NEXTGEN PROTEINS

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Contents

1 Executive summary

This report consists of a risk assessment of the value-chain of the four alternative protein producers taking part in the NextGenProteins project. Two of the firms, Mutatec and EntoCube, have developed technology to produce proteins from insects, one, ARBIOM, is engaged in the production of single-cell proteins (SCP) and the fourth, VAXA, produces proteins from microalgae.

The risk assessment was conducted using information gathered for the Deliverable 6.3 in NextGenProteins which provided a thorough analysis of the input-output structure of the production and processing of each firm, and this mapping formed the basis for questions that were put to representatives of each of the four firms. The risk assessment is therefore based on a qualitative methodology.

In the first step, representatives from each firm were asked to go carefully through each stage in the production and processing of their protein products and identify any risks. Participants were also asked about to identify risk in other stages of the value chain. In the second step, participants in the risk assessment assigned likelihoods to each risk identified. In the third step, participants were asked to estimate the maximum impact of each risk.

The final step in the analysis consisted of the risk evaluation. The risk level was defined by a combination of the likelihood level and the impact score. The risk assessment was done in a qualitative manner and involved no numerical values.

The risk assessment revealed that the number of risk factors identified in each case varied somewhat between firms. In three of the four case-studies, most of the risks identified were either minor or moderate, but many of the risks identified in the fourth case were either categorized as major or severe. This is not surprising, given that the analysis was qualitative in nature and therefore based on subjective risk evaluation.

Although the four companies have all developed technology to produce alternative proteins, the production and processing differ. Some of the risks identified are therefore idiosyncratic and firm-specific. There are, however, two sets of risks that are common to all the four companies. The first concerns the risk of being unable to attract funding, which is of special relevance for start-up firms that may particularly find it difficult to attract the necessary funds. The other risk factor concerns the willingness of consumers to accept the new, alternative proteins. This risk can be mitigated by better marketing, more information and greater transparency.

2 Introduction

Over the next 25 years, the world population is expected to grow by from 7.7 billion to 9.7 billion and could peak at nearly 11 billion around 2100 (UN, 2021). This larger population, together with changes in consumption patterns and rising income level, will increase the demand for food. Production may even have to double by 2050 to keep pace with demand (Hunter et al., 2017).

Protein is an essential part of any diet. The global protein consumption increased by just over of a third during the period 1961-2018, with most of the increase coming from the consumption of animal-based proteins. However, greenhouse gas emissions (GHG) associated with the production of meat and dairy products is generally much higher than with the production of plant-based proteins. The water footprint and land use of animal husbandry is also much higher (NextGenProteins, 2021b).

By contrast, production of plant-based proteins and alternative proteins carry a much smaller carbon, water, and land footprint. As efforts to mitigate climate change become more pronounced, a larger share of the global protein production will therefore have to take the form of these protein types.

While alternative proteins today only represent a small part of the global production, the share of the total protein market could rise to 11% by 2035. The market could grow even more if technological step changes occur that would improve quality and if governmental policies and regulations become more supportive (Witte et al., 2021).

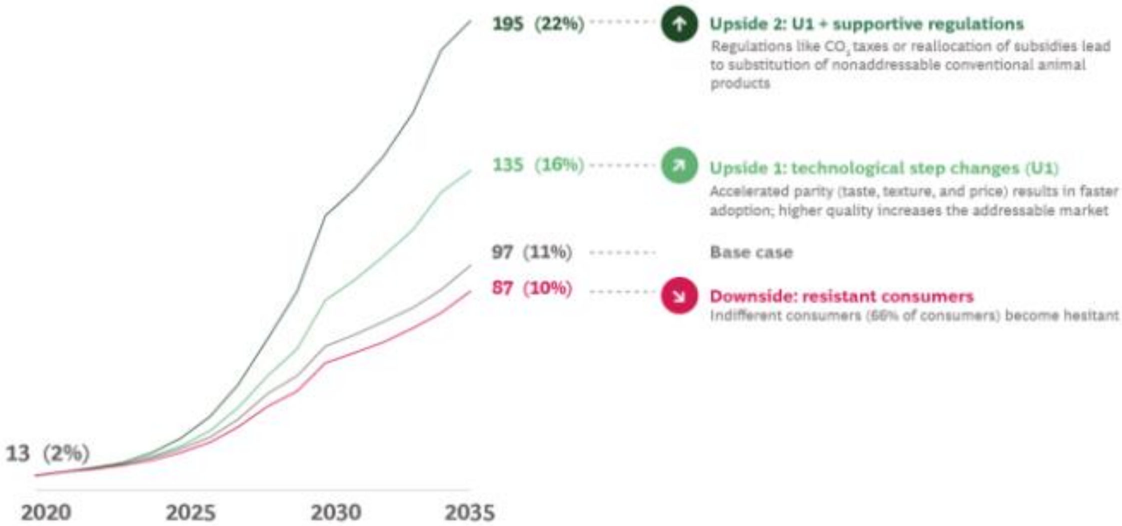

Figure 1 Possible growth of global consumption of alternative proteins. Source: Witte et al., 2021.

Like all other firms, the firms engaged in the production of alternative proteins face a multitude of risks throughout their value-chain. As many of the companies are young start-up firms they are more vulnerable than more developed firms in other markets. This report throws some light on the risks these firms must deal with, as it provides risk assessment of the value-chain of four alternative protein producers taking part in the NextGenProteins project. Two of the firms, Mutatec and EntoCube, have developed technology to produce proteins from insects, one, ARBIOM, is engaged in the production of single-cell proteins (SCP) and the fourth one, VAXA, produces proteins from microalgae.

The risk assessment was conducted using information gathered for the Deliverable 6.3 in NextGenProteins which deals with the circular potentials of the alternative proteins production processes. That deliverable provided a thorough analysis of the input-output structure of the production and processing of each firm, and this mapping formed the basis for questions that were put to representatives of each of the four firms. The risk assessment is therefore based on a qualitative methodology.

3 Value-chains

Although value-chains in various forms have existed for centuries, the concept of a value-chain only began to take shape in the latter part of 20th century. Fasse, Grote and Winter (2009) trace the origin to the French "filière concept" and Wallerstein's concept of a commodity chain. The former was developed in the 1960s as an analytical tool for empirical agricultural research, in particular to gain a better understanding of the economic processes within production and distribution systems for agricultural commodities. This concept has since been applied to domestic value chains. Wallerstein (1974) developed the concept of commodity chains, embedded in the Marxist world system theory, where the inter-regional and transnational division of labour divides the world into core countries, semi-periphery countries, and the periphery countries. This approach forms the basis of the global value-chain analysis and the global commodity chain developed by Gereffi and others (Gereffi 1994a, 1994b, 1999; Gereffi, Humphrey and Sturgeon, 2005; Gereffi and Kaplinsky 2001) which regards the international division of labour as the main driver of the dynamics of the distribution of value-chain activities.

Porter's (1985) concept of the value-chain is based on a set of activities that a company performs in order to generate value to its customers, which in turn improve the firm's competitive advantage and profitability. Porter distinguished between two important value-adding activities of a firm: primary activities (inbound logistics, operations, outbound logistics, marketing and sales) and support activities (strategic planning, human resource management, technology development, and procurement).

A value-chain is today normally taken to refer to the full range of activities that are required to bring a product or service from conception, through the various stages of production, and to delivery to final consumers. More recent definitions have also included final disposal after use (Kaplinsky and Morris 2001; Sturgeon 2001). A generic value-chain can thus be said to consist of six stages:

- Input supply
- Production
- Processing
- Marketing
- Consumption
- Recycling

As all stages generally don't occur in precisely the same location, transport frequently takes place between the various stages.

The term "value-chain" refers to the process in which firms add value to their inputs to create a final, finished product. In so doing, the firms take very opportunity within their organization to add value to their business and gain competitive advantage.

By contrast, the term "supply-chain" represents the steps in the production of a good from sourcing of all relevant inputs to selling the final product and filling a consumer request. Thus, the supply-chain comprises all the flows of materials, products, information and funds through the various stages of production. In a sense, the value-chain therefore includes the supply-chain. The supply-chain and logistics management may even be viewed as the main elements of the value-chain (Walters and Lancaster, 2000).
As noted by Kumar and Rajeev (2016), the value-chain concept originates from supply-chain, but it elucidates the value that is created at each stage of the chain which is vital for the firm's ability to satisfy its consumers.

4 Risk-assessment

The international standard on risk management, ISO 3100, defines risk simply as the effect of uncertainty on objectives where the effect is a deviation from the expected which can be positive, negative or both, and can address, create, or result in opportunities and threats. Risk is further expressed in terms of risk sources, potential events, their consequences, and their likelihood (ISO, 2018).
ISO 3100 defines risk assessment as the overall process of risk identification, risk analysis, and risk evaluation. Risk identification consists of identifying, recognising, and describing risks that might help or prevent an organization achieving its objectives. The aim of risk analysis is to understand the nature of risk, as well as the level of risk and other characteristics. The analysis can involve a detailed study of issues related to risk, such as uncertainties, risk sources, consequences, likelihood, scenarios, controls, and their effectiveness. Further, the analysis can be undertaken at various levels of complexity, depending on the purpose of the analysis, and the amount of information, data, and resources data available. A variety of techniques may be applied, including both qualitative and quantitative, as well as a combination of these. Risk evaluation is the last step in risk assessment and involves comparing the results of the risk analysis with the established risk criteria.
As noted by Aven (2016), the concept of risk and risk assessment has a long history and can even be traced back more than 2400 years to the practice of the Athenians who assessed risk before making decisions. However, risk assessment and risk management are a much younger field that has developed quite rapidly in the last 30-40 years. Risk analysis as practiced today, is predominantly asset-focused, aimed at identifying vulnerabilities in a system's components (Linkov et al., 2020). Risk-based management deals primarily with known and predictable threats but has been shown to be extremely costly in managing less known or unpredictable events (Bostick et al., 2018). Pettit et al. (2019) argue that risk analysis for business focuses primarily on discrete events rather than the build-up of gradual chronic stresses.
Risk management has been applied to a number of fields, including analysis of risk in supply-chains (see for instance Nyamagh et al., 2017; Tran, Dobrovnik, & Kummer, 2018; Rostamzadeh et al., 2018) and value-chains (see for instance Atherstone, Roesel, and Grace, 2014; Mattsson et al., 2017; Majekodunmi et al., 2019).

5 Methodology

The aim of this deliverable is to undertake value-chain risk assessment of four alternative protein case studies: protein production from microalgae, single-cell protein (SCP) production from yeast, black soldier fly (*Hermetia illucens*) cultivation and protein production, and cricket (*Grylloidea*) rearing and protein production. The four firms – VAXA, ARBIOM, Mutatec and EntoCube – producing these alternative proteins are all engaged in cutting-edge research.

In September 2019, VAXA, previously known as Algaennovation Iceland, opened a microalgae facility at the geothermal park of ON Power's Hellisheidi Geothermal Power Plant, just outside Reykjavik, the capital of Iceland.

ARBIOM was founded in 2011 and in 2017 the company launched its fermentation activity as well as SYLFEED, an international and multidisciplinary 4-year project, aimed at scaling up ARBIOM's technology to convert wood residuals into a protein-rich feed ingredient comprised of SCP. SYLFEED was successfully completed in 2021 when ARBIOM reached demonstration scale (TRL-7).

Mutatec was founded in 2015 with the aim to research, design, develop and operate bioconversion farms, recycling organic waste from agriculture, retailers and agrofood industry in order to produce and sell whole insects, valuable insect-based products, or by-products. Mutatec has been focusing on working out black soldier fly (*Hermetia illucens*) reproduction and breeding since the set-up of the company.

EntoCube was founded in 2014 to develop value-chains for food insect production and utilization as consumer foods. The firm has developed technology for rearing edible insects and the case study in NextGenProteins focuses on how protein can be produced from crickets (*Grylloidea*).

As can be seen the firms are all relatively young. Most of them have left or are in the process of leaving the prototype stage and preparing to ramp-up production. The emphasis has so far been on developing the technology for producing and processing protein from these different sources, but the downstream activities – marketing and selling – will need more attention in the future. The value-chain is therefore not yet well developed for all four products.

The production and processing are described in Deliverable D6.3 and the following descriptions are taken from that deliverable. The microalgae production starts when a very small amount of algae biomass is introduced into the system and allowed to continuously reproduce (see Figure 2). Water and CO2 are provided to the microalgae, as well as LED lighting to allow photosynthesis to occur. The light generates heat, which is then countered by cooling water being pumped through the system. Once the algae have been produced, protein is then extracted with the primary product being fish feed. The final product will take the form of dry powder at 71% protein by mass.

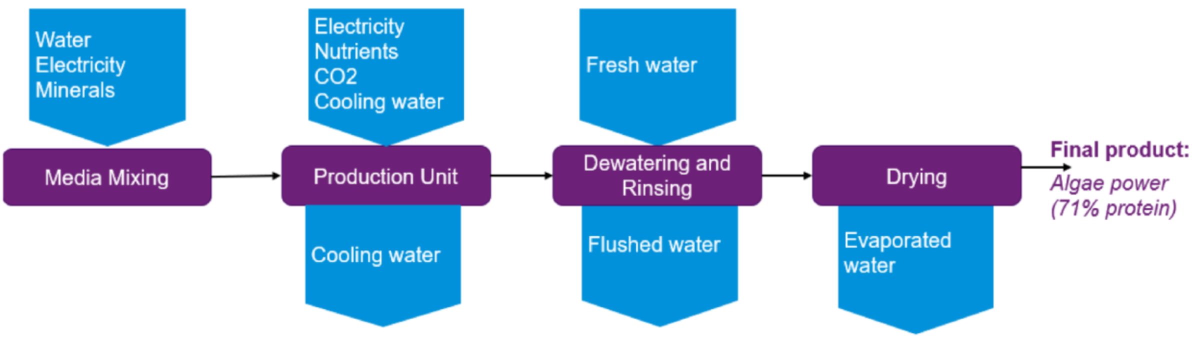

Figure 2 Microalgae case study simplified production process with key inputs and output. Source: NextGenProteins Deliverable D6.

In the SCP case, microorganisms are grown through a fermentation process (seen Figure 3), where the sugar source stems from sustainably managed agriculture or from hydrolysates of undervalorized agricultural by-products and wood residues. The output of this fermentation is then processed and dried into the final product, which takes the form of a protein rich powder (55% protein by mass) with potentially beneficial nutritional and sensory properties for industrial applications. The company sells its product as a protein ingredient both for human and animal consumption. In Deliverable D6.3, two production processes are discussed, where the first process uses primary sugar products as the primary feedstock and the second process allows for the more circular use of agricultural by-products and wood residues. As the first process is the one currently being followed, we concentrate on that process in this report.

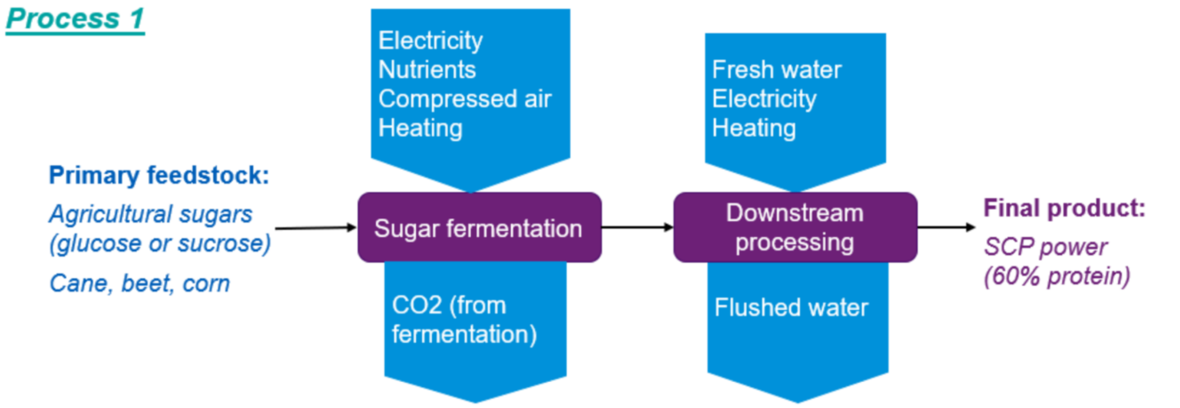

Figure 3 SCP case study simplified production process with key inputs and outputs. Source: NextGenProteins Deliverable D6.3.

In the first stage of the black soldier fly protein production, a powdered, liquid, and solid biomass is received and prepared into a substrate, which is then handled and placed in trays (see Figure 4). As the larvae begin to grow, the oviposition and fattening process starts, and this is then continued until the insects can be processed to protein concentrate. The final product consists of an insect meal form, which is a grinded powder with a 60% protein content. The case study's production location is in a European context with a low-carbon electricity grid but with fossil fuel produced heating.

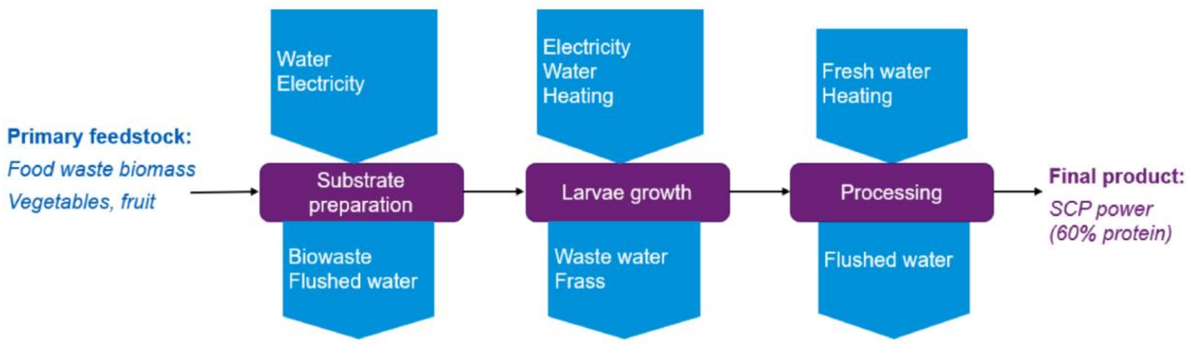

Figure 4 Black soldier fly simplified production process with key inputs and outputs. Source: NextGenProteins Deliverable D6.3.

The crickets process begins with the insects being propagated by placing adult crickets with the egg-laying substrate, where the cricket eggs are then incubated and hatched (see Figure

5). The crickets are then grown out over approximately 30 days, after which the insects are inactivated through either a boiling or freezing process. The crickets are then processed into dry cricket protein. The company's production typically takes the form of dehydrated powder for food ingredient and direct consumption.

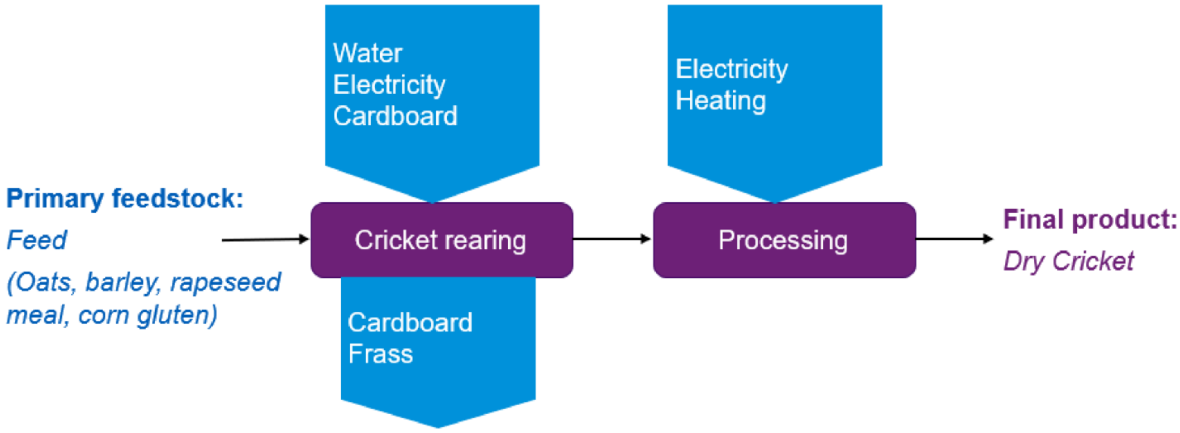

Figure 5 Cricket simplified production process with key inputs and outputs. Source: NextGenProteins Deliverable D6.3.

Deliverable D6.3 also discussed in detail assessments of the circular potential of each cases study and produced for that purpose detailed tables on the input-output structure of the four firms which may be found in the Appendix to this deliverable.

The information contained in Deliverable D6.3 on the production and processing in the four case studies, as well as on other parts of the value-chain was used to construct case-specific Excel files that where then made available to representatives of the four protein producers. The risk at each stage of production and processing was then assessed in conjunction with the firms' representatives. The risk associated with other parts of the value chain was also discussed in the interviews conducted.

As mentioned above, the risk assessment process may be broken down into risk identification, risk analysis, and risk evaluation. While the risk identification was undertaken together with representatives from each firm, the risk analysis and evaluation were conducted using tools developed in the Horizon 2020 research project ClimeFish (grant agreement No. 677039) and discussed in detail in Deliverable D4.3 of that project.

In the first step, representatives from each firm were asked to go carefully through each stage in the production and processing of their protein products and identify any risks. Participants were also asked to identify risk in other stages of the value chain. This step formed the basis of the

In the second step, participants in the risk assessment assigned likelihoods to each risk identified. Three levels of likelihood were defined: unlikely, possible, and likely. No numerical values were attached to these risk levels.

In the third step, participants were asked to estimate the maximum impact of each risk. Four categories were suggested: negligible, minor, moderate, and major. While the risk would ultimately be expected to have a quantifiable financial impact on operations and thus the firm, through for instance lower revenue and/or higher cost, the participants were not advised to assign any monetary value to the various impacts, but simply state what level of maximum impact each risk could have. As the risk assessment focused on risks that could have some impact, further analysis excluded all risks that had negligible impact and concentrated instead on events that were judged to have at least a minor impact. The firms' representatives also indicated which actions could be undertaken to remedy or mitigate the risk.

Table 1 Impact categories

Negligible	Not measurable impact, no expected effect
Minor	Minimal impact, no action needed
Moderate	Medium impact, some action recommended
Major	Major impact, immediate action should be recommended

Source: ClimeFish Deliverable D4.3.

The final step in the analysis consisted of the risk evaluation. The risk level was defined by a combination of the likelihood level and the impact score. The resultant risk matrix has four categories: minor, moderate, major, and severe, as shown in Table 2.

Table 2 Likelihood level – impact score risk matrix.

		Likelihood		
		Unlikely	Possible	Likely
Impact	Minor	Minor	Moderate	Moderate
	Moderate	Moderate	Major	Major
	Major	Moderate	Major	Severe

Source: ClimeFish Deliverable D4.3.

The risk levels in the risk matrix are further defined in Table 3. Whereas minor and moderate risk levels either require no special attention or some measures in the medium to long term, major and severe risk levels demand immediate action and possibly some drastic changes to management.

Table 3 Definition of risk level in risk matrix.

Minor	Acceptable, no specific control measure needed.
Moderate	Maximum acceptable level. Management measured required in the medium to long term.
Major	Not desirable. Increase management actions or implement further risk control in the near future.
Severe	Unaccpetable. Major changes required to management in immediate future.

Source: ClimeFish Deliverable D4.3.

The risk assessment presented above was then used to analyse the risks identified in each of the four case studies.

It should be stressed that the risk analysis was partly based on information contained in Deliverable D6.3 on the production and processing in the four case studies. This part of the questionnaires put to each protein producers and was thus firm-specific. In addition, all the firms were asked to identify risk associated with more general topics, such as economic conditions, financing, social aspects, technology, policy, climate change, environmental impacts, storage, transport, marketing and selling. These questions were broader, and the risk associated with each topic fleshed out in more detail in conversation with representatives from the four firms when the risk analysis was conducted for each firm. The general questions can therefore to a certain degree also be regarded as firm-specific.

6 Risk assessment results

6.1 Microalgae production

The microalgae production of VAXA takes place at facilities located in Hellisheidi, just outside Reykjavik, the capital of Iceland. The facilities are integrated into a geothermal plant next door, which produces electricity to the grid and hot water used for space heating and other purposes in nearby the capital and other towns and villages in the region (Innovation, n.d.). Access to electricity or water is thus not deemed a risk.

Of the five risks identified, three were classified as minor, one as moderate and one was defined as severe (see Table 4). Fresh water is one of the primary inputs in the algae production, where it acts both as the media in which the microalgae grow, and as cooling water to reduce heat generated by the lights the microalgae need to photosynthesize. Two of the minor risks are related to the media water. One concerns the risk of VAXA not finding an industrial symbiosis partner, in which case the firm can use processes to remove all non-desirable materials from the water and then recycle it. The other concerns anaerobic digest outputs, but anaerobic digestion is a sequence of processes by which microorganisms break down biodegradable materials in the absence of oxygen. To cope with this risk, VAXA has redundancy systems to deal with technical failures. The third minor risk level concerns natural disasters. The facilities of VAXA are located in a region where small earthquakes are frequent, but earthquakes larger than 5 on the Richter scale are very rare. Despite active volcanoes in the region, no eruptions have been recorded in the last 2,000 years (Guide to Iceland, n.d). Although the risk is small, all facilities have been designed with earthquakes and volcanic eruptions in mind.

VAXA is a young start-up firm that is yet to show profits. The firm is though well-financed with binding agreements in place. Economic and financial difficulties are therefore deemed unlikely, but they could have a moderate impact.

The most serious risk concerns consumer acceptance of the protein produced from microalgae. To counter this, consumers need to be educated and informed further.

Table 4 Risk assessment of the microalgae value-chain.

		Impact			Likelihood				
Factor	**Risk**	**Minor**	**Moderate**	**Major**	**Unlikely**	**Possible**	**Likely**	**Score**	**Remedy / mitigation**
Media water (bio-waste)	No industrial symbiosis partner found							**Minor**	Remove all non-desirable materials and then recycle the water
Media water (bio-waste)	Anaerobic digestion outputs							**Minor**	Redundancy systems to deal with technical failures
Economic	Operating at a loss							**Moderate**	Start-up firm not yet showing profit. In ramp-up stage.
Financial	Unable to attract capital							**Moderate**	Well-financed with binding agreements.
Environment	Natural disasters							**Minor**	All facilities designed with earthquakes and volcanic eruptions in mind
Marketing and selling	Not accepted by consumers							**Major**	Consumers are not well informed. Need to provide the market with information on the quality of food and algae.

6.2 SCP production

A total of 10 different risks were identified in the production of SCP, whereof four minor and six moderate risks (see Table 5). One of the minor risks refers to the need for consistent composition, which will be countered by securing a stable supply of biomass from selected suppliers that can both guarantee quality and quantity. Another minor risk is associated with the economic performance of the firm, as these worries have been alleviated by optimizing ARBIOM´s strategy and business and bringing the SYLFEED project to a successful conclusion (SYLFEED, 2021). There is also a minor risk associated with technology not being available, but ARBIOM has shown that the production and processing are viable and based on a proven technology. The final minor risk concerns difficulties in marketing and selling the protein product, but this is thought to be unlikely and only have a minor impact as the firm has obtained letters of support or intent to buy future production.

The moderate risks refer to insufficient supply of renewable/low carbon electricity, but this will be countered by locating the production sites in areas where there are many producers of this kind of electricity, or a renewable energy credit trading market exists. Closely related is the risk that the firm will not be able to obtain renewable heating, as there is low agency to make change. However, the firm can use a biomass burner to produce heat and thus reduce this moderate risk.

Another moderate risk refers to the availability of nutrients. The market for the nutrients is small, but the firm has the option to circulate and thus optimise input needs.

The ability to implement a carbon capture system is also regarded a moderate risk. Due to small scale, it is not feasible for ARBIOM to valorise these emissions, but synergies with nearby firms could be possible.

Like other innovation forms, ARBIOM always faces the risk of not being able to attract operating capital, but the firm has secured financing for most of the costs of the future production plant (ARBIOM, 2022) so that this is regarded as a moderate risk.

Finally, a moderate risk was identified because of the negative environmental impact of the production. The firm does, however, have strict regulations regarding both the production and processing as well as the production site itself.

Table 5 Risk assessment of the SCP value-chain.

		Impact			Likelihood				
Factor	**Risk**	**Minor**	**Moderate**	**Major**	**Unlikely**	**Possible**	**Likely**	**Score**	**Remedy / mitigation**
Biomass - circular input	Need for consistent nutrient composition							**Minor**	Supply of biomass will come from selected suppliers which will guarantee a stable supply interms of quantity and quality
Rewnewable/ low carbon electricity	Insufficient supply							**Moderate**	Production sites will be located in areas where the electricity mix is low carbon/transitioning to renewable sources (France, Northern Europe).
Nutrients	Small existing market							**Moderate**	Recirculate, thus optimise input needs
Renewable heating	Low agency to make change							**Moderate**	Use a biomass burner to produce heat
Carbon capture and released CO_2	Uneconomical due to the small scale							**Moderate**	Synergies with nearby firms in order to valorize the enriched CO_2 emissions. Continuous improvement of the process to reuce $C0_2$ emissions.
Financing operation	Unable to attract capital							**Moderate**	Secured financing for most of cost of future production plant
Environment	Negative impact							**Moderate**	Strict regulations on process and production site
Economic	Operating at a loss							**Minor**	Arbiom strategy and business plan have been optimized, notably via the SYLFEED project.
Technical	Technology							**Minor**	Viable process and proven technology
Selling	Difficulties in marketing and selling							**Minor**	Obtaining letters of support/intent to guarantee selling of future volumes produced

6.3 Black soldier fly production

Twelve risks were identified in the production and processing of black soldier flies, whereof five minor, six moderate and one was categorised as a moderate/major risk (see Table 6).

Three of the minor risks were associated with marketing and selling and concern consumer acceptance, lobbyism of animal welfare groups and the fact that the price of protein produced from black soldier flies is higher than protein from other sources. These challenges can be addressed by educating both consumers and lobby groups and providing information in a transparent manner. In the long-run prices of the black soldier fly protein will also have to drop to be competitive.

There is also a minor risk associated with the stock of flies being wiped out, but the firm does have it's own stock of black soldier fly. A new stock can also be sourced from other firms.

A minor risk is also attached to sanitary issues related to the frass produced by the black soldier fly, but the risk can be reduced by following regulations strictly.

Breakdown in the supply of renewable electricity is regarded a moderate risk that can be addressed by having many suppliers and backup facilities. Other moderate risks include the risk of contamination in the organic wheat bran and the food waste which are used for feed, but these risks can be reduced by following strict regulations. Food waste is sourced from local collection systems, and it may be quite a challenge to collect enough volume to use in the production, as the collection systems should be no further than 50 km away from the production facilities.

During the rearing, there is always the risk that the black soldier fly stop laying eggs and that there is therefore no production of flies. This moderate risk can be met by taking sanatory breaks, stop production and clean everything.

Financing the operation is also regarded as a moderate risk, although the inability to attract capital is regarded unlikely. To counter this, Mutatec needs to show profitability at small- or medium-scale.

The most serious risk identified in this case study concerns price fluctuations of the organic wheat bran which forms part of the feed for the blue soldier flies. Although this is a small part of the feed cost, and the total cost, the price fluctuations can have a moderate impact on the operation. The firm also has the option to switch to other substitutes.

Table 6 Risk assessment of the black soldier fly value-chain

		Impact			Likelihood				
Factor	**Risk**	**Minor**	**Moderate**	**Major**	**Unlikely**	**Possible**	**Likely**	**Score**	**Remedy / mitigation**
Renewable electricity	Breakdowns							**Moderate**	Many sources, have backups
Organic wheat bran	Price fluctuations							**Moderate/Major**	Substitution possibilitites, small part of the feed cost
Organic wheat bran	Possible contamination							**Moderate**	Strict regulations
Feed (fruits and vegetables (food waste))	Local food waste collection system							**Moderate**	Challenge to collect enough volume, should come from 50 km radius from plant
Feed (fruits and vegetables (food waste))	Possible contamination							**Moderate**	Strict regulations
Frass	Sanatory risk							**Minor**	Strict regulations
Black soldier flies	No production, no egg laying							**Moderate**	Sanitory breaks. Stop production and clean everything
Black soldier flies	Stock wiped out							**Minor**	Have own stock. New stock avaiable from other firms
Financing operation	Unable to attract capital							**Moderate**	Need to show profitability at small or medium scale
Marketing	Consumer acceptance							**Minor**	Improve information and guidance to consumers
Selling	Animal welfare lobbyists							**Minor**	Improve information and transparency
Selling	Uncompetative prices							**Minor**	Align prices with those of competing industries

6.4 Crickets production

Of the four case studies, the largest number of risks was identified in the crickets value-chain, or a total of 17 different types risks, whereof six were regarded as minor, two moderate/major, five major and four severe (see Table 7).

As in the other case studies, there is a minor risk related to supply of electricity, which can be countered by having backup power sources. There is also a minor risk that the cricket population will be wiped out, but certified disease-free crickets are available as backup for fast restart. Corrugated cardboard that doesn't meet hygiene and sanatory standards is also a minor risk but can be addressed by following rules and legislation. Sanitation issues with frass can be dealt with similarly. The use of inputs can carry some negative environmental impact, but this will be outweighed by the positive impact of the output.

The two moderate/major risks are both related to a population collapse, either brough about by technical or biological failure. The production system has warning systems and traffic lights that can warn of technical failures, but optimization also takes place as the technical mishaps can lead to a better understanding and improved redundancy systems. In the case of biological failure, certified disease-free crickets are available.

Fatalities in reproduction due to disease is a major risk that can be addressed by having disease-free crickets available, but also by following strict sanitation procedures and install sound disease analytics service. Contamination or hygiene issues can also threaten the crickets, but this major risk can be minimized by following rules and legislation and learning from doing.

The inability to find buyers for the frass produced by the crickets is also a major risk, but the commercial use of frass has been expanding, for instance as fertilizer.

EntoCube specializes in developing the technology for rearing crickets and other insects and providing this technology to others. The firm does for instance offer an EntoCube beginner kit for those interesting in farming crickets on a small scale, perhaps in the garage, and a kit for those bent on having a large-scale crickets farm (EntoCube, n.d.). Insufficient access to components used in the technology could prove difficult, but the increased availability of these technical components at global level has reduced this major risk.

The regulatory framework within the EU also poses a major risk, as the process for obtaining authorization to use alternative proteins in food and feed takes a long time, and these difficulties are in stark contrast to the emphasis of policy makers in Europe to encourage the production and use of new proteins sources.

The most serious risks involve fatalities in reproduction due to environmental failure, problems with implementing circularity in feed, securing financing, and gaining consumer acceptance. The severer risk of fatalities in reproduction has been addressed b improvements in rearing facilities, and by – literally – not placing all the eggs in the same basket. The possibility of using circular alternatives, such as food waste, instead of feed has been examined but this research is currently ongoing.

EntoCube is well financed but financing start-up and innovative firms is difficult in a volatile world. Consumer acceptance constitutes another severe risk which can be countered by strengthening marketing efforts and providing more information. Transparency is also important.

Table 7 Risk assessment of the crickets value-chain.

		Impact			Likelihood				
Factor	**Risk**	**Minor**	**Moderate**	**Major**	**Unlikely**	**Possible**	**Likely**	**Score**	**Remedy / mitigation**
Electricity	Power failure							**Minor**	Bakcup power source
Adult crickets	Technical failure - population collapse							**Moderate/Major**	Warning system, traffic lights, optimization
Adult crickets	Biological failure- population collapse							**Moderate/Major**	Certified disease-free critcket available as backup for fast restart
Adult crickets	Population wiped out							**Minor**	Certified disease-free critcket available as backup for fast restart
Crickets eggs	Fatalaties in reproduction - due to disease							**Major**	Availability of disease-free crickets, sanitation procedures, disease analytics service
Crickets eggs	Fatalaties in reproduction - due to environmental failure							**Severe**	Improvements in rearing facilities - not all eggs in same backet
Feed	Circularity not implemented							**Severe**	Research area
Corrugated cardboard (sent for recycling)	Issues with hygiene and sanitation							**Minor**	Follow rules and regulation. Learning-by-doing.
Corrugated cardboard (purchased with high recycling content)	Contamination or hygiene issues that threaten crickets							**Major**	Follow rules and regulation. Learning-by-doing.
Frass (output)	Unable to find buyers							**Major**	Commercial use expanding, e.g. as fertilizer
Frass (output)	Sanitation issues							**Minor**	Follow rules and regulation. Learning-by-doing.
Financial	Insecure financing							**Severe**	Have raised funds in three rounds. Are now passed the start-up stage and generating revenue.
Economic	Price of feed inputs							**Minor**	Feed cost are not a large part of total costs. Find substitutes
Technical	Insufficient access to technology							**Major**	Increase availability of technical components at global level
Environment	Negative impact							**Minor**	Negative impact of input usage counterbalanced by positive impact of output, as the ecological footprint is lower than of many competing proteins
Marketing and selling	Consumer acceptance							**Severe**	Strenghtening marketing efforts and provide more information. Transparency. Crickets are a niche market
Policy	Legal barriers							**Carry on campaingning for their products.**

7 Discussion

The risk factors identified in each case study and their severity are compared in Table 8. Three things immediately stand out. While the number of identified risks is similar for Mutatec and ARBIOM, only half as many were identified in the VAXA case, and almost twice as many in the EntoCube case.

It is also interesting that although the level of risk severity is very similar in the Mutatec, ARBIOM and VAXA case studies, the risks in the EntoCUbe case study are generally perceived to be more severe. As noted by Emblemsvåg and Kjølstad (2006) qualitative risk assessment requires experience, knowledge and creativity, and this reliance on subjectivism is a challenge in itself, as discussed by Backlund and Hannu (2002).

Table 8 Comparison of risk factors and risk severity.

Risk factor	Mutatec	ARBIOM	VAXA	EntoCube
Access to renewable electricity	Moderate	Moderate		Minor
Access to renewable heating		Moderate		
Price fluctuations of inputs	Moderate/Majo	Moderate		Minor
Consistent nutrients composition		Minor		
Contamination in feed	Moderate			Major
Acess to renwable feed	Moderate			
Non-circular feed				Severe
Issues with hygiene and sanitation				Minor/Major
Unable to find buyers for frass				Major
Sanatory risk in frass	Minor			Minor
No insect production	Moderate			Major/Severe
High insect stock casuality	Minor			Moderate/Majo
Carbon capture and released CO_2		Moderate		
Bio-waste water			Minor	
Natural disasters			Minor	
Unable to attract capital	Moderate	Moderate	Moderate	Severe
Operation losses		Minor	Moderate	
Consumer acceptance	Minor	Minor	Major	Severe
Animal welfare lobbyists	Minor			
Uncompetitive output prices	Minor			
Negative environmental impact		Moderate		
Access to technology		Minor		Major
Legal barriers in policy				Major

Although the four companies have all developed technology to produce alternative proteins, the production and processing differ. Some of the risks identified are therefore idiosyncratic and firm-specific. There are, however, two sets of risks that are common to all the four companies: the risk of being unable to attract capital and the risk that consumers will not accept the product. The risk level of securing funding is deemed moderate in three of the case studies and severe in the fourth. The non-acceptance risk is considered minor in two cases, major in one and severe in one.

Investment in innovation, which for the most part takes the form of research and development (R&D), differs from ordinary investment in three fundamental ways (Hall, 2010). First, most of the expenditure consist of workers' wages and salaries, in particular scientists, engineers, and other professionals. Second, the "output" created consists to a large degree of intangible capital, much of which is in the form of human capital in the heads of those engaged in R&D. Third, the innovative process is shrouded in uncertainty, which tends to be largest at the outset of the project or research program. A fourth dimension, closely linked to the uncertainty, is the fact that a considerable time may elapse before the investment begins to pay dividends. For these reasons it may be difficult for firms to acquire sufficient funds for their investments and non-innovators may also be reluctant to undertake innovation due to the high costs involved. New start-up firms may particularly find it difficult to attract the necessary funds.

As discussed in NextGenProteins deliverable D5.1, consumer attitudes towards the three NextGen proteins, their production processes, and the use of the resulting protein ingredients in food products was analysed using both online focus group discussion (selected consumers from Finland, Germany, Iceland and Italy) and online surveys (in Finland, Germany, Iceland, Poland, Sweden and the UK). In general, consumers in these countries were mostly positive or neutral, but 10-20% of consumers had negative views regarding torula and microalgae, and 30-50% of the respondents were negative towards the idea of obtaining protein food ingredients through the cultivation of house crickets.

Although participants were often positive, even excited, about the NGP concept, their personal interest in the products were much lower. Consumers are interested in testing the food products, provided their expectations are met as regards sensory pleasantness and other product characteristics. Respondents also made clear that they would need some more information on the production methods before making up their mind on potential use and consumption of the products. Transparency throughout the production system was also regarded important. This included information on the origin of the material, production methods and ingredients being honestly listed on the product label. Consumers also needed to be able to trust that the claimed benefits are indeed true, and that all risks are minimized with thorough investigations and authority controls.

Regression analysis clearly revealed that consumers' attitudes towards the NGP protein concepts are primarily determined by what they believed about the consequences for sustainability, animals and their health. Consumers did not appear to be overly concerned about risks, although attitudes towards the three concepts was negatively related towards risk for human health and food safety. The risk of being misled by food companies also had a small impact on the attitude for the protein concepts, but the risk of unpredicted negative consequences for the environment had no statistically significant impact on attitudes.

Regression analysis was also conducted to analyse what shaped consumers' interest to use the three food applications mentioned: vegetable-protein patties, sausages and salty snacks. Concerns for risk only had a significant impact in the case of the risk for human health and food safety in the case of torula yeast.

Consumers do, however, have some preconceptions about food applications that impacted both on their attitudes towards the NGP protein concepts, and their interest to use the three food applications mentioned above. The attitudes are to a certain degree shaped by the belief that the food applications are either bad or good for health, and unsafe or safe. The interest to use the food applications is seriously curtailed by the fact that consumers find the use of insects repulsive and worry about the taste of the products.

Neither of the two firms that do regard non-acceptance as a minor risk are in direct contact with consumers. One of those sells the products as feed and not as input into food, and believes the product is generally accepted socially. The other sells only to other businesses and does therefore not face consumer-related issues directly. The firms that believe consumer acceptance carries a more risk both believe that this uncertainty can be reduced by better marketing, more information and greater transparency.

It should also be noted that three of the protein producers attach a minor or moderate risk to access to renewable electricity and believe price fluctuations of inputs constitute similar risk levels.

The protein production of the four firms has limited impact on climate change. The production of some of the inputs, such as electricity and feed, may have some negative environmental impacts that can contribute to climate change. These effects are, however, negligible at the current level of scale, but would of course become larger should production become more voluminous and the technology more widespread. The risk assessment undertaken in this deliverable only focuses on the perceived risk at various stages of the value-chain of the four alternative proteins. These risks can of course be weighed against the benefits the production of these proteins brings, in particular the circular economy options, the smaller carbon and water footprints, and smaller land use. These issues are beyond the scope of this report but are discussed in more detail in NextGenProteins deliverable D6.3.

8 Conclusions

Like all other firms, the firms engaged in the production of alternative proteins face a multitude of risks throughout their whole value-chain. As many of the companies are young start-up firms, they are more vulnerable than more developed firms. This report throws some light on the risks these firms must deal with as it provides risk assessment of the value-chain of four alternative protein producers taking part in the NextGenProteins project. The risk assessment revealed that the number of risk factors identified in each case varied somewhat between firms. In three of the four case-studies, most of the risks identified were either minor or moderate, but many of the risks identified in the fourth case were either categorized as major or severe. This is not surprising, given that the analysis was qualitative in nature and therefore based on subjective risk evaluation.

Although the four companies have all developed technology to produce alternative proteins, the production and processing differ. Some of the risks identified are therefore idiosyncratic and firm-specific. There are, however, two sets of risks that are common to all the four companies. The first concerns the risk of being unable to attract funding. Investment in innovation, such as the production of alternative proteins, differs from ordinary investment in that most of the expenditure on research and development usually consists of wages and salaries, and the innovation results often take the form of intangible capital. The innovation process itself is often shrouded in uncertainty, both as regards the outcome and the length of time it takes for the research to bear fruit. For these reasons it may be difficult for firms to acquire sufficient funds for their investments and non-innovators may also be reluctant to undertake innovation due to the high costs involved. New start-up firms may in particular find it difficult to attract the necessary funds.

The other risk factor concerns the willingness of consumers to accept the new, alternative proteins. Two of the firms do though regard this as a minor risk. One of the two sells the products as feed and not as input into food, and believes the product is generally accepted socially. The other sells only to other businesses and does therefore not face consumer-related issues directly. The firms that believe consumer acceptance carries a more risk both believe that this uncertainty can be reduced by better marketing, more information and greater transparency. Indeed, as revealed in deliverable D5.2, this will be tackled in NextGenProteins by boosting consumer trust and acceptability towards alternative proteins.

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Appendix

Table A1 Microalgae circular assessment

Input/ Output	Source	Unit	Type of resource	Circular options	Scale of option	Barriers	Circular potential (H/M/L)
Input	Fresh water	kg	Water	Water recirculation	Internal to system	- Supply of freshwater -Need for uncontaminated water	L
	Minerals and nutrients	kg	Resource	Circular mineral inputs	Global	- Relatively small existing market - Green price premium	L
	CO2	kg	Resource	Direct supply from local industrial source or direct air capture.	Local	- Need for pure CO2 - Infrastructure required	M
				Supply of captured CO2 from global markets	Global/ regional	- Relatively small existing market - Green price premium	L
	Cooling water	kg	Energy	Wastewater from industrial source	Local	- Distance to partner - Infrastructure required	H
	Electricity	kWh	Energy	Use of renewable electricity	Local/ regional	- Supply of renewable electricity	H
				Purchase renewable energy credits	National/ International	- Must be in region where CO scheme exists - Green price premium	H
	Heat usage	kWh	Energy	Use renewable heating	Local	- Must be located near a source of renewable heating - Lack of a CO market for renewable heat - Low agency to make change	L
Output	Media water	kg	Bio-waste	Industrial symbiosis with nearby industry	Local	- Need to find a suitable partner	L
				Anaerobic digestion	Local	- Need to find a suitable partner	L
	Flushed water	kg	Water	Industrial symbiosis with nearby industry	Local	- Need to find a suitable partner	L

Source: NextGenProteins Deliverable D6.3

Table A2 SCP circular assessment

I/O	Source	Unit	Type of resource	Circular options	Scale of option	Barriers	Circular potential (H/M/L)
Input	Bio-mass	kg	Resource	Use of circular input (i.e. wood chips, saw dust, or residual straw)	Local/ regional	- Circular biomass supplier at scale - Need for a consistent composition	H
	Nutrients	kg	Resource	Circular inputs	Global	- Relatively small existing market - Green price premium	L
	Enzymes	kg	Resource	Circular inputs	Global	- Relatively small existing market - Green price premium	L
	Water	kg	Water	Water recirculation	Internal to system	- Supply of freshwater - Need for uncontaminated water	L
	Cooling Water	kg	Water	Industrial symbiosis	Internal to system	- Need to find suitable partner	H
	Electricity	kWh	Energy	Use of renewable electricity	Local/ regional	- Supply of low-carbon electricity	M
				Purchase renewable energy credits	National/ International	- Must be located in region where CO scheme exists - Green price premium	H
	Heating	kWh	Energy	Use renewable heating	Local	- Must be located near a source of low-carbon heating - Lack of a CO market for renewable heat - Low agency to make change	L
Output	Solid losses (organic)	kg	Bio-waste	Industrial symbiosis with nearby industry	Local	- Need to find a suitable partner	L
				Anaerobic digestion	Local	- Need to find a suitable partner	M
	CO2	kg	Resource	Carbon capture of released CO2	Internal to system	- Small scale of carbon capture makes such a system uneconomic	L
	Water	kg	Water	Industrial symbiosis with nearby industry (such as agricultural use)	Local	- Need to find a suitable partner	L

Source: NextGenProteins Deliverable D6.3

Table A3 Black Soldier Fly circular assessment

I/O	Source	Unit	Type of resource	Circular options	Scale of option	Barriers	Circular potential (H/M/L)
Input	Wheat	kg	Resource	Organic wheat	Global	- Potential price volatility due to external shocks	M
	Fruits	kg	Resource	Food waste	Local	- Need for an efficient and incentivized local food waste collection system	H
	Vegetables	kg	Resource	Food waste	Local	- Need for an efficient and incentivized local food waste collection system	H
	Frass	kg	Resource	Internal circulation	Internal to process	- Requires system design	H
	Water	m^3	Water	Internal circulation	Internal to process	- Requires system design	M
	Electricity	kWh	Energy	Use of renewable electricity	Local/ regional	- Supply of renewable electricity	M
				Purchase renewable energy credits	National/ International	- Must be located in region where CO scheme exists - Green price premium	H
	Gas	kWh	Energy	Use renewable heating	Local/Municipal	- Must be located near a source of renewable heating - Lack of a CO market for renewable heat - Low agency to make change	L/M
Output	bio waste (liquid)	kg	Bio-resource	Internal circulation	Internal to process	- Waste may not be suitable for recirculation	M
				Industrial symbiosis with nearby industry	Local	- Need to find a suitable partner	L
				Anaerobic digestion	Local	- Need to find a suitable partner	M
	Waste Water	kg	Water	Industrial symbiosis with nearby industry (such as agricultural use)	Local	- Need to find a suitable partner	L
	Frass	kg	Bio-resource	Internal circulation	Internal to process	- Requires system design	H
			Bio-resource	Industrial symbiosis with nearby industry (such as agricultural use)	Local/Regional	- Need to find a suitable partner	M

Source: NextGenProteins Deliverable D6.3

Table A9 Crickets circular assessment

I/O	Source	Unit	Type of resource	Circular options	Scale of option	Barriers	Circular potential (H/M/L)
Input	Feed	kg	Resource	- Use circular feed - Ensure regenerative farming	Global	- Relatively small existing market - Green price premium	M
	Nutrients	kg	Resource	Circular inputs	Global	- Relatively small existing market - Green price premium	L
	Corrugated cardboard	kg	Resource	Make use of cardboard sent for recycling	Local	- need for an efficient and incentivized cardboard collection system	M
				Purchase with high recycling content	Global	- Green price premium	H
	Water	L	Water	Use of water from another industrial system	Local	- Need for clean water	L
	Electricity	kWh	Energy	Use of renewable electricity	Local/ regional	- Supply of renewable electricity	M
				Purchase renewable energy credits	National/ International	- Must be located in region where CO scheme exists - Green price premium	H
Output	Frass	kg	Resource	Internal circulation	Internal to process	- Requires system design	H
				Industrial symbiosis with nearby industry (such as agricultural use)	Local/Regional	- Need to find a suitable partner	M

Source: NextGenProteins Deliverable D6.3