Hard facts. Clear stories.

Copenhagen Economics

THE POTENTIALS OF BIO SOLUTIONS

Climate and sustainability potentials, barriers to growth, and Danish strongholds

ALLIANCE FOR BIO SOLUTIONS
20 SEPTEMBER 2022

AUTHORS AT COPENHAGEN ECONOMICS

Helge Sigurd Næss-Schmidt
Signe Rølmer Vejgaard
Morten May Hansen
Jasper Lutz

PREFACE

Reaching the targets in the UN Paris Agreement of a global temperature increase well below 2°C and pursuing efforts to limit it to 1.5°C requires new solutions and transformations across all industries in the global economy.

Biotechnological climate solutions, or ***bio solutions***, are important enablers for the decarbonisation of processes in industries that are otherwise difficult to decarbonize. Certain bio solutions can be used to increase the yield of agriculture, reduce land use, provide alternative proteins for food, lower demand for plastic and pesticides, prevent food waste, and improve biodiversity, food supply, and food security.

However, the deployment of these bio solutions is being held back by a wide range of barriers. The absence of CO_2 pricing and an outdated regulatory system are holding back several mature technologies ready for large scale deployment.

Against this backdrop, the Alliance for Bio Solutions under the Danish Chamber of Commerce has commissioned Copenhagen Economics to analyse how bio solutions can help industries and households in their decarbonisation. An important part is not only to assess the impact of bio solutions on greenhouse gas emissions or the substitution of materials but also the cost of these bio solutions relative to their alternatives, and the framework conditions required to secure the uptake of these solutions.

Concretely, we have been asked to analyse:

1. The global potentials of bio solutions.
2. Barriers that bio solutions face and policy recommendations for improved framework conditions.
3. The future market opportunities for the Danish bio solutions industry.

Bio solutions are many and diverse. In this study, however, we group bio solutions into broader categories for the sake of overview, simplicity, and the ability to draw *general* conclusions and offer recommendations. By these groupings, we are abstracting from the many technical differences and nuances between various kinds of bio solutions that are, however, *not* important for the evaluation of the economic and environmental potentials of bio solutions as a whole.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF BOXES

LIST OF FIGURES

EXECUTIVE SUMMARY

Bio solutions have a strong potential to deliver on climate goals

Many countries have set ambitious climate targets to reach the goals set out in the Paris Agreement. In the 'Fit For 55' policy proposal, the EU has a 55 per cent CO_2 emission reduction target in 2030 relative to 1990. As of 2019, the emission reduction was 25 per cent, i.e., almost halfway to the target. The EU will have to deliver even higher emission cuts towards 2030 than it did in the past 30 years. To reach these targets, it will need to utilize and develop existing solutions, as well as innovate and deploy new ones. One important group of solutions are biologically-based products and processes, or so-called **bio solutions**. Bio solutions are products made from living organisms: see definition below. The key definer of most bio solutions is that they *enable* reductions of emissions, typically in industries where emissions are difficult to abate, for example in industry, agriculture, and transport.

> *Bio solutions are composed of* ***biological products that are anchored in biotech****, i.e., they utilize* ***living organisms****, including enzymes, microorganisms, bacteria cultures, pheromones, etc. for concrete applications and products that are used in other industries' manufacturing processes and as end products to* ***enable sustainable transformations such as emission reductions****.*

A more turbulent world has also increased the focus on wider economic resilience and strategic economic security. Access to energy and key minerals in the green transition has become a more important concern for governments and companies worldwide. In this context, biosolutions can also provide a contribution by developing energy sources (biofuels and gas) that are not dependent on an external supply from potentially unstable regions.

Bio solutions range from already globally scaled products that people use in their everyday life to early state research ideas and solutions that need to mature before mass deployment. Fermentation, food cultures, and enzymes have already been fully commercialized and scaled globally and are now used in many peoples' everyday lives, whereas other solutions are not fully commercialized yet. In this report, we examine *some of the many bio solutions* that are available today or could be solutions in the future. Figure 1 lists examples of bio solutions and their use in different sectors.

Figure 1: Bio solutions usages in different economic sectors

Industry	Agriculture	Transport
• Bio plastics	• Bio controls, incl. bio fertilizers	• Bio fuels
• Fermentation-based solutions, food cultures, ingredients in the food industry	• Fermentation of feedstock	• Fermentation-based jet and marine fuels
• Alternative proteins for food	• Biological plant protection	
• Probiotics for human consumption	• Anaerobic digestion of slurry	
• Enzymes	• Probiotics for animals	
• Bio fuels	• Alternative proteins for fodder	
• Enzyme-based CCS and CCU	• Microbial milk proteins	
• Bio cement		
• Microbial materials		

Note: Examples of bio solutions marked in grey are solutions that are currently being developed and may be fully matured and scaled after 2030. Biofuels for transport consist of different product generations.
Source: Copenhagen Economics.

Towards 2030, we find the global achievable[1] emission reduction potential of mature, ready to deploy technologies to be around **4,300 million tons of CO_2 equivalents in 2030**,[2] corresponding to around eight per cent of current emissions globally, and this is expected to increase past 2030. This potential is on top of the emissions already avoided: for example, through reduced energy consumption enabled by laundry detergent with enzymes, or less food waste due to longer shelf life of food products, such as dairy, meat, sea food, ready-to-eat foods and wine, brought about by fermentation processes using food cultures.

We find that the world markets for the bio solutions in Figure 1 could surge from EUR 240 billion in 2020 to **EUR 640 billion in 2030**. A greater uptake of bio solutions globally creates economic opportunities for countries with a strong bio solution industry as the market would expand, resulting in new value creation and new green jobs supported by bio solutions.

Looking beyond 2030, bio solutions that could further contribute significantly to CO_2 emissions reductions include expansion of the use of fermentation technology in feed and food production, enzyme-based carbon capture, fermentation-based gases for the production of jet and marine fuel, microbial production of milk protein for foods, spider silk, e.g., for the automotive industry, bio cement for construction, and fermentation to improve the digestibility in animal feed, which also leads to a reduction of phosphor and nitrogen in aquatic environments.[3] The markets for alternative proteins and other ready to deploy bio solutions are also expected to increase past 2030.

1 Achievable here means the potential that is achievable in 2030 given the right framework conditions. The technical potential is larger when bio solutions can achieve it if more extreme regulation, investments, consumer preference changes and market changes happen over a relatively short time span.
2 We consider metric tons throughout the report.
3 Copenhagen Economics, based on input from the Novo Nordisk Foundation.

In addition to decarbonisation, bio solutions can lower land use, increase yields, increase biodiversity, reduce feed, food waste, pesticides use, and water consumption, and enhance the food supply and food security. For example, alternative proteins free up agricultural land which can be used to restore biodiversity. Alternative proteins can also help grow a low carbon food supply for an expanding population. Bio controls can substitute pesticides, thus reducing negative impacts on the environment, ground water, etc.

Addressing key deployment barriers needed to attain full potential

While bio solutions hold large potential to enable decarbonisation in other industries, they face barriers that hinder their operationalisation and placement in the market. To deliver on the nearer term potential towards 2030, it is essential to address a number of **regulatory barriers and market barriers** that prevent mass deployment of mature products that have costs on a par with or above traditional solutions.

At the EU level, that includes an inefficient, inflexible, and outdated product classification and regulation that do not follow technological developments and innovation. Regulations that today cover bio solutions were originally designed to address concerns about products made from fossil fuels or chemicals, or to support conventional agriculture, as with the EU's Common Agricultural Policy (CAP). One example is the subsidies regarding the EU's CAP, which is not designed for modern farming techniques, such as algae food production.

These policies may have made sense at the time, but with the technological development of new solutions, the policies and product classifications have not been adapted and revised to the extent needed to reflect the current state of bio solutions. In addition, slow and expensive product approval processes pose another barrier to efficient market access for bio solutions in the EU, and its taxonomy for sustainable activities does not properly account for *enablers* of decarbonisation in other industries, which have implications for how bio solutions are perceived in this context.

What is needed is an update of the regulatory approach in this area, and some of the most developed countries in the area of bio solutions are leading the way. The US leads a very open policy towards new technologies with an innovation-focused regulation to attract bio solution investments, market shares, and economic activity to the US. They have, for example, implemented fast-track product approval processes and a regulation that allows for products to enter the market relatively quickly; US regulation is better suited for technological developments, concerning, for example, new genetic editing technologies and modern farming techniques. Similar policy movements can be seen in other high growth tech countries, like China.

In the short term, the EU can try the so-called "regulatory sandboxes" in which experimental regulatory designs can be developed and tested on a small scale to explore innovative ways of approving new products that are otherwise hampered by existing regulation. We provide examples of how regulatory sandboxing is already being used in different sectors and industries. In 2020, the EU council encouraged more exploration of this approach within the union.

One of the key **market barriers** to address is insufficient CO_2 pricing to remove any production cost gap between more expensive sustainable solutions and their alternatives. Bio solutions are not all currently economically viable products that can compete with already established non-sustainable solutions. Among the bio solutions we have studied, we found that a tax of EUR 70 per ton of CO_2e could make many mature bio solutions fully price competitive today, with the potential to reduce *more than two billion tons of CO_2e emissions globally in 2030*. The implementation of minimum carbon pricing instruments across the EU and different industries could lower the risk for bio solution companies and help bring sustainable products to the global markets faster, benefitting consumers, bio solution companies, national economies, and the environment.

Moreover, there is a need for new internationally recognized carbon pricing instruments that provide remuneration to providers of carbon capture and storage. Ideally, the size of the remuneration should be linked to the carbon pricing instruments already in place, as well as other instruments, to incentivize the development and deployment of carbon neutral production of energy.[4]

In an international context, the EU takes a leading role in regulatory design for carbon pricing. In early 2022, the EU ETS mechanism was imposing a de facto carbon price of EUR 80 per ton of CO_2 on energy-intensive activities such as the production of electricity, heavy industry, as well as domestic air transport. The European Commission is now proposing to tighten this mechanism, both with respect to future pricing and its industrial scope.

A key challenge in the coming years will be to entrench effective carbon pricing within the EU and to extend its scope to other sectors and link it where appropriate with regions outside of the EU to promote the economic viability of the production and uptake of climate mitigating technologies such as bio solutions. At the moment, no other global players have put in place equivalent carbon pricing mechanisms with the same scope and regularity stability.

To enable the development of the next generation of technologies to deliver on a net zero objective, it is also essential to address **financial barriers**, notably by improving access to risk capital all through the development phase, i.e., closing the financing gaps, including lack of financing in research and development (R&D) and demonstration plants. Public financing can, to a larger degree, support product development, not only in the early R&D stages but also later when scaling up to the demonstration stage.

Finally, the taxation of entrepreneurial income plays an important role: Innovation is often driven by dedicated leaders that leave a well-paid position in a successful company to create a business, often characterized by both high risks and high returns.[5] To underpin such value-creating career moves, it is important not to be penalized by the taxation system, particularly the taxation of dividends and capital gains in personally held companies. Denmark is an outlier with the highest effective taxation of such companies,[6] retarding growth and innovation in high risk and high return businesses.[7]

[4] Mogensen, Birgitte, Gorm Boe Petersen, Helge Sigurd Næss-Schmidt og Holger Nikolaj Jensen (2021), *Beskatning af CO2-procesemissioner i praksis – en model til inspiration.*.

[5] Copenhagen Economics (2018), Copenhagen Economics 2019.

[6] US Tax Foundation provides recurrent updates of global tax rules, showing that the rates for taxation of capital gains and dividends are arguable the highest in OECD.

[7] Axcelfuture (2014)

We provide 12 concrete policy recommendations in Chapter 2. For a short summary of the barriers and recommendations, see Table 1 at the end of the executive summary.

Strong Danish position in bio solutions

Denmark has a strong international position within bio solutions with well-established companies and innovative start-ups that deliver high-quality products to the global market. Products include alternative proteins, bio energy, bio-based ingredients, bio pesticides, bio plastics, enzymes, probiotics, food cultures, and fermentation solutions for feed and food. Denmark's strengths within biotechnology are centred around a unique ecosystem of companies providing Denmark with a comparative advantage[8] for developing bio solutions in close cooperation between the industry and research institutions.

The Danish bio solution industry contributed **EUR 1.8 billion** to Danish gross domestic product in 2020[9] and supported approximately 6,800 jobs in Denmark[10], many of which are highly productive jobs in research, development, and skilled manufacturing. The industry employs people with different educational backgrounds, such as laboratory technicians, economists, process operators, veterinarians, and chemists. Around four out of ten people in the industry have either a vocational education or are unskilled workers. The industry is heavily internationalized with Danish exports of bio solutions reaching **EUR 3.6 billion** in 2020[11], constituting almost 80 per cent of the industry's revenue.

Danish companies can increase their global sales to more than **EUR 14 billion in 2030** if the companies hold their current market share moving towards 2030. This could add an **additional 7,200 jobs** across Danish bio solution companies by 2030. In addition, the bio solution industry could help maintain rural jobs in Denmark, even with the ambitious Danish climate goals, through its enabling of emission reductions in hard to abate industries, like agriculture, often located in rural areas.

---

8 A comparative advantage is a country's ability to produce a good at a lower opportunity cost than its international competitors, i.e., the cost of producing the good is lower than producing other goods. See Investopedia (2021).
9 Equivalent to 0.5 per cent of total Danish GDP. Based on numbers from Statistics Denmark.
10 Equivalent to 0.2 per cent of total employment in Denmark.
11 Equivalent to 2.2 per cent of Danish exports.

Table 1
Barriers and policy recommendations

Category	Barrier	Policy recommendation
Regulatory barriers	Outdated product classification and regulation	• Continuously update product classifications with the technological development of newer solutions. • Include enabling technologies as a relevant parameter in the taxonomy for sustainable activities for sustainable financing. • Update to more flexible regulation to allow for technological advancements and innovation: for example, in GMO regulation. • Ensure a level playing field (LPF) between traditional solutions and newer solutions by considering indirect subsidies given to traditional solutions (e.g., agriculture) and consider implementing an assessment of emissions of solutions as a relevant parameter to determine LPF.
	Restrictive labelling	• Support the development of standardized labels for CO_2, biodiversity, etc., to allow companies to advertze positive impacts.
	Long-term product approval processes and high costs	• Reduce time-to-market for sustainable solutions with a fast-track solution for approval of new products. • Lower the administrative cost burden, particularly for smaller companies. • Make more use of regulatory sandboxes to test new regulatory approaches to safeguard public policy objectives.
Market barriers	Cost gap	• Strengthen the current EU ETS system with potentially a floor to ETS price and extend the scope to more sectors as proposed by the EU Commission. • Introduce carbon pricing of negative emissions, i.e., remuneration to providers of carbon capture and storage. • Encourage other global players to follow the EU's lead in establishing systematic carbon pricing, notably for intensive producers of greenhouse gases.
Financial barriers	Access to risk capital	• Increase public financing of biotech R&D and the demonstration phase to crowd-in private capital. • Ensure that taxation of capital income does not penalize entrepreneurs that have a key role in driving innovation in highly promising areas of innovation.

Source: Copenhagen Economics.

CHAPTER 1

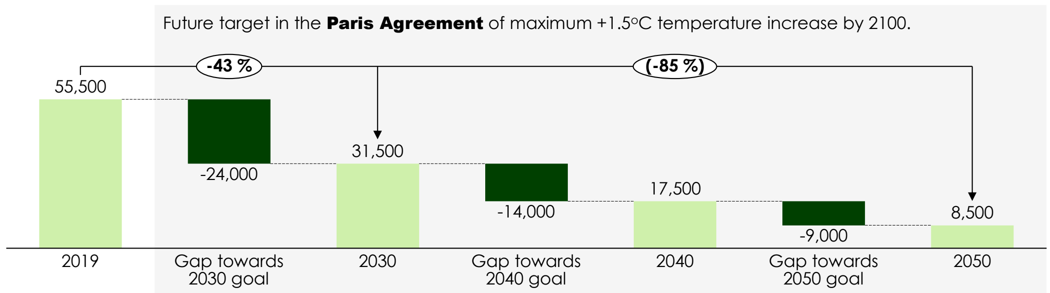
BIO SOLUTIONS HOLD GREAT POTENTIALS TO DELIVER ON CLIMATE GOALS

Attaining the Paris Agreement targets will require a massive effort to reduce greenhouse gases on a global scale, yet current policies will fall short of delivering on such targets. Bio solutions will help reduce emissions, together with other climate policy technologies. In this chapter, we explain both the target gaps (1.1) and how bio solutions may progressively help to close these gaps over the coming decades (1.2).

1.1 GLOBAL DECARBONISATION NEEDS TO SPEED UP

To reach the Paris Agreement target of a maximum 1.5°C global temperature increase, world emissions should be reduced by more than 80 per cent by 2050 to 8,500 million tons of CO_2e, see Figure 2. Half of these reductions should be achieved already by 2030. This requires a dramatic reversal in emission trends: when the Paris Agreement was signed in 2015, the world's population emitted around 52,000 million tons of CO_2-equivalent (CO_2e)[12] after decades of increasing emissions, reaching 55,500 million tons in 2019.

Figure 2
Global CO_2-equivalent emissions in 2015 and future emission targets for 2030-2050
Million tons of CO_2e

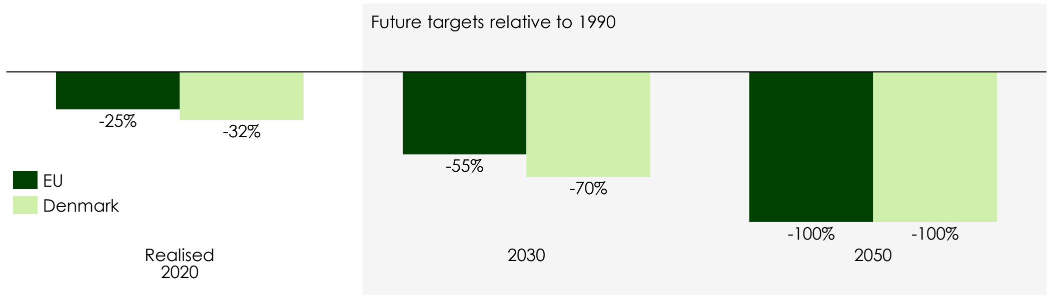


Note: Future targets are the IPCC Scenario for +1.0 to + 1.9°C (SSP1.0-1.9). Methane and nitrous oxide are converted into CO_2-equivalent emissions using the factors 25 and 298, respectively: see link. Numbers have been rounded to the nearest thousand.
Source: Copenhagen Economics based on IPCC (2021), p. 17.

The EU and Denmark have started the path to decarbonisation, and by 2020, Denmark had lowered its emissions by 32 per cent relative to 1990, and the EU had lowered emissions by 25 per cent, see Figure 3. Denmark has a more ambitious emission reduction target in 2030 of 70 per cent reduction, whereas the EU reduction target is 55 per cent. Both the EU and Denmark plan to become carbon neutral by 2050.

[12] CO_2-equivalent emissions convert into a "Global Warming Potential" measured in effect of *per ton of CO_2*. For example, this means that 1 ton of CO_2 = 1 ton of CO_2e, 1 ton of methane (CH_4) = 25 tons of CO_2e.

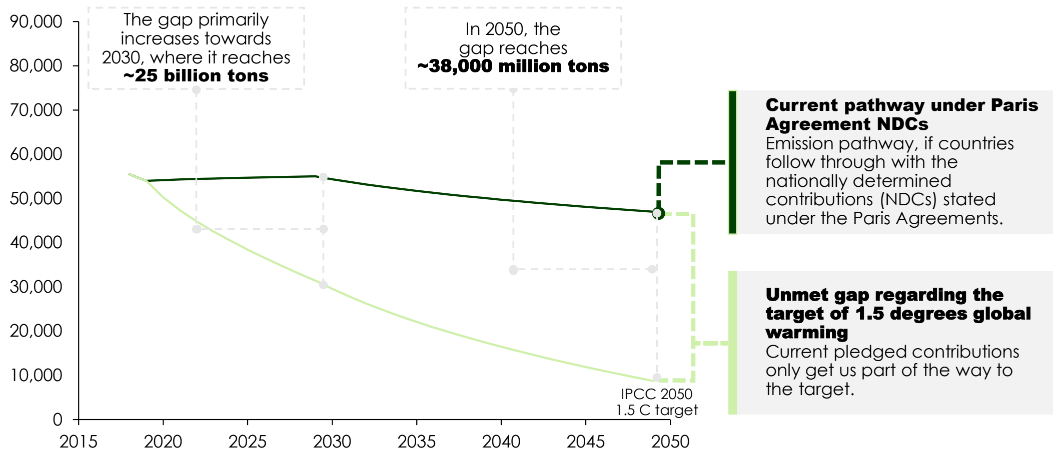
Figure 3
The CO_2 reductions of the EU and Denmark and future targets relative to 1990 levels
Per cent relative to 1990



Source: Copenhagen Economics.

These targets are ambitious and require big transformations in decarbonisation in all sectors of the global economy. But there is a global *unmet gap* to these targets, as current technologies and pathways are not providing enough reductions, and the global gap increases to around 25,000 million tons in 2030 and to 38,000 million in 2050, see Figure 4. New novel solutions will have to be developed, supported, and rolled out globally – including ***bio solutions***.

Figure 4
Global emission reduction pathways and gaps towards 2050
Million tons of CO_2e



Note: Pledges are as of October 2021, i.e., not considering potential new pledges during and after COP26 in Glasgow. Future targets are the IPCC Scenario for +1.0 to + 1.9°C (SSP1.0-1.9). Methane and nitrous oxide are converted into CO_2-equivalent emissions using the factors 25 and 298, respectively.
Source: Copenhagen Economics based on UNEP (2021) & IPCC (2021).

The EU has ambitious goals to lower emissions by 55 per cent by 2030, reduce plastic waste and pesticide use, and increase biodiversity and food supply: see Table 2. While the EU is moving in the right direction for these initiatives, there is still a long way to go. Certain bio solutions can help the EU reach its goals in addition to emission reduction potentials concerning land use, biodiversity, food supply, etc. *Throughout this chapter, we show examples of these benefits in boxes.*

Table 2
EU strategies and statuses

EU strategies	Description	Status
FitFor55	**Goal by 2030:** 55 per cent reduction in the EU's emissions in 2030 relative to the level in 1990.	As of 2020: EU emissions were **25 per cent lower** than in 1990
Plastic Strategy	**Goal by 2025**: Ten million tonnes of recycled plastics on the EU market.	A **gap of 3.4** million tonnes of recycled plastic remains **in 2020** before reaching the target.
Farm2Fork	**Aim:** The Farm to Fork Strategy aims to transition to a sustainable food system: - Have a neutral or positive environmental impact. - Everyone has access to sufficient, safe, nutritious, sustainable food. - Reduce food waste by 50 per cent by 2030.	The use of chemical pesticides in the EU has **decreased by 5%** in 2019 compared to the 2015-2017 baseline period; the use of hazardous pesticides decreased by 12%.[13]
EU Biodiversity Strategy	**Goal by 2030:** - Protect a minimum of 30% of the EU's land and sea area. - Reduce the use and risk of pesticides by 50% by 2030. - Restore 25,000 km of EU rivers to a free-flowing state. - Plant 3 billion trees by 2030.	Currently, **26% of EU land is protected**.

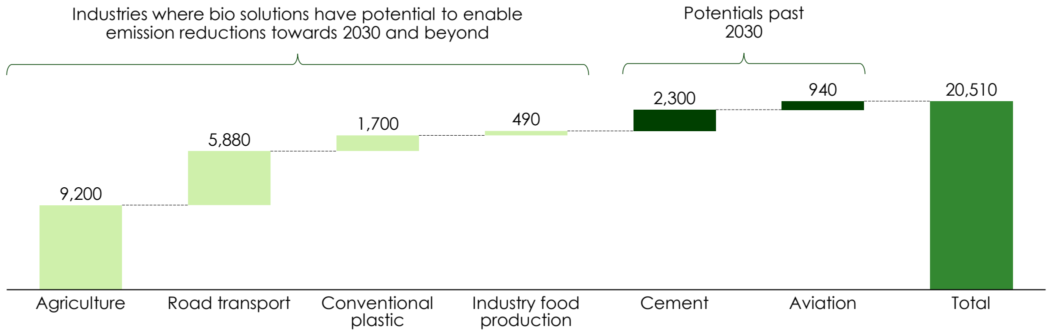
Note: Most strategies are relatively recent, and their statuses have not yet been assessed.
Source: European Commission (2018), European Commission (2020, d), European Commission: *Fit for 55,* European Commission (2020, e), European Commission: *Circular Plastic Alliance* & European Commission (2021, c).

Bio solutions are particularly useful in industries accounting for a large share of total emissions and very high GHG intensity in production. This includes the agricultural sector, including animal proteins (meat and dairy), fermentation, slurry solutions, fodder, and fertilizers. Agriculture's global emissions account for 9,200 million tons CO_2e, see Figure 5. Similarly, bio solutions can help decarbonize parts of the plastics industry, and the feed and food industry. Advanced biofuels, with a low land use impact, can play an important role in the transport sector, notably in regions or industries where electric vehicles will be a challenge to implement in practice. Bio solutions also have additional potentials past 2030: for example, in the cement industry, in aviation, and for carbon capture and storage or utilisation in manufacturing industries.[14]

[13] Denmark has a five-years strategy to lower pesticide use in agriculture and has recently started a partnership and 20 initiatives to improve the environment in Danish waters. Source: Miljøministeriet (2021) and Miljø- og Fødevareministeriet (2017)

[14] CCS potential overlaps with other industry emissions, which is why they are not included in the figure.

Figure 5
Global emissions in industries in which bio solutions can help abate emissions
Million tons of CO_2-equivalent emissions in 2016



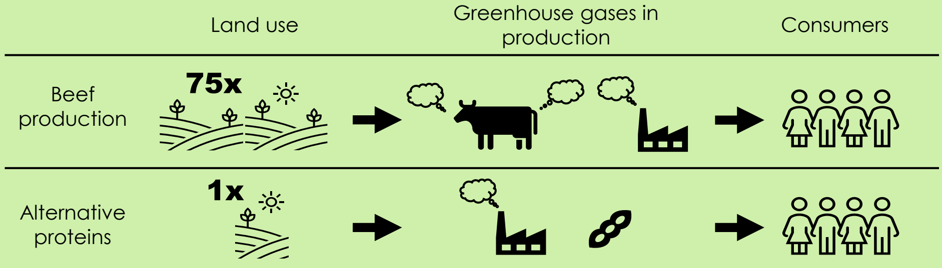
Note: The bio solutions *are not expected to remove all emissions in these industries*, see Figure 7. Numbers are rounded to the nearest 10 million. The number for conventional plastic emissions is for 2015. Agriculture covers livestock, slurry, energy used, rice cultivation, agricultural soils, crop burning, and deforestation.

Source: Copenhagen Economics based on Our World in Data, Global Efficiency Intelligence (2021), and Zheng & Suh (2019).

Box 1 Bio solutions can have positive impacts on land use and biodiversity

Bio solutions can free up agricultural land to help preserve biodiversity. Many bio solutions reduce the surface required for agricultural land use. For example, beef production uses *up to* 75 times more land than certain alternative proteins, such as industrial proteins: see below.[15] In fact, farmland needed to feed the world's population could decrease by 75 per cent if meat and dairy were to be substituted with other protein sources.[16] In addition, food cultures and probiotics can increase agricultural yield and food industry productivity, while also decreasing waste and land use.

A stylized representation of beef and certain alternative protein ecosystems



If 10 per cent of the world's animal protein was replaced with alternative proteins, this would free up 900,000 km^2 of agricultural land and avoid 700 million tons of CO_2, almost equal to the cultivated land in Brazil and the annual CO_2e emissions in Mexico.[17] The land can be restored and provide living space for wild plants, indigenous animals, etc. Alternatively, it can serve as carbon sequestration through afforestation or can provide biomass for construction, energy or biofuels.[18] Some bio solutions, such as the first generations of biofuels, require biomass input and could, therefore, lead to an increase in land use and a potential loss of biodiversity unless there is a redistribution of current biomass.[19]

Alternative proteins also increase the security and supply of food globally. The world population continues to grow, and more people need to be fed, while the land available to agriculture remains the same, or is potentially reduced due to climate change and droughts.[20] Alternative proteins, thus, help safeguard the global food supply as the same nutrition needed to satisfy global food demand can be farmed on less land than needed for animal-based protein sources.

[15] IRIS Group (2021) p.18. There are many types of alternative proteins, some of which use the same amount of land as traditional proteins, but key to all is that they all lower the amount of CO_2e emissions.
[16] Poore and Nemecek (2018)
[17] Novozymes (2021, b).
[18] Hayek et al. (2020).
[19] Wiens et al. (2011).
[20] Valin et al. (2013).

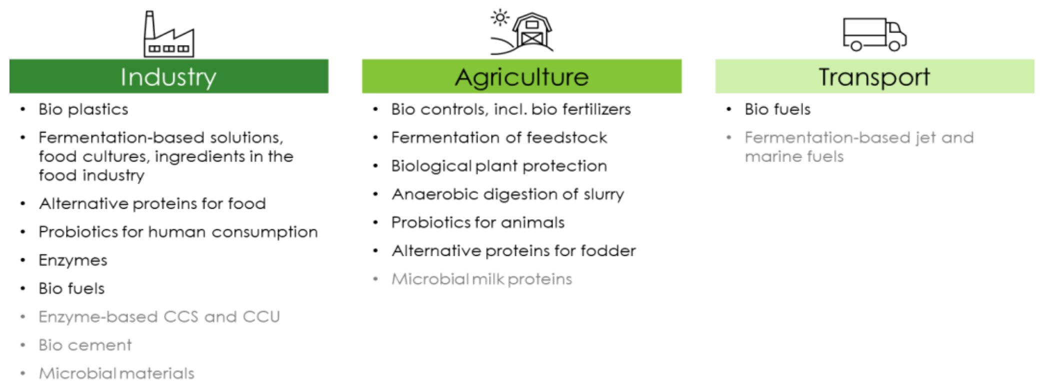
1.2 BIO SOLUTIONS ARE ENABLING TECHNOLOGIES WITH MANY DIFFERENT USES

Part of the solution to global decarbonisation is the development and use of biologically-based products and processes or **bio solutions**. Bio solutions comprise upstream enabling technology that allows a wide range of downstream industries to decarbonize by increasing efficiency in production processes and use, or by substituting conventional products 1-to-1: see definition below.[21] Bio solution companies make use of, for example, microorganisms and fermentation technology to obtain results that cannot be achieved through conventional processes.[22]

*Bio solutions are composed of **biological products that are anchored in biotech**, i.e., they utilize **living organisms**, including enzymes, microorganisms, bacteria cultures, pheromones, etc. for concrete applications and products that are used in other industries' manufacturing processes and as end products to **enable sustainable transformations such as emission reductions**.*

Bio solutions are notably important for the decarbonisation of industry, agriculture, and transport, and we concretely examine solutions within these sectors, see Figure 6.

Figure 6
Bio solutions usages in different economic sectors



Note: Examples of bio solutions marked in grey are solutions that are currently being developed and may be fully matured and commercially scaled towards 2040. Biofuels for transport comprise different product generations: while the 1st generation is already commercialized, the following 2nd and 3rd generations, with much lower land use, are growing in importance (the so-called advanced biofuels).

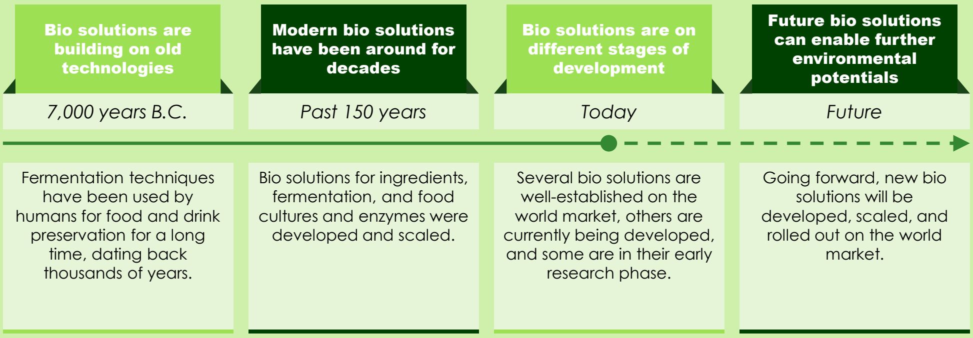
Source: Copenhagen Economics.

[21] The definition is based on the definition by Alliance for Bio Solutions (2021). See Appendix A for a description of different bio solution groups and utilisations. We do not examine biobased pharmaceutical products or other bio solutions not mentioned in Figure 6.

[22] IRIS Group (2021), p. 6.

Box 2 A timeline for bio solutions

Bio solutions are not new inventions. For thousands of years, people have used fermentation techniques for brewing and to increase the durability of food: see below. The solutions range from early-stage basic research bio solutions to globally scaled bio solutions that people use in their everyday life. Some bio solutions are currently being tested and could be the next to be rolled out: for example, carbon capture and utilisation with enzymes or algae.[23] Other bio solutions that were developed in the last decades have been rolled out on the global markets. These include industrial enzymes, food culture solutions, and biofuels for road transport.



Source: Copenhagen Economics and University of Pennsylvania (2004).

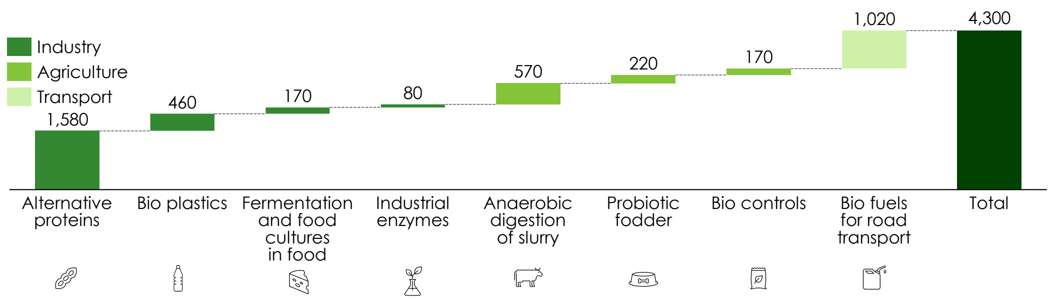
Some bio solutions are already globally scaled and are now mitigating emissions, including enzymes in laundry detergent, fermentation processes, food cultures; however, there is a large potential for further increases.[24] By 2030, we find that the global climate potential of eight bio solutions in these three industries could deliver **4,300 million tons** of CO_2e reduction, equivalent to eight per cent of global emissions, see Figure 7, notably in agriculture and transport. The potentials vary greatly between different solutions, from 80 million tons of CO_2e from industrial enzymes to 1,580 million tons of CO_2e for alternative proteins.[25]

[23] See Novozymes (2021, a) and Algae Biomass Organization (2019).

[24] For example, the bio solution company Novozymes enabled these bio solutions to an annual reduction of around 90 million tons of CO_2e in 2019. Novozymes (2020), page 5.

[25] Assuming a global market share of 20 per cent for alternative proteins in 2030. The results depend on the market share that is achieved in 2030: see Appendix A. The impact may be greater if the bio solution takes a larger market share, or less if the market share does not materialise: for example, due to consumer preferences or if the market does not develop as expected.

Figure 7
Selected bio solutions' global emission reduction potential in 2030
Million tons of CO_2e



Note: For details on the assumptions and calculation of the emission reduction potentials, see Appendix A.
Source: Copenhagen Economics based on sources listed in Appendix A.

Biofuels and bio plastics also have large emission reduction potentials, primarily for transport and industry, of 1,020 and 460 million tons of CO_2e, respectively, by 2030. Other technologies show relatively smaller emission reduction potentials. This is mainly due to the development of these products and processes to date as they are already widely implemented, for example, in laundry detergents, and the large utilisation today implies smaller future emission reduction potentials.

Box 3 Biogas as an energy bio solution

Biogas is a well-established source of energy that has many different uses as substitute for natural gas and is thus abating CO_2 in industrial processes, in power generation, and for heating buildings. There is a large potential for expansion of biogas worldwide from 35 million tons of oil equivalent (Mtoe) to 730 Mtoe.[26] In this report, we consider one additional source of biogas, namely the anaerobic digestion of slurry, but there are many other production methods, for example, from other agricultural, industry, and household waste, etc.

Imports of natural gas from unstable regions pose a risk as gas is currently a key input in many production processes for power generation and for heating. An advantage of producing more biogas is, therefore, apart from the environmental benefits, that it makes the producing country less reliant on imported natural gas.

In Box 4, Box 5, Box 6, and Box 7 below, we provide a more detailed description of the bio solutions in terms of alternative proteins, biofuels, and fermentation, and we deep dive into different uses of bio solutions for the reduction of pesticides, water use, and food and plastic waste, respectively.

[26] Based on numbers from 2018. Source: IEA: Outlook for biogas and biomethane: Prospects for organic growth

Box 4 Deep dive into selected bio solutions

Alternative proteins

Alternative proteins are specialized foods based on biological material or processes which are consumed as substitutes for the protein in animal products, such as meat, fish, or dairy. Alternative proteins can also be used in the feedstock for livestock. We consider alternative proteins for beef, pork, poultry, and dairy for consumers. Examples of alternative proteins are enzyme-enhanced or fermented plant protein, insects, mycoprotein, or algae.

The many products and uses of alternative proteins also mean that there are versatile technologies used to produce, extract and improve these proteins, including the use of enzymes, fermentation, growing algae in silos, etc. One aspect is to produce protein-rich food products from biological material; another is to improve flavour and texture so that consumers will actually buy these products.

The future market for alternative protein is difficult to predict since it depends not only on the price developments of alternative proteins, but also the product taste, texture, and consumer preferences, all of which have a potentially significant impact on the market for alternative proteins. If consumers broadly lower their consumption of meat and dairy proteins and substitute to a more traditional plant-based food consumption, this could have a sizeable impact on emissions but may not result in a large market share for modern alternative proteins.

Alternative protein can free up agricultural land which can be used for afforestation, producing biomass (for example for biofuels), among others.

Biofuels

Biofuels are biologically produced fuels that are used as substitutes for fossil fuels in transport, heating, power generation, and industrial processes, and are often grouped into different generations based on the maturity of the technology:

- 1st generation: edible biomass
- 2nd generation: non-edible biomass, such as organic waste, wood, and crop waste
- Newer generations: microorganisms, genetically engineered crops, pyrolysis

Over the coming decades, decarbonisation will increasingly be driven by advanced biofuels. While 93 per cent of the current production of liquid biofuels for transport is made with 1st generation processes (for example, from corn), large increases in 2nd and newer generation biofuels are expected towards 2030, such that later generations could make up to 45 per cent of production in 2030 and 90 per cent in 2050. Some argue that 1st generation biofuels compete with food production for use of land, although no correlation has been found between food prices and biofuel demand in Europe.[27] There is an increased focus on developing and maturing the later generations of biofuels. This is important for one reason in particular: the next generations are based on technologies and inputs that put much less strain on the use of land for food production. However, we consider all types in this report as they may all contribute to emission reduction.

[27] Based on European analyses: see European Commission (2020, f), page 16.

Fermentation

Fermentation of food is an old technology used to safely preserve food for a longer period of time: for example, in bread, cheese, wine, fish, etc. The technology is widely used in the current food system, where it is used in anything from animal fodder to yogurt.

The technology has the potential to enable a more sustainable food system with safer food by reducing spoilage and pathogens. Fermentation can also help produce healthier food and reduce food waste: for example, by improving the nutritional composition of food and prolonging the shelf life.

Given the impacts on prolonged shelf life and improved food production, fermentation technologies also have potentials to reduce global emissions.

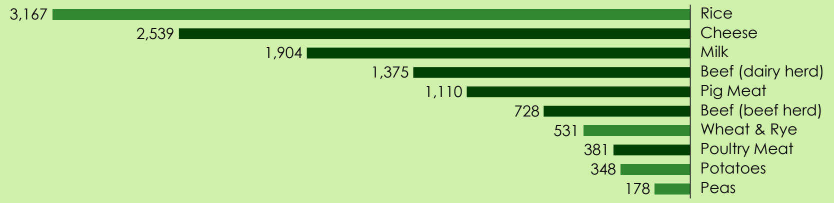
Source: Allied Market Research (2021), Precedence Research (2021), Australian food and agribusiness: *Alternative protein sources*; McKinsey & Company (2019, a), IEA (2021), page 106-107, Chr. Hansen

Box 5 Bio solutions can reduce water use

Bio solutions can reduce water use, as cattle consume more water than plants for the same level of nutritional production. For example, beef production requires up to 1,400 litres of water per 100 grams of protein: see below. Substituting some plant-based alternatives could lower the use of water, and substituting alternative proteins from, for example, algae could, in some cases, lower the water consumption even more.[28] The water consumption to produce alternative protein using fermentation is estimated at 3.6 litres per 100 grams.[29] Algae that grow in sea water require no filtered water to grow, and can be used as fodder, biofuels, or to capture and utilize carbon emissions.[30] Similarly, industrial enzymes use less water than chemical processes. For example, using certain bio solutions in the textile industry results in less wastewater.[31]

Water use in food production

Litres per 100 grams of protein



Source: Poore and Nemecek (2018).

[28] European Protein estimates that they only require 250 litres of water *per ton final product*. Note that this is only in their own production process and does not factor in water consumption in producing the crop used in their production.

[29] Based on preliminary data from Novozymes (2019).

[30] Araújo et al. (2021).

[31] Chen et al (2007).

Box 6 Bio solutions can reduce waste

Food waste

170 Kg of food is, on average, wasted per person in the EU every year, equivalent to around 20 per cent of total food production.[32] Food waste results in the *overproduction* of food which is, therefore, also a source of global emissions, estimated at six per cent.[33] Most of the waste stems from households, food production, and retail, leading to higher food production and higher emissions from European food production. Food cultures can help prolong the shelf life of a wide range of food products, ranging from dairy to meat, seafood and ready-to-eat foods, by delaying the growth of spoilage and pathogenic bacteria. For example, food cultures can reduce yogurt waste by up to 2 billion tons globally per year.[34] Similar waste reductions are achieved by using fermentation for feed (silage).

Plastic waste

The world produces around 240 million tonnes of plastic waste annually.[35] Starch-based bio plastics are, per se, biodegradable and can help reduce the amount of non-degradable plastic waste on land and in the oceans.[36] Further, certain enzymes can degrade plastic by 90 per cent within 10 hours.[37] A wide roll-out of such enzymes could reduce considerable amounts of plastic waste. Other bio solutions can replace plastics in our economies. For example, Bio resin glues all sorts of natural materials to create sturdy fibres.[38] Applications have been explored in wind turbine construction, car manufacturing clothing, food packaging, etc.[39]

Box 7 Bio solutions can reduce pesticide and chemical remnants

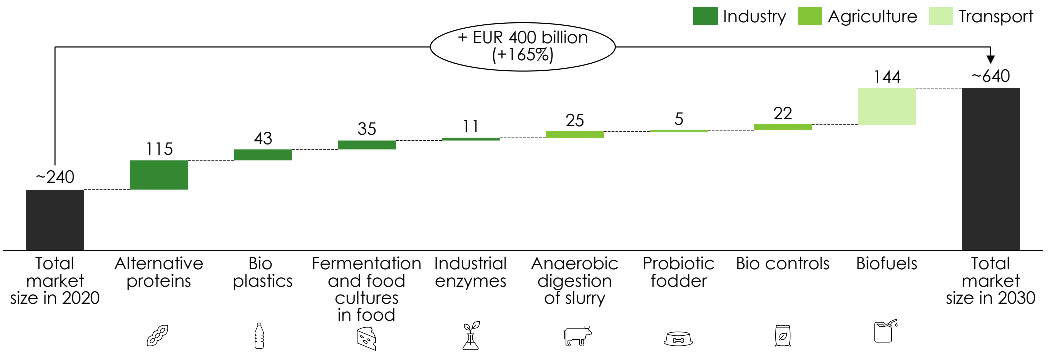
Pesticides are used on crops and agricultural land. Over time, pesticide remnants ooze into the groundwaters.[40] If 10 per cent of chemical pesticides were replaced by biologicals, this would save 250 million kg of chemicals from entering our ecosystems. If all detergents were bio-based, this could reduce the use of fossil-based chemicals by five million tons.[41]

---

32 European Commission: *Food Waste*.
33 Our World in Data (2021)
34 Chr. Hansen (2020), page 6.
35 World Bank: *What a Waste 2.0*.
36 Van den Oever et al. (2016).
37 HBS (2021a).
38 Developed by Pond Global.
39 IRIS Group (2021), p. 20.
40 IRIS Group (2021) p.16.
41 Based on information from Novozymes & Novozymes (2021, b).

On aggregate, the bio solutions we examined had a global market size of **EUR 240 billion in 2020**, see Figure 8, where, in particular, biofuels[42] (incl. biogas) and industrial enzymes (for example, in laundry detergent) are well-established markets. The global market potentials in 2030 of these bio solutions could reach around **EUR 640 billion**, i.e., an increase of EUR 400 billion (165 per cent) over 10 years. This growth depends on an increase in demand for green solutions, expected reductions in cost differences, as well as changes in policies.[43]

Figure 8
Global market potential for selected bio solutions from 2020 to 2030
Billion EUR



Note: We extrapolate the numbers for the global market potential in 2030 based on the assumption that the annual growth rate between 2020 – 202x ("x" differs across markets) continues towards 2030. For details about assumptions and calculations, please refer to Appendix A. "Biofuels" mainly include fuels for road transport.
Source: Copenhagen Economics based on sources listed in Appendix A.

The markets for biofuels and alternative proteins are expected to be the main drivers of the increase towards 2030, with expected market increases above EUR 100 billion for both. Furthermore, fermentation using food cultures, anaerobic digestion of slurry, and biological plant protection products and fertilizers are expected to increase, with a combined increase of also around EUR 100 billion. Future market potentials are uncertain as many factors are still unknown, such as price developments, end-user uptake, developments of new cost-competitive products that could take over the market, and policy developments, all of which can influence the markets.

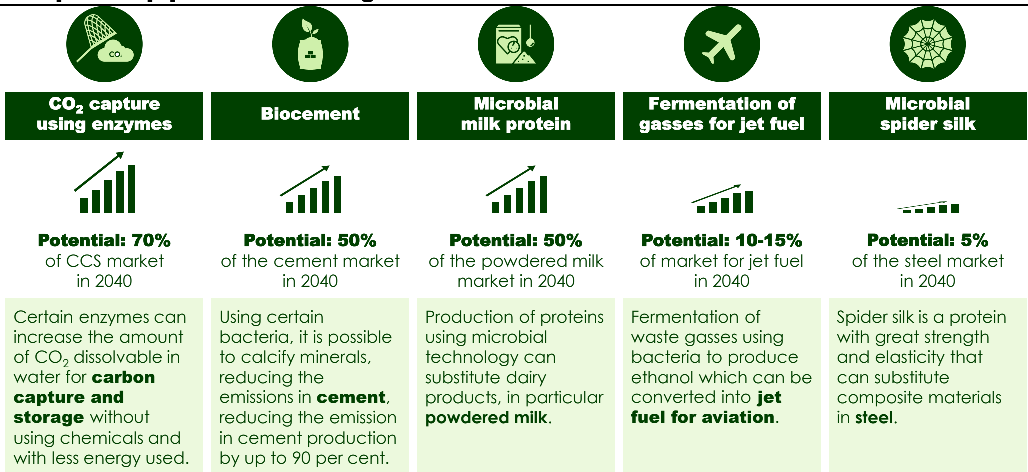
42 Includes first, second, and third generation of biofuels. Second and third generation account for approximately one-third of the expected market increase: see Allied Market Research (2021). For third generation biofuels, which cover microorganisms, including algae, see, for example, Neto et al. (2019).

43 Based on market research analyses of markets, factoring in demand forecasts, price developments, and some policy changes. Policy changes are only accounted for in some markets. For example, the industry report for anaerobic digestion includes "*stricter regulation to minimize greenhouse gas emissions*". We use industry forecasts for 2026 and 2028, and we extrapolate the year-on-year increases to reach a market potential in 2030. See sources in Figure 8.

Pipeline technologies after 2030

When we look past 2030, bio solutions could play a significant role to curb and reduce emissions. Upcoming bio solutions include enzyme-based carbon capture, fermentation-based gases for the production of jet fuel, microbial production of milk protein for foods, and microbial production of materials like spider silk (e.g., for the automotive industry), and bio cement (e.g., for construction).[44] Although the figures are uncertain, Figure 9 below illustrates areas where pipeline technologies may produce emission reductions further down the road.

Figure 9
Examples of pipeline technologies further down the road



Note: Illustrative examples of potentials with uncertainties as these technologies have not been tested on a large scale yet.
Source: Copenhagen Economics based on information from the Novo Nordisk Foundation.

44 Copenhagen Economics based on input from the Novo Nordisk Foundation.

CHAPTER 2

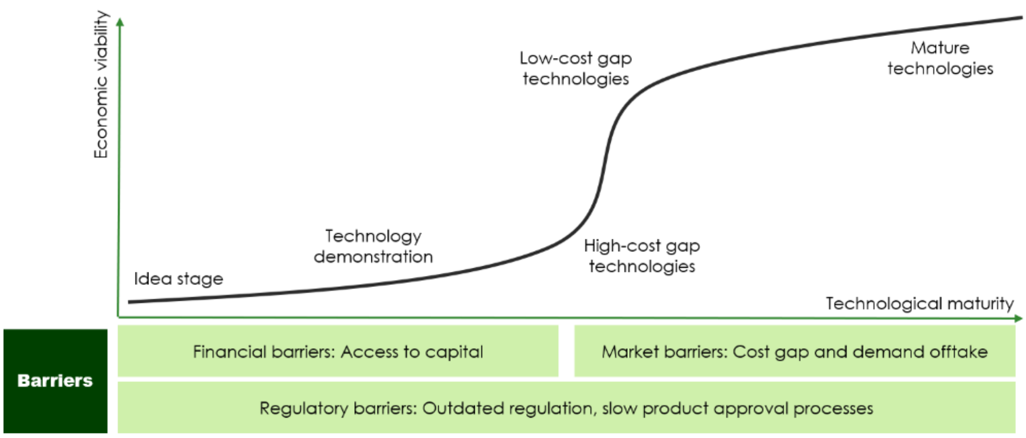
POLICIES TO SPEED UP REDUCTIONS OF GREENHOUSE GASES AT THE GLOBAL LEVEL

As highlighted in Chapter 1, there is a large potential to address the climate challenge by deploying mature bio solutions over the coming decade, as well as to develop the next generations for the coming decades. This raises the questions: What can policymakers do to unlock that potential, and what are the barriers that must be broken down? In answering these, we first define a typology of barriers that hold back the deployment of mature technologies (2.1). Then, we go deeper into how we can speed up the near-term deployment of bio solutions focusing on breaking down *regulatory and market barriers* (2.2), and finally *financial barriers* for funding new technologies (2.3), based on research, interviews, and international best practices.

2.1 A TYPOLOGY OF BARRIERS: FROM THE IDEA STAGE TO GLOBAL ROLL-OUT

Barriers exist throughout a bio solution's lifetime, from the idea stage to fully technically mature technologies, where the solution is ready to be rolled out globally, see Figure 10.[45] **Financial barriers** are particularly relevant in the early development stages, while **market barriers** are more relevant for more mature technologies. **Regulatory barriers** exist throughout a bio solution's lifetime. Regulation should – to the degree possible – relate to these stages of development and should not hinder the deployment or innovation of new bio solutions. It should, to the degree possible, lower the time-to-market for new solutions, while still adhering to high standards of consumer and environmental safety.

Figure 10
Barriers in different levels of development – from the idea stage to mature technologies



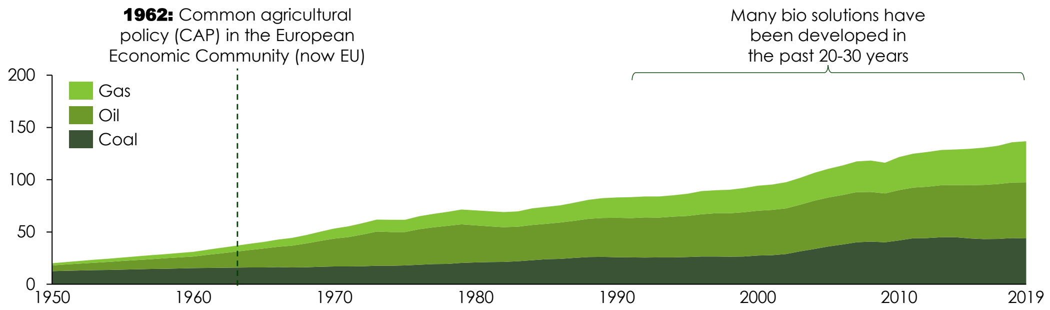
Source: Copenhagen Economics based on interviews and desk research.

45 We list identified barriers in Appendix B, of which we analyse some in this chapter.

2.2 REMOVING REGULATORY AND MARKET BARRIERS TO SPEED UP NEAR-TERM DEPLOYMENT

Regulation is a product of needs at different times, and traditional farming, fossil fuels, and chemicals have been a part of the world much longer than most of the bio solutions examined in this report, see Figure 11, as many bio solutions, apart from traditional fermentation, have only been developed in the past decades. Given the importance of agriculture and fossil fuels historically, it is natural that past regulation was designed to facilitate the positive uses and to limit the concerns in these industries, and not to facilitate the use of novel bio solutions that did not exist at the time. However, if regulation is not agile and adaptable, or continuously, or at least periodically, updated to support advancing technologies and innovation, it creates a divide between established products and the near-term deployment of newer, more mature bio solutions.

Figure 11
Energy consumption of fossil fuels globally, the introduction of the EU CAP, and the development of bio solutions, 1950 to today
Petawatt hours



Source: Copenhagen Economics based on Our World In Data, retrieved November 1, 2021.

2.2.1 A level playing field in product classification and regulation

Product classifications are key regulatory tools used to group products and processes under certain regulations. These regulations and classifications were originally designed for safety, human health, consumer information and securing nutritional value. However, despite the technological advances in new bio solutions, product classifications have not been updated accordingly, everywhere. For example, new food products *designed* for human consumption would fall under the EU's *Novel Food regulation*[46] if the food product has not previously been consumed in the EU, meaning that new solutions are delayed in their deployment, resulting in missed CO_2 avoidance. Table 3 provides more examples of distortionary regulation that was designed for other purposes than bio solutions, and the problems it gives rise to.

46 European Commission: *Novel Food*.

Table 3
Identified problems with EU product classification and regulation

REGULATION	DESCRIPTION	PROBLEM
Product classification	Product classification categorizes newer products under product regulation, which is designed for the *traditional* product characteristics.	Certain bio solutions have to follow regulations designed for product characteristics that are not relevant for them, which can increase time-to-market, missed CO_2 avoidance, lower profitability, etc.
Common agricultural policy	Industrially produced proteins do not achieve the same level of subsidy as traditional farming.	The uneven playing field between traditional agricultural products and new bio solutions lowers opportunities for bio solutions.
Novel foods	A specific food regulation for food products not consumed in the EU before 1997 to get a product or additives approved in the EU.	Longer time-to-market for novel food products, resulting in missed CO_2 avoidance.
By-products from animal production	Regulation limiting the use of by-products/side streams to use in human consumption.	Removes possibilities to upcycle by-products from animal production, for example, to use as fodder for later human consumption, and lowers opportunities to use waste products efficiently.
Genetically modified organisms	EU GMO regulation is from 2001, and modern genomic techniques have evolved since then.	Low market access for new genomic techniques in the EU, resulting in innovation and investments moving to other regions

Source: Copenhagen Economics based on IRIS Group (2022), literature review and interviews.

Product classification

Newer solutions that resemble the *uses of traditional products* are sometimes grouped under the same regulation as the traditional product, which effectively means that newer solutions are boxed in the same product class as their non-sustainable alternatives as there is no separate NACE classification for the given bio solution. One example is biological plant protection which is defined under the same regulation as chemically produced pesticides.[47] There are several problems with the EU's product classification and regulation:

1. The bio solution has to adhere to stringent regulations that may not be relevant: for example, risk assessment design based on one set of technologies, namely, to control hazardous substances in *chemical pesticides*.[48]
2. Product classifications are used to determine public subsidy levels and can, therefore, lead to lower subsidies for bio solution companies if they are grouped under a certain industry.
3. Microorganisms and fermentation technologies are not regulated *per se* in the EU, and food cultures are perceived as *food ingredients*. The development of new fermentation technologies has resulted in an unharmonized regulatory approach, where some member states require pre-market approvals of these technologies as *additives*, which complicates the approval procedure.[49]
4. Product classifications can lead to higher financing costs as investors increasingly focus on sustainable investments, for example, as defined under the EU taxonomy for sustainable investments,[50] which lowers investors' willingness to invest in companies defined as pesticide or chemical producers. As there is no separate NACE code for industrial bio solutions,

47 Examples from interviews.
48 The bio solution may contain other substances that still require a safety evaluation.
49 Based on information from Chr. Hansen.
50 European Commission: *EU taxonomy for sustainable activities*.

> these are categorized under, for example, chemicals, which is misleading as these products are often alternatives to chemicals. In addition, bio solutions often serve as an input into other industries as an enabler of decarbonisation, and it is not clear whether this characteristic is reflected in the taxonomy framework.[51]

In comparison, the US takes a more open approach by keeping a more updated regulation and adjusting to technological developments. For example, the US has adopted a separate regulation for biological plant protection, whereas biological plant protection is regulated under pesticide regulation in the EU.

Recommendation 1

Policymakers should continuously update product classifications with the technological development of newer solutions that substitute old production processes or traditional products with distinctive characteristics.[52] Adapt regulations to technical progress by classifying newer products according to their risk profile and not the technology used to produce them.

EU CAP

Newer bio solutions with food products do not have the same level of subsidy as competing agricultural products in the EU due to the design of the EU CAP. For example, the EU CAP financially supported farmers with so-called *income support* using an annual budget of above EUR 50 billion in 2019.[53] This support was given based on the *number of hectares of farmed land*. The regulation design creates an unlevel playing field as the CAP supports *farmed land* and, therefore, is given to bio solutions for alternative proteins when these are developed using enzymes, produced in silos or in water.

A recent critique of the EU CAP[54] highlights that the current system design does not work to lower emissions in EU agriculture but, rather, actively finances climate-damaging practices by paying farmers to, for example, cultivate agriculture on drained peatlands with a high emission footprint. Therefore, the EU Commission has begun to design new enabling measures to nudge farmers towards more climate-friendly practices.[55] In the US, in comparison, the USDA has announced grants for urban agriculture, and innovative production to promote the development of sustainable food systems.[56]

Recommendation 2

Policymakers should ensure a level playing field for food products by aligning subsidy levels to also include newer low carbon and sustainable production techniques and by considering the inclusion of avoided emissions as part of this evaluation of a level playing field to help enable climate-friendly practices. This effectively means that a sustainable solution has better conditions than a non-sustainable solution, all other things being equal.

---

51 Based on information from Chr. Hansen.

52 This means that biological plant protection could be grouped under a different product/industry group than pesticides if they do not contain the harmful substances that pesticides do. Similarly, companies should not be grouped as a chemical producer if they produce alternatives to chemical solutions that does not contain the same harmful substances.

53 *The EU CAP* was originally designed in 1962 and has been revised several times since then. European Commission: *The common agricultural policy at a glance* and *Income support explained*.

54 European Court of Auditors (2021).

55 European Commission: *The Effort Sharing Regulation and Land, Forestry and Agriculture Regulation*.

56 USDA (2021).

Novel foods regulation

Whereas food products in the EU, in general, adhere to the EU's General Food Law,[57] novel food products must first be accepted in the EU's *Novel Food* approval process,[58] which set up a stricter set of rules for novel foods that were not consumed to a significant degree in the EU before 1997. One of these principles is that "*novel food must not differ in a way that would be nutritionally disadvantageous for the consumer*". The regulation causes at least two problems:

1. Bio solution companies are spending more resources documenting and adhering to the regulation than they would have under the General Food Law.[59]
2. The regulation restricts the process of using nutritional additives in food products as food ingredients and additives.[60]

The US have another approach to novel foods that are not specifically regulated. The FDA considers any new food ingredient to be either a food additive (requiring pre-market approval by the FDA) or a "Generally Recognized as Safe" (GRAS) food.[61] Other countries like Canada, Australia and New Zealand, China, and a range of Southern American countries within the Mercosur common market, have adopted policies regarding new foods that are stricter than in the US, and they all require the application of pre-market approval before the introduction of novel foods.[62]

Recommendation 3

EU policymakers should consider allowing novel food products to follow only the EU's General Food Law, while still ensuring food safety.

GMO regulation

The *EU GMO directive* sets up the same requirements for 'traditional' genetic modification as newer genetic technologies,[63] which lowers the incentive to innovate using modern gene-editing.[64] The directive relies on the *technology used to develop* an organism for safety evaluation procedures. This approach was developed in the 1980s[65] before biotechnological innovation accelerated in more recent years. Today, the regulation still focuses on product technology rather than product characteristics in

57 In the General Food Law, the producer is responsible for the safety of the products and the national authorities perform controls to ensure safety of the products. European Commission: *Food law general requirements*.

58 European Commission: *Novel Food* and IRIS Group (2022).

59 A Danish bio solutions company needed three years to gain approval for a specific type of rapeseed that was not harmful to humans. Rapeseed/canola oil has, for many years, been used for human consumption, but in this case, the novel food product approval process had to start over, as human consumption of the type of rapeseed could not be traced back to before 1997 and, thus, required a new novel foods approval. The approval was given in Q1, 2021. The final decision to approve the product was not based on the data from the Danish company. Source: Interview with FermentationExperts AS in October 2021.

60 For example, companies are only allowed to use a small amount of additives in cocoa and yogurt alternatives as these products resemble traditional products too much and, therefore, cannot be too different in nutritional content. "*If foods and/or food ingredients were used exclusively in food supplements, new uses in other foods require authorisation under the Novel Food Regulation*". European Commission: *Novel Food Catalogue*.

61 Vapnek, Jessica, Kai Purnhagen and Ben Hillel, *Regulatory and Legislative Framework for Novel Foods*, Bayreuth Working Paper Series Food Law 03/2020, p. 16.

62 Ibid. p. 12-15.

63 Targeted mutagenesis methods, developed after 2001, are in the scope of Directive 2001/18. This follows the ruling from the Court of Justice of the European Union (CJEU) judgement in Case C-528/16. This includes recent advances in the gene-editing/CRISPR-Cas-9.

64 The EU GMO risk-assessment, for example, questions what foreign DNA is in a gene modified crop, which is not relevant to gene-edited crops as there is no foreign DNA in this process. Source: Labiotech (2020), IRIS Group (2022).

65 Based on information from Novozymes.

the safety evaluation, which has led to research investment being pulled out of the EU and a stalling of innovation there.[66] In addition, sustainability criteria are not considered in the evaluation. Therefore, the European Commission's Chief Group of Scientific Advisers have recommended revising "*the existing GMO directive to reflect current knowledge and scientific evidence, in particular on gene-editing and established techniques of genetic modification*".[67]

Certain biological products, including microorganisms, are not covered properly by the regulation. Some microorganisms cannot be distinguished from counterparts found in nature due to the increased accuracy of modern techniques. This constitutes a challenge for their traceability in the present framework.[68] In addition, the European Commission does not include microorganisms in its impact assessment for plants using new genomic techniques.[69] Consequently, microorganisms will remain subject to the current GMO legal framework in the EU while developments in other parts of the world are expected to continue rapidly. In addition, in GMO cultivation approvals, Member States can independently forbid the cultivation of an EU-approved crop on their national territory.

Many countries, including the US, Canada and several South American and Asian countries, exempt gene-editing from GMO regulation if it does not involve foreign DNA,[70] and the UK government has proposed certain gene-edited crops be allowed in England, and have recently allowed for more gene-editing research.[71] The number of approved GMO crops is, therefore, much greater in the US than in the EU (three times greater, as of 2016). Moreover, the amount of cultivated GMO crop land was more than 70 million hectares in the US in 2015, while the EU, altogether, grew around 0.2 million hectares across only five EU member states, allowing a limited set of genetic changes.[72]

Recommendation 4

EU policymakers should consider updating the GMO directive, to not focus on the production process but rather the potential risk pertaining to the product itself, while still upholding safety requirements for the environment and consumers. Further, the EU should consider including microorganisms in the new GMO legislation.

2.2.2 Labelling

The EU labelling requirements[73] are restrictive in the case of appraisals, health effects, and climate effects.[74] This limits bio solution companies' ability to use claims for marketing purposes showcasing the positive effects of their products. Some bio solution companies, therefore, do not publish the beneficial effects of their products as it is too difficult or cumbersome to label claims in the EU. There are also different appraisal opportunities within the EU.[75]

66 Labiotech (2020).
67 European Commission (2018).
68 As highlighted in Joint Research Centre (2019)
69 European Commission: *Legislation for plants produced by certain new genomic techniques*
70 Labiotech (2020).
71 The proposal includes gene-edited (GE) crops, which is simpler alterations to the plant's genetics than, for example, in genetic modification. The Welsh, Scottish, and Northern Irish governments can decide if they wish to adopt these changes. The separation of regulations applies as long as there is no foreign DNA involved. UK Gov (2021), BBC (2021), Labiotech (2020).
72 The Royal Society: *What GM crops are currently being grown and where?*
73 In the EU, the regulation falls under the Nutrition and Health Claims regulation. European Commission (2020, b)
74 This is both the case B2B and B2C sales. Based on interviews with bio solution companies in October-December 2021.
75 See IRIS Group (2022).

For example, the term *'Probiotics'* is interpreted by the European Commission as a health claim, but the EU health claims' approval system is not fit to consider the characteristics of probiotic microorganisms.[76] Despite being a well-known term in the EU, *'Probiotics'* cannot be used on claims for food supplements and food products. Outside of the EU, the term is widely understood and used for labelling.

Recommendation 5

Policymakers should support the development of standardized labels for CO_2, biodiversity, etc.

With the EU Green Deal and EU's Circular Economy Action Plan,[77] *there is a wish to standardize environmental claims to be substantiated using product and organisation environmental footprint methods.*

The problem with the EU organic label – and the Danish *Ø-label*[78] – is that they are only given to plants that are naturally grown in soil.[79] Food produced without pesticides, for instance, alternative proteins produced in tanks or from micro algae or products produced in vertical farming facilities that are typically grown in water (so-called *hydroponic production*), cannot obtain these labels, even though the production otherwise adheres to the organic regulation.

Recommendation 6

EU policymakers should consider expanding the organic label to include modern food production techniques when they adhere to the other regulation for organic products: for example, for alternative proteins.

In the US, hydroponic production is already considered organic.[80]

2.2.3 EU product approval processes and their cost burden

Slow product approval processes are one of the main causes of the long time-to-market that bio solution companies face in the EU. The slow processes add additional costs, lower the economic viability of new bio solutions, and postpone EU decarbonisation for two reasons:

1. Although the EU has the ambition that every process for pesticides should take 2.5-3.5 years,[81] there are examples of the processes taking up to eight years.[82] Similarly, the process for EU novel food products takes two years from submission to full application, but the process can be longer.[83] Slow product approval processes are caused by few administrative resources, low frequency of panel meetings,[84] and complicated and lengthy processes.

---

76 Based on information from Chr. Hansen.
77 European Commission: *Initiative on substantiating green claims*.
78 The organic labels follow EU's regulation on organic farming. European Commission: *Organic Farming*.
79 European Commission: *Organic production and products*.
80 Hydroponic farming in the US has to adhere to certain conditions to be considered organic. Source: Politico (2021).
81 European Commission: *Food Safety, Approval of active substances*.
82 Based on IRIS Group (2022) and Chr. Hansen & Novozymes: *Danmark kan blive førerende inden for godkendelse af biopesticider*.
83 To date, no health claims have been accepted for the beneficial effects of probiotics despite ample clinical evidence. Based on information from Chr. Hansen.
84 EFSA Calendar.

2. Compliance and processing costs are particularly harmful to smaller bio solution companies. For example, costs for testing, dossier preparation and registration in the EU can be up to EUR 1 million,[85] which is a relatively large cost for small companies.

In the US, the product approval process for biological pesticides in the US takes two to four years due to a fast-track process,[86] and similar solutions have also been adopted in other countries.[87] For novel food products, the US GRAS procedure lowers the time-to-market for novel food products as independent expert panels assess the safety of a novel food product, and food producers do not need to go through long procedures at the FDA.[88]

Recommendation 7

EU policymakers should adopt fast-track approval procedures for innovative, low-risk biological and sustainability-enabling solutions by allocating targeted resources in the European Food Safety Authority and the Member States to secure fast time-to-market.

Recommendation 8

Policymakers should consider lowering the administrative cost burden, particularly for smaller companies, where the costs are relatively larger, e.g., by differentiating procedural cost by company size, while still ensuring proper risk assessment of the product.

2.2.4 Policymakers can create a market pull to lower market barriers

Potential price gaps between mature bio solutions and their alternatives can stem from more expensive input costs and costly production process of the bio solution. In addition, less-technological mature bio solutions may be more expensive than their alternatives because these solutions have not been scaled and have, thus, not yet achieved the benefits accruing from economies of scale.

Product cost differences between a bio solution and its non-sustainable alternative are best illustrated in a **marginal abatement costs curve (MACC)** as this curve also illustrates to potentials for CO_2 reductions: see Box 8 and Figure 12.

85 lsbi (2019) and IRIS Group (2022).
86 EPA (1997).
87 European Parliament (2021), page 20, and Novozymes (2021): *Background on the issue regarding approval timelines for biological Plant Protection Products*.
88 Lsbi (2019).

Box 8 MACCs illustrate relative costs and emission potentials

A MACC visualizes the interplay between **marginal abatement costs** (vertical axis) and **the emission reduction potential of a technology** (horizontal axis).

The marginal abatement cost is the *current relative cost* between the bio solution and its non-sustainable alternative measured in *EUR per ton of CO_2e* that is displaced. These costs vary with market and technological developments and there are, thus, *price differences at a certain moment in time*. The emission reduction potentials shown in Figure 12 are those in 2030, from Chapter 1.

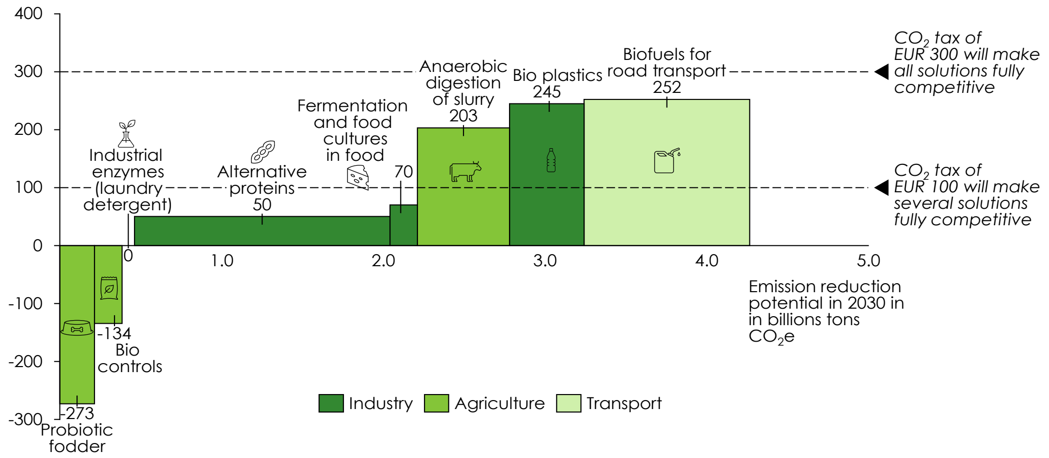
Source: Copenhagen Economics.

Certain bio solutions are currently much more expensive than their non-sustainable alternatives, including anaerobic digestion of slurry, bio plastics, and biofuels, see Figure 12, all of which have a marginal abatement cost above EUR 200 per ton of CO_2. These bio solutions are not fully scaled yet; they face an underdeveloped market and experience strong competition from fossil fuel solutions that are highly efficient and enjoy economies of scale from large scale production and decades of knowledge and experience in optimising production and distribution.[89] An exception is 1st generation biofuels, which have already been scaled. The newer generations of biofuels, however, are still a small part of the market, see Figure 12.

Probiotic fodder and bio controls (incl. bio fertilizers) currently have negative abatement costs and alternative proteins have a relatively low abatement cost, see Figure 12. There is still potential for these products to further decrease in cost.

89 Musonda et al. (2020).

Figure 12
MACC for selected bio solutions
Abatement cost In EUR per ton CO2-equivalent (current)



Note: See Appendix A. For example, the abatement cost for 'biofuels for road transport' is based on lifecycle costs differences from using biodiesel, biogas and bioethanol in large road vehicles.
Sources: Copenhagen Economics based on sources listed in Appendix A.

In 2021, the average global CO_2 price was EUR 3 per ton of CO_2,[90] which is too low to have a significant global effect, while the European carbon price was around EUR 80 at the beginning of 2022.[91] A global carbon price of EUR 70 per ton of CO_2 would ensure that half of the achievable emission reduction potential is cost-competitive, see Figure 12. A high global carbon price at 250 EUR per ton of CO_2e would make *all* of the bio solutions we have examined competitive *now*, see Figure 12. This price is expected to decrease as the bio solutions are scaled and become more cost-effective.

A global CO_2 tax would create a long-term market pull towards sustainable solutions as the tax can lower or eliminate the price gap between sustainable and non-sustainable solutions. CO_2 taxes have the advantage that they increase public revenue, all things being equal, as compared to, for example, subsidising the green alternatives, which would have a negative impact on public budgets. However, carbon pricing also increases consumer prices, so governments can consider compensating low-income households for this additional cost with some of the revenue gained from CO_2 taxes.

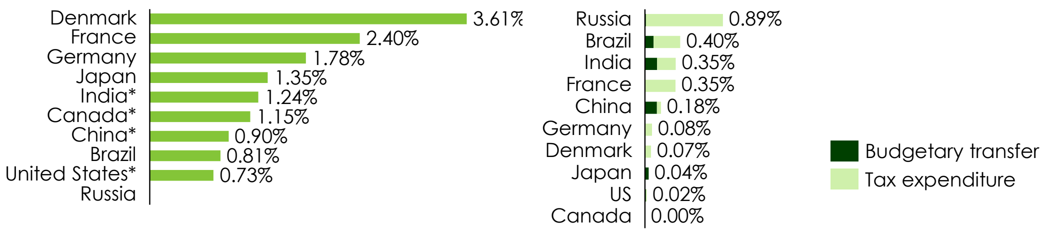
While there already exist environmental taxes in several countries, there are still public subsidies for fossil fuels and for carbon-intensive production processes, like agriculture, in some countries, see Figure 13, which adds to the cost differential between fossil-free solutions and solutions using fossil fuels.

[90] IMF blogs (2021).
[91] The EU carbon price only covers emissions in some sectors. Based on EUA futures. Source: Ember-Climate: *EUA (EU ETS) Future Prices,*

Figure 13 Environmental taxes and subsidies for fossil fuels, 2019

Environmental tax revenue for selected countries
Per cent of GDP

Public subsidies for fossil fuels
Per cent of GDP



Note: * Data for India and China is from 2018, data for the US is from 2016 and data for Canada is from 2015. Tax expenditures imply tax exemptions or rebates to certain fossil fuel activities/certain sectors using fossil fuels. Budgetary transfer implies direct government support: for example, subsidies to energy costs for low-income groups.

Source: OECD, Dataset: Environmentally related tax revenue, and OECD, Dataset: Fossil fuel support.

Recommendation 9

Policymakers should remove all subsidies for fossil fuels and start implementing minimum carbon pricing instruments with a wide geographical and industrial scope. It could also be considered whether other support schemes should contain an emission element: for example, in distributing public agricultural support.

Regulatory sandboxing

Comprehensive regulation imposes high barriers of entry, hampering the emergence of new innovative players. The use of *regulatory sandboxes* is an innovative way of developing regulations for new areas or technologies where it is, at the outset unclear which regulatory tools are best suited to regulate an upcoming area or technology. The idea is to create a separate "track/sandbox" of regulation that is tested in a small sample of countries or companies, and the regulation is then continuously developed in a collaboration between policymakers and companies.

Using this method requires more flexibility by the regulator but diminishes the risk of overregulating or implementing unnecessary strict regulation that will hamper the development of, e.g., new technology. This could be the case for bio solutions too, as described in the analysis above.[92]

Regulatory sandboxes have proven successful in fostering new players in finance. In the EU's financial regulation, small financial services start-ups face *less restrictive* or *comprehensive regulation* as these players are not a threat to financial stability because they are too small. This allows these emerging companies to scale sufficiently before the full-scale financial regulation is phased in.

[92] Bertelsmann Stiftung & Copenhagen Economics (2018), page 28.

In recent years, the interest in novel regulatory design to foster innovation has increased substantially in the EU and Member States and across sectors. Sectors, apart from finance, where regulatory sandboxes have been used to develop 'future proof' regulation include health, legal services, aviation, transport and logistics, and energy, as well as sectors making use of new, emerging technologies like artificial intelligence and blockchain technologies. [93]

Recommendation 10

Policymakers should consider the *targeted use of regulatory sandboxing for bio solutions to test alternative regulation models at the national and sub-national levels.*

2.3 MORE EARLY-STAGE FINANCING OF BIO SOLUTIONS LOWERS FINANCIAL BARRIERS

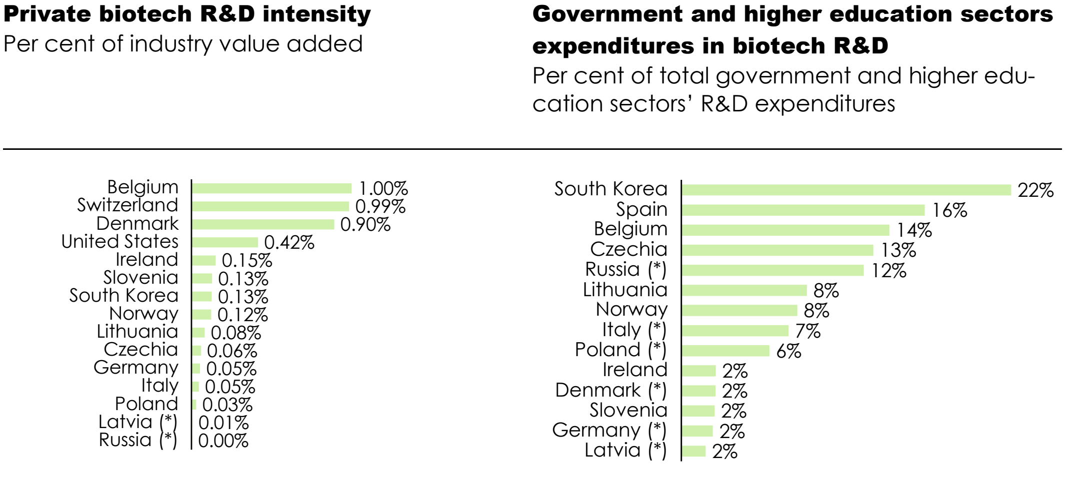
For new technologies, the key barrier is access to capital, which is evident in the research, development, and demonstration phases of the product maturity. Biotech R&D funding is important for new bio solutions development in the early stages of a bio solution's maturity as tools for funding, de-risking research, and developing ecosystems and scientific research.

Several countries have relatively low biotech R&D intensity, see Figure 14, which ultimately will lead to fewer developments of new bio solutions. In Italy, Germany, Latvia, and Poland, the public and private biotech R&D investment levels are much lower than in, for example, Belgium or Switzerland. Globally, investments in start-ups producing alternative proteins rose by more than 300 per cent, from 40 investments in 2016 to 166 in 2020, with an increase in funding from around EUR 275 million in 2016 to EUR 2.5 billion in 2020.[94] Some of the largest investments are found in the US, and the top investors are also US-based.

93 EU: Council of the European Union (2020), Ranchordás, Sofia (2021), Germany: Federal Ministry for Economic Affairs and Energy (2019), Bertelsmann Stiftung & Copenhagen Economics (2018)

94 Innovation Centre Denmark (2021), page 8, 9 and 11.

Figure 14 Public and private investments in biotech, 2017



Note: Biotechnology includes DNA/RNA, proteins and other molecules, cell and tissue culture and engineering, process biotechnology techniques, gene and RNA vectors, bioinformatics, and nanobiotechnology. Exceptions to this definition are marked with *: For Canada and Latvia, this includes medical, environmental, industrial, and agricultural biotechnology. For Russia, this includes bioengineering, biocatalysts, biosynthesis and biosensor technologies, biomedical and veterinary technologies, genomics, pharmaco-genetics, and living cell technologies.

Source: Copenhagen Economics based on OECD dataset, *Key Biotechnology Indicators*; and OECD dataset, *Main Science and Technology Indicators Database*.

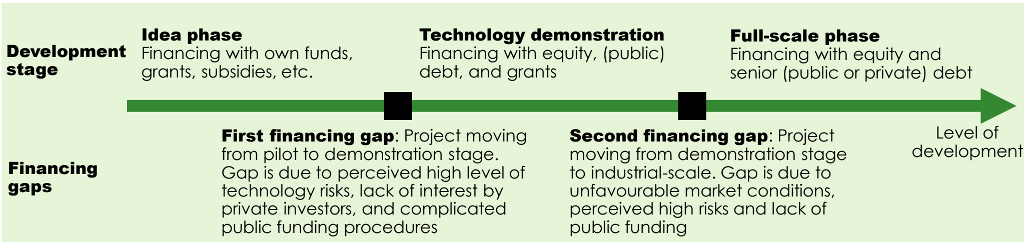
Also, later in their development, bio solutions face problems with access to finance. In a European survey of bio-based industry projects, 75 per cent of the projects reported issues with access to finance after the R&D stage.[95] Public financing is available in several countries, but it is usually restricted to the R&D *idea stage*, and less focus is on projects when they increase in size; this leads to a financing gap. Conversely, India has invested heavily in its biotech industry in recent years across different stages of development. Investments have been made in human resources, innovation, and infrastructure in the biotech industry, and on improving the collaboration and commercialisation between universities, laboratories, and the public and private sectors.[96]

95 The European Investment Bank (EIB) surveyed the need for financial instruments for public risk-sharing in bio-based industries in the EU. A "bio-based industry" is defined as a segment of the bioeconomy where renewable resources are used for the production of bio-based products and biofuels. This barrier is also evident from our interviews with bio solution companies during this project. Source: EIB (2017), pages iii, 1, 3-4.

96 Government of India (2020).

In the *technology demonstration* phase, public funds are either unavailable, can be complicated to apply for, or have unfavourable terms attached to them, see Figure 15. In addition, projects are perceived by private investors to have too large risks, partly because of the complex technical characteristics of bio solution products.[97] China has publicly funded biotech industrial parks to assist companies with their demonstration and scaling[98] stages and now supports more than 100 high-tech industrial parks and 400 provincial biotech parks. Also in the EU, there are public funds like the InnovFin, the European Fund for Strategic Investments, and the European Circular Bioeconomy Fund, but awareness of these funds is relatively low, and the funding is not effectively managed across all relevant industries; for example, the funding to the aquacultural sector is poorly managed by national authorities, according to the EIB.[99] This may hamper the effect this funding actually has on bio solution development in practice. The EU could also stimulate financing and awareness of bio solutions by defining biotech as a Key Enabling Technologies (KET) under the Horizon Europe funding programme. Biotechnology was part of the KETs under the Horizon 2020 programme but is not directly included in the new Horizon Europe.[100]

Figure 15
Illustration of financing gap barriers in the development of new bio solutions



Source: Copenhagen Economics based on interviews, EIB (2017), page 59, and McKinsey & Company. (2019, b).

Recommendation 11

Policymakers should consider increasing public financial instruments for biotech R&D and later-stage financing to crowd-in private capital.[101]

---

97 EIB (2017).

98 These parks provide infrastructure, talent pools, and business support, i.e., they employ administrative personnel that help with regulatory filings and financing to assist companies residing in the parks. GlobalX (2020), The 13th five-year plan for economic and social development of the people's republic of China (2016-2020).

99 The European Investment Bank (2017), pages iii, 49.

100 The industry is indirectly mentioned under life-science technologies: see Interreg Europe: *Key Enabling Technologies*.

101 In the EU, this includes increasing the awareness of InnovFin, the European Fund for Strategic Investments, and the European Circular Bioeconomy Fund. See European Circular Bioeconomy Fund (www.ecbf.vc), EIB (2017), pages 8-9, 59.

Finally, innovation is often driven by dedicated leaders that create new businesses on a path that is often characterized by high risks and high returns.[102] To underpin such ventures, it is important not to penalize the individuals through the taxation system, notably the taxation of dividends and capital gains in personally-owned companies. Denmark has the highest effective taxation of personally-owned companies,[103] which risks slowing down the growth and innovation created by high risk and high return innovation businesses.[104]

Recommendation 12

Policymakers should ensure that taxation of capital income does not penalize entrepreneurs that have a key role in driving innovation in highly promising areas of innovation.

We provide a summary of the barriers and policy recommendations in this chapter in Table 4. The table also presents our attempt at a prioritized action plan for policymakers based on considerations of which recommendations are most easily or quickly implemented (quick fix, but potentially limited impact) and which recommendations would provide the largest impact if implemented (impactful but potentially slower to change).

We find that in the very short run, a faster product approval process could lower the barriers significantly for rolling out new products. In the medium run, the EU should focus on updating their regulatory framework to also consider bio solution products and processes that substitute or complement traditional farming, pesticides, food, etc., and consider updating the GMO legislation to open up for certain gene-editing techniques, while ensuring food safety. Policies aimed at reducing the cost gap between fossil technologies and bio solutions and ensuring access to capital could be addressed as a third priority.

---

102 Copenhagen Economics (2018), Copenhagen Economics 2019.
103 US Tax Foundation provides recurrent updates of global tax rules, showing that the rates for taxation of capital gains and dividends are arguably the highest in the OECD.
104 Axcelfuture (2014)

Table 4
Barriers and policy recommendations

Barrier	Policy recommendations	A prioritized action plan for the EU
Outdated product classification	1) Ensure that regulation allows for product classifications with the technological development of newer solutions.	2
Unlevel playing field in agricultural subsidies	2) Ensure a level playing field for food products by aligning subsidy levels to also include newer production techniques (e.g., growing protein in silos or water).	2
Separate regulation for novel foods (EU)	3) Allowing novel food products to follow the EU's General Food Law only.	2
Outdated GMO regulation (EU)	4) Focus on product characteristic evaluation rather than process in the GMO regulation to enhance the development of safe modern genetic techniques.	2
Restrictive labelling	5) Support the development of standardized labels for CO_2, biodiversity, etc.	2
Organic label is limited	6) Expand the organic label to also cover modern food production techniques.	2
Long product approval processes	7) Allocate targeted resources to make a fast-track solution for approval of new products.	1
High procedural cost of product approval process	8) Lower the administrative cost burden, particularly for smaller companies.	1
Cost gap	9) Remove all subsidies for fossil fuels and implement a global CO_2 tax.	3
	10) Consider the use of regulatory sandboxes for bio solutions to test alternative regulation models.	3
Low access to capital in R&D and demonstration phases	11) Increase public financing of biotech R&D and demonstration phases to crowd-in private capital.	3
	12) Policymakers should ensure that taxation of capital income does not penalize entrepreneurs that have a key role in driving innovation in highly promising areas of innovation.	3

Note: IRIS Group (2022) has an in-depth analysis of the EU regulatory aspects and differences in implementation of EU regulation in different countries. Numbers 1-3 for the prioritized action plan is based on our own assessment.

Source: Copenhagen Economics based on sources throughout Chapter 2 and IRIS Group (2022).

2.4 SUMMARY OF INTERNATIONAL BEST PRACTICES

While several countries and regions produce bio solutions, framework conditions differ considerably. With the market for bio solutions expanding, the competition between some of the larger players in the US, China, India, and the EU to gain market shares will become even more fierce.

Hence, regulatory conditions and other conditions are important factors for where bio solution companies will choose to invest in new ventures, research, and production facilities. Overstrict, inflexible or burdensome regulation in a country or region could result in a loss of investment and market potential and, subsequently, postpone the transition towards global decarbonisation. The EU, for example, has the potential to update and improve regulations to avoid this by adopting best practices from other countries. On the other hand, the EU is an international front runner when it comes to carbon pricing, a facilitating factor for green solutions like bio solutions. Table 5 below provides an overview of the international best practices mentioned in this chapter, linking them to the barriers they address.

Based on our research, we furthermore find that at least 41 countries have adopted a national biotechnological strategy – mainly Western and BRICS countries, including all G7 countries.[105] These strategies contain overall goals as well as concrete initiatives, in some cases.

[105] Dietz et. Al (2018)

Table 5
Examples of best practices to overcome barriers in different countries

	BARRIER	BEST PRACTICE
Regulatory barriers	Lack of a level playing field	The **US** secures a more level playing field to accommodate modern agricultural solutions. The USDA provides grants to urban agriculture, including vertical farming and innovative production, to promote the development of new food solutions.
	Outdated product classification and regulation	The **UK** government has proposed it enable the commercial growing of gene-modified crops in England. A similar separation of regulation is found in the US, Canada, and in several South American and Asian countries.
		The **US** regulation on organic food products is updated when new production techniques arise. For example, hydroponic food production (for example, in vertical farming) can be considered organic under certain conditions.
	Slow product approval process	In the **US**, the product approval process for biological pesticides takes two to four years due to a fast-track process, and similar solutions exist in other countries. For novel food products, the US GRAS procedure lowers the time-to-market for novel food products. **China** has increased the number of administrative personnel in the product approval process to lower waiting time.
Market barriers	Lack of carbon pricing	The **EU**'s emission trading system effectively taxes CO_2 emissions in selected industries, including manufacturing and intra-EU aviation, with a CO_2 quota system. There are ongoing discussions to expand this system.
	Slow demand uptake (for example, due to transition risks)	In **France**, the roadmap of the "Green Chemistry and Biofuels" industrial plan contains measures to support the use of bio-based products in the public procurement context. Public procurement will consider the environmental performance of products, and in particular their bio-based character.
Financial/ early-stage barriers	Lack of early-stage financing	The **US** venture capital market is second-to-none, resulting in investments in biotech companies. **Switzerland** and **Belgium** have relatively high R&D investments in biotech.
	Poor possibilities to test new products	The governments of **China** and **Norway** have invested in publicly funded testbeds and demonstration facilities for biotech start-ups and companies that are ready to demonstrate their product.
	Lack of public coherent vision/strategy	**India** has a vision to have a EUR 130 billion bioeconomy industry by 2025 and to be among the top five largest bio economies globally by: • building human resource capacities and infrastructure • strengthening the innovation ecosystem, • encouraging commercialization and collaboration between universities, laboratories, public and private sector, • ensuring quality by living up to international standards, • enhancing venture capital for high risk science.

Note: Non-exhaustive list of countries and framework conditions in different countries.
Source: Copenhagen Economics based on USDA (2021), Politico (2021), IRIS Group (2022), UK Gov (2021), BBC (2021), Labiotech (2020), EPA (1997), European Parliament (2021), Dietz et al (2018), Marvik and Philp (2020), The Federal Government of Germany (2020), The Government of India (2020), French Republic (2016), GlobalX (2020).

CHAPTER 3

WORLD-LEADING DANISH BIO SOLUTIONS TO SEIZE FUTURE GLOBAL OPPORTUNITIES

Denmark has a strong historical record of offering bio solutions worldwide. In this chapter, we map out the structure and size of this industry (3.1) and we provide a ballpark estimate of the growth potential towards 2030 that the global climate challenge offers for this industry, providing the right framework conditions are in place (3.2).

3.1 DENMARK HAS A STRONG INTERNATIONAL POSITION

Denmark holds a global leading position in bio solutions. This position has been developed around the internationally strong Danish industries of agriculture, refined food, pharmaceuticals, and universities,[106] supplying the basis for innovation and knowledge for developing bio solutions to enable efficiencies and emission reductions in these industries as demonstrated by:

- Its bio solutions industry being globally competitive with 4-5 times as many biotech patents per capita as the average of the 10 leading research nations[107]
- It ranks second worldwide behind Switzerland in the number of scientific publications within the biotech field per capita.

130+ companies in Denmark develop and produce bio solutions,[108] primarily fermentation technology, alternative proteins, bio-based ingredients, bioenergy, biopesticides, bioplastics, probiotics and enzymes.[109] Danish bio solution companies are particularly strong in industrial enzymes, food cultures and probiotic ingredients. Examples include companies such as Novozymes, Chr. Hansen, Arla Food Ingredients, and IFF Nutrition & Biosciences, all of which are global players, see Table 6. The strengths have been built around a tradition of producing and exporting food products, along with in-depth know-how, collaboration with academia, and continuous investments in developing new solutions within the companies. Moreover, there are several smaller Danish bio solution companies that are developing new products. These, and these companies, could grow rapidly in the coming years when their respective markets grow.

[106] For these industries, Denmark is a net exporter, which indicates Danish comparative advantages relative to other countries. This covers the industries of agriculture (010000), fishing (030000), food and beverage (10xxxx and 11xxxx), pharmaceuticals (210000), and the manufacturing of motors, including wind turbines (280010). Source: industry import and export numbers from Statistics Denmark input-output tables from 2018 and IRIS Group (2021), p. 5-6, 14.

[107] ATV (2020), p.33. Bio solutions is a part of the broader biotechnological industry.

[108] HBS Economics (2021a), p.11.

[109] IRIS Group (2021), p.5.

Table 6
Examples of Danish bio solution companies and their position (non-exhaustive)

Company	Bio solution(s)	Position
Novozymes	Industrial bio solutions for household care products, food and beverages, bioenergy, agriculture and feed, and alternative proteins.	Market leader with around 50 per cent market share in the global enzymes market.
Chr. Hansen	Food cultures, probiotics and enzymes for feed and food, human and animal health and nutrition, and microbial solutions for agriculture.	10th most patents in biotechnology and 9th most patents in food technology in Europe.
Arla Food Ingredients	Whey ingredient and milk minerals supplier, for example, for medical nutrition products.	Arla Foods, in total, is the 9th largest dairy company globally.
IFF Nutrition & Biosciences*	Bio protection, for example, for animal feed, bio solutions for the food industry.	6th most patents in biotechnology globally.
BioPhero	Pheromones as alternatives to pesticides.	Danish-based production.
Pond	Bioplastics.	Collaborates with international companies, including Adidas.
NatuRem Bioscience	Microalgae food products.	Danish-based production.
European Protein/FermentationExperts	Fermented protein feed, ensilage, alternative proteins.	Operates Danish production and affiliates abroad.
UniBio	Microbial protein fermentation.	Danish headquarters and production, UK-based innovation centre.
21st Bio	Scaling hub for industrial biotech innovators.	Danish-based hub.

Note: *Former DuPont Nutrition & Biosciences.
Source: Copenhagen Economics based on company websites, ATV (2020) IRIS Group (2021); Rabobank Research (2020).

3.1.1 Employment

Danish companies with important contributions to bio solutions employed **6,800 people** in 2020[110], many of whom were in high productive jobs in research & development and skilled manufacturing: 3,400 people worked in bio solution companies in the agriculture and food industry (for example, Chr. Hansen) and 2,700 worked with industry solutions (for example, Novozymes). An additional 6,800 people were employed in Denmark in companies supplying goods and services to Danish bio solution companies in 2020.

Average earnings in the industry are EUR 66,000 per year,[111] and the industry employs people with a range of educational backgrounds, including laboratory technicians, economists, process operators, veterinarians, chemists, etc. Around a quarter have attained higher education, which is more than double the average in the overall Danish workforce. Four out of ten have either received a vocational education or are unskilled workers.[112]

110 Equivalent to 0.2 per cent of total employment in Denmark. HBS Economics (2021, a), p.11 and 16 and numbers from Statistics Denmark.
111 Source: HBS Economics (2021, a), page 14.
112 Source: HBS Economics (2021, a), page 17.

3.1.2 Economic contribution

The Danish bio solutions industry contributed more than **EUR 1.8 billion** to the Danish gross domestic product in 2020, which is approximately the same contribution as the financial services industry in Denmark.[113] The industry has one of the highest productivities in Denmark and achieves double the average productivity in private jobs in Denmark.[114]

Most of the revenue generated by Danish bio solution companies stems from exports; Danish bio solution companies had an export revenue of **EUR 3.6 billion** in 2020 out of a total revenue of EUR 4.6 billion, see Figure 16.[115]

Figure 16
Danish domestic sales and exports of bio solutions in 2020
Billion EUR

Source: HBS Economics (2021a), p.21

3.2 DANISH BIO SOLUTION COMPANIES CAN CREATE NEW GREEN JOBS

The expected surge in the global demands for bio solutions towards 2030, as seen in Figure 8, will also benefit Danish bio solution companies and bring them additional revenue, exports, and jobs. [116]. This has similarities to the Danish wind turbine industry success story, although without the need for large subsidies, see Box 9.

[113] Equivalent to 0.5 per cent of total Danish GDP (measured in GVA in 2019). HBS Economics (2021, a) and numbers from Statistics Denmark, NABP69.

[114] The industry productivity is the 17th highest in Denmark out of 117 industries measured in BVT per full-time employed. Source: HBS Economics (2021, a), page 11, 13.

[115] Among 11 industries, biotechnology is rated the second internationally strongest industry in Denmark after wind technology when it comes to the degree of patents and publications in the industry. Source: ATV (2020), p.13.

[116] See, for example, Earth.org (2021): *Denmark- Ranked 2nd in the Global Sustainability Index*, where Denmark is ranked 2nd in the global sustainability index.

Box 9 The Danish wind turbine success story

Today, the Danish wind industry is among the leading in the world, contributing EUR 4 billion to Danish GDP.[i] Wind energy is a substitute for fossil fuels used for power generation in countries all over the world, lowering CO_2 emissions by up to 99.5 per cent compared to an average power plant using fossil fuels.[ii]

Although the first public subsidies were given to the development of wind turbines on land in the 1890s,[iii] the Danish wind turbine adventure truly started in the 1970s as Denmark aimed to be more self-reliant on energy following the oil crisis. In 1979, public subsidies for wind turbines were 30 per cent, and in the 1980s there was a requirement to set up new wind turbines when also constructing power plants. The world's first *offshore wind farm,* Vindeby, was erected in Danish waters in 1991 with a capacity of 0.45 MW per wind turbine. Now, the largest offshore wind turbine produces up to 15 MW and has a wing diameter of 160 metres.

Over the past 50 years, the Danish wind turbine industry has developed from an inefficient and heavily subsidized energy source into a cost-competitive power player on the global market, enabling large emission reductions around the world.

Note: i) Measured as direct impacts only. Wind Denmark (2020), page 5. ii) Based on the lifecycle premise that large wind turbines emit 4 g CO_2 per kWh and global power plants emit 865 g CO_2 per kWh. iii)Ing (2016)
Sources: The Danish Embassy in Oslo (2019). KEFM (2019), Danish Wind Industry Association, Wind Denmark (2020), Viden om Vind (link, accessed November 23, 2021). Ing (2016).

3.2.1 The future potential contribution of the Danish bio solution industry

We find that the market potential for Danish bio solution companies is **EUR 14 billion** (~DKK 100 billion) in 2030,[117] i.e., an increase of 200 per cent, see Figure 17. For each solution, we use the expected global market increase and the Danish market share in 2020 to estimate a global revenue for Danish bio solution companies in 2030. The Danish market share of the global market is 1.9 per cent on average in 2020, varying between close to zero per cent and up to around 50 per cent depending on the bio solution market.[118]

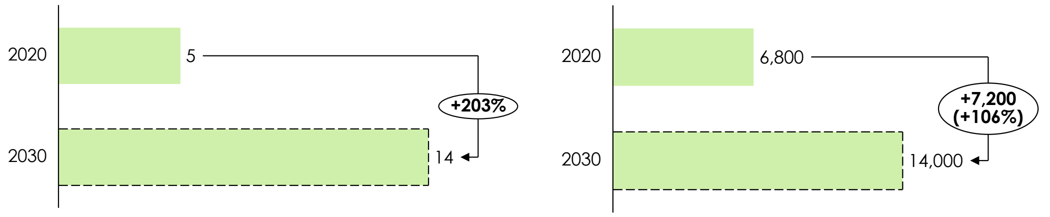
[117] This potential would be greater if Danish bio solution companies were able to achieve a higher market share than their current one, or if Danish bio solution companies sought new potential markets. For example, Novozymes expects an annual revenue potential of EUR 65-130 million (DKK 0.5-1.0 billion) in new ventures around 2030. Novozymes (2021, b), p.21.

[118] Based on the global revenue of EUR 4.6 billion (DKK 34.2 billion), see Figure 16, and a global market value of EUR 240 billion, see Figure 8. The Danish market share differs across products; Novozymes global market share in industrial enzymes is 48 per cent: see Novozymes (2020).

Figure 17 Potentials for Danish bio solution companies in 2030

Market potentials | **Job potentials in Denmark**

Billion EUR | Jobs



Note: Based on current market shares and the size of Danish bio solutions forecasted for 2030 and rounded to the nearest 100 due to uncertainties. Job numbers are based on the market potentials and corrected for an assumption of two per cent productivity growth per worker per year and annual inflation of two per cent. In addition, we assume that Danish bio solution companies have the same share of jobs in Denmark in 2030 they had in 2020.

Source: Copenhagen Economics based on market potential analysis.

Danish bio solution companies could create 7,200 new green jobs (both skilled and unskilled) if they can achieve a market potential of EUR 14 billion in 2030, see Figure 17, which is a doubling of the number in 2020. The percentage increase is smaller than the increase in market potential as people employed in bio solution companies are expected to increase their productivity over time.

Most of the additional jobs are expected to be in the food industry, related to fermentation, food cultures, ingredients and alternative proteins; a quarter of the jobs are expected to be in industrial solutions, such as industrial enzymes.[119] A smaller number of jobs is expected to be in agricultural solutions and other solutions.

Development of bio solutions can also help maintain a balanced growth performance for Denmark. While the majority of the Danish bio solution workforce is employed in cities in Denmark,[120] the industry enables emission reductions in companies and industries located outside the larger urban areas. This applies, in particular, to the wider agricultural sector. These industries are characterized by a relatively high cost of abating CO_2, and considering the Danish ambition of carbon neutrality in 2050, they will either have to find solutions to decarbonize or stop producing in Denmark. Bio solutions can, therefore, help to avoid job losses in the Danish agricultural sector.

The job potentials are only achievable if Danish bio solution companies have proper regulatory framework conditions that reduce barriers, support development, lower time-to-market, and facilitate the global roll-out of bio solutions, as analysed in Chapter 2. Otherwise, Danish bio solution companies may decide to invest more in facilities outside of Denmark or risk losing market shares to companies abroad.

119 Note that the number of jobs on a granular level is more uncertain than as a gross number.

120 In particular, certain municipalities around Copenhagen, but also in Central Jutland and Western Zealand. The largest employers by municipality in 2020 were (in descending order) Gladsaxe, Rudersdal, Lyngby- Taarbæk, Kalundborg, Hvidovre, Aarhus, Billund, Køge, Copenhagen, and Roskilde. Source: HBS Economics (2021, a), page 18.

REFERENCES

Advanced Food (2017): *Barriers to advanced liquid biofuels & renewable liquid fuels of non-biological origin*

Agreement between the Danish Government (Socialdemokratiet), Venstre, Radikale Venstre, Socialistisk Folkeparti, Enhedslisten, Det Konservative Folkeparti og Alternativet (2021): *Genstart af dansk eksport*

Algae Biomass Organization (2019): *The Opportunity for Algae in Carbon Utilization*, link accessed December 13, 2021

The Danish Alliance for Bio Solutions (2021): *Join the Challenge towards a Green Future,* link accessed December 13, 2021

Allied Market Research (2021): *Next Generation Biofuels Market by Biofuel Type (Biodiesels, Biogas, Biobutanol, and Others), Process (Biochemical Process and Thermochemical Process), Raw Material (Lignocellulose, Jatropha, Camelina, Algae, and Others), and Application (Transportation, Power Generation and Others): Global Opportunity Analysis and Industry Forecast, 2021–2030*

Altenburg et al. (2021): *Cost-effectiveness of decarbonisation options for the vegetable-oil and -fat industry in the Netherlands*

Araújo et al. (2021): *Current Status of the Algae Production Industry in Europe An Emerging Sector of the Blue Bioeconomy*

ATV (2020): *Verdens førende tech-regioner*

Australian food and agribusiness: *Alternative protein sources*, link accessed December 2021

Axcelfuture (2014): *Vækst og Innovation i danske virksomheder*

BBC (2021): *Brexit paves the way for gene-edited crops*

BCG (2021): *Food for Thought: The Protein Transformation*

Bertelsmann Stiftung & Copenhagen Economics (2018): *Subsidiarity and Proportionality in the Single Market*

Bio solutions Alliance (2021): *Vær med til at skabe Danmarks grønne fremtid*

Bloomberg Intelligence (2021): *Plant-Based foods Poised for Explosive Growth*

Buttazzoni (2019): *GHG Emission Reductions With Industrial Biotechnology: Assessing the Opportunities*

Canadian Biomass (2021): *Advanced biofuels market size expected to top $848.6 billion U.S. by 2030*

Cassidy et al. (2013): *Redefining agricultural yields: from tonnes to people nourished per hectare*

Chen et al. (2007): *Research and application of biotechnology in textile industries in China*

Copenhagen Economics (2018): *Undersøgelse af vækstiværksættere*

Copenhagen Economics (2019): *Taxation of personal capital income*

Copenhagen Economics (2021): *Study on equity investments in Europe: mind the gap*

Council of the European Union (2020): *Council Conclusions on Regulatory sandboxes and experimentation clauses as tools for an innovation-friendly, future-proof and resilient regulatory framework that masters disruptive challenges in the digital age*

The Conversation (2015): *How we got to now: Why the US and Europe went different ways on GMOs*

Chr. Hansen (2020): *Sustainability - Roadshow presentation 2020/21*

Chr. Hansen & Novozymes: *Danmark kan blive førerende inden for godkendelse af bio-pesticider*

The Danish Embassy in Oslo (2019): *Det danske vindeventyret*.

Danish Wind Industry Association: *The Wind Pioneer – Poul la Cour*,

Dietz et al (2018): *Governance of the bioeconomy: a global comparative study of national bioeconomy strategies*

Dufey and Grieg-Gran (2006): *Biofuels production, trade, and sustainable development*

EA Energianalyse (2019): *Klima-KPI for Dansk Industri*

Earth.org (2021): *Denmark- Ranked 2nd in the Global Sustainability Index*, link accessed November 23, 2021

EFSA (2019): *FAQ: phthalates in plastic food contact materials*

EFSA Calendar, link accessed November 30, 2021

Ember-Climate: *EUA (EU ETS) Future Prices*, link accessed January 13, 2022.

EPA (1997): *PRN 97-3: Guidelines for Expedited Review of Conventional Pesticides under the Reduced-Risk Initiative and for Biological Pesticides*, link accessed December 7, 2021

European Investment Bank, EIB (2017): *Study on Access-to-finance conditions for Investments in Bio-Based Industries and the Blue Economy*.

European Commission (2018): *A European Strategy for Plastics in a Circular Economy*

European Commission (2018): *A Scientific Perspective on the Regulatory Status of Products Derived from Gene Editing and the Implications for the GMO Directive*

European Commission (2020, a): *Progress made in cutting emissions*

European Commission (2020, b): *Regulation (EC) No 1924/2006 on nutrition and health claims made on foods with regard to nutrient profiles and health claims made on plants and their preparations and of the general regulatory framework for their use in foods*

European Commission (2020, c): *Commission regulation of January 14, 2011, on plastic materials and articles intended to come in contact with food*, link accessed December 13, 2021

European Commission (2020, d): *A Farm to Fork Strategy*

European Commission (2020, e): *EU Biodiversity Strategy for 2030*

European Commission (2020, f): *Renewable Energy Progress Report*

European Commission (2021, a): *EU Agricultural outlook*

European Commission (2021, b): *EC study on new genomic techniques*, link accessed November 28, 2021

European Commission (2021, c): *Trend in the use and risk of chemical and more hazardous pesticides*

European Commission: *Bio-based, biodegradable and compostable plastics*, link accessed December 13, 2021

European Commission: *Circular Plastic Alliance*, link accessed December 13, 2021

European Commission: *The common agricultural policy at a glance* and *Income support explained*, link1 and link2 accessed November 22, 2021

European Commission: *EU taxonomy for sustainable activities*, link accessed November 22, 2021

European Commission: *Fit for 55*, link accessed December 13, 2021

European Commission: *Food law general requirements*, link accessed November 22, 2021.

European Commission: *Food Safety, Approval of active substances*, link accessed November 28, 2021

European Commission: *Food Waste*, link accessed December 7, 2021

European Commission: *GMO legislation*, link accessed November 22, 2021

European Commission: *Initiative on substantiating green claims*, link, accessed November 28, 2021

European Commission: *Novel Food,* link accessed November 22, 2021

European Commission: *Novel Food Catalogue*, link accessed November 22, 2021

European Commission: *Organic Farming*, link accessed November 28, 2021

European Commission: *Organic production and products*, link accessed November 28, 2021

European Commission: *Questions and Answers - The Effort Sharing Regulation and Land, Forestry and Agriculture Regulation*, link accessed January 7, 2022

European Court of Auditors (2021): *Common Agricultural Policy and climate*

European Parliament (2017): *Briefing, Bioeconomy – Challenges and Opportunities*

European Parliament (2021): *The use of pesticides in developing countries and their impact on health and the right to food*

FAO (2010): *GLEAM 2.0*, link accessed November 29, 2021

FAO (2013): *Tackling Climate Change Through Livestock. A Global Assessment of Emissions and Mitigation Opportunities*

FDA (2020): *How GMOS Are Regulated for Food and Plant Safety in the United States*

The Federal Government of Germany (2020): *National Bioeconomy Strategy – summary*

Federal Ministry for Economic Affairs and Energy (2019), Making space for innovation. The handbook for regulatory sandboxes

Feed Additive (2021): *Use of probiotics in animal feeds and market dynamics*, link accessed December 13, 2021

French Republic (2016)*: A bioeconomy strategy for France*

Frost and Gilkinson (2011): *27 Months Performance Summary for Anaerobic Digestion of Dairy Cow Slurry at Afbi Hillsborough*

GlobeNewswire (2021): *Global Bio-Based Biodegradable Plastics Market is Expected to Grow at a CAGR of 25.0% from 2021 to 2030; Quince Market Insights*

GlobalX by Mirae Asset (2020): *China Government Initiatives in Biotechnology*

Government of India (2020): *National biotechnology development strategy 2021-2025*

Havukainen et al. (2018): *Carbon footprint evaluation of biofertilizers*

Harvard University blog by Jessica Lau (2015), *Same Science, Different Policies: Regulating Genetically Modified Foods in the U.S. and Europe*

Hayek et al. (2020): *The carbon opportunity cost of animal-sourced food production on land*

HBS Economics (2021a): *Økonomisk, klima- og miljømæssigt fodaftryk af biosolutions i Danmark*

HBS Economics (2021b): *CO_2e reduktionspotentialet fra biosolutions i 2030*

Hepburn et al. (2019): *The technological and economic prospects for CO_2 utilization and removal and supplementary material*

IEA (2021): *Net Zero by 2050 A Roadmap for the Global Energy Sector*

IEA: Outlook for biogas and biomethane: Prospects for organic growth, link accessed March 2, 2022

IEA: *Sustainable Development Scenario*, link accessed December 13, 2021

IMFblogs (2021): *A Proposal to Scale Up Global Carbon Pricing*

Ing (2016): *Poul la Cour skrev Danmark ind i vindmøllehistorien*

Innovation Centre Denmark (2021): *Investment & Market overview: Alternative proteins, a new take on food production*

Interreg: North-West Europe BioBase4SME; (2018): *Needs and challenges of companies in the bioeconomy in NW Europe*

Interreg Europe: *Key Enabling Technologies – A European Priority for Industrial Modernisation,* link accessed February 10, 2022.

IPCC (2021): *Climate Change 2021: The Physical Science Basis*

IRIS Group (2021): *Biosolutions i Danmark*

IRIS Group (2022): *Regulatoriske barrierer for udvikling af biosolutions*

Investopedia (2021), *Comparative Advantage*, link accessed December 13, 2021.

Jegannathan and Nielsen (2013): *Environmental assessment of enzyme use in industrial production - a literature review*

Joint Research Centre (2019): *Technical report on detection methods*

KEFM (2019): *Danmarks største havvindpark skal ligge i Nordsøen*

Labiotech (2020): *GMO Regulations in Europe Are "Not Fit for Purpose"*

LSBI (2019): *Navigating regulations (EU novel foods, US GRAS) to deliver food innovation*, link accessed on December 13, 2021

Markets and Markets (2016): *Fermented Ingredients Market by Type (Amino Acids, Organic Acids, Biogas, Polymers, Vitamins, Industrial*

Enzymes), Application (Food & Beverages, Feed, Pharmaceuticals, Paper), Form (Dry, and Liquid), and Region - Global Forecast to 2022

Markets and Markets (2020): *Agricultural Biologicals Market by Function (Biocontrol, Biofertilizers, Biostimulants), Product Type (Microbials, Macrobials, Semiochemicals, Natural), Mode of Application (Foliar Spray, Soil and Seed treatment), Crop Type, and Region - Global Forecast to 2025*

Markets and Markets (2021): *Probiotics in Animal Feed Market by Livestock (Poultry, Ruminants, Swine, Aquaculture, Pets), Source (Bacteria, Yeast), Form (Dry, Liquid), and Region (North America, Europe, Asia Pacific, South America, & Rest of World) - Global Forecast to 2026*

Markoviak and Śliżewska (2018): *The role of probiotics, prebiotics and synbiotics in animal nutrition*

Marvik & Philp (2020): *The systemic challenge of the bioeconomy - A policy framework for transitioning towards a sustainable carbon cycle economy*

McKinsey & Company (2019, a): *Alternative Proteins: The race for the market share is on*, link accessed December 13, 2021

McKinsey & Company (2019, b): *Biotech in Europe – A strong foundation for growth and innovation*

Miljø- og Fødevareministeriet (2017): *Pesticidstrategi 2017 - 2021*

Miljøministeriet (2021): *Partnerskab og 20 nye initiativer tager kampen op mod miljøfarlige stoffer i vores vandmiljø*

Mitter et al. (2021): *Rethinking Crop Nutrition in Times of Modern Microbiology: Innovative Biofertilizer Technologies*

Mogensen, Birgitte, Gorm Boe Petersen, Helge Sigurd Næss-Schmidt og Holger Nikolaj Jensen (2021), *Beskatning af CO2-procesemissioner i praksis – en model til inspiration.*

Musonda et al. (2020): *Greenhouse Gas Abatement Potentials and Economics of Selected Biochemicals in Germany*

Neto, Komesu, Martins, Gonçalves, Allan, Oliveira, & Rai (2019): *Chapter 10 - Third generation biofuels: an overview*, Sustainable Bioenergy, Advances and Impacts, Pages 283-298

nova-Institute (2015): *Knowledge-Based Bio-based Products' Pre-Standardization*

Novozymes (2020): *The Novozymes Report 2019*

Novozymes (2021, a): *Novozymes to deliver on strategy with carbon capture collaboration agreement*, link accessed December 13, 2021

Novozymes (2021, b): *Unlocking Growth – powered by biotech*

Novozymes: *Background on the issue regarding approval timelines for biological Plant Protection Products*

OECD (2011): *Demand-side innovation policies*

Our World in Data (2021): *Food waste is responsible for 6% of global greenhouse gas emissions*, link accessed January 7, 2022

Plantvision (2019): *Global Bioplastics Market Prediction: $324 billion by 2030*, link accessed December 13, 2021

Poore and Nemecek (2018): *Reducing food's environmental impacts through producers and consumers*

Precedence Research (2021): *Biofuels Market Size Worth Around US$ 307.01 Billion by 2030*

PitchBook-NVCA (2021): *Venture Monitor*

Politico (2021): *Vertical farming's sky-high ambitions cut short by EU organic rules*

Rabobank Research (2020): *Global Dairy Top 20*

Ranchordás, Sofia (2021), *EU Law Live, Weekend edition, October 22-23, 2021] Experimental Lawmaking in the EU: Regulatory Sand-boxes*

Rähse (2014): *Production of Tailor-Made Enzymes for Detergents*

Research and Markets (2021): *The Worldwide Industrial Enzymes Industry is Expected to Reach $17.4 Billion by 2027*

RethinkX (2019): *Rethinking Food and Agriculture 2020-2030*

Reuters (2021): *EU proposes effective ban for new fossil-fuel cars from 2035*

Rouphael and Colla (2020): *Biostimulants in Agriculture*

The Royal Society: *What GM crops are currently being grown and where?*, link accessed November 28, 2021

Shah et al. (2021): *Bioplastic for Future: A Review Then and Now*

Statista (2021): *Total value of venture capital investments in Europe in 2020, by country*

STAR4BBI (2019): *Standards and Regulations for the Bio-based Industry*

Swedish Air Pollution & Climate Secretariat (2015): *Biogas solutions for methane abatement*, link accessed December 13, 2021

Swedish Energy Agency (2020): *Greenhouse gas reduction mandate*, link accessed December 13, 2021

Terefe (2016): *Food Fermentation*

Twine (2021): *Emissions from Animal Agriculture – 16.5% is the New Minimum Figure*

UK Gov (2021): *Press release - Plans to unlock power of gene editing unveiled*

UK Committee on Climate Change (2015): *Review and Update the UK Agriculture Marginal Abatement Cost Curve to Assess the Greenhous Gas Abatement Potential for the 5th Carbon Budget Period and to 2050*

UNEP (2021): *Emission Gap report 2021*

University Of Pennsylvania (2004)*: 9,000-year History of Chinese Fermented Beverages Confirmed.*

Urban Agenda for the EU (2020): *Survey report on regulatory obstacles and drivers for boosting a sustainable and circular urban biobased economy*

USDA (2021): *USDA Announces Grants for Urban Agriculture and Innovative Production*, link accessed November 30, 2021

Valin et al. (2013): *The future of food demand: understanding differences in global economic models*

Valutes (2021): *Global Industrial Enzymes Market Size, Manufacturers, Supply Chain, Sales Channel and Clients, 2021-2027*, link accessed December 13, 2021

Van den Oever et al. (2016): *Bio-based and biodegradable plastics – Facts and Figures*

Viden om Vind: *Hvor meget CO_2 sparer en vindmølle?*

Vision Gain (2021): *Anaerobic Digestion (AD) Market set to grow at CAGR of 3.8% by 2031: Visiongain Research Inc.*

Wiens et al. (2011): *Biofuels and biodiversity*

Wind Denmark (2020): *Branchestatistik - Vindmøllebranchens samfundsbidrag i 2018*

World Bank: *What a Waste 2.0*, link accessed December 13, 2021

World Economic Forum (2021): *Meat: the future Series, Alternative Proteins*

APPENDIX A

DETAILED INFORMATION ON THE BIO SOLUTIONS

For the bio solutions to realise their emission reduction and market potentials, the right framework conditions and market developments must happen. For some bio solutions, the *current* marginal abatement cost is too high to realise the potentials *in 2030*. We expect that the marginal abatement cost will decrease over time for these solutions, enabling the 2030 market and emission reduction potentials presented in this report.[121] In this appendix, we describe a situation where these elements are enabled towards 2030 for each bio solution:

Alternative proteins

Alternative proteins are specialised foods from biological material that are consumed as substitutes for the protein in animal products, such as meat, fish, or dairy.[122] We consider alternative proteins for beef, pork, poultry, and dairy. Examples of alternative proteins are enhanced plant protein, insects, algae, mycoprotein, meat products produced in vitro, algae.

The future market for alternative protein is particular difficult to predict, since the market depends not only on price developments of alternative proteins, investments made in production facilities, or whether CO_2 taxes are implemented, but also product taste and texture, and consumer preferences, all of which have potential large impact on the market for alternative proteins. If consumers broadly lower their consumption of meat and dairy proteins and substitute to a more traditional plant-based food consumption this could have a massive impact on emissions but may not result in a large market share for modern alternative proteins.

This also means that the market forecasts found in literature differs greatly. For example, the European Commission[123] expects a small decrease in European meat consumption of a few per cent per capita in 2030, a recent report[124] finds a 11-22 per cent market share for alternative proteins in 2035, whereas another study finds that US demand for cow products will decrease by 50 per cent in 2030.[125]

One estimate for the *current* global market share for alternative proteins is 2 per cent in 2020.[126] We assume a market share of 20 per cent for alternative proteins in 2030 requiring that the right policies and market developments are in place. This could be higher or lower depending on developments in products, investments, markets, regulation, and consumer preferences.

[121] Note that some of the emission reductions reported in this appendix are achieved from investments made in previous years, for example investments in anaerobic digestion facilities generate emission reductions for many years, and it can therefore be difficult to compare market sizes in value in one year to the emission potential in the same year for all solutions. Also, the emission and market forecasts stem from different sources that may not use the same definitions, which means that one should be careful in comparing these numbers or use them in combination. In addition, the market development *in value* depends on the price development of the bio solution *and* its alternative which are uncertain. We state our assumptions and report the numbers that are available.

[122] Australian food and agribusiness: *Alternative protein sources*; McKinsey & Company (2019, a).

[123] European Commission (2021, a), pages 2-3.

[124] BCG (2021).

[125] RethinkX (2019), page 7.

[126] BCG (2021).

Table 7
Alternative proteins impacts

Sustainability impacts	• Climate change • Food security • Land use • Biodiversity
CO_2 emission reduction potential in 2030	1,580 million tons CO_2e *We extrapolate the emission reduction in HBS Economics (2021, b) to also include alternative proteins for pork, chicken, and dairy based on their current contribution to global emissions and their emission intensities relative to those of pea protein.* *Comparison:* • *"If 10% of the world's animal protein was replaced with alternative protein, 700 million tons of CO_2 avoided", equivalent to 1,400 million tons for a 20 per cent replacement of the current market. Quote; Novozymes (2021, b), p. 5.* • *Total emission by cattle (beef and milk) is 4,615 $MtCO_2e$ per year, see FAO (2013) based on numbers from 2005. This is equivalent to roughly 920 million tons for a 20 per cent market share in 2005 for cattle only.*
Market growth potential in 2030 relative to 2020	+ EUR 115 billion *Based on Bloomberg Intelligence (2021) who finds a global market for alternative proteins of EUR 140 billion in 2030 (up from EUR 25 billion in 2020). This covers a market share of 8 per cent in of a broader protein market definition (including proteins from fish, other poultry, and sheep which we do not include). If we were to reach 20 per cent market share using these numbers, the increase would be in the order of EUR 340 billion, although this is with a different definition. Our number is therefore likely to be a conservative estimate the market development for a 20 per cent market share for the products we examine.* *Triangulation:* • *BCG (2021) finds a total market of EUR 250-500 billion in 2035 with market shares of 11-22 per cent, where investments of EUR 9-24 billion are needed towards 2035. These numbers depend heavily on rough assumptions on future prices and production, which is why we use the more conservative numbers.*
Marginal abatement cost (current)	EUR 50 per ton CO_2e *Calculated from two enhanced protein alternatives: 50% enhanced pea (price difference at ~EUR 0 per ton CO_2e), and 50% algae (price difference at ~EUR 100 per ton CO_2e). We use the price and emission intensity differences of these alternatives to conventional beef as presented in World Economic Forum (2019).*

Sources: See table.

Anaerobic digestion of slurry

Anaerobic digestion of animal slurries involves bacteriological breakdown of organic matter to produce biogas and digested effluent (digestate) in tanks.[127] The biogas can be used as an alternative to natural gas in already established gas systems. Digestate lowers the pollution, has less odour, contains fewer viable weed seeds, has fewer pathogens than the input slurry and can be used for bio fertilisers.

Table 8
Anaerobic digestion of slurry impacts

Sustainability impacts	• Climate change
CO_2 emission reduction potential	570 million tons CO_2e in 2030 *Based on HBS Economics (2021, b) where 35 per cent of the global slurry is handled with anaerobic digestion.*
Market growth potential in 2030 relative to 2020	+ EUR 25 billion *Based on Visiongain Ltd, see GlobeNewswire (2021).*
Marginal abatement cost (current)	EUR 203 per ton CO_2e. *Based on a medium-scale plant in 2015, see Air Pollution & Climate Change Secretariat (2015). Large cost reductions are expected with large scale plants.*

Sources: See table.

[127] Frost and Gilkinson (2011); HBS Economics (2021a)

Biofuels
Biofuels can be defined as liquid fuels produced from biomass for either transport or other combustion purposes and include bio ethanol, biogas, bio diesel.[128] Biofuels are already used for land transport in several countries, including Sweden[129] that has an ethanol blending requirement in petrol. Biofuels can be produced from:

- 1st generation: edible biomass
- 2nd generation: non-edible biomass, such as organic waste, wood, and crop waste
- Newer generations: microorganism, genetically engineered crops, pyrolysis

Most of the current production is made with 1st generation (for example, from corn) but increases in 2nd and newer generation biofuels are expected towards 2030. Since the application of these biofuels is different than for anaerobic digestion of slurry (natural gas system vs. road transport) there is no overlap between the impacts of the two solutions.

The table below shows numbers for road transport only. In case heavy road transport primarily transition into using other types of energy than biofuels (for example electric or hydrogen), these impacts do not necessarily disappear, as biofuels can be used in other industries, including maritime transport, heavy industry processes, or perhaps aviation.

Table 9
Biofuels impacts (road transport only)

Sustainability impacts	• Climate change • Negative impact on land use for certain types of biomasses.
CO_2 emission reduction potential	1,020 million tons CO_2e in 2030 *Based on the ambitious scenario in HBS Economics (2021, b).*
Market growth potential in 2030 relative to 2020	+ EUR 144 billion *Based on Precedence Research (2021). The growth mainly includes expected biofuels growth in road transport, but other uses are also included. The shares of these are not reported.* *Comparison:* • *Precedence Research (2021) finds a market size of a broader use of biofuels of EUR 735 billion in 2030.* • *Second and newer generations account for approximately one-third of the expected market increase, see Allied Market Research (2021).*
Marginal abatement cost (current)	EUR 252 per ton CO_2e *Based on EA Energianalyse (2019). The calculation is based on a fuel mix containing 73% biodiesel, 10% biogas, and 17% bioethanol weighted by emission reduction potentials (all ranging between EUR 230 and EUR 300 per ton CO_2e).*

Sources: See table.

[128] See Dufey (2006) p.7
[129] See Swedish Energy Agency (2020).

Bio plastics

Bio plastics are fully or partially made from biological resources, rather than fossil raw materials. Bio plastics differ in how compostable and biodegradable they are depending on the material and technology used in production of the bio plastics.[130]

Table 10
Bio plastics impacts

Sustainability impacts	• Plastic waste • Climate change
CO_2 emission reduction potential	460 million tons CO_2e in 2030. This covers a market share of 35 per cent. *Based on HBS Economics (2021, b).*
Market growth potential in 2030 relative to 2020	+ EUR 43 billion *Based on GlobeNewswire (2021).* *Comparison:* • *Plantvision (2019) finds a market of EUR 280 billion in 2030, but it is unclear how these numbers have arrived.*
Marginal abatement cost (current)	EUR 245 per ton CO_2e. *Based on Musonda et al (2020), p.11.*

Sources: See table.

130 See European Commission: *Bio-based, biodegradable and compostable plastics*; Shah et al. (2021) p.62.

Bio fertilizer and bio controls

Bio fertilizers are living microbes that enhance plant nutrition by either mobilizing or increasing nutrient availability in soils.[131] Examples include bio fertilizers (for example rhizobium bacteria) to optimise yield of existing crops.

Table 11
Bio fertilizer and bio controls impacts

Sustainability impacts	• Climate change • Pesticide use • Food supply and security
CO_2 emission reduction potential	170 million tons CO_2e in 2030 *Based on HBS Economics (2021, b).*
Market growth potential in 2030 relative to 2020	+ EUR 22 billion *Based on Markets & Markets (2020). Under the assumption of same growth rate 2025-2030 as in 2019-2025.*
Marginal abatement cost (current)	Negative (-) EUR 134 per ton CO_2e *Based on product prices and emission intensities in Havukainen et al (2018), table 6.*

Sources: See table.

131 See Mitter et al. (2021), Integro, link.

Fermentation and food cultures in food

Fermentation is a food processing technology exploiting the metabolic activity of microorganisms.[132] Fermentation provides better protection against spoilage caused by yeasts and molds, thereby prolonging the lifetime of food products. Examples include lactic acid bacteria that can out-compete contaminants through fermentation, for example, in cheese, yoghurt, or wine.

Table 12
Fermentation and food cultures in food impacts

Sustainability impacts	• Climate change • Food supply and security • Food waste
CO_2 emission reduction potential	170 million tons CO_2e in 2030 *Based on HBS Economics (2021, b).*
Market growth potential in 2030 relative to 2020	+ EUR 35 billion *Based on Markets and Markets (2016). Under the assumption of same growth rate 2022-2030 as in 2017-2022.*
Marginal abatement cost (current)	EUR 70 per ton CO_2e *Based on Altenburg et al (2021).*

Sources: See table.

[132] See Terefe (2016); Chr. Hansen – Fresh Q; Altenburg et al. (2021); HBS Economics (2021, a).

Industrial enzymes

Enzymes are protein molecules functioning as specialized catalysts for chemical reactions and act as natural catalysts which support many chemical industries.[133] Industrial enzymes are produced by living organisms to increase the rate of an immense and diverse set of reactions. Examples include laundry detergents, cosmetics, and digestive aid.

Table 13
Industrial enzymes impacts

Sustainability impacts	• Biodiversity • Climate change
CO_2 emission reduction potential	80 million tons CO_2e in 2030 *Based on HBS Economics (2021, b).*
Market growth potential in 2030 relative to 2020	+ EUR 11 billion EUR *Based on Research and Markets (2021). Under the assumption of same growth rate 2027-2030 as in 2020-2027.*
Marginal abatement cost (current)	Around EUR 0 per ton CO_2e *Own calculation for laundry detergent: Price of laundry detergent with enzymes is 120% of the price of ordinary detergent. (Rähse (2014)), and we assume that the price difference cancels out with the energy savings and longer lifetime of clothes, i.e., a relative cost close to 0.*

Sources: See table and Jegannathan and Nielsen (2013).

[133] See Valutes (2021), HBS Economics (2021a) p.60.

Probiotic fodder

Probiotics are live microorganisms that provide health benefits when consumed or taken into the body.[134] Probiotics used in animal nutrition are generally produced commercially and offered to the market in liquid and solid forms. They classify as bacteria, yeast, and fungi.

Table 14
Probiotic fodder impacts

Sustainability impacts	• Climate change • Food supply and security
CO_2 emission reduction potential	215 million tons CO_2e in 2030 *Based on HBS Economics (2021b).*
Market growth potential in 2030 relative to 2020	+ EUR 5 billion *Based on Markets and Markets (2021) under the assumption of same growth rate 2020-2021 and 2026-2030 as in 2021-2026.*
Marginal abatement cost (current)	Negative (-) EUR 273 per ton CO_2e *Based on UK Committee on Climate Change (2015) p.92*

Sources: See table.

[134] See Feed Additive (2021), HBS Economics (2021a). The bacteria most used as animal-feed probiotics include lactobacillus, bacillus, streptococcus, pediococcus, enterococcus, and bifidobacterium.

APPENDIX B

IDENTIFIED BARRIERS FOR BIO SOLUTIONS

BARRIER	TYPE	DESCRIPTION
Outdated product classification	Regulatory	Bio solutions could end in a classification where they have to adhere to stringent regulations that may not be relevant to the characteristics of the product.
EU regulation does not follow technological development	Regulatory	This is for example the case for the Common Agricultural Policy (CAP), Novel Foods regulation, Genetically Modified Organisms regulation
Restrictive labelling in the EU	Regulatory	The EU regulation of nutrition and health claims falls under the Nutrition and Health Claims regulation from 2006. These limit companies' ability to use claims for marketing purposes highlighting the positive effects of their products.
Slow product approval processes in the EU	Regulatory	Bio solutions face barriers in the EU product approval process due to slow product approval processes due to few administrative resources and complicated and lengthy processes.
Expensive product approval processes in the EU	Regulatory	In the EU, the product approval process is characterised by high processing costs. For example, costs for testing, dossier preparation and registration can range can go up to € 350,000, and a total documentation cost of € 1 million.
Difficult approval of new initiatives in seawater	Regulatory	In Denmark, it is difficult to get approval for launching large scale production of for example mussels in seawater.
Plastics in contact with food does not consider biomaterial	Regulatory	The regulation on the migration of plastics in contact with food does not allow for all safe biomaterial to migrate.
Biodegradable regulation in the EU	Regulatory	EU regulation requires compostable plastics to completely biodegrade within six months, limiting the possibility for bioplastics to be biodegradable.
Difficult to use agricultural side streams	Regulatory	It is difficult to get food product approval for products using agricultural side streams.
Public subsidies to fossil fuels	Market	There are public subsidies for fossil fuels in some countries which adds to the cost differential between fossil-free solutions and solutions using fossil fuels.
Persistent cost gap to alternatives	Market	Price gaps between the bio solution and its traditional alternative can stem from more expensive input costs and costs in production processes.
Incumbent industry lowers market accessibility	Market	Long-term contracts for supply with incumbent providers lower the market access for new solutions.
Offtake risk and transition costs for the buyer	Market	Lack of market readiness and uptake for bio solutions due to transition risks, transition costs, or knowledge lack for the buyer of the solution, and public procurement policies do not always address an offtake of bio solutions.
Low R&D intensity	Financial	Several countries have low biotech R&D intensity.
Low financing in demonstration and scaling phases	Financial	Low public financing and support for developing new bio solutions, lowering the financing available for developing solutions.

Note: Some barriers are assessed in the report (in **bold**), whereas others have not been assessed, as there may not be any clear regulatory solutions, or they fit under some of the other barriers described.
Source: Copenhagen Economics based on interviews with bio solution companies, IRIS Group (2022).

Table 15
Barriers and policy recommendations

Barrier	Policy recommendations	Relevant regulations (not exhaustive)
Outdated product classification	1) Ensure that regulation allows for product classifications with the technological development of newer solutions.	• EU 1107/2009 (plant protection) • EU 91/414 (plant protection) • EU 1069/2009, 142/2011, 999/2001 (bioproducts and TSE) • EU 10/2011, 1935/2004 (plastic) • EU 1069/2009 (bi-products)
Unlevel playing field in agricultural subsidies	2) Ensure a level playing field for food products by aligning subsidy levels to also include newer production techniques (growing protein in silos or water).	• EU 1307/2013
Separate regulation for novel foods (EU)	3) Allowing novel food products to follow EU's General Food Law only.	• EU 2015/2283 (novel foods) • EU 178/2002 (general food law)
Outdated GMO regulation (EU)	4) Focus on product characteristic evaluation rather than process in the GMO regulation to enhance the development of safe modern genetic techniques.	• EU 2001/18 (GMO)
Restrictive labelling	5) Support the development of standardised labels for CO_2, biodiversity etc.	• EU 1924/2006 (appraisals)
The organic label is limited	6) Expand the organic label to also cover modern food production techniques.	• EU 834/2007, 889/2008, 2018/848 (organic products)
Long product approval processes	7) Allocate targeted resources to make a fast-track solution for approval of new products.	
High procedural cost of the product approval process	8) Lower the administrative cost burden, particularly for smaller companies.	
Cost gap	9) Remove all subsidies for fossil fuels and implement a global CO_2 tax.	
	10) Consider the use of regulatory sandboxes for bio solutions to test alternative regulation models.	
Low access to capital in R&D and demonstration phases	11) Increase public financing of biotech R&D and demonstration phase to crowd-in private capital.	• EU 1407/2013, 1408/2013, 707/2014 (de minimis) • EU 651/2014, 702/2014 and 1388/2014 (state aid)

Note: IRIS Group (2022) has an in-depth analysis of the EU regulatory aspects and differences in implementation of EU regulation in different countries.
Source: Copenhagen Economics based on sources throughout Chapter 2 and IRIS Group (2022).