmap focuses on packaging (i.e. finished products), packaging materials and alternatives to packaging. The definition of packaging used here aligns with the Packaging and Packaging Waste Regulation (PPWR). During the research phase, additional potentially relevant applications were identified outside the primary scope of this study. These are addressed briefly but do not form part of the core focus of the packaging roadmap.

Geographically, the roadmap is limited to Europe, and all referenced organisations, policies and legislation are relevant to the European market.

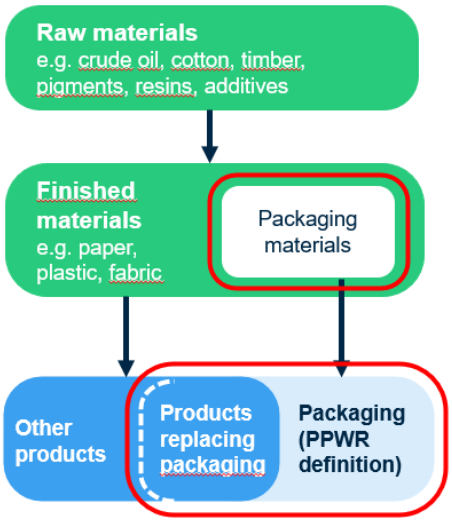


Figure 1: Visualization of the scope of the report; Where the highlighted boxes indicate that both packaging by official definition PPWR as well as products replacing packaging (not officialy defined as packaging) are within the scope of the report. Other products are not further considered for the roadmap.

## 1.4 Definitions

### Biobased materials

'Biobased' refers to where the material comes from rather than what happens to it after use. Conventional plastics are largely oil-based. Biobased plastics are made – either wholly or partly – from polymers drawn from organic sources such as plants, microorganisms, and greenhouse gases (examples include corn, algae, yeast and CO2). They can be naturally or chemically modified, which determines whether they are defined as a (bio)plastic or not.

### Biodegradability

When packaging is biodegradable, it means that it is able to be broken down into carbon dioxide, water, and biomass by the natural action of microorganisms over an unspecified length of time and in undefined conditions.[1]

**Compostability**
When packaging is compostable, it means that it is able to be broken down into carbon dioxide, water, and biomass within a specific time-frame and under specific conditions. This can mean either home-compostable (at ambient temperatures and with a natural microbial community) or industrially compostable (under increased temperatures, humidity, and specifically formulated microbial conditions). Compostable material can be made from either biobased or petrochemical inputs. Compostable packaging is subject to certification standards in North America, Japan, and Europe.[2]

**Finished products**
'Finished products' are fully functional end items that are ready for use or sale, and packaging itself is often considered a finished product.

**Materials**
'Materials' refers to processed substances derived from raw materials and prepared for use in manufacturing finished products. Some materials are also used for packaging.

**Packaging**
The PPWR defines packaging as 'an item, irrespective of the materials from which it is made, that is intended to be used by an economic operator for the containment, protection, handling, delivery or presentation of products to another economic operator or to an end user, and that can be differentiated by packaging format based on its function, material and design.[1]
In this report it is relevant to note that water soluble or edible films to hold product are not considered packaging according to the PPWR. Cutlery is also not considered packaging. Disposable plates, cups and containers (if intended to be filled at the point of sale) are considered packaging.

**Packaging and Packaging Waste Regulation (PPWR)**
The PPWR is a legislation officially published in January 2025, replacing the Packaging and Packaging Waste Directive. It introduces measures that impact the entire packaging value chain, establishing requirements for recyclability, recycled content, and more. Producers, importers, and all other stakeholders in the chain will be affected by the new legislation. The rules are not yet fully finalized; at least 30 additional documents are expected, detailing further legal requirements through to 2029.

**Polysaccharide**
Seaweed contains key polysaccharides like alginate, agar, and carrageenan. These are extracted from different types of seaweed (brown, red, and green algae) and have unique film-forming and gelling properties. A polysaccharide is a macromolecule formed by more than ten monosaccharides through glycosidic bonds, which is one of the four basic substances that constitute bio-organisms, apart from protein, nucleic acid and lipid. [3]

**Plastic**
According to the PPWR, plastic is 'a material consisting of a polymer to which additives or other substances may have been added, and which is capable of functioning as a main structural component of

[1] https://www.ellenmacarthurfoundation.org/compostable-biodegradable-and-bio-based-plastic-whats-the-difference#:~:text=Biodegradable%3A%20able%20to%20be%20broken,time%2Dframe%20under%20specific%20conditions
[2] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L_202500040&pk_content=Environment&pk_keyword=Regulation
[3] https://doi.org/10.1016/j.ijbiomac.2023.123924

packaging, with the exception of natural polymers that have not been chemically modified[2]. The SUPD definition is the same.[4]

### Plastic packaging

Packaging that contains plastic is not automatically classified as plastic packaging. The SUPD defines plastic packaging as packaging 'made wholly or partly from plastic', which leaves room for interpretation. The PPWR defines plastic packaging as packaging where plastic makes up the majority—more than 50%. As a result, it remains unclear at the EU level whether packaging with less than 50% plastic falls under measures specifically targeting plastic packaging.
The ambiguity in the SUPD has already led to different national interpretations of these definitions in the implementation of the SUPD. For example, the Netherlands considers any packaging containing more than 0% plastic as plastic packaging. This means that even paper packaging with a 1% plastic layer falls under Dutch SUP regulations. Other countries have different, often less strict, approaches.

### Raw materials

'Raw materials' refers to natural substances, such as minerals or crops, as well as chemical or synthetic components, such as additives, pigments, and resins, that are used to produce or modify other materials.

### Renewable

Renewable is often interchangeably used with 'biobased', but 'renewable' is more commonly used when referring to crops that replenish quickly.

### Single Use Plastics Directive (SUPD)

The SUPD was published in July 2019. Since July 2021, EU member states have incorporated the directive into their national legislation, resulting in variations in implementation across countries. The directive bans specific single-use plastic products (so not only packaging) such as straws, cutlery, and stirring sticks. For other single-use plastic items, including food containers and beverage cups, reduction targets have been established.

[4] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019L0904

# 2 Approach

## 2.1 Starting point

The development of the roadmap commenced with a comprehensive information gathering phase to establish a clear understanding of the current landscape of seaweed-based packaging. The objective was to define preliminary ambitions, which would then be refined through continuous stakeholder interviews. The desk research concentrated on market developments, underlying technologies and scientific advancements, as well as relevant legislation, including regulations specific to seaweed-derived packaging.

Starting from a list of existing and potential seaweed packaging applications, the focus was placed on those with the greatest capacity to mitigate environmental crises. From this foundation, three core ambitions were articulated, encapsulating the benefits of these applications: reducing plastic waste, replacing fossil-based plastics, and substituting wood fibers.

## 2.2 Stakeholder landscape and interviews

To validate the draft roadmap, a diverse group of relevant stakeholders was interviewed. These semi-structured interviews combined prepared topics tailored to each interviewee's background with open discussions that allowed new themes to emerge naturally. Stakeholders included producers of seaweed-based packaging, current and potential customers, independent research institutes, and industry organizations representing relevant market actors.

Throughout the process, the roadmap was continuously updated based on insights gained from these interviews. All input extracted from the interviews and incorporated into the roadmap is securely stored by North Sea Farmers. The processed and structured results of these consultations are presented and analysed in the following section.

# 3 Feasibility study

This chapter consists of three dimensions: market, technology and regulatory. The market dimension describes the potential market demand for seaweed-based packaging, and what properties potential and current users of seaweed-based packaging consider important. The technology dimension describes what packaging solutions are currently available. The regulatory dimension describes potential opportunities and challenges arising from legislation. At the end of this chapter, an overview table is provided, where each technology is reflected upon with the insights obtained from the interviews.

## 3.1 Market dimension

This chapter explores the potential positive impacts of seaweed-based packaging from the demand-side perspective, drawing mainly from interviews with potential and current users of seaweed-based packaging, focusing on the properties that current and prospective users consider important.

### 3.1.1 Functional properties

First and foremost, a packaging material must meet the functional requirements that a certain product application brings. Requirements that were mentioned are for example food safety, heat-resistance, a water barrier, a grease barrier, oxygen barrier, shelf-life of the product and processability on production lines.

### 3.1.2 Cost price

One of the biggest barriers for buyers is the cost of seaweed-based packaging. These materials are often more expensive than conventional alternatives, have limited supply capacity, and may not meet the same quality standards. While some buyers are willing to pay a sustainability premium of up to 20%, it remains uncertain whether the price of seaweed-based packaging currently falls within—or will soon reach—this range. (Potential) buyers recommend that the seaweed industry focusses on improving production efficiency and scaling up volume to benefit from economies of scale and reduce costs. Other interviewed stakeholders recommend to not replace conventional packaging on a one-to-one basis as this is not feasible cost-wise.

### 3.1.3 Sustainability benefits

The sustainability characteristics of seaweed packaging are an opportunity as well as a challenge. It became clear that most (potential) users were concerned with being compliant with the current legislation, especially the recently introduced PPWR (See 3.4 Regulatory dimension). Characteristics of seaweed-based materials indicated as relevant for packaging are:

#### 3.1.3.1 Plastic reduction

Organizations are increasingly committed to reducing their overall plastic consumption. Many companies have set targets specifically to reduce their use of virgin plastics.[5] This focus creates potential opportunities for unmodified, plastic-free seaweed-based packaging as a viable alternative.

#### 3.1.3.2 Lower $CO_2$ emissions

As companies strive to reduce their greenhouse gas (GHG) emissions, seaweed presents an intriguing opportunity as a low-carbon alternative feedstock. However, questions remain about whether the harvesting and production processes of seaweed-based packaging are genuinely more sustainable than those of alternative materials. Even if seaweed packaging proves to be more sustainable, there is still uncertainty regarding which sustainability claims can be credibly made. Nonetheless, if these claims can be validated, they would represent a clear competitive advantage for seaweed-based packaging.

[5] https://www.ellenmacarthurfoundation.org/global-commitment-2023/overview

#### 3.1.3.3 Biodegradability/compostability

Biodegradable packaging offers significant potential to address challenges related to pollution. For instance, single-use packaging in food takeaways is particularly susceptible to ending up as litter. When such packaging contains plastic coatings, it contributes to plastic pollution if not properly disposed of. Biodegradable materials could provide an effective solution for these applications. Also, biodegradability may be a viable alternative to materials that cannot be recycled. However, current legislation prioritizes recyclable packaging and does not yet recognize biodegradable packaging as a viable alternative. To fully realize the potential of biodegradable packaging, policy reforms or regulatory exceptions will be necessary to capture the potential of biodegradability.

#### 3.1.3.4 Recyclability

Seaweed-based packaging producers are generally committed to packaging recyclability. If seaweed-based packaging can contribute to enhancing the recyclability of packaging, it would represent a significant opportunity. Current developments show that plastic-free seaweed-based coatings on paper can be compatible with the paper recycling process. Next to biodegradability, it is therefore considered important to further investigate the recyclability of seaweed-based packaging and packaging materials.

Other potentially relevant sustainability propositions, though less explicitly addressed in the interviews, are that seaweed can be microplastic-free, renewable, fossil-free and locally grown in Europe.

In addition to the benefits outlined above, potential buyers emphasize the importance of credible evidence to support sustainability claims. Therefore, exploring existing certifications or developing new certification standards that verify the sustainability of the entire value chain for seaweed-based packaging and materials could be highly valuable.

### 3.1.4 Marketing opportunities

Several interviewees highlighted that seaweed-based packaging could present unique marketing advantages. Such packaging can convey a more sustainable image, which aligns well with products positioned as organic, fair-trade, or environmentally conscious. Additionally, using seaweed as a raw material for packaging can create a direct connection to certain products, such as seafood or sushi, offering a more holistic and authentic brand experience that may add greater value than conventional packaging. However, it is important to note that consumer awareness about the benefits of seaweed remains limited. To fully capitalize on the marketing potential of seaweed-based packaging, these benefits may need to be clearly and effectively communicated to consumers.

### 3.1.5 Industry commitments

There are numerous commitments that are voluntarily adopted which stem from governmental organizations, NGO's and industry organizations expressing a long-term commitment for sustainable packaging. For example, the Global Commitment[6], the Sustainable Development Goals[7] and the World Wildlife Fund[8] all aim to contribute to sustainable packaging. These commitments strive for sustainable sourcing, reducing (plastic) packaging, increasing reusable, recyclable and compostable packaging, and using recycled materials. Additionally, a lot of these overarching commitments are also adopted by companies as organizational sustainability targets for packaging. This could stimulate the adoption of sustainable packaging solutions by companies.

### 3.1.6 Market conclusion

This chapter has highlighted essential properties required for packaging, including recyclability and specific barrier functions for various applications. Furthermore, it has demonstrated unique advantages that could drive companies to choose seaweed-based packaging over alternative materials, such as its

[6] https://www.ellenmacarthurfoundation.org/global-commitment-2023/overview
[7] https://sdgs.un.org/goals
[8] https://www.worldwildlife.org/initiatives/plastics

plastic-free nature and biodegradability. For seaweed-based packaging to succeed in the market, **it must deliver a unique value proposition by combining both functional performance and sustainability benefits that fit the specific application.**

## 3.2 Technological dimension - Product applications

This chapter examines the current technological landscape of seaweed-based packaging, drawing mainly from interviews with producers of seaweed-based packaging and research institutes, including what raw materials are commonly used, what existing market applications are and the associated technological challenges and opportunities for further development.

### 3.2.1 Raw materials/feedstock

Sodium alginate, a polysaccharide extract from brown seaweed, is currently the most widely used seaweed-based material in packaging applications, such as films and coatings. Alginate provides an effective barrier against lipids and oxygen but is permeable to moisture. While chemical modifications can indeed enhance its moisture resistance, such alterations would mean that the product would no longer be classified as 'plastic-free' under the Packaging and Packaging Waste Regulation (PPWR). While other seaweed-derived components may have potential for packaging, agar-agar and carrageenan were the only ones mentioned during stakeholder interviews. There are several promising polysaccharides for future exploration, including fucoidan, laminarin and ulvan, each with unique properties that could benefit packaging applications. The prevalence of alginate can be attributed to its well-established European supply chains, which serve the cosmetics and food industries. This accessibility facilitates its use in packaging development.

### 3.2.2 Coating on paper/cardboard (plastic free)

A plastic-free seaweed coating consists of a biodegradable layer derived primarily from alginate extracted from seaweed, applied to paper-based packaging. This coating provides an effective barrier against grease and moisture while remaining fully compostable. As the natural polymers from seaweed are not chemically modified, the coating is considered to be plastic-free.

Highly advanced processes (usually mechanical) have already been developped for producing seaweed-based coatings for paper and cardboard. Implementing this coating will not require any changes to current packaging production processes. The demand for this application has been stimulated by the strict Single Use Plastics legislation in the Netherlands, and this plastic-free application provides a solution. While the producer offers a range of seaweed-based packaging options, their primary focus is on this application due to its strong market demand. Furthermore, the coating is known to dissolve during the paper recycling process. It is claimed that this does not cause any issues with the paper recycling process.

Although not yet validated, potential future applications include multi-material packaging, where conventional plastic layers often hinder recycling. The replacement of plastic with a water-soluble alginate coating has the potential to facilitate the dissolution of the material during the recycling wash phase, thereby enabling the more effective recovery of materials such as paper and cardboard. An example of this is beverage cartons, where the plastic lining is difficult to recycle.

Seaweed-based coatings on paper represent a sustainable alternative to traditional plastic coatings, offering a renewable, biodegradable, and plastic-free solution. This positions the packaging coating market as a significant opportunity for seaweed adoption. Furthermore, the technology has the potential to be applied to other packaging types that currently rely on plastic coatings, enhancing recyclability without compromising barrier properties. For these reasons, this application is considered promising and has been incorporated into the roadmap.

### 3.2.3 Modified coating on paper/cardboard (not plastic free)

A modified seaweed coating on paper involves applying a biodegradable layer made from seaweed extracts onto paper-based packaging. The natural polymers from seaweed are chemically modified, meaning the polymers are now classified as plastic, which could offer extra properties such as a water-, grease- and moisture-resistant barrier.

However, because of the chemical modification, the coating is classified as plastic under current definitions, positioning it alongside other biobased and biodegradable plastics such as PLA and PHA, and thereby opening up market competition. Another key challenge faced is variability in material structure, which regulators sometimes interpret as impurities, complicating the approval process.

From interviews also several opportunities were identified. One is replacing multilayer plastic packaging in the cosmetics industry, where brands are often willing to invest in sustainable packaging that can be effectively marketed. Additionally, the growing trend toward 'paperisation' (substituting plastic with coated paper packaging) is expected to further stimulate demand for this application. There appears to be a particular potential in the US market, where packaging waste is frequently landfilled, making biodegradability a valuable attribute.

Given its direct competition with more established biobased plastics like PLA and PHA, the unique selling proposition of seaweed-based coatings is limited. Seaweed is more costly than land-based biomass due to its production complexity. Therefore, this application is not currently adopted as a priority in this roadmap.

### 3.2.4 Edible coating on fruits and vegetables

Edible seaweed-based coatings for fruits and vegetables form a thin, invisible layer made from seaweed extracts such as alginate. Sprayed directly onto the surface, the coating slows moisture loss and oxidation, thereby extending shelf life without affecting taste or appearance. It is edible, which means it leaves no waste, and has the potential to replace plastic packaging.

At the moment, several practical challenges remain, including the coating's stickiness and the difficulty of controlling layer thickness—too thick a coating can trap moisture, accelerating spoilage. Additionally, potential buyers have raised hesitations; for instance, a fresh produce packaging company noted that adopting this coating would limit their ability to communicate with consumers via on-pack labeling. Furthermore, implementation of this spraying technique would demand substantial modifications to existing production lines.

While edible coatings are not classified as packaging under the PPWR, they could reduce reliance on plastic by potentially making conventional packaging unnecessary. The PPWR's proposed ban on plastic packaging for certain fresh produce under 1.5 kg further opens the door for seaweed-based edible coatings as a viable alternative.

Other edible seaweed-based products, such as edible coffee cups, are already available on the market. Although additional stakeholders in this field have not yet been interviewed, competition exists from alternative materials like potato starch and wheat flour. Despite these challenges, edible seaweed coatings remain a promising area, in which product development is on the rise.

### 3.2.5 Water soluble film

Alginate is a seaweed-derived biopolymer known for its hydrophilic properties—meaning it absorbs water and dissolves in it. As a result, unmodified alginate lacks a moisture barrier, which can limit its use in conventional packaging. However, this water solubility can also be an advantage in applications where temporary, dissolvable films are desired and where leaving no microplastics is a benefit.

This property enables innovative uses such as portion packs for food products designed to be boiled—like pasta or rice sachets—or laundry detergent pods that fully dissolve during use. In these cases, dissolvability is not a drawback but a functional benefit. Water soluble films however do not have a long shelf life, and the production technology is quite complex.

Whether these water-soluble films are classified as packaging under EU law depends on their use. For instance, laundry pods are not considered packaging under the PPWR. However, when used as part of a composite structure,like in beverage cartons ,they are considered packaging under the PPWR, and thus subject to its rules.

Current water soluble films are often made from polyvinyl alcohol (PVA), which is potentially linked to the pollution of waste water[9,10], leaving room for more sustainable alternatives. Considering that this is a growing market[11], this application is considered potentially interesting and requires further research at this stage.

### 3.2.6 Biomaterial for rigid packaging

Seaweed can also be used to produce rigid materials suitable for applications like cutlery and packaging. This involves processing seaweed into pellets from biopolymers that can be molded or extruded into solid forms. Currently, at least one known producer already manufactures rigid cutlery from seaweed, while other organisations focus on producing the seaweed-based pellets, which can be used in existing plastic processing equipment to create rigid packaging alternatives. This application offers a potential low-impact substitute for conventional fossil-based plastics in single-use items.

Rigid materials have competition from both conventional plastics and alternative biobased materials such as PLA and PHA, which are much further developed than seaweed. Additionally, seaweed does not yet have the same properties as its competitors in terms of durability, shelf life and compatibility with existing waste processing infrastructures. Similar to the solubility of the packaging, this can be both an advantage and a disadvantage. Therefore, it should only be considered for particular applications where seaweed's unique properties are of added value.

Up until now, there has been no mature application on the market where this added value has come to fruition and has therefore not been included in the roadmap at this point. However, it may still hold potential as an interesting solution, possibly to be sold in conjunction with another seaweed based packaging item.

### 3.2.7 Fiber in paper/cardboard

Seaweed fibers might be used as an alternative to wood fibers in paper-based packaging. Technically, it is possible to produce paper with up to 100% seaweed content, although blends with other fibers are more common to balance performance, cost, and processability. This application offers a renewable, potentially lower-impact material source for paper packaging, contributing to diversification of fiber supply and reduced dependence on traditional forestry. Lastly, the demand for paper is growing but the availability of wood fibers has not, hence alternative fiber sources are being explored.

However, seaweed fibers face strong competition from more abundant and cost-effective land-based alternatives such as grass, hemp, straw, and wood. Additionally, questions remain about whether seaweed fibers possess the necessary properties to function effectively as a paper feedstock. Several stakeholders have emphasized that maximizing the value of seaweed requires utilizing as much of the plant as possible. Since seaweed fibers are likely to be a by-product or waste stream (e.g. from alginate extraction), their use in paper or cardboard production could be a promising avenue for valorization.

The volume requirements for paper production are also high (e.g. 1 mln ton of feedstock-input for a standard paper mill-factory combination), making supply a possible limitation rather than cost.When cultivated seaweed breaks the production barrier of 500,000t of fresh weight per year, then it may become an option. Hence, growing seaweed solely for its fibers is currently not technically and consequently also not economically viable. Therefore, this application has been excluded from the final roadmap.

### 3.2.8 Additive (binder) in paper/cardboard

Modern paper typically contains up to 2% additives to enhance properties like strength, printability, or water resistance. These additives are often derived from fossil resources. Replacing them with seaweed-based alternatives could support the transition to fossil-free paper packaging.

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[9] https://pmc.ncbi.nlm.nih.gov/articles/PMC8199957/
[10] https://academic.oup.com/etc/article/44/2/563/7942759
[11] https://www.fortunebusinessinsights.com/water-soluble-polymers-market-106175

In the past, alginate from seaweed was already used to increase the properties of paper as an adhesive. However, fossil alternatives were found to be cheaper and to have better functionality. Currently, paper producers are looking to step away from these fossil additives to develop paper that is completely fossil free, meaning seaweed-based polymers may be an attractive alternative.

As additives to paper are not defined as nor replace packaging or packaging material, this application is not included in the roadmap. However, this application is still noteworthy and may be an interesting application in moving towards fossil-free paper and cardboard.

## 3.3 Regulatory dimension

This chapter explores the regulatory landscape relevant to seaweed-based packaging, drawing from all stakeholder groups' interviews, focusing on current and legislation, perceived barriers, and opportunities for regulatory alignment and innovation.

The Green Deal outlines the common direction and vision of the EU on sustainable packaging. The most important legislations part of the Green Deal that are applicable to seaweed-based solutions defined as 'packaging' are the Packaging and Packaging Waste Regulation and the Single Use Plastics Directive.

### 3.3.1 European Green Deal

The European Green Deal comprises a set of regulations aiming to achieve the overarching goal of the EU to become climate neutral in 2050[12]. Two key pillars of the Green Deal are the 'Circular Economy Action Plan' and the 'Zero Pollution Action Plan'. The Circular Economy Action Plan aims to make Europe climate neutral and resource-efficient by 2050. It focuses on designing sustainable products, promoting circular business models, and reducing waste in key sectors. The Zero Pollution Action Plan's vision for 2050 is to reduce air, water and soil pollution to levels that are no longer considered harmful to health or natural ecosystems, thereby creating a toxic-free environment within the boundaries that our planet can cope with. Key commitments stemming from these pillars include:

- Making sustainable products the norm in the EU, aiming for product durability, recyclability, and repairability
- Focusing on the sectors that use most resources and where the potential for circularity is high, such as packaging and plastics
- Reducing overall waste generation[13]
- Improving water quality by cutting plastic litter in seas by 50% and microplastics released into the environment by 30%
- Halving residual municipal waste.[14]

### 3.3.2 Packaging and Packaging Waste Regulation (PPWR)

The PPWR is part of the Green Deal and strives to make all packaging reusable or recyclable by 2030. It sets strict requirements to reduce packaging waste and increase the use of recycled materials, supporting the circular economy and environmental goals. These requirements also become progressively stricter over time.

#### 3.3.2.1 Scope

The PPWR has clear definitions of what is a packaging, and thus subject to the requirements of the PPWR, and what is not packaging. Water soluble films (e.g. for laundry detergents) and edible coatings, for example on fruits and vegetables, are not defined as packaging by the PPWR. Other applications, or when the film or coating is applied on a packaging (material), are subject to the requirements of the PPWR.

#### 3.3.2.2 Main requirements

- Recyclable packaging: The PPWR mandates a ban on non-recyclable packaging by 2030, requiring all packaging to meet design-for-recycling standards as of 2030, and be recyclable at scale as of 2035. The standards to assess this are still unknown and will be published at a later moment, which means this is a critical issue for all packaging, including seaweed-based packaging.
- Compostable packaging: The PPWR requires compostability for some specific applications (e.g. stickers on fruits and vegetables and coffee- and teabags). Yet, the specific requirements, such

[12] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en
[13] https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en
[14] https://environment.ec.europa.eu/strategy/zero-pollution-action-plan_en

as the composting conditions that these packaging should meet, are to be published at a later moment, which creates uncertainty for companies aiming to produce packaging for these applications.
- Biobased content in plastic packaging: The PPWR currently lacks clear policy and guidelines on the use of biobased content in plastic, which introduces uncertainty for seaweed-based packaging. It could also pose an opportunity, If the delegated acts create favorable policy for the use of biobased content in plastic.
- Ban on some packaging types. The PPWR bans single use plastic packaging for unprocessed fruits and vegetables <1.5 kilograms and single use plastic portion packs in the Horeca. This creates an opportunity for plastic-free alternatives, such as edible coatings or plastic-free coatings on paper.

#### 3.3.2.3 Future developments

There are still a lot of decisions that need to be made within the PPWR, which creates uncertainty. The outcome of these decisions may be critical for the future of seaweed-based packaging and should be monitored. Some relevant dates to monitor are:

- 2026 – Standardized technical specifications for (home) compostability published
- 2028 – Standards for using biobased feedstock and its sustainability criteria introduced
- 2028 – Design-for-recycling standards published
- 2030 – Recyclability score >70%, PCR targets apply
- 2035 – Recyclability on scale required and recyclability score >80% applies

### 3.3.3 Single Use Plastics Directive (SUPD)

The SUPD aims to reduce litter from plastic. It does so by outright banning the use of plastic within specific applications. As it is a directive, the implementation of this legislation differs per country. In this section the Dutch Implementation Is described, as this one Is deemed relevant due to Its strict definition of plastic.

#### 3.3.3.1 Scope

The SUPD mandates a ban on specific single-use plastic items for which alternatives are available or are easier to replace. This includes: Plastic cutlery (forks, knives, spoons, and chopsticks), Plastic plate, Plastic straws, Plastic cotton buds, Plastic balloon sticks, plastic food containers and plastic beverage containers

#### 3.3.3.2 Main requirements

- Ban of single use Items containing plastic: The Netherlands adopted a definition that allows no plastic at all. This created an opportunity for cardboard food containers with a (proven) plastic-free seaweed-based coating.
- Extra tax on single use plastic Items: Companies pay an extra tax on 'SUP' Items as part of their waste management contribution. This created an opportunity for (proven) plastic-free alternatives, as they do not have to pay this tax.

#### 3.3.3.3 Future developments

In 2027, the SUPD will be evaluated and may be revised which can create new opportunities but may also create barriers for seaweed-based packaging.

A relevant date to monitor is:

- 2027- Evaluation of SUPD finished.

### 3.3.4 Other regulations

There are also other relevant regulations to keep in mind when developing seaweed-based alternatives or packaging materials. It depends strongly on the application which legislation is relevant and therefore no complete list can be given at this moment. However, some suggestions are provided:

- Food Contact Materials Regulation, which applies to all materials intended to come into contact with food.
- Green Claims Directive, which applies to all sustainability claims made about a product or packaging
- General Food Law, which applies to all products intended for human consumption, so also edible packaging

### 3.3.5 Regulatory conclusion

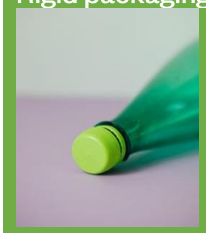
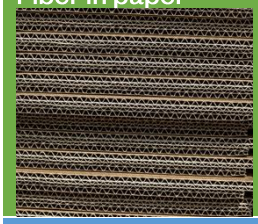
The main legislations applicable to packaging are the PPWR and the SUPD. Both could create challenges and opportunities for seaweed-based packaging (materials). It Is therefore recommended to monitor developments such as evaluations and the publishing of delegated acts closely. As many PPWR-articles are still in development, could be beneficial to lobby with policy makers to ensure favorable conditions for seaweed-based packaging.

## 3.4 Overview of current applications

This table provides an overview of the applications that have been discussed as part of this research. each application is reflected upon from the three perspectives (technology, market and regulatory) and the strengths and weaknesses are listed.

Table 1: An overview of seaweed-based packaging applications, their up- and downsides per dimension and estimated potential. An estimated potential rate of ≥3 is considered to be interesting potential for future seaweed for packaging applications as replacement of fossil-based plastics.

| Application | Unique proposition | Strengths | Challenges | Estimated potential (on a scale from 1-5) |
|---|---|---|---|---|
| Packaging | | | | |
| Coating (on paper)  | Biodegradable plastic free (SUP-proof) coating on paper. Suitable for products consumed quickly after packaging, such as single-use food takeaway containers. | + Developed technology<br>+ Oil & oxygen barrier<br>+ Recyclable<br>+ Biodegradable | - High cost price<br>- Limited moisture barrier | □□□□ |
| Modified coating (on paper)  | Modified coating on paper, meaning better barrier properties. Suitable for wide range of applications. | + Microplastic free<br>+ Good barrier to moisture, grease and more possible. | - High cost price<br>- High competition from more developed biobased materials | □□ |

| Application | Unique proposition | Strengths | Challenges | Estimated potential (on a scale from 1-5) |
|---|---|---|---|---|
| Rigid packaging  | | + Compatible with current machinery | - High cost price<br>- High competition from more developed biobased materials<br>- Unknown compatibility with PPWR requirements | □□ |
| Fiber in paper  | Valorising the residual stream of fibers that arises when processing seaweed, leading to lower cost price of seaweed. | | - Costly feedstock<br>- Unknown fiber properties | □ |
| Non-Packaging replacing packaging | | | | |
| Water soluble film  | Replace less biodegradable conventional solutions such as PVA | + Plastic-free<br>+ Highly biodegradable<br>+ Susceptible to water | - High cost price<br>- Low shelf-life<br>- Complex technology | □□□ |
| Edible coating  | Using an edible coating can make a current (plastic) packaging redundant. | + Extends shelf-life<br>+ Coating can enhance product (flavor, nutrients, color) | - Not market-ready yet | □□□ |
| Non-packaging out of scope | | | | |
| Paper additive  | Improve the environmental footprint of paper by using fossil-free additives | + Developed technology<br>+ Fossil free solution | - Lesser functional performance than fossil alternative | *Out of scope* |

### 3.4.1 Key opportunities

Several seaweed-based packaging applications are currently on the market or in development by parties not yet identified or consulted and thus are not covered in the overview above. Consequently, this

overview should not be considered exhaustive. Continued exploration of innovative seaweed-based packaging solutions remains highly relevant.

In general, the following categories or markets are considered particularly promising:

- Packaging with a short shelf-life: Due to its limited durability, seaweed-based plastic-free packaging is best suited for products consumed quickly after packaging, such as single-use food takeaway containers.
- Litter-sensitive packaging: Seaweed biodegrades significantly faster (6-8 weeks) than other biodegradable bioplastics like PLA and PHA . Its ability to degrade in natural environments without leaving microplastics makes it ideal for on-the-go packaging prone to littering.
- Products entering waterways: Packaging for items such as laundry detergent pods and washing machine tablets, which often end up in aquatic environments, could benefit from biodegradable and microplastic-free seaweed-based materials.
- Edible materials: Applications where edible materials can replace plastic packaging, such as a coating on fruits and vegetables or sausages, or sachets for energy gels for athletes.

## 3.5 SWOT

A SWOT analysis is a strategic tool used to evaluate Strengths, Weaknesses, Opportunities, and Threats related to a product. It provides a clear framework to assess internal capabilities and external factors, helping to identify areas for improvement, potential growth, and risks. By structuring the input from the interviews into this framework, an overview of the potential of seaweed-based packaging is obtained.

**Strengths**

- Seaweed-based packaging material is renewable
- Seaweed-based packaging material can be plastic-free
- Seaweed-based packaging material can be microplastic-free
- Seaweed-based packaging material can be compostable/biodegradable
- Seaweed-based packaging material could have a lower $CO_2$ impact than other packaging (materials)
- Seaweed grows rapidly in nature, making it a highly renewable and scalable raw material

**Weaknesses**

- For many seaweed-based packaging, the production technology is still in development.
- Currently, seaweed-based packaging materials have a high cost-price and require investment to scale-up.
- Currently, the supply chain for seaweed-based packaging is in development and there is a lack of partners to collaborate with.
- The general technical knowledge on seaweed as packaging material is still limited.

**Opportunities**

- The combination of unique properties of seaweed is hard to compete with in some applications.
- A plastic free seaweed-based packaging (material) can be a SUP-compliant alternative for plastic.
- Seaweed may enhance the quality of compost, making this end-of-life route more attractive.
- Seaweed-coated paper does not obstruct the paper recycling process.
- Seaweed-based coatings can be thinner than alternatives, all whilst keeping comparable barrier properties. This reduces the unit-cost.
- Seaweed fibers can be an alternative to supplement wood fibers in paper packaging.
- Seaweed-based packaging material with a lower carbon footprint can be a stimulant for users to choose this packaging, to achieve their GHG reduction targets.
- Seaweed-based (edible) coating for fruits and vegetables can be a solution to both reduce plastic and as an alternative for plastic in fruits and vegetables, which will be partially banned by the PPWR by 2030.

- Seaweed-based packaging materials can be a fossil free alternative, making the EU more resource independent.
- Biomaterial is an interesting alternative for where recycled content is not possible due to food contact.
- Using the sea instead of agricultural land, this can shift the burden away from land.
- Using the sea instead of agricultural land, this possibly provides a solution to unpredictable weather patterns, as seaweed is resistant to droughts and floods.
- As seaweed does not need irrigation, pressure on water resources is alleviated.

Threats

- Seaweed-based packaging faces competition from more developed biobased materials.
- There is also competition from virgin fossil-based packaging materials, which often perform better.
- Production capacity is limited because many seaweed packaging producers are start-ups.
- Compatibility with a recycling stream is unknown for some seaweed packaging applications.
- Similarly, compatibility with plastic recycling streams remains uncertain for certain uses.
- There is a lack of established recycling routes for compostable packaging, and current legislation favors reuse and recycling, while composting is not considered recycling.
- The PPWR leaves uncertainty regarding definitions and requirements for biobased and compostable packaging.
- Regulatory approval processes are difficult due to irregularities in seaweed-based packaging materials.
- Fossil fuel subsidies create an uneven playing field, favoring conventional plastics over biobased alternatives.

## 3.6 Ambition level

**Market ambition**

An ambition for the seaweed packaging roadmap has been formulated based on where the most added value for the unique properties of seaweed for specific packaging applications is seen. This resulted in the following overarching ambition:

*Reducing stress on the globe by replacing virgin plastic with seaweed-based materials, utilizing their unique set of properties.*

Although the seaweed packaging market is still in its infancy, it is developing rapidly. The global market for seaweed packaging was valued at around 699 million USD in 2023 and is expected to grow to 1.1 billion USD by 2030, representing a compound annual growth rate (CAGR) of 6.6%[15]. The packaging coatings market was valued at 4 billion USD in 2024[16]. If all efforts of seaweed packaging were aimed at replacing packaging coatings about 15% of the coatings market could be captured. Furthermore, if efforts were aimed at edible films and coatings instead, about 25% of the market could be reached. The edible films and coatings is a rapidly growing market with an estimated CAGR of 7.7% until 2028 and a value of 2.7 billion USD in 2021[17].

Although it is unlikely that one market will be targeted completely, and there may already be some overlap between the seaweed packaging market and the others, this does illustrate that seaweed can play a significant role in certain niche markets and contribute to the ambition of reducing global stress through the use of seaweed in packaging applications. Given the variability of the contribution of seaweed packaging market to certain niche markets, it is assumed that about 10% of certain fossil packaging

[15] https://www.grandviewresearch.com/industry-analysis/seaweed-packaging-market-report
[16] https://www.grandviewresearch.com/industry-analysis/packaging-coatings-market-report
[17] https://www.grandviewresearch.com/industry-analysis/edible-films-coating-market-report

applications can be partially or fully replaced thanks to a seaweed alternative by 2050. This brings us to how seaweed packaging can concretely contribute to the main ambition, namely:

*By 2050:*

- *10% of plastic coatings on paper are replaced with a plastic free seaweed-based coating*
- *10% of plastic single use film are replaced with edible, water soluble, and compostable films.*

**Plastic reduction potential per ambition**

To give an indication of what seaweed volumes this ambition would represent, the following estimates have been made:

I. Replacing 10% of plastic coatings on paper:

In coatings in food packaging:

- Plastics production in Europe totaled 54 million metric tons in 2023[18], of which 39,1% is for packaging[19]. This means that approximately 21 million metric tons of plastic packaging is produced yearly in the EU.
- Assuming that around 2/3rd is for food[20], this amounts to 14 million tons plastic packaging.
- The market value of the European food packaging market is estimated at a value of 105 billion USD[21], representing this 14 million tons plastic[25]. The plastic coatings market was valued at 4 billion USD in 2024[22].
- Taking this ratio to estimate the volumes of plastic coatings, this is 0.66 million tons of plastic coatings used for food in Europe.
- If 10% is made redundant using seaweed-based coatings on paper, this reduces **66.600 ton plastic** per year.
- Based on 2% yield from wet, this results in a need for **1.3 mT** seaweed.

II. Replacing 10% of plastic single use films with edibles, water solubles, and compostables:

In AGF (replacing plastic with edible coating):

- Plastics production in Europe totaled 54 million metric tons in 2023[23], of which 39,1% is for packaging[24]. This means that approximately 21 million metric tons plastic packaging is produced yearly in the EU.
- Assuming that around 2/3rd is for food[25], this amounts to 14 million tons plastic packaging.
- Fruits and vegetables account for a significant share, but because much produce is sold unpackaged, estimates suggest that around 5-10% of total food packaging plastic goes to fruits and vegetables.
- This translates to roughly 0.7-1.4 million tonnes of plastic per year for fruits and vegetables in Europe.
- If 10% is made redundant using seaweed-based edible coatings, this reduces **70.000-140.000 ton plastic** per year.
- Based on 2% yield from wet, this results in a need for **1.4-2.8 mT** seaweed.

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[18] https://www.statista.com/statistics/987838/plastics-production-volume-in-the-eu-28/#:~:text=Plastics%20production%20in%20Europe%20totaled,plastic%20in%20Europe%20since%202021

[19] https://www.eea.europa.eu/en/analysis/maps-and-charts/nearly-40-percent-of-plastic

[20] https://rethinkplasticalliance.eu/news/paper-based-food-packaging-at-the-centre-of-europes-waste-crisis-new-report-reveals/

[21] https://www.grandviewresearch.com/horizon/outlook/food-packaging-market/europe#:~:text=Europe%20food%20packaging%20market%20highlights,food%20packaging%20market%20in%202024.

[22] https://www.grandviewresearch.com/industry-analysis/packaging-coatings-market-report

[23] https://www.statista.com/statistics/987838/plastics-production-volume-in-the-eu-28/#:~:text=Plastics%20production%20in%20Europe%20totaled,plastic%20in%20Europe%20since%202021

[24] https://www.eea.europa.eu/en/analysis/maps-and-charts/nearly-40-percent-of-plastic

[25] https://rethinkplasticalliance.eu/news/paper-based-food-packaging-at-the-centre-of-europes-waste-crisis-new-report-reveals/

[26] https://www.sciencedirect.com/science/article/pii/S030438942501862X?via%3Dihub

In other applications such as water solubles, it depends strongly per application what reduction could be achieved. As the use of water-soluble seaweed films has not been clearly adopted by one market yet, no further estimates have been made.

# 4 Conclusion

## 4.1 What applications are already on the packaging market using seaweed?

A multitude of packaging applications have been identified. Most noteworthy are coatings on paper/cardboard that are plastic free, edible coatings on fruits and vegetables and water-soluble films. Plastic-free coatings are particularly promising because they can be exempt from the Single-Use Plastics Directive (SUPD) in countries that prohibit plastic packaging, and thus this may represent a significant market opportunity. Edible coatings on fruits and vegetables have already been developed and have been shown to extend the shelf life while also offering the ability to add nutrients, coloration, smells or even taste. Lastly, water soluble films have the potential to not interfere with recycling of other materials and leaving no waste at all in applications that come in touch with water. All other applications can be found in section 3.1.

## 4.2 What characteristics should seaweed packaging have for (potential) users to adopt it?

The applications mentioned above are just some examples of applications that have been identified so far. Other applications may also exist or may come to fruition in the (near) future. What is most important to keep in mind is that applications that offer a unique value proposition by using the properties of seaweed are deemed to have the highest potential. Propositions that try to directly compete with existing (land-based) biobased or conventional packaging will be more challenging. This is because price remains a key consideration for most buyers, and sustainability benefits alone are often insufficient to convince them. To justify a premium, seaweed-based solutions need to deliver additional benefits or functionalities beyond what conventional packaging currently offers.

## 4.3 What is the current regulatory and policy landscape for seaweed-based packaging in Europe, and how does seaweed packaging fit in?

Legislation and corporate commitments have been key drivers for the development of seaweed-based packaging. In the Netherlands, the SUPD has been particularly influential, as the country prohibits plastic packaging for certain products, creating strong demand for plastic-free alternatives. The PPWR further drives the shift towards more sustainable packaging. Seaweed packaging may qualify for exemptions or help companies meet their ambitious reduction targets, making it an attractive option. However, it is important to recognize that legislation also imposes stringent requirements regarding recyclability compostability, hygiene, green claims, and food safety, which must be carefully addressed. Compliance with recyclability and reusability may be especially challenging for seaweed packaging, even though many of these requirements still need to be defined. An important detail here is that recyclability requirements are (currently) determined by increasing percentages (70% must be recyclable soon and increasing to 90% in the future). Therefore, this may become more challenging for packaging solutions with more than 30% seaweed than solutions with small amounts of seaweed (that do not impair the overall recycling process)

## 4.4 What are strengths, weaknesses, opportunities and threats for the use of seaweed in sustainable packaging?

Seaweed-based packaging offers several promising strengths, including being renewable, free of (micro)plastics, and compostable. However, production technologies and supply chains are still evolving and face challenges such as high costs and lack of technical expertise. Key opportunities arise from legislation and organizational commitments aimed at reducing the environmental impact of packaging. However, seaweed packaging still has to compete with other materials, deal with regulatory uncertainties, and address questions around recycling compatibility. While seaweed-based packaging shows great potential, it still has to overcome significant challenges to achieve large-scale adoption.

## 4.5 What is a feasible ambition for the European seaweed industry for more sustainable packaging towards 2050?

Considering the challenges and opportunities outlined earlier, the European Seaweed Industry should aim to replace virgin plastic in packaging solutions, leveraging its unique combination of plastic-free,

biodegradability, low-carbon and functionally favorable properties. The ambition of the European Seaweed Industry for 2050 is formulated as follows:

- Replace 10% of plastic coatings on paper with a plastic free seaweed-based coating
  - For this ambition – around 1.3 million tonnes of wet seaweed is needed
- Replace 10% of plastic single use films with edible, water soluble, and compostable seaweed-based films.
  - For this ambition – around 1.4-2.8 million. tonnes of wet seaweed is needed

## 4.6 What actions are necessary among stakeholders to achieve this ambition?

To achieve the full potential of seaweed packaging, the barriers that limit the potential need to be overcome first. Some key next steps are to develop an action plan to achieve an attractive value proposition, advocate for legislation that favors seaweed-based packaging, and cooperate within the industry as well as with other (competing) industries. The complete overview of recommended actions can be found in 5.4 Action plan.

# 5 Roadmap


## AMBITION

Today's packaging solutions contribute significantly to fossil-based climate change and plastic pollution. As an alternative packaging solution, seaweed demonstrates a combination of properties that makes it unique to other alternatives and helps reduce the footprint and plastic pollution of existing packaging.
The European Seaweed Industry aims to replace virgin plastic in packaging solutions, leveraging its unique combination of plastic-free, biodegradability, low-carbon and functionally favourable properties.

**Global Crises** — Plastic Pollution; Climate Change

**EU Climate Law** — EU Green Deal; PPWR*

**Seaweed combines Benefits** — Plastic Free + Renewable + Biodegradable

**Packaging and Packaging Waste Directive 2025*

**By 2050, the European Seaweed Industry aims to:**

- **Replace 10% of plastic coatings on paper with a plastic free seaweed-based coating**
- **Replace 10% of plastic single use films and foils with seaweed-based alternatives**

**2025** **This ambition requires at least 2.7 - 4.1 mln ton-wet seaweed in 2050** **2050**

## KEY INSIGHTS

**Business opportunity as Single-Use Plastic alternative**

Unmodified seaweed based packaging is plastic-free plus other benefits. This gives it a competitive edge to land-based alternatives in complying with the EU's SUP directive.

**Supply of seaweed may be the limiting factor**

When successful packaging solutions require scaling, then the limited capacity of EU's cultivation and also wild-harvest supply chain may become restrictive.

**Will seaweed packaging comply with PPWR?**

Although seaweed based packaging is often biodegradable it may not be compliant with the (yet to be defined) recyclability & reusability requirements in the PPWR.

**High price point requires smart market selection**

Higher cost often outweighs ESG benefits. First focus on propositions that require little seaweed (coating) and/or focus on closed marketplaces where higher prices can be paid (festivals, concerts).

## RECOMMENDED INDUSTRY ACTION

*These actions could be followed-up in Joint Industry Projects and/or by research & innovation projects in Europe*

**Identify & agree on high-potential market segments** where the combination of benefits of seaweed outweigh cost (unique, little seaweed) and/ or competition (no viable alternative).

Closely **monitor the further recyclability & reusability requirements** in the PPWR and their impact on the future admissibility of seaweed-based packaging on the EU market (2027 onwards).

**Identify quality and composition requirements** for seaweed feedstocks that allow cultivated seaweeds to have a marketable advantage in the future.

*Full roadmap available here*

## 5.1 Strengths, weaknesses, opportunities, threats (short version for roadmap)

### 5.1.1 Strengths

- Renewable
- (Micro)plastic-free
- Compostable/biodegradable
- Low $CO_2$ impact

### 5.1.2 Weaknesses

- Underdeveloped production technologies and supply chain (partners)
- High cost-price and investment costs for scale-up.

### 5.1.3 Opportunities

- Unique combination of seaweed properties are USP
- SUP-compliant alternative for plastic.
- Seaweed-based (edible) coating can achieve plastic reduction

### 5.1.4 Threats

- Competition from more developed biobased and virgin fossil-based materials.
- Compatibility with current recycling infrastructures
- Lack of established waste management routes for compostable packaging
- Uncertainty on biobased and compostable packaging in the PPWR.

## 5.2 Do's and Don'ts

### 5.2.1 Do's

- Leverage seaweed's unique properties in targeted niches.
    - To overcome competition from cheaper or better performing alternative materials
- Fully utilize all seaweed components to minimize waste and maximize value.
    - Higher chances of success and profitability
- Scale up to improve price competitiveness.
- Ensure recyclability and compatibility with existing waste systems.
    - To ensure compliance with PPWR
- Unite producers and brand owners in an industry organisation.
    - To develop a more efficient and effective supply chain
- Collaborate with policymakers to create favorable conditions in legislation.

### 5.2.2 Don'ts

- Avoid direct one-to-one replacement of plastic or paper packaging.
    - As seaweed cannot compete on price and functionality with conventional materials
- Don't compete in areas where bioplastics outperform seaweed without unique advantages.
    - As seaweed cannot compete on price and functionality only with other biobased materials
- Don't compromise product safety or functionality.
- Don't rely solely on start-ups for supply chain development.
    - Demand and capital is too low

# 6 Recommendations

This report and enclosed roadmap are intended as a living document. Therefore, we include recommendations for next steps to further develop this roadmap through time.

We have the following recommendations:

- Continue to innovate and explore new applications not yet on the market.
- Build business cases for potential users of seaweed packaging.
- Treat the 10% market ambition as an initial benchmark, to be refined over time based on progress and insights.
- Monitor and influence legislation and regulation, in order to create more room for fossil free and compostable solutions and remove current barriers that producers experience, such as regulatory approvals.
- Unite seaweed packaging producers and brand owners (users) in an industry organization and together build leverage with policymakers and work on further improvement of the image of seaweed in packaging.
- The absence of microplastics in seaweed-based packaging could be a relevant topic for further investigation. As scientific understanding of the environmental and human health impacts of microplastics in conventional packaging continues to evolve, further research is essential to fully assess and quantify the benefits of microplastic-free alternatives like seaweed-based materials.
- Continue to find applications where seaweed is unique, instead of competing with other (cheaper) materials. Use the unique properties of seaweed (long polymers where chemical modification is not needed).
- A stakeholder group that has not been represented in this study yet is the consumer. It is recommended to also explore opportunities and challenges that lie with this stakeholder group.