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The viability of feeding seaweed to cows

An assessment of the key opportunities and barriers facing the commercialization of factory-produced *Asparagopsis taxiformis* as a methane-reducing additive for dairy cows in Sweden.

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Abstract

An estimated 6% of human greenhouse gas emissions are the result of enteric methane production by cows. *Asparagopsis taxiformis*, a semi-tropical alga, is one solution. Supplementation of this alga to cows at a small percentage of their daily intake has reduced their methane emissions by over 98% in trials. This success has led to multiple commercialization attempts globally, although no *Asparagopsis taxiformis* company has yet proved its viability. This thesis investigates the commercial viability of factory *Asparagopsis taxiformis* production, via a case study. The focal firm is Swedish start-up Volta Greentech, the first and only factory-based *Asparagopsis taxiformis* producers. This work draws on grounded theory and stakeholder theory perspectives to elicit key opportunities and barriers facing the case-study firm. Data was collected from interviews with 26 key external stakeholders and 7 team members, 2 multi-day observations of company operations, a workshop with the team and extensive literature and grey paper review. Three major barriers - production of *Asparagopsis taxiformis*, risks associated with *Asparagopsis taxiformis* and competition from other enteric-methane-reducing measures were identified and investigated further. Six short-term opportunities were also identified and investigated. These are political support, celebrity endorsement, a methane-reduction label for the *Asparagopsis taxiformis*-fed cow-products, collaboration with other algae experts, symbiotic production mechanisms in the factory and capitalizing on alternative uses of *Asparagopsis taxiformis*. This investigation concludes that Volta Greentech is a radical and innovative venture, and a useful model for understanding factory produced *Asparagopsis taxiformis* production. This case is used to highlight how and why support should be provided for such innovative ventures.

Keywords: *Asparagopsis taxiformis*, methane-reducing additive, commercial viability

Executive Summary

Methane produced by flatulent ruminants, especially cows, is a major contribution to anthropocentric greenhouse gas emissions. To meet climate targets, mitigating these emissions is recognised as an issue of high importance. One promising solution is the red algae, *Asparagopsis taxiformis*. The first trials were conducted on this alga in 2014, and the unprecedented methane reduction levels witnessed led to subsequent commercialisation attempts in Australia, the U.S.A. and Sweden. However, the recent status of research into this alga, as well as the novelty of producing and using it have raised problems for these companies and none are yet producing on a commercial scale.

The **research aim** is to understand the commercial viability of factory-produced *Asparagopsis taxiformis* production. This is achieved via a case study. Swedish start-up Volta Greentech are the only company to have initiated production of the alga in this way. The commercial viability is investigated here through an assessment of the key barriers and opportunities facing the firm. This commercial viability assessment typology is based on a prior study by Vijn et al. (2020). Both the Vijn et al. (2020) study and this thesis use stakeholder perspectives to determine opportunities and barriers facing the use of *Asparagopsis taxiformis*. Stakeholder theory is used as the theoretical lens for understanding the value of this mechanism of assessment. Grounded theory is used to analyse empirical data. Analysing data in this way enabled the emergence of the opportunities and barriers from the bottom-up. The research questions investigated are as follows:

Research Question 1 (RQ1): Is the factory production of *Asparagopsis taxiformis* for use as a methane reducing additive for dairy cows commercially viable in Sweden?

Sub question 1 (SQ1): What are the key barriers for case-study firm Volta Greentech?
Sub question 2 (SQ2): What are the key opportunities for case-study firm Volta Greentech?

The **research design** employs an exploratory, case-based approach. This exploratory, single case-based approach was chosen as appropriate given that commercial success is highly complex and context dependent. Volta Greentech are also the only factory producers of *Asparagopsis taxiformis*. Data about the opportunities and barriers for the company was collected from interviews with 26 key external stakeholders and 7 team members, 2 multi-day observations of company operations, a workshop with the team and extensive literature and grey paper review. This data was coded iteratively according to grounded theory principles.

The **research results** to RQ1 were determined through answering SQ1 and SQ2.

The key barriers to the commercial success of *Asparagopsis taxiformis* were categorized in terms of severity of threat. The three major barriers were found to be the unprecedented and complex process of growing the alga, the risks associated with the intracellular bioactive compounds and the competitive presence of other enteric-methane-reducing options. The literature and stakeholder perspectives were sufficient for assessing the production and risk barriers. There were, however, minimal objective perspectives and published information on the competitive threat posed. Consequently, a framework was developed to comprehensively assess this barrier. Stakeholder perspectives and literature findings were used to comment on possible remediation of these barriers.

The key opportunities to the commercial success of *Asparagopsis taxiformis* were selected in terms of their propensity for immediate or short-term impact. There were multiple linkages between these identified opportunities and, if initiated, they would likely be mutually reinforcing. These opportunities are political support, celebrity endorsement, a new funding mechanism,

collaboration with other algae experts, symbiotic production mechanisms and alternative uses of *Asparagopsis taxiformis*. Stakeholder perspectives and literature findings were used to comment on possible problems with these opportunities, as well as present recommendations for how the opportunity could be best exploited.

The **broader applicability** of this research includes a commentary on the future commercial viability of factory produced *Asparagopsis taxiformis*, which is also partially valid for the entire *Asparagopsis taxiformis* industry. Volta Greentech is found to be a good model for representing future viability. While firm success definitively indicates viability, firm failure would also provide interesting insights - were the barriers too large? Could additional opportunities have been seized? Assessment of Volta Greentech's current status does not enable forecasting of commercial viability, but instead indicates their business *idea* has commercial potential. This research found Volta Greentech to be an innovative, potentially market driving firm and highlights the important role of such innovative leaps. This is especially the case for climate change mitigation solutions. The barriers and opportunities that emerged for Volta Greentech are used to comment on the requirement of support for other innovative firms. This research also presents a new mode by which commercial viability can be assessed and suggests future applications for this.

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Abbreviations

AT - Asparagopsis taxiformis

CAP – Common Agricultural Policy

CO_2e – Carbon dioxide equivalent

GHG - Greenhouse gases

MRA - Methane reducing additive

LRF – Lantbrukarnas Riksförbund (English: Federation of Swedish Farmers)

SLU – Sveriges Lantbruksuniversitet (English: Swedish University of Agricultural Sciences)

tCO_2e – Tonnes of carbon dioxide equivalent

VG - Volta Greentech

1 Introduction

1.1 Background and significance

1.1.1 The climate problem

Anthropogenic greenhouse gas (GHG) emissions are contributing to a changing climate on Earth. The concentration of atmospheric carbon dioxide has increased from 350 to 410 ppm since 1950, whilst methane concentrations have risen from 1100 to 1875 ppb over the same period (U.S. EPA 2021). A mean increase in global temperatures of 1.0ºC above pre-industrial levels has already been observed (Allen et al., 2018). The increases in atmospheric GHG concentration and corresponding climate shifts are threatening ecosystems and posing major threats to human health and livelihoods.

Given the threat posed by rising GHG concentrations, a key challenge for 21st century humanity is to limit this warming to below 1.5-2.0ºC, whilst maintaining and improving living standards for a human population expected to reach around 10 billion by 2050 (Ouatahar et al., 2021).

1.1.2 Agricultural and cow-related emissions

Agricultural emissions are responsible for around 20-25% of global GHG emissions (IPCC 2014), with the livestock sector contributing approximately 14.5% (FAO 2017). Within the livestock sector, ruminant animals (hoofed mammals with a digestive system able to ferment feedstuff) represent 75% of overall CO_2e emissions. Cows constitute the major chunk of these emissions (IPCC 2019). Ruminants primarily contribute to GHG emissions through production of methane. The majority of this, around 80%, is enteric methane, produced by the ruminants when their unique digestive systems ferment plant material (Herrero et al., 2016). The remaining fraction is associated with manure management. Ruminant production is the largest single contributor to the global methane budget, with enteric methane responsible for 30% of released methane (Global Methane Initiative 2021). It is estimated that the total contribution of ruminant enteric methane to global GHG emissions is 6% (Beauchemin et al., 2020; Ripple et al., 2014).

Before understanding strategies to reduce enteric methane, it is important to understand the mechanism by which it is produced. This is a well understood process, having been extensively studied and reviewed in the literature (e.g. Beauchemin et al., 2020). Although all herbivorous mammalian species emit methane (Black et al., 2021), ruminant digestion is unique and produces significantly higher quantities. Digestion for ruminants takes place in the rumen, the animal's forestomach, where microbial communities ferment consumed plant biomass. A diverse array of micro-organisms are involved in this process. In order to identify them, they are categorized by function for example sulphate reducing bacteria and methane-producing methanogens (Choudhury et al., 2015). In the process of enteric fermentation, hydrogen and CO_2 are converted either into nutrients (by beneficial bacteria) or methane (by methanogens). The production of methane in ruminants uses up 2-12% of their total dietary energy. This substantial metabolic loss means there is great potential for improved animal productivity if methane production can be reduced. However, it must be noted that perturbating the ruminal microbiome has previously had detrimental impact on animal health and productivity (Choudhury et al., 2015) and thus careful consideration of intervention strategies is required.

1.1.3 Future enteric methane emissions

There is a clear need for reducing methane from animal production whilst maintaining or improving the supply of animal products. The growing global population and wealth-level will likely increase the demand for animal products, with an estimated doubling of demand from 2015 to 2050 (Rojas-Downing et al., 2017). The demand for ruminant products will be especially great in developing countries, where the FAO (2017) predicts that demand for red meat will grow by 1.5% annually because of improving living standards and growing populations in these developing states. In these developing countries, animal products are of major importance to achieve SGD 2 (zero hunger) as they provide human food by grazing marginal land (Arndt et al., 2021). Similarly, the size of the livestock sector (already one of the fastest growing sectors of the agricultural economy) is predicted to double by 2050 (Herrero et al., 2016). Thus, despite calls from the academic community to reduce meat/dairy consumption (Bryngelsson et al., 2016; Pais et al., 2020), it seems likely ruminant numbers will increase. Effective enteric methane mitigation strategies are therefore clearly needed.

The agriculture, forestry and other land use sector has been highlighted as one with a key role to play in mitigating further climate change (Popp et al., 2017). Although decreases in methane emissions in this sector have already been shown, there is scope for more. From 1990 to present, European regions' agricultural methane output decreased by 22% (FAO 2018). This decrease has been attributed to farm management changes driven by the Common Agricultural Policy (CAP), such as reductions in animal numbers. This is indicative that policy measures may be able to help drive further reductions. In terms of specifically tackling enteric methane emissions, mitigation measures are already available although their feasibility varies with access to natural and economic resources (Rojas-Downing et al., 2017). Whilst there has been some implementation of these schemes, Ortega et al. (2021) describe how their broader impact has been delayed by the long experimental timescales of researching the mitigation strategies. Using data from FAOSTAT and computer models, Ortega et al. (2021) project that full suppression of enteric methane emissions is not possible by 2050, but various mitigation measures can combine to give significantly reduced methane output.

1.1.4 Reducing enteric methane to meet climate ambitions

There is widespread acknowledgement of the importance of reducing methane emissions to meet global climate goals. Arndt et al. (2021) notes how the goal of the Paris Agreement (limiting warming to 2ºC) is unlikely to be achieved if food systems are operating on their current business as usual basis. To meet this Paris target, it is estimated that methane emissions need to be reduced by between 24-47 %. The perceived urgency of reducing methane emissions is also made clear by the recent publication of the EU Methane Strategy (European Commission, 2020). The EU Commission describes this strategy as an essential part of meeting the EU's nationally determined contributions and it's 2050 climate neutrality goal.

Institutions on various levels have begun to implement schemes that will reduce methane emissions from ruminants. Table 1-1 gives examples of strategies related to enteric methane from four EU countries. More local strategies and programs are also in place, for example at a state-level, California has passed a bill requiring 40% methane emission reduction from livestock and dairy manure management by 2030 from 2013 levels (Lazo, 2017). At an industry level, Australian Meat and Livestock Industry has committed to be carbon neutral by 2030 (Black et al., 2021). This commitment to enteric methane reduction is evidence of the political momentum behind methane reduction schemes.

Table 1-1: Examples of political strategies related to enteric methane reduction in four EU countries.

Country	Strategy	Targets	Objectives related to enteric methane
Belgium	VEKP Climate Plan /Convenant Enterische Emissies Rundvee 2021-2030	Emissions not covered by EU ETS: 35% reduction in emissions by 2030 compared to 2005. Agricultural and horticultural: 26% % reduction in emissions by 2030 compared to 2005.	Reduce enteric emissions through market-orientated and initiative-driven measures, supplemented with awareness raising. Government policy should be stimulated, including through CAP.

		Enteric methane emissions: 0.44 Mton CO_2e compared to 2005 (or a limit of 1.9 Mton)	
Germany	Climate protection programme	Reduce agricultural sector emissions by 14% by 2030 compared to 2020 levels	Reduce emissions in livestock production (less consumption of animal products and reduce food waste). No particular enteric methane measures.
Luxembourg	National Energy and Climate plan	40% reduction in emissions in 2030 compared with 2050	Measures to reduce GHGs including methane from agricultural sector. Methane strategy to be developed at a later time.
Denmark	Climate Neutral 2050	Food Industry should be carbon neutral by 2050	One focus area of the target is enteric methane production.

Data sourced from: Coordination Committee for International Environmental Policy (2019); German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (2016); European Commission (2021); Searchinger et al., (2021).

1.2 Problem definition

1.2.1 The *Asparagopsis taxiformis* solution is worth investigating

Ruminants produce significant amounts of GHG emissions, and the ruminant population is predicted to expand (Ortega et al., 2021). Methane-reducing additives have high potential to reduce ruminant GHG emissions in a feasible and economically competitive manner. Amongst others, Herrero et al. (2016) describes how feed additives are one of the most promising options for reducing emissions in the entire livestock sector (Figure 1-1). Of these additives, multiple reviews highlight *Asparagopsis taxiformis* (AT) as the highest potential option (Black et al., 2021; Kebreab & Feng, 2021; McCauley et al., 2020; Ortega et al., 2021). The wide and growing array of companies commercializing AT and other alga as a methane-reducing additives for cows (Morais et al., 2020) indicates that competitive commercial success is viable. Therefore, investigation of the commercial viability of this solution is a meaningful contribution.

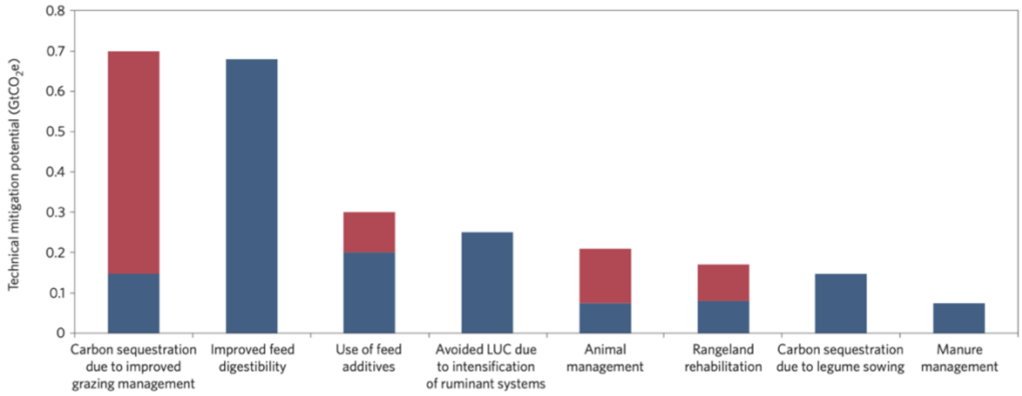


Figure 1-1: A comparison of technical mitigation potential for reducing emissions in the livestock sector. Source: (Herrero et al., 2016)

1.2.2 There are significant knowledge gaps

1.2.2.1 The gap: regular reviews of the AT field

The rapidly evolving state of AT research necessitates frequent reviews (Figure 1-2). Frequent reviews minimise duplicated academic research effort and acts to synchronise work in the field. The need for frequent updates is also emphasised by practitioners in the field. '*A summary of the state of the art [of AT research] is needed frequently, with constant research updates.'* (Respondent T1). Thus, the provision of an AT research summary and commentary in this thesis is timely and important.

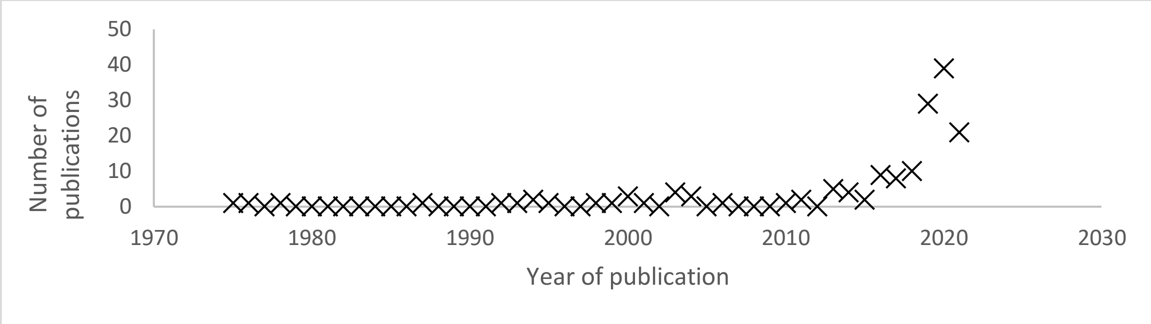


Figure 1-2: The rapid increases in publications related to AT. The number of annual publications recorded on Scopus for search 'Asparagopsis taxiformis' and 'methane.' Own illustration.

1.2.2.2 The gap: understanding the commercial potential of *Asparagopsis taxiformis*

The literature cites a need for studies on additive viability in addition to scientific performance (Abbott et al., 2020; Vijn et al., 2020). According to a recent review by Abbott (2020), '*there is also a lack of evidence that using seaweed-based ingredients to reduce methane emissions will be competitive, feasible and technically and economically successful*.' The few studies published that relate to commercial viability have been linked to life cycle analyses (Alvarez-Hess et al., 2019), with a focus on whether additional feed efficiency or carbon markets can make additives economically viable. This thesis will expand this limited perspective by considering all opportunities and barriers linked to the commercialization of this additive.

One major outcome of this thesis is an analysis of the competition facing factory-produced AT. This fills a large knowledge gap in the literature related to additive competitor comparison. In particular, the current literature shows a poor compilation of scientific findings on MRA. Whilst there is some consistency in research design amongst, for example, 3-NOP trials (Jayanegara et al., 2018), the research design consistency for comparing between additives is weak. This thesis will pull together research findings and present them in an easily comparable format. Thus far, no set framework has been proposed or drafted in from other literature areas to compare additives (scientifically or otherwise). This knowledge gap will be filled by assessing MRA within a set framework.

1.2.2.3 The gap: understanding the commercial potential of factory produced *Asparagopsis taxiformis* for dairy cows in Sweden

The commercial potential of a product is highly context dependent. Early reviews of AT (Maia et al., 2016; Makkar et al., 2016) focused on its generic potential. As expertise has developed, some commentaries have become more specific, indicating the importance of accounting for place in AT commercialization. Black et al. (2021) looked at the viability of additives in the Australian market, for example, and Kebreab & Feng (2021) considered MRA in the California market. The only Swedish publication on AT (Jardstedt & Holmström, 2021) limited discussion to beef cows, and focused mostly on relevant scientific findings rather than any aspect of commercialization. Therefore, there is value in investigating the Swedish dairy context.

There is a limited amount of research on the viability of AT produced in a factory- or land-based fashion Aquaculture of AT was first recorded in New Zealand (Bonin & Hawkes, 1987), and has since been discussed in two other publications related to AT growth in Portugal and Hawaii respectively (da Mata, 2008; Mickelson, 2013). Only the Rodrigues da Mata, (2008) publications touched upon the link of AT with methane reduction in cows, and this paper did not consider the commercial implications of production for this purpose. The conditions for AT aquaculture cultivation in these studies are significantly different to the factory cultivation being conducted by Volta Greentech (VG). da Mata (2008) cultivated AT in outdoor tanks whilst Mickelson (2013) focused on growing the alga in a lab-based environment. By contrast, VG is growing in an enclosed facility on a large scale. Therefore there is a need to investigate more fully the viability of the factory-based form of AT production for the particular commercial purpose of feeding it to cows.

1.2.2.4 The gap: a stakeholder perspective on the opportunities and barriers facing land produced AT commercialization in Sweden

This thesis is not new in assessing AT's viability via opportunities and barriers; however, it does provide a new perspective. This research expands on the perspective paper 'Key Considerations on the Use of Seaweed as a Methane-Reducing Additive for Cattle' by Vijn et al. (2020). To create this article, the authors convened around 50 stakeholders. These stakeholders were drawn from the following fields: research and production of seaweed, animal feeds, dairy cattle, and beef and dairy foods. The paper condensed findings from a single workshop with these stakeholders to compile AT issues and related research recommendations. These considerations can be understood as a combination of barriers, such as long-term animal safety, and opportunities, such as the. ability of AT to enter carbon markets.

This thesis is not a repetition of previous work. There are limitations to the Vijn et al. (2020) paper that mean this thesis can contribute a new and meaningful perspective. Table 1-2 describes the benefits of this thesis in terms of its expansion on the Vijn et al. (2020) paper.

Table 1-2 How does this thesis contribute to knowledge expansion on the previous work done by Vijn et al. (2020)?

Limitation of Vijn et al. (2020) paper	**Why is this a limitation?**	**How does this research expand on this?**
No comparison with other MRA	It is challenging to determine the commercial viability of a product without comparing it to other options on the market or in development.	This research considers all barriers related to AT including the competitiveness of AT in relation to other MRA on the market. A comparison table of the most effective MRA is included in this research.
Consideration of barriers and opportunities through a traditional lens of animal productivity, health, and profitability only.	This approach can miss important barriers and opportunities that exist outside the traditional sphere.	This research used a grounded theory approach and consultation of a broad range of stakeholders to identify any possible barriers or opportunities related to the commercialization of AT.
No differentiation or ranking of opportunities and barriers	No categorization of barriers or opportunities can make it difficult for actors to dedicate appropriate resource to solving or pursuing them.	This research used the stakeholder consultations to rank barriers according to their severity. Barriers and opportunities were also separated and addressed separately. This is important as the research was conducted on the premise that the major purpose of the opportunities was to contribute to removing the barriers.
Lack of case-study specificity	The barriers and opportunities are likely to be highly specific to the firm business model (e.g. client type), country (e.g. research grant availability, dairy value chain structure) and production style (e.g. processing mechanism)	This research considers the particular case of Volta Greentech and is thus specific to one business model (selling to retailers), one country in which production is based (Sweden) and one production type (factory).

1.3 Aim, Objective, Research Questions and Audience

1.3.1 Aim

The specific aim of this thesis is to improve understanding of the commercial viability of factory-produced AT as a methane reducing additive for dairy cows. This will be achieved by making a case study of focal firm VG, the only company currently aiming to commercialize factory-produced AT. The overview of the commercial viability of this focal firm will be gained by eliciting their major opportunities and barriers. Elicitation of these opportunities and barriers will be achieved through a literature review, consultation of various stakeholders, both internal and external to VG, in-person observation of the company operations and a workshop with the team. A broader aim of this thesis is to better understand opportunities and barriers related to other innovative green tech firms. This improved understanding will hopefully contribute to more effective intervention to promote their success.

1.3.2 Research questions

The following research question and sub-questions are used to guide investigation into the commercial viability of land produced AT as a methane reducing additive for dairy cows.

Research Question 1 (RQ1): Is the factory production of *Asparagopsis taxiformis* for use as a methane reducing additive for cows commercially viable in Sweden?

Sub question 1 (SQ1): What are the key barriers for case-study firm Volta Greentech?
Sub question 2 (SQ2): What are the key opportunities for case-study firm Volta Greentech?

1.3.3 Audience

Academically, this thesis will contribute to the rapidly evolving literature on AT as well as making methodological contributions. As discussed in Section 1.2.2.1, the pace of research on this additive is rapidly accelerating. This thesis will provide AT researchers in the academic community with a state-of-the-art update on the additive. It will also highlight important future areas of research that are needed to enable AT commercial viability. This may either be with respect to solving the major barriers identified or capitalizing on the identified opportunities. The combined use of stakeholder consultation and of grounded theory principles as a research methodology for assessing the commercial viability is also new to this MRA field (indeed, no evidence was found of similar techniques in other fields). If the results of this thesis are deemed useful, this general framework, and methodology for data collection, may also prove replicable for other, unrelated, assessments of firm commercial viability. This methodology includes the MRA comparison (Appendix 2, 3 and 4). This comparison fulfils similar requirements to academic review articles in which all papers related to a subject matter are systematically assessed. It provides a thorough, but concise overview of the status of different MRA. It may therefore be useful for future academics who seek to assess cow enteric methane reduction options.

Stakeholders with potential interest in this thesis include the focal firm, other additive producing companies, policy makers, retailers, and any other actors in the Swedish dairy value chain. The barriers and opportunities identified, as well as take-home suggestions are linked to focal firm VG. There is therefore potential for expansion of VG's relevant knowledge and network. For additive producing companies, a direct comparison with their competitors may enable them to recognize their niche in the market, as well as providing a resource for showing investors. In terms of policy, there is minimal awareness of the potential of these additives in this domain (Section 7.2.2). This project may provide a useful starting point for demonstrating additive potential to policy makers and indicating useful intervention points: which additive should they support for maximum methane reduction and how? Consultation of actors along the dairy value chain will make intervention easier by showing who is relevant to contact. Finally, retailers are already showing an interest in stocking dairy products from methane-reduced cows. A clear comparison and understanding of additive viability may impact their decisions. Other actors in the Swedish dairy value chain, for example LRF (an organisation for Swedish farmers), ruminant feed companies, individual farmers, and consumers, may also be interested in results of this work.

1.4 Ethical considerations

This research is not externally funded but was conducted with support from focal firm VG. The firm obliged the researcher by enabling two observations of company operations, one workshop and multiple phone and email exchanges. The firm had no influence over any research findings. These findings are noted to be highly relevant to the firm's operations, as well at the operations of closely connected firms including other AT or MRA producers. The process is exploratory, and therefore findings may have the potential to harm or influence the reputation of these companies.

The participation of all stakeholders in this research, whether team or external, was voluntary and all were informed about the purposes of the research. Participants were given the option to have their organization anonymized to account for confidentiality concerns. They were also able to check the final thesis prior to publication to ensure no quotes or opinions were skewed in the write-up. To record interview responses, notes were transcribed by the researcher during the interview. All interview participants were given the option to opt out and asked for their consent for this prior to commencement.

1.5 Scope

In conducting case study research, it is important to clearly delineate boundaries. Creswell (2013, p97) describes case study research as an investigation of a "*real-life, contemporary bounded system*." To ensure cases have a clearly defined 'bounded system,' one should set forward a clear unit of analysis or a 'thing' that will be analysed. The following table explains the unit of analysis (VG) by describing what is in and out of the scope of the research process. The table justifies the limited scope/ specificity of this case study, whilst also describing how the findings may have potential for more widespread applicability.

In scope	Out of scope	Justification of selection	Potential for broader applicability
Product: *Asparagopsis taxiformis*	Other algae	**Why narrow it down to a single alga?** There is a significant amount of research and relevant stakeholders connected to each methane-reducing algae species. Due to time constraints, the scope of this research was limited to only one algae type. **Why AT?** This alga has been demonstrated as having the highest methane-reducing potential. Most commercial efforts using algae to reduce enteric methane use AT.	Lessons learnt on barriers and opportunities for *Asparagopsis taxiformis* are likely to be applicable to other methane-reducing algae. This is particularly the case for close relative *Asparagopsis armata.*
Location: Sweden	Other countries	**Why narrow it down to a single country?** Opportunities and barriers are often specific to the nation that a business resides within (for example, national research programs). **Why Sweden?** The focal firm is based here.	Sweden is an advanced agricultural economy, with aims to reduce GHG but no clear solutions for emissions in agriculture sector. Lessons learnt from a Swedish case study may be broadly appliable to other advanced economies, particularly in the Nordic region.

Process: Factory-based AT production	Sea or land based AT production	**Why narrow it down to only one production method?** Opportunities and barriers are specific to the production mechanism (for example, the possibility to combine operations with fish farms). **Why factory-based?** This is the mode of operation used by the focal firm. It is novel, and there is value in better understanding it.	There are similarities between the AT producers, particularly in terms of barriers related to product risk and economic competitiveness. Lessons learnt from studying the commercial viability of factory-produced AT may be applicable to other AT production systems, as well as potential future factory ones.
Ruminant type and product: Dairy cows	Other ruminants / beef cattle	**Why narrow it down to one ruminant product type?** Value chains vary drastically between different ruminant types and even within dairy/beef production. Due to time constraints, the scope of this research was limited to only one value chain from which stakeholders should be consulted. **Why cows/why dairy cows?** Cows are responsible for the largest chunk of ruminant enteric methane emissions. At the commencement of this research, dairy cows were the focus of VG. This focus has since shifted to beef cows.	There are similarities between the beef and dairy value chains, especially as many dairy cows will end their lives as beef. Lessons learnt on barriers and opportunities for use of this algae for dairy cows are extremely relevant for the beef industry.

1.6 Structure

The following table provides a brief overview of the structure of this work.

	Summary of chapter
Chapter 1: Introduction and problem definition	Overview of the cow enteric methane problems and the aim and structure of this thesis.
Chapter 2: Literature review	A summary of the state of the art related to *Asparagopsis taxiformis*
Chapter 3: Conceptual framework	An introduction to the grounding principles behind this research
Chapter 4: Research design and methodology	A description of the process by which the barriers and opportunities facing Volta Greentech were elicited, categorised and investigated.
Chapter 5: Barriers: the stakeholder perspective	A compilation of the evidence gathered from stakeholders and the literature on the key barriers facing Volta Greentech.
Chapter 6: Opportunities: the stakeholder perspective	A compilation of the evidence gathered from stakeholders and the literature on the key opportunities facing Volta Greentech.
Chapter 7: Conclusion and broader applicability of findings	A summary of the findings in this thesis and an extension to consider their broader applicability outside the case study to other innovative green tech firms.

2 Current knowledge on *Asparagopsis taxiformis*

Asparagopsis taxiformis is a red macroalgae which was first noted as highly effective in suppression of enteric methane when used as a feed additive in 2014 (Machado et al., 2014). Since then, the impact of AT on enteric methane has been investigated in 6 published *in vitro* studies (Brooke et al., 2020; Chagas et al., 2019; Kinley, Nys, et al., 2016; Kinley, Vucko, et al., 2016; Machado et al., 2014; B. Roque et al., 2019) and 5 *in vivo* studies (Kinley et al., 2020; Li et al., 2018; B. Roque et al., 2020; B. M. Roque et al., 2021; Stefenoni et al., 2021), as well the subject of or mentioned in numerous reviews (D. W. Abbott et al., 2020; Kebreab & Feng, 2021; Maia et al., 2016; Morais et al., 2020; Vijn et al., 2020).

Whilst the 2014 paper was the first to identify these algae as a potential MRA, there is history in the literature to refer to, both in terms of feeding algae to livestock and the methane suppression properties of the algae. In a review of seaweed as livestock feed, Makkar et al. (2016) describe the long history of feeding macroalgae to ruminants. This review describes how the benefits of this diet have been well known for many years. These benefits include positive contribution to animals' energy requirements and improved productivity as a result of the presence of bioactive compounds. The literature indicates how this alga has also been traditionally used within human Hawaiian cuisine with no detrimental impact (Gribble, 2000). There is also historical precedent with respect to AT's effect on methane suppression. The primary active substances in AT, halogenated compounds such as bromoform and chloroform, were tested for their effect on ruminant methane production as early as 1971 (Wood & Johnson, 1971). For example in the Johnson et al. (1972) trial, feeding 10.39 mg bromoform per kg of cow live weight daily resulted in 100% methane suppression. A 31% increase in productivity was also witnessed in this trial. Other bromoform trials showed a range of 29 to 91% suppression (Abecia et al., 2012; Dittmann et al., 2016; Tomkins et al., 2009). High reductions have also been seen for chloroform, in the range of 38 to 58% (Clapperton, 1974; Knight et al., 2011; Martinez-Fernandez et al., 2016). The knowledge of bromoform presence in AT, amidst other halogenated compounds, is well document in the Burreson et al. (1976) paper. As in many other fields, the recent success of findings on AT methane suppression abilities in livestock can be traced back to earlier work. This earlier work provides a more robust base upon which the growing mound of recent AT evidence can sit.

The mechanism by which AT reduces methane is linked to the anti-methanogenic potential of the halogenated compounds that the alga accumulates (McCauley et al., 2020). These compounds are halogenated analogues of methane and can inhibit methane production in the rumen through reaction with vitamin B12. This reaction inhibits a vital step in the methanogenesis process (Machado, 2018). This paper used RNA sequencing and quantitative PCR to confirm that methane decrease from AT is correlated to a decrease in the relative abundance of methanogens, methane-producing bacteria. *In vitro* shifts in the microbial community structure due to AT were similar to those seen for supplementation with 5 µM bromoform. For both, the abundance of the three main orders of methanogens was reduced. However, the effectiveness of AT was found to be greater than for equivalent concentrations of bromoform, indicating the importance of other bioactive compounds in the seaweed. Given the studies mentioned above, it may appear sensible to avoid complications in algal production and supplement cows directly with bromoform. However, the industrial production of bromoform is currently prohibited under the Montreal protocol due to its ozone depletion potential (Montreal Protocol, 2020). Whilst the International Agency for Research on Cancer does not classify bromoform as a carcinogen (IARC, 1999), it is listed by the U.S. EPA as a probable human carcinogen (Environmental Protection Agency, 1990). There would therefore likely be significant consumer concerns related to consuming bromoform-fed animal products. This is despite evidence that bromoform does not accumulate in tissue (National Toxicology Program, 1989). In addition to subverting complications with legal restrictions and consumer preference, the alga's natural production of these bioactive, halogenated compounds also presents potential benefits for its use as an MRA. Bromoform is extremely volatile and thus its accumulation within the algal cell of AT itself is useful, both in terms of safer storage and release when inside the ruminant's rumen (Manley, 2002). This accumulation of bromoform within the cell is relatively unique to this AT genus (McCauley et al., 2020) and highlights the importance of further investigating this distinctive species.

The literature highlights lack of sufficient scientific evidence and production mechanism as two key technical issues related to AT. The number of research trials for AT significantly lags those conducted for DSM's additive, 3-NOP, which has been tested in at least 15 *in vivo* trials (Van Wesemael et al., 2019). Although research efforts on AT are accelerating, there is variability in results presented (Vijn et al., 2020), which makes creation of a comprehensive evidence base more challenging. To be successfully commercialised, more data is needed on AT methane reduction under different conditions, animal productivity, milk quality and animal safety (Abbott et al., 2020). If AT is to be adopted on a large scale as a livestock feed ingredient, production systems will also need to be vastly scaled up and intensified. McCauley et al. (2020) estimates that feeding AT to 350 dairy cows at an inclusion rate of 0.5% dry matter would require approximately 265 kg fresh algae daily. Feeding the world's current population of 1.5 billion cows would require 415 million tons per year. This is potentially problematic given that only 30 million tons of seaweed biomass are currently harvested globally (Buschmann et al., 2017). Large-scale production of AT is especially challenging given that red algae are notoriously difficult to grow (Garcia-Jimenez & Robaina, 2015). Part of their natural life cycle involves being dried out on beaches, which is extremely hard to replicate in farm conditions. Besides one failed French experiment to grow land-based AT for use in cosmetic products (Bonin & Hawkes, 1987), there is a minimal history of large-scale cultivation attempts to draw inspiration or expertise from.

Attempts to commercialize AT as an MRA are already happening. Four companies are beginning to scale up production of this macroalgae for use as a feed additive (Section **Error! Reference source not found.**). Three patents relating to the use of AT as a feed additive have been published (de Nys, 2020; Machado, 2015; Tomkins, 2018). Despite the limited commercialization thus far, the literature indicates high potential for the AT industry. Black et al. (2021), for example, predict that the first practical applications of AT will occur within the year. Looking further ahead, Davison et al. (2020) estimate that by 2030, 20% of Australian ruminants could be fed AT supplements, resulting in a 13 Mt decrease in GHG emissions by Australian farmers. To put this in context, all renewables in Australia as of 2019 were estimated to have reduced GHG emissions by 4 Mt (Commonwealth of Australia, 2019). The cost of AT will clearly depend on the success of upscaling production, although McCauley et al. (2020) notes that a strong carbon price or similar financial motives will likely be required to incentivize farmers to adopt AT usage. Despite academic optimism, caution is advised here. This can be examined by considering the Swedish case. Whilst Black et al. (2021) predict that a sufficiently low price for AT to enable practical mitigation in ruminant industries is 'highly achievable,' calculations for this thesis (Appendix 4) indicate the cost of CO_2e reduction for VG's algae is around €230 /tCO_2e reduced. This does not compare favourably to the carbon tax of €114 /t CO_2e levied in Sweden. Sweden's carbon tax is also the highest in the world and is levied only on heating and motor fuels. In comparison, Australia, which has an emission reduction fund covering the agricultural sector, pays A$18.40 (€11.64) /t$CO_2$e reduced (Department of Industry, Science, Energy and Resources, 2020). The high cost of AT, alongside potential AT risks and the challenges of cultivating the algae must be considered carefully when assessing the commercial potential of this feed additive.

3 Research approach

The conceptual framework of this thesis is indicated in Figure 3-1. The different stages of the research process were guided by two major theoretical perspectives, stakeholder theory and grounded theory, and then by the successful publication by Vijn et al. (2020). Stakeholder theory is used as a theoretical lens to understand the value of a stakeholder-based assessment. Grounded theory principles were used to guide the data processing methodology. The patterns that emerged from the grounded theory coding process were organised into opportunities and barriers, and used to assess commercial viability, as in the Vijn et al. (2020) paper.

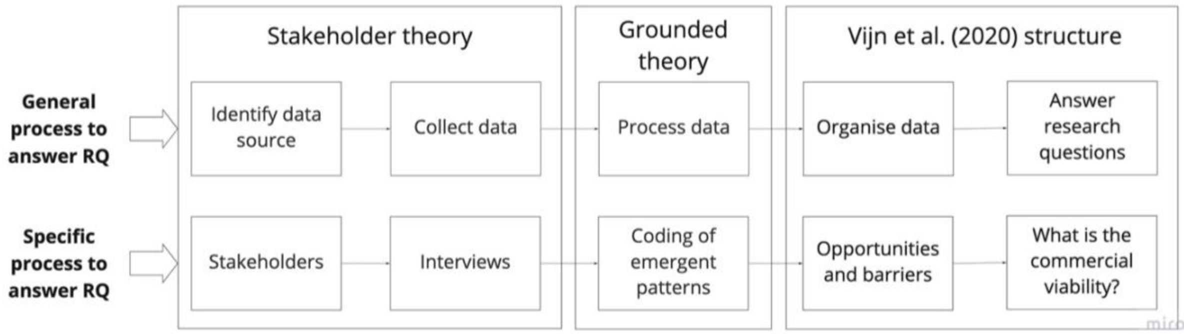


Figure 3-1 Overview of the research process and the theoretical perspectives used to guide it.

3.1 Assessing commercial viability through investigation of opportunities and barriers

This thesis uses the UNFCCC definition of barriers and opportunities. A barrier is defined as "*any obstacle to reaching a potential that can be overcome by a policy, programme, or measure*." An opportunity is defined as "*a situation or circumstance to decrease the gap between the market potential of a technology or practice and the economic, socioeconomic, or technological potential*" (UNFCCC, 2008). Assessing commercial viability via opportunities and barriers is used in the Vijn et al. (2020) paper and thus taken to be appropriate.

There are several limitations to the opportunities and barriers approach. This is a qualitative research methodology and does not provide definitive answers on the commercial viability of the firm. In contrast, quantitative indicators that emerge from more technical assessments, such as techno-economic assessments (TEA) or Strategic Technology Evaluation Programs (STEP), can objectively inform commercialization decisions (Bandarian, 2007). Other commercialization assessments also provide a set framework for assessment These frameworks enable greater comparability between different assessments than do opportunities and barriers.

In defence against these limitations, it can be argued that the opportunities and barriers approach is most suitable for assessment of commercial viability via stakeholder consultation. Commercial viability is a fuzzy and subjective concept, but interviewed actors can clearly comment on their perceived barriers and opportunities. This contrasts frameworks such as a TEA which rely on technical criteria. Opportunities and barriers provide a more available entry point for stakeholder consultation The criterion for TEA-style assessments, for example profitability indicators and global warming impact, are also typically defined prior to starting. This prevents emergence of commercialization issues arising from the research. Overall, this opportunities and barriers approach to assess VG commercial viability is highly appropriate to the conceptual framework employed.

3.2 Consulting stakeholders to elicit opportunities and barriers

Stakeholders are consulted in this thesis based on an assumption of the salience of their perspective to the commercializing company. 26 stakeholders were interviewed, either external to the company (listed as Respondent E-) or internal to the company team (listed as Respondent T-). Interviewee details are included in Appendix 1: Respondent list The use of stakeholders to understand the commercial viability of VG and consequently factory-produced AT in Sweden is based on the normative concepts of stakeholder identification and salience underlying stakeholder theory. These normative concepts are, according to Donaldson and Preston (1995), at the core of stakeholder theory.

According to Donald and Preston (1995) the accuracy of this stakeholder theory model depends on managers and other agents recognizing and acting as *if* stakeholders have intrinsic value. The high citation level of this article indicates that this normative concept is widely used and accepted. This is supported by the large and growing literature base connected to stakeholder theory (Mitchell et al., 1997; Reed, 2008), indicating that there is general acceptance of the intrinsic value of stakeholder interests and their salience in corporations. Thus, the normative approach at the heart of this theory is taken to be true for the purposes of this research. This normative approach provides strong reasoning for why consultation of stakeholders is a legitimate base upon which to build a case for assessing VG opportunities and barriers.

One of the main reasons that stakeholder theory is 'useful' is linked to the notion of stakeholder management. Donaldson and Preston (1995) describe the key tenet of stakeholder management as the ability to attend, simultaneously, to the legitimate concerns of appropriate stakeholders. Awareness of these legitimate concerns should be a starting point for managing these stakeholders. Taking the salience of stakeholders as a given, this thesis then aims to provide this awareness. This is both with respect to identification of the appropriate stakeholders and identification of legitimate concerns. This identification and awareness step is clearly important for moving towards recommendations for more effective attitudes, structures, and practice within businesses such as VG. This could be argued to be useful only in aiding the company towards commercial success and not an assessment of commercial success. However, it can be argued that through development of a clearer model of the corporation through assessment of the salient stakeholders which comprise it, a higher quality qualitative assessment of viability can be achieved.

There are several limitations to selecting a stakeholder-centred model by which to assess the barriers and opportunities facing factory-based production of AT in Sweden. Stakeholder theory is one amongst many models used to understand corporations. Why choose this one? In answer, whilst this theory is ultimately one of many descriptive ways to understand a corporation, it presents benefits over rival models in accounting for the constellation of cooperative and competitive interests of value to the company. As described by Hill and Jones (1992), there is considerable information asymmetry between managers and other stakeholders. Acknowledging these stakeholders as important, identifying them, and contacting them, as conducted in this thesis, is thus one mechanism to correct this asymmetry. Stakeholders' perspectives are added to those of the company team to gain a more 'symmetrical' understanding of the firm. In addition to correcting information asymmetry, the different theories all have varied purposes and implications. For example, Aoki's (1984) cooperative game theory of the firm is concerned with internal governance, whilst more neoclassical theories centre around guiding economic principles (Cyert and March 1963). Thus, while neither more right or wrong than other theories, stakeholder theory's 'purpose' is better suited to the research conducted here. It's perspective on the firm as an organizational entity with diverse participants, each with different aims, provides a useful channel by which VG barriers and opportunities can be investigated.

The usefulness of employing stakeholder theory in this thesis can also be questioned. Even if the decision to apply stakeholder theory is made, one could ask what use does this theory actually provide? Is it just an empty idea – corporations have stakeholders? This theory does not say which stakeholders to identify or classify their salience. In one way, this is certainly a disadvantage in that consequently no clear framework is provided. A researcher cannot then refer to one definitive framework used earlier and apply all lessons learnt to their own research progress. However, this lack of framework can also be seen as an acknowledgement of the complexity and context-dependence of identifying and classifying stakeholders. In essence, by not providing a framework, this theory or model highlights the importance of adapting research to fit the case. This could also be seen as support for why creation of my own framework in this research is appropriate.

3.3 Using grounded theory concepts to process stakeholder data

This thesis uses concepts based on grounded theory to inform the research process. Figure 3-2 illustrates this grounded theory process, as based on the original theory developed by Glaser and Strauss (1967). The use of grounded theory in this research meant the collection of qualitative data related to the commercial viability of VG, and then letting ideas or concepts emerge from this data. This data was coded in a way that summarized the emergent ideas, whilst the researcher was concurrently collecting and analysing further data. The tagged or coded concepts were frequently reviewed and updated as data collection progressed, as well as being used to inform further data collection. As larger amounts of data were compiled, the data was categorized into higher level concepts and eventually theoretical codes. In this research the theoretical codes were the 6 opportunities and 3 barriers discovered. Various stages of coding were carried out, starting with initial coding (early labelling of incidents or patterns in the data) and advancing to intermediate coding (generation of more abstract concepts) as the categories developed. The final stage, theoretical coding, is an integrative process, that weaves the fractured pieces (codes) back together (Charmaz & Belgrave, 2015).

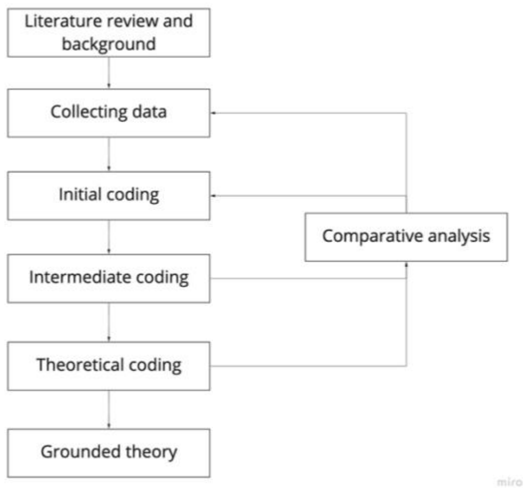


Figure 3-2 The grounded theory process that was employed in this research. Own illustration, adapted from Chun Ti et al. (2019).

There are various limitations to this data processing methodology including the high potential for researcher bias to influence results. Researchers run the risk of being influenced by prior literature or data findings and forcing data into a priori categories (Timonen et al., 2018). In grounded theory, researchers must engage in detective work to derive concepts. This leaves space for human error or innate preferences to enter data processing. In addition, there are no standard rules to follow when employing this methodology. This can be problematic for inexperienced researchers who may fail to appreciate the core tenets of the methodology.

Despite the limitations, grounded theory was taken to be an appropriate methodology for this research. Grounded theory is open to new, unanticipated findings, which meshes well with the bottom-up stakeholder consultation used to elicit possible opportunities and barriers for VG. It is also noted to be suitable for complex, context-dependent cases (Conlon et al., 2015). Various measures were taken to mitigate the limitations of this theory. Literature resources were consulted prior to commencing research to ensure the core principles of grounded theory were adhered to. To avoid hypothesis testing or the forcing of data into categories, this research employed unstructured or lightly structured interview guides with open questions. Data collection, including during company observations, purposefully remained flexible and probed into findings for clarification. Constant comparison of data with data was employed during the research process to ensure any emergent theory was fully grounded.

4 Research design and methodology

4.1 Case study selection

This section explains and justifies the assessment of commercial viability of factory-produced AT via a specific case study. Section 4.1.1 gives a background introduction to the focal firm and their commercial progress. Section 4.1.2 justifies the selection of case study research in this thesis.

4.1.1 Introduction to Volta Greentech

VG are a small company based in Stockholm, Sweden. A. basic summary of the company is shown in Table 4-1. The company was founded in 2018. The three founders were young on company inception (<25 years), but since a wider range of experience levels have been employed.

Table 4-1 A summary of characteristics of the focal firm Volta Greentech, correct as of March 2021.

CEO	Fredrik Åkerman
Size of firm	6 executive team employees; 2 board members; 11 investors
Location of firm	Sweden. Stockholm (base); Lysekil (factory)
Primary industry	Commercial products. Developer of a algae-based feed supplement to reduce cow methane emissions
Financing status	Grant and venture capital-backed

The company aims to be the first factory-AT producer for cows. Whilst there are multiple other AT producers (Section 5.3.1.1.2), VG is the only one who is attempting to grow AT in a factory environment. VG are currently in the process of developing and producing the algae. The company is backed by venture capital and government grants, with no funds yet incoming from alga sales. Incoming funds are mostly channelled into the production and development of AT (Respondent T2). The commercial arm of the firm (based in Stockholm) is involved in discussion with a wide range of potential future clients for the alga. They are also responsible for incoming funds in the form of grants or investment.

VG are algae producers. The current business model of the firm involves providing algae to farmers free of charge. Revenue comes instead from clients, the retailers who pay VG. In exchange, these retailers acquire methane-reduced dairy products from the farmers. The retailers are expected to pass on the green premium of this methane-reduced dairy to consumers.

In terms of current infrastructure provision, VG is currently operating a pilot factory with plans to expand to larger premises in 2022. As of March 2021, the pilot factory was '*20-25% built*' (Respondent T2), and producing enough seaweed to feed the first farm, as part of a research trial. This factory has the capacity, when fully built, to feed 500-1000 cows (Respondent T1). It is seen as a blueprint model upon which production can be optimized (Respondent T2).

VG is unique amongst AT producers for growing AT in a factory system. Typically, any factory aquaculture is more expensive and resource consuming than sea or outside tank-based systems. Table 4-2 uses compiled evidence to explain the motivation for VG to invest in developing a factory-based system.

Table 4-2 The motivation for VG to pursue factory production as a means of cultivating AT.

Reason	Explanation	Evidence
Upgrade product	Grow a product with a higher proportion of bioactive (methane - educing) compounds. Grow a product that confirms to feed additive safety standards (for example, reducing iodine concentration).	Literature findings indicates that the concentration of active compounds in AT is influenced by the environment (Greff et al., 2014). da Mata (2008) found that while production mechanisms behind the production of the active compounds are "*elusive,*" environmental factors including CO_2 level, H_2O_2 and total available nitrate can impact bromoform levels. Therefore, VG should be able to upgrade their product by cultivating under controlled environmental conditions.
Regular and consistent harvest	A regular and stable supply of AT is needed Wild-grown AT changes bromoform content and has specific growing seasons.	Zhu et al., (2021): "*The variability of bromoform contents is another hindrance to commercialization, which can only be overcome through environmentally controlled cultivation in aquaculture.*"
Swedish production	AT is a semi-tropical species that would not grow in Sweden hence a controlled environment is required.	AT is a species distributed throughout the tropical and warm-temperate parts of the Atlantic and Indo-Pacific. (Abbott & Williamson, 1974). The Mediterranean clade of AT has temperature limits of 9 to 31^{o}C, the widest range of survival and growth temperature limits of the genus. (Chualáin et al., 2004).

4.1.2 Why is Volta Greentech appropriate as a case study?

This research employs an exploratory case study research approach. Exploratory studies, as opposed to explanatory or descriptive, are the type of case study used when there is no pre-determined outcome. The exploratory case study aims to build theory from case studies to "*create theoretical constructs, propositions, and/or midrange theory from case based, empirical evidence*" (Eisenhardt & Graebner 2007, p25). This exploratory case study approach is then clearly consistent with the conceptual framework discussed previously. In this thesis, the conceptual framework assumes a constructivist standpoint and employs a grounded-theory-based methodology. Both this framework and exploratory case studies assume a complex system from which dedications of theory can be elucidated. Yin (2014) also describes the importance of this style of case study for gaining an in-depth understanding of a social phenomenon. Given the complexity associated with assessing the commercial viability of factory-produced AT, an exploratory case study is appropriate. A case study of this type avoids "*(all variants of) tunnel vision*" (Verschuren 2003, p137) and enables ''*description and explanation of complex and entangled group attributes, patterns, structures of processes.*" Overall, this exploratory case study approach was taken to be an appropriate methodology for investigating the highly complex and context-dependent commercial viability of factory-produced AT.

4.2 Data collection

Collection of literature data and stakeholder consultation data are intertwined in this thesis. Literature review was used to provide background knowledge on AT and the Swedish dairy value chain, and to triangulate, support or disprove claims made in stakeholder interviews. On the other hand, data collection from stakeholders was used to inform appropriate areas of literature to consult, as well as highlight potential new stakeholders for consultation. The data collection process was done iteratively, with concurrent data collection and analysis informing further data collection. Incorporation of most literature findings into the results, rather than Chapter **Error! Reference source not found.**, the literature review, was therefore deemed more appropriate.

The timeline for collection of data in this thesis is shown in Figure 4-1. The three stages of data collection are split in *early, mid* and *late* stage. These breakpoint of these three stages is provided by the two observations of the company.

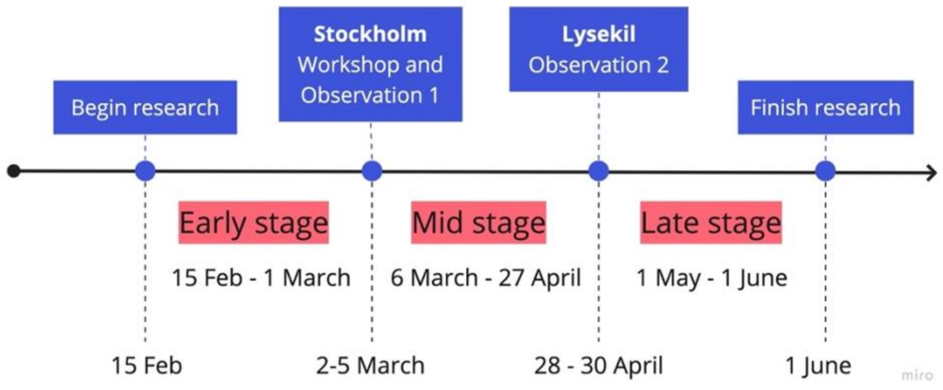


Figure 4-1 The timeline for data collection in this thesis.

The data collection process of this thesis was reliant on the source of information. These sources are literature and internet review, team consultation and external stakeholder consultation. Table 4-3 summarizes the data collection technique for each data source. For each source, five aspects are discussed: the input (information or work done prior to data collection), medium of data collection (process by which the data was extracted), immediate outputs (unprocessed results) and processed outputs (results following processing or reflection). The limitation of each method of data collection and analysis is also briefly discussed.

Table 4-3 A summary of the data collection methods and limitations for the three data sources used in this thesis.

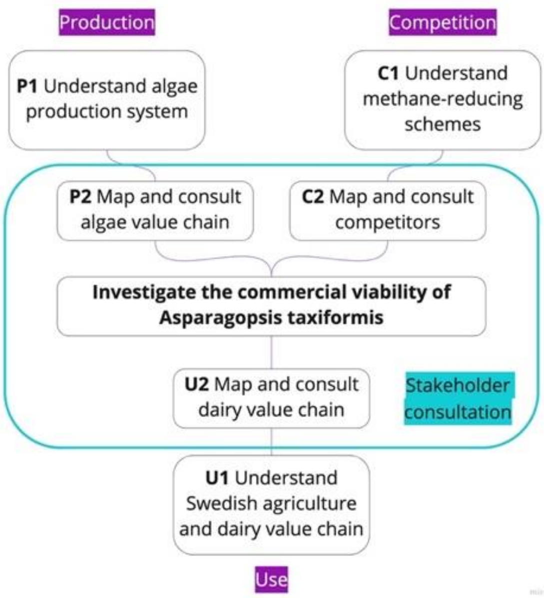
	Literature/ internet review	**Team consultation**	**Stakeholder consultation**
Input	N/a	Background knowledge on AT was gathered prior to the workshop, observation, and team interviews via **literature review** and **stakeholder consultation** (*early-stage* interviews). A basic map of the VG barriers and opportunities was prepared for the workshop (Appendix 5)	A basic mapping of the dairy value chain was prepared prior to *early-stage* stakeholder consultation to identify appropriate interviewees. Background knowledge on AT was gathered prior to *early-stage* stakeholder consultation via **literature review.** Background knowledge on AT was gathered prior to *mid-* or *late-stage* stakeholder consultation via **stakeholder consultation. literature review** and **team consultation.** The more detailed map of barriers and opportunities map (Appendix 5) was used to identify appropriate interviewees for *mid-* or *late-stage* stakeholder consultation. Where appropriate, recommendations from **stakeholder consultation** were also used to inform future stakeholder selection (snowball interviewing).
Medium of data collection	Google scholar search; Scopus search; websites;	In person workshop (1 hour); Stockholm Observation (3 days); Factory Observation (2	In person meetings (2 stakeholders); phone (20 stakeholders); zoom (3 stakeholders) and email (1 stakeholder). 2 webinars (12 speakers) (Appendix 1).

or data extraction	Swedish/EU reports.	day); Interviews (7 team members); Regular calls with CEO/CCO (bi-weekly).	
Immediate outputs	Literature synthesis matrix	Interview: transcribed notes, Workshop: recording and transcribed notes; Factory observation: process flow map, improved process understanding. All: improved commercial status understanding	Transcribed interviews and notes.
Processed outputs	Information for data triangulation in results section.	Quotes, codes and categories for opportunities/ barriers. Relevant and up to date research.	Quotes, codes and categories for opportunities/ barriers.
Limitation of this source	Only English-speaking papers or resources were returned by Scopus/ Google Scholar. Swedish reports by recommendation only.	Commercial secrets limit information sharing; bias of team members towards a positive perception of VG success.	Selection of stakeholders may implicitly create bias (English speaking interviewees only; greater likelihood of hearing about and thus interviewing larger companies); snowball interviewing method may miss out major actors; stakeholders have vested interests and may report inaccurately.

4.3 Data analysis: Finding opportunities and barriers

This section describes the process by which the major barriers and opportunities facing the focal firm VG were established. This process was iterative, following grounded theory principles. The steps involved were (1) general background reading on factory AT production and AT commercialization; (2) deductive development of coding categories in both the opportunity and barrier domains; (3) analysis of data (literature, interviews, workshop, and observation) and (4) preparation of results. Data collection via literature review, team consultation and stakeholder consultation were ongoing during this process. In addition, review of the coding categories was also ongoing according to patterns emerging from the analysed data.

Step 1 (*early stage*) involved reviewing the academic and grey literature. This involved primarily consulting reviews and commentaries on AT to gain a basic comprehension of barriers and opportunities facing the firm. At the time of writing, four reviews on AT as a methane-reducing additive for cows had been published (Abbott et al., 2020; Maia et al., 2016; Morais et al., 2020; Vijn et al., 2020). Grey literature including company website, investor sites and news articles were used to gain a better understanding of the focal firm. Following basic comprehension of the major barriers and opportunities, a broader literature review was conducted (Table 4-3).



Step 2 (*early stage*) involved deductive development of codes within the opportunities and barriers. Literature and internet findings enabled categorisation of opportunities and barriers by three domains: use, production, and competition (Figure 4-3). These domains were used to organise relevant further research (P1; C1; U1), as well as identify appropriate stakeholders (P2; C2; U2). The process thus allowed appropriate interviewees to be selected, and lightly-structured interview guides to be prepared.

Figure 4-2 Early-stage deductive development of codes.

In step 3 (*mid* and *late stage*), the data from the interviews, observation and workshop was analysed alongside additional literature. Transcribed data was read, and the content coded. Primary codes were ascribed according to the initial domains (production, use, competition), with additional coding categories identified and ascribed inductively as patterns emerged. At this stage, codes begun to be differentiated between barriers and opportunities. Multiple reviews of the coded barriers and opportunities were conducted during this process to prevent overlap and redundancy.

Step 4 (*late stage*) involved the final review and update of the coded barriers and opportunities. This led to the creation of a final, well-structured, comprehensive framework. There was a progression of codes throughout the process, including the final compilation of organised barriers and opportunities (Appendix 5).

4.4 Data analysis: determining the major barriers and opportunities

The barriers found to be facing VG were categorized and compiled into a mind map (Appendix 5). These barriers were then categorised by severity of threat posed. This categorization was based upon data collected from literature review, stakeholder and team interviews and the workshop. The following quotes are example of the evidence used for categorizing these barriers. This categorization was an open-ended process, that could be refined at any point. If further interviews highlighted new serious barriers to focus upon, or indicated the lack of importance of one selected barrier, the framework was adjusted (Table 4-4).

Table 4-4 A selection of evidence used to determine the severity of barriers.

Specific barrier	**Barrier classification**	**Evidence**
Risks	Serious	Respondent E17: *Public opinion on bromoform and Montreal treaty are a problem…. [investigating] this is where I would start.*
Traceability of methane reduction	Medium	Respondent E3: *There are different production types and carbon footprint [between different types of beef/dairy cows]– how to split it. A model is needed to split this.* Respondent T2: *SLU have created a model for predicting methane reduction… If a farmer knows how much seaweed is being fed, they know how much [AT] to deliver and tonnes of methane reduced.* Respondent T2: *Right now there doesn't really exist a good enough system for quantifying how much emissions that have been reduced*
Impractical for farmers	Minimal	Respondent E3: *Large scale farms- no problem. They have feed mixers. Feed mixers for dairy cows are common – the investment pays off for larger firms. Probably not a challenge for smaller dairy farms also.*

Due to time constraints, only the three barriers categorized as 'major' were investigated. These three barriers were ranked in order of seriousness from 1 (most serious) to 3 (least serious). This ranking was based evidence from observation (factory visit), the workshop, consultation with external stakeholders and team consultation. A selection of the evidence used to determine this ranking is included in Table 4-5.

Table 4-5: Ranking the barriers facing Volta Greentech from most to least serious.

Ranking	Barrier	Evidence
1	Production	Respondent T3: *We haven't reached the production performance yet. That's needed for making this survival economically, and volume wise.* Respondent E17: *We need to establish robust aquaculture. Supply is key…Asparagopsis is a notorious difficult seaweed to farm – not like browns.*
2	Risks	Respondent T1: *[A major barrier is] the public view of bromoform…if it's not the cancer question, it's the ozone depletion question.* Respondent E17: *[BCM] is a bioactive, volatile compound – need to think about processing, drying, formulation, transport, and everything else along every step of the supply chain.* Respondent T2: *[We are] confident on resolving iodine …A scientific conclusion is needed on dangers of bromine…we are waiting for the official status that it is harmless.*
3	Economic competitiveness	Respondent T2: *One of the other key things for us is competitiveness…making sure that that our cost of production is low* Respondent E19: *10% is hardly anything in the end unless you can stack them up to get cumulative reduction. [Other MRA] are a distraction.'*

Categorization of opportunities into minimal, medium and serious, as per barriers, was taken to be an inappropriate mechanism for the following reasons. Firstly, the opportunities are future-based and therefore their 'seriousness' assessment would be based on extremely speculative criteria. Secondly, the perception of opportunity would depend on stakeholder expertise: engineers for example would likely rank the 'seriousness' of production improvement as more important than politicians who would probably view 'political support' as the most serious opportunity. Thirdly, the ability of various opportunities to support VG depends on both their potential impact and likelihood. Attempting to assess the 'seriousness' of opportunities by asking stakeholders to rank opportunities would run the risk of conflating these two criteria. As an alternative to severity, the opportunities were categorized instead by timescale. The opportunities selected for further consideration were those that were able to have short-term or immediate impact. There are two major benefits to categorizing opportunities in this fashion. Firstly, this is a more objective criterion. Team members or experts in the field are likely able to accurately assess the relative timescale of opportunities. Secondly, most companies fail at an early point in their development. Therefore, assessment of immediate or short-term opportunities is more appropriate for understanding commercial viability.

This categorisation process resulted in an initial focus on 6 short-term opportunities. One opportunity (carbon certification) was rejected later based on poor evidence that it could support VG. An additional opportunity (alternative uses for AT) was also added in the *late stage* after being highlighted in stakeholder interviews.

4.5 Data analysis: Investigating barriers and opportunities

This section describes the process by which the 3 major barriers and 6 short-term opportunities were examined. Table 4-6 gives a brief overview of these to aid comprehension.

Table 4-6 A summary of Volta Greentech's major barriers and opportunities, as elicited from this research.

Barriers	
Production	VG experiences challenges with cost, scaling up, difficulty of farming AT and downstream problems associated with their production.
Risks	VG experiences challenges associated with the risk of the halogenated compounds in AT and chemical residues in milk.
Competitiveness	VG experiences challenges from other schemes to reduce enteric methane, which are cheaper, more easily produced and less risky.
Opportunities	
Funding mechanism	VG could market their product through a 'methane-reduced' label on the final dairy product.

Celebrity endorsement	VG could invest time and resources into increased media and celebrity attention to publicise their cause.
Collaboration	VG could develop relationships and share learning with other relevant experts.
Political support	VG could push politicians to provide greater support for this alga
Symbiotic production	VG could use symbiotic techniques to enhance the environmental and economic profile of their production mechanism.
Alternative uses for AT	VG could exploit other high-value commercial uses for AT

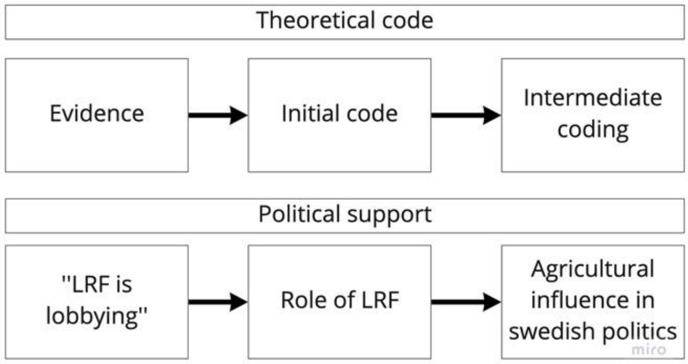
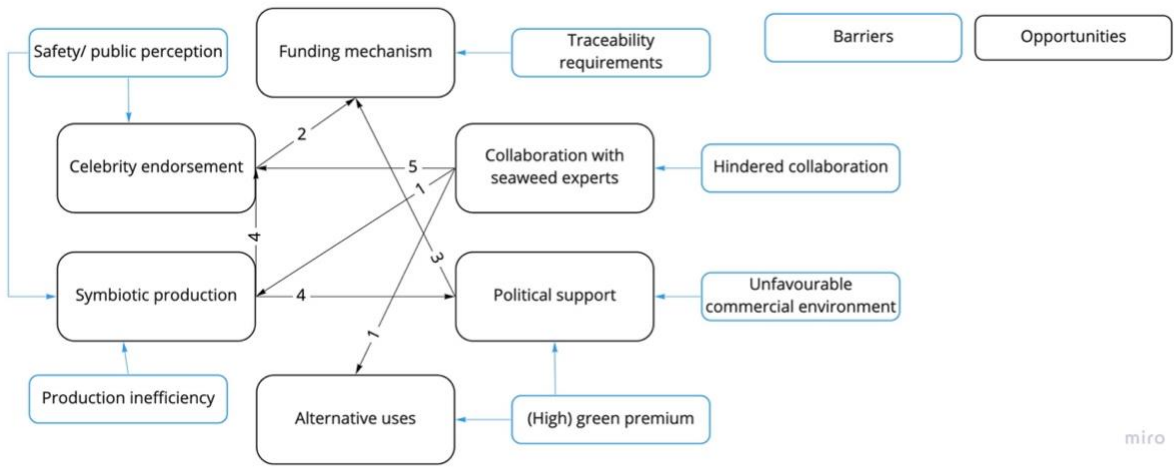


Figure 4-3 The process of coding evidence within a theoretical category. General process (above) and specific example (below).

To link stakeholder perspectives to the elicited barriers and opportunities, relevant pieces of empirical evidence were categorized by theoretical code. There were 9 theoretical codes: 3 barriers and 6 opportunities. Within these 9 categories, the evidence was organised into inductively determined codes, according to the grounded theory methodology (Figure 4-4). Once coded, literature resources were reviewed to triangulate the collected data. The data and triangulated literature results were stored together and finally written up. In the barrier's domain, each paragraph within the categories 'production' 'risk' and 'competitiveness' corresponds to a code. This is equally true for the opportunities section.

The literature and stakeholder perspective on the barriers 'production' and 'risk' were found to be comprehensive enough for the purposes of this thesis. These barriers have been discussed in some depth in previous reviews (Abbott et al., 2020; Morais et al., 2020; Vijn et al., 2020). In addition, these constitute technical barriers. A thorough investigation of these barriers would require in-depth engineering and/or topic-specific scientific knowledge. Therefore, they are less suited to in-depth investigation by the qualitative assessment process used in this thesis. In contrast, competitiveness is non-technical. The literature and stakeholder perspective in relation to the competitiveness of AT was also found to be insufficient for drawing meaningful conclusions. There were no papers found that provided either a) a process for comprehensive identification of the AT competitors or b) a comprehensive comparison of these competitors (Section 1.2.2.2). Among others, Vijn et al. (2020) cite the need for a rigorous process of comparison of AT with other MRA on the market. For this reason, an assessment of the competitors to VG was conducted. This constituted a major research project within the thesis and is therefore described separately in Section 4.6.

The data collected indicated that the barriers facing VG are large. Therefore, the major benefit of any opportunity is to overcome these commercialization challenges. After all, it doesn't matter how extensive VG collaboration is if they cannot produce enough of their product at reasonable cost. In addition, the opportunities are not mutually exclusive and may act to support each other. The final step in the initial analysis of these barriers and opportunities then was to determine the relationship between them (Figure 4-5). This model was reviewed and refined during the data collection process.



(1) Sharing knowledge with seaweed experts could enhance production method success or enable development of new AT uses.
(2) Celebrity support could help promote a new funding mechanism.
(3) Political support for AT could increase the trustworthiness of a methane-reduced label.
(4) Environmentally friendly production methods could increase the probability of political or celebrity support
(5) Collaboration between AT producers could enable non-company specific AT endorsement by celebrities.

Figure 4-4 How can the opportunities open to Volta Greentech enable the firm to overcome their major barriers?

Initial coding or deduction of the opportunities occurred before categorization of the barriers into production, usage, and competitiveness. In the original attempt to ensure all opportunities contributed to solving barriers (Figure 4-5), more specific, uncategorized, barriers were used. These specific barriers were later adopted into the larger categorizations. Table 4-7 demonstrates the relationship of the specific barriers to the categories. This table was used to ensure that all opportunities were related to solving the three major problems.

Table 4-7 Linking the specific barriers in Figure 5-1 to the major barriers and opportunities

Major barrier	**Specific barrier**	**Explanation of relationship between specific barrier, major barrier and opportunity.**
Production	Production inefficiency	Tackling **production inefficiency** through **symbiotic production** techniques will help face the **production** barrier.
	Hindered collaboration	Tackling **hindered collaboration** to promote **greater collaboration with seaweed experts** on AT production/ processing could help face the **production** problem.
	Political environment	Tackling the unfavourable Swedish **political environment** through greater **political support** for development improvements in AT production could help face the **production** problem.
	Safety / public perception	Tackling AT **safety/public perception issues** by developing a safer product through **symbiotic production** techniques may help VG face some of their **production** problems.
Risks	Safety/ public perception	Tackling **safety/public perception issues** surrounding AT through **celebrity endorsement** may help VG face the public **risk** concerns
	Hindered collaboration	Tackling **hindered collaboration** to promote **greater collaboration with seaweed experts** on resolving AT safety issues could help face the **risk** problem.
	Political environment	Tackling the unfavourable Swedish **political environment** through greater **political support** or funding for trials related to solving AT safety concerns could help face the **risk** problem.
Competitiveness	Production inefficiency	Tackling **production inefficiency** through **symbiotic production** techniques could help lower the costs of AT and help it face the **competitiveness** problem
	Hindered collaboration	Tackling **hindered collaboration** to promote **greater collaboration with seaweed experts** to share marketing or lower development costs could help VG face the **competitiveness** problem.

	Political environment	Tackling the unfavourable Swedish **political environment** through greater **political support** for subsides or grants supporting the uptake or lowering the costs of AT production could help face the **competitiveness** problem.
	(High) green premium	Tackling **the high green premium** of AT through exploring **alternative uses** or **political support** for purchasing the product could help face the **competitiveness** problem
	Traceability requirements	Tackling the **traceability requirements** of AT clients through development of an effective **funding mechanism** could enable more clients to purchase the product and help VG face the **competitiveness** problem
	Safety/ public perception	Tackling the **safety/public perception** concerns associated with AT using **symbiotic production methods,** through effective promotion via **celebrity endorsement** or by proving the additive is safe for **alternative uses** could enable more clients to purchase the product and help VG face the **competitiveness** problem

These table indicates all the opportunities are indeed linked to resolving one or more of the major barriers facing VG. The production barrier could be improved by symbiotic production, political support and collaboration. The risk barrier could be improved by celebrity endorsement, collaboration and political support. Finally, the competitiveness barrier could be improved by all 6 of the noted opportunities. This finding supports the earlier discussed notion that the most useful opportunities will help overcome the major barriers. This finding was used in the discussion of VG opportunities (Chapter 5).

For each opportunity and barrier, a summary and suggestion section was included at the end. Although these recommendations are relevant to the academic community, they are geared towards actions that could be taken by VG. This decision to pivot suggestions towards VG was made as this research is ultimately an assessment of commercial viability of the firm. This viability can be impacted by firm decisions. Therefore, if there are available opportunities or recommendations for VG is pursue, this is an indirect result related to firm viability. If recommendations were instead based on what external actors, for example politicians, should do, this rests outside the ability of the firm to control.

4.6 Data analysis: investigating *Asparagopsis taxiformis* competition

To investigate the severity of threat facing AT from its competitors, 3 steps were followed. Firstly, the sources of competition to AT are identified and classified by their market commonality and resource similarity. Secondly, the level of threat of these competition sources was assessed. The final part involved an in-depth analysis of the major competition source.

There are various methods and frameworks by which to identify competitors. This thesis used the notion put forward by Bergen & Peteraf (2002, p4) which takes "*the perspective that firms compete with one another to the extent that they satisfy the same customer need*." The customer need that AT was fulfilling was defined here as, 'reducing enteric methane emissions from dairy cows.' Literature and internet searches, team consultation and external stakeholder consultation were used to identify the sources of competition. 3 major categories of competitor were identified: other AT producers, other MRA, and other methods for reducing enteric methane. These competitors were mapped according to their market commonality and resource similarity to VG (Bergen & Peteraf, 2002, p4). Market commonality is understood here as "*the degree to which a given competitor overlaps with the focal firm in terms of customer needs served*" and resource similarity as, "*the extent to which a given competitor possesses strategic endowments comparable, in terms of type, to those of the focal firm*."

VG was found to be in direct competition with other MRA-producing firms. To better understand how serious a threat this competitor constituted, a framework of assessment was created. In this analysis, evidence was collected, organised, and graded to produce a final 'hotspot' matrix. The process for assessing was conducted in three stages, as described in Figure 4-5.

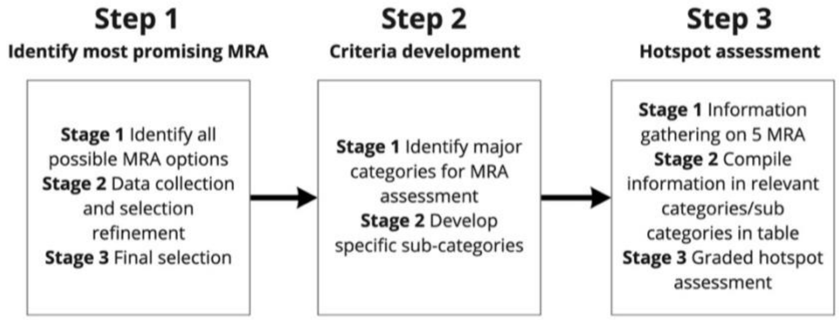


Figure 4-5 The process for creating a hotspot assessment matrix to gauge the threat posed by other methane-reducing additives.

Step 1 involved identifying all prospective MRA. 9 reviews and perspective articles on MRA were reviewed to ensure all MRA with proven potential were considered (Arndt et al., 2021; Black et al., 2021; Chagas et al., 2019; Honan et al., 2021; Kebreab & Feng, 2021; Keller et al., 2018; Klop, 2016; Mitloehner et al., 2020; Ortega et al., 2021). Any promising MRA options discussed in these reviews were stored in a literature summary matrix. Summarizing these articles, it can be concluded that, as of May 2021, there are over 90 scientifically tested MRA. For most of these additives, there is not sufficient statistical evidence to conclude they are methane-reducing (Feng and Kebreab 2020). Final selection of the most promising MRA was based on the following criteria (Table 4-8).

Table 4-8 Criteria for selection of the most promising methane-reducing additives.

Criteria	**Criteria specifications**
Presence in the academic literature	There must successful *in vivo* and *in vitro* trials of the additive
Commercial status	There must be at least one company aiming to commercialize the additive
Official recommendation for use	There must be at least one official report that describes the additive as high potential

In addition to these criteria, MRA were rejected if their practical usage in Sweden was questioned in the literature. This research rejected the usage of grape pomace and nitrate, despite their recommendation in various reviews. The rejection of grape pomace was made of the basis of a recent review (Black et al., 2021). This highlighted the limited applicability of this additive due to its detrimental impact on ruminant productivity and the requirement for proximity of farm to grape pomace source. There are not many wineries in Sweden. The rejection of nitrates was based on concerns surrounding nitrate poisoning, which is an even greater issue for ruminants in grazing systems (Callaghan et al., 2014). Grazing for cows is required in summer in Sweden.

Step 2 involved developing criteria for assessment. The major categories in this hotspot assessment (foundational research; production; use) were developed inductively based on analysis of literature findings. The Vijn et al. (2020) paper was used for development of the 6 sub-categories within 'foundational research.' These categories are: enteric methane mitigation; animal performance; animal safety; understanding of additive mechanism; man food safety and palatability and intake. For production and usage, the sub-categories were generated inductively.

Step 3 involved the final creation and grading of the hotspot assessment. The assessment of 'foundational research' aimed to include information from all academically published *in vitro* and *in vivo* trials related to their viability. This proved possible for all MRA except 3-NOP, for which over 15 *in vivo* trials have been conducted. Summary reviews of the evidence (Dijkstra et al., 2018; Van Wesemael et al., 2019)) were used instead to ensure that all relevant information was discussed. Relevant findings were included in a synthesis matrix, with one matrix per MRA. Once all the academic publications related to the MRA had been reviewed, findings were transferred to a comparative assessment table (Appendix 3). This comparative table assessed two research parameters: (1) findings from the scientific trials and (2) the strength of evidence (number of research trials). Both the summary of findings and strength of evidence were assessed and graded to produce a final hotspot matrix. Hotspot assessment of the 5 MRA was based on the grading criteria displayed in Table 4-9.

Table 4-9 Criteria used to assess the foundational research underpinning the five most promising methane-reducing additives on the market. Assessment criteria developed inductively by researcher.

	Criterion 1	Criterion 2	Criterion 3
Research findings	Evidence is promising for commercializing this MRA for the purpose of reducing enteric methane	Minor issues to be resolved before commercializing this MRA for the purpose of reducing enteric methane	Major issues to be resolved before commercializing this MRA for the purpose of reducing enteric methane
Strength of evidence	≥ 10 relevant studies	3-9 relevant studies	≤ 2 relevant studies

Within the full assessment table (Appendix 3), findings were synchronized between MRA to make the additives directly comparable. For parameter (1), the major results for each MRA were firstly summarized according to each category and sub-category (e.g. *Foundational research: human safety*) in the framework. Within each sub-category, topic headings were created that were applicable for all MRA (e.g. *Foundational research: human safety: potential risks)*. Between 1 and 4 topic headings were included for each sub-category. For parameter (2), the same standards of evidence (i.e. scientific publications or reports) were required for each MRA.

The assessment of 'production' and 'usage' relied on literature and online reviews, interviews, and personal calculations. This process was less objective than the assessment of foundational research. To differentiate the methodologies, an alternative grading system was developed (Table 4-10).

Table 4-10 Criteria used to assess the foundational research underpinning the five most promising methane-reducing additives on the market. Assessment criteria developed inductively by researcher.

	Criterion 1	Criterion 2	Criterion 3
Research findings	Evidence is promising for commercializing this MRA for the purpose of reducing enteric methane	Evidence is promising for commercializing this MRA for the purpose of reducing enteric methane	Evidence is promising for commercializing this MRA for the purpose of reducing enteric methane

5 Barriers: the stakeholder perspective

This section discusses the 3 major barriers found to be facing VG. These are **AT production:** VG experiences challenges with the production cost, scaling up, difficulty of farming and downstream problems associated with AT. **AT risks:** VG experiences challenges associated with the risk of the halogenated compounds in AT and chemical residues in milk. **AT competitiveness:** VG experiences challenges from other schemes to reduce enteric methane, which are cheaper, more easily produced and less risky.

5.1 Production

5.1.1 Understanding the *Asparagopsis taxiformis* production barrier

VG are currently a long way off producing the large volumes required for mass commercialisation of this product. A **large and stable supply** of this seaweed will be required for commercial success. Multiple sources noted the importance of being able to supply this product in the quantities needed. For example, an LRF representative noted, '*we would want a stable supply of AT,*' (Respondent E6). According to a leading ruminant feed additive company, there is a lot of progress still to be made. '*Their biggest challenge is how to scale up production. They can provide 1000 cows with this additive – that's not a lot.*' Considering the 1.5 million cows in Sweden, and a requirement of 0.5kg wet weight AT daily per cow (Respondent E17), that adds up to 137,000 tons of AT needed annually in Sweden. Not all cows need to be fed AT, but this gives an indication of the scale of production required by VG. Prior to current commercialisation attempts, no previous attempts on mass scaling of AT production have been attempted (da Mata, 2008). Overall, VG have not reached the scale of production required for commercialization which poses a threat to the viability of the firm.

The **high cost** of AT production in the VG factory is a major barrier to commercial success. Based on production in the pilot plant, the estimated cost per tonne of CO_2 reduced is greater than other MRA (Observation 2). Even accounting for the larger margins that VG clients are likely to pay to tackle a climate problem at source, a seaweed expert from Cawthon estimated that €100/ tCO_2e is the maximum viable price (Respondent E17). VG must consider additional costs on top of production expenses. FutureFeed currently own a patent on the use of AT as a methane reducing additive for ruminants (Respondent E25). It is estimated their costs will be around $1 /kg AT sold (Thompson, 2021). This high cost will prove problematic for VG even if they are to be supported politically: politicians will likely want the lowest cost option for methane mitigation. Without political support, this **green premium** will fall upon consumers. As Wa3rm CEO comments, even with only 1 SEK premium per milk, the '*[VG products will] have difficulty competing next to other things in the grocery store*' (Respondent E23). In summary, high production costs translate into a high cost for the final VG product which will limit its prospects of commercial success.

Red algae, such as AT, are **notoriously difficult seaweeds to farm**. Part of their lifecycle involves being dried out, which makes growing them in a controlled environment exceptionally challenging. Seaweed experts, including those at Cawthron, are attempting to close the lifecycle of AT and produce juveniles that can scale (Respondent E17), however, this process may take time. Species domestication is certainly a **slow process**: it took 20 years to domesticate the mussel and 10-15 years for salmon (Towle, 1983). The difficulty in farming this species is compounded by the **lack of expertise** in this specific area. According to Respondent E17, all the current AT growers are originally from Roque's team (one of the first AT researchers). He commented that, '*Formal education is needed in [AT growing]….if we want expansion, we need 15 aquaculture scientists- who will train them?*' Overall, the complexities with growing AT and the lack of experienced personal to guide this process mean production improvements may be slow and limit commercial viability.

There are also production problems that are very particular to VG's factory-based system of algae cultivation. More **inputs**, such as temperature and nutrients are required. According to da Mata (2008), temperature is a particularly difficult and expensive variable to control, especially where some form of open-flow systems are used. This is related to a problem noted by an algae/ fish farm expert who noted that, '*[A] potential problem is that these algae give out substance which reduces their own growth*' (Respondent E23). Thus, there is a need to bring occasional water influxes up to the temperature required: at a large scale this can be a significant cost. Inputting of unnatural substances such as nutrients also has the potential to cause problems related to wastewater output. According to the CEO of a fellow algae company, there are '*Big problems getting permit from government for putting [excess nutrients out]*' (Respondent E12). Given that VG is currently adding nutrients to enhance algal growth, this may constitute a problem. These additional inputs and outputs from the VG factory contribute to a production system that is more **costly and challenging** to operate.

This AT production process is new, and VG must overcome significant challenges related to the **drying, processing, and storage** of their algae. The requirements for this downstream processing include a low-cost method of drying that preserves the bromoform content of the seaweed for as long as possible. The complication here is that the bromoform is extremely volatile and studies indicate significant quantities are lost if the algae is kiln or sun-dried (Vucko, 2017). In addition to the drying challenge, AT appears to lose significant amounts of bioactivity over the course of three months (Regal et al., 2020) and is therefore unsuitable to long-term storage. This means VG must either develop a new technology to better preserve their seaweed or develop means by which to regularly supply their farmers. One new, patented, technique for maximising the long-term bromoform retention is preservation of the algae in oil (Magnusson et al., 2020). No bromoform was lost from AT after 12 weeks of oil immersion. However, this oil immersion technology raises additional challenges including license fees for using a patented concept, oil immersion of an additive being in a **different legislative category** (Respondent T4) and complications for farmers who, '*would not like to have big tanks of oil on their farms*' (Respondent E17). Overall, the downstream processing of AT poses problems for VG, who will need to invest in research to develop the most effective techniques.

5.1.2 Potential amelioration of production problems

VG are constantly improving their production recipe. This improvement enables them to **maximise productivity** and **increase the effectiveness** of their product. In terms of productivity improvement, VG is testing parameters to maximise AT growth on a small, cost-effective scale in their lab in Stockholm. This **constant experimentation** is resulting in regular productivity improvement. In addition, VG have succeeded in increasing the proportion of bioactive compound in their seaweed. This successful manipulation of the seaweed environment to generate more effective product is promising. It not only reduces the amount of AT that they need to cultivate, but also indicates the team are gaining **AT-related expertise**. This expertise may also be usefully applied to other production problems. Overall, the production improvement shown by VG over their short existence bodes well for their ability to develop towards large-scale production.

The cost of VG's product does not necessarily make it commercially unviable. The price increase is not a drastic, especially when compared to benchmarks (Table 5-1). These benchmarks, all successful products, indicate Swede's are willing to pay more for milk that conforms to their preferences. Given the high importance attached to the environment by Swedish consumers (Lefébure & Rosales Muñoz, 2011), it seems viable that some Swedish consumers would be willing to pay the VG premium. Research conducted by the researcher prior to the thesis supports this conclusion (Appendix 6). The results of two focus groups (14 persons) indicated **high interest and willingness** to pay 1 SEK extra for VG's milk. These findings were supported by a café trial, in which 83% of 130 consumers indicated a willingness *at point of purchase* to pay 10% extra for hot drinks made with seaweed-fed cow milk (Appendix 6). Customers were then told this milk was not yet available, but their answer was recorded. In sum, personal research findings, current milk premiums and high environmental awareness in Sweden all indicate that the cost of VG's milk may not be an impenetrable barrier.

Table 5-1 Benchmarking milk product prices. Information source: Coop 2021.

Milk brand	**Cost SEK/litre**
Coop own brand	9.25
Arla Eko	11.95
Oatly	18.95

There is **support available** for developing the factory AT production operated by VG. This mode of production is increasingly being advocated by the literature. Zhu et al. (2021) recommended AT cultivation under 'controlled environmental conditions' and, in a report commissioned by Danish Government on how to reach climate-neutral agriculture, the World Resources Institute recommended AT growth in 'controlled factories' (Searchinger et al., 2021). This **academic and institutional interest** is likely to increase the visibility of VG, and consequently increase their potential to gain funding. This funding will be important in addressing the barriers described above. Sufficient funds would enable research to better understand the physiology of AT and thus how best to domesticate it, to develop and train AT experts, to investigate new processing techniques and so on. There is also research external to VG that is attempting to address these barriers. For example, the other AT producers are also working on domesticating the algae, and research institute Cawthon is focusing on how AT production can be scaled. Academic institutions globally are also showing increasing interest and support for AT use and production (e.g. (Jardstedt & Holmström, 2021). This **collaborative effort** to solve AT production barriers is far more likely to be successful than VG operating alone.

Aquaculture is a **rapidly evolving** area. Major advancements in computational fluid dynamics, mechanical engineering, informatics and electrotechnical engineering and biological sciences all offer potential for improving the productivity and thus lowering the cost of AT production **Computational fluid dynamics** is a powerful tool for improving macroalgae production through simulation (Bitog et al., 2011). It enables optimization of tank conditions, with a substantially lower lead time, fewer experimental design and operational costs and reduction of experimental waste generation compared to conventional experiments. If VG were able to use simulations to determine the best conditions for AT, they could drastically speed up the production development process. Improvements in mechanical engineering could provide benefits to VG through system optimization via sensors. Installing various sensors through aquaculture systems enables real-time assessments of water and environmental parameters (Xing et al., 2019). If VG were to use the data collected by these sensors to help control the system, they may be able to maximise efficiency whilst preventing seaweed disease and contamination. Advancements in the biological science also may support the scale-up of AT. Significant breakthroughs in **algal strain development** (Leong et al., 2021), for example, may prove useful for VG in developing a more easily cultivated and higher bromoform seaweed. Genetic improvement programs may also enable VG to develop 'super seaweed' strains. Genetic modification is currently high restrictive, however the effects of climate change may be an encouragement to do more studies in this area (García-Poza et al., 2020). To sum up, rapidly developing scientific disciplines offer high potential to improve aquaculture systems. VG may be able to make use of these developments to reduce their costs.

Two other options to directly improve the viability of VG production involve **symbiosis** with other industry and co-concurrent use of AT as a **human foodstuff**. These opportunities are discussed in Section 6.5 and 6.6.

5.1.3 Summary

In summary, the crux of the VG production issue is being able to deliver **enough AT, fast enough and at a low enough price**. The novelty of the VG process means significant amounts of research are needed into topics ranging from AT physiology to post-harvest processing. There is minimal knowledge and expertise to draw from in the field, which means VG are reliant on time-consuming and expensive experimentation. Fortunately, the team appear to be on the right track in terms of production improvements and there are new technologies available that could improve the efficiency of their operations. In addition, various external efforts may support their goal of successful AT commercialisation. There are multiple opportunities VG may be able to seize as they upscale (Chapter 6): with clever management these may enable VG to surmount this obstacle.

5.2 Risks

5.2.1 Understanding the risks associated with *Asparagopsis taxiformis*

5.2.1.1 Potential risks of halogenated compounds

The bioactive compounds in AT that cause enteric methane reduction also have potentially **harmful effects** on both humans and animals. Examples of these bioactive compounds are haloforms (e.g. $CHBr_3$, $CHBr_2$,I, CHBrClI) dihalomethanes (e.g. CH_2Br_2) and halogenated acetones (e.g. $CHCOCH_2Br$) (Burreson et al., 1976). The major bioactive constituent is bromoform. Of the haloforms present in AT, bromoform comprised approximately 80% by mass in the Burreson et al. (1976) study, in which AT was processed into oil.

There is a **dearth of evidence** that VG can use to ascertain the safety of the bioactive compound in their product. According to Muizelaar et al. (2021), prior to their trial, no toxicological research of bromoform in ruminants has ever been conducted directly, nor any toxicological research of bromoform within carriers such as AT. Forced aadministration of pure bromoform to mice and rats has been found to be linked to kidney and liver toxicity (Anders et al., 1978). It should, however, be noted that a **dose-dependent relationship** between bromoform and toxicity was found in this study. The harmful effects were noted at doses hundreds of times that which the cows receive per kilogram of bodyweight. The Muizelaar et al. (2021) study found that cow carcasses showed abnormalities of the rumen wall papillae indicating irritation of the rumen as a result of this supplement. This paper has been criticized for the high dosage of AT used as a % of dry matter intake (Respondent E17). It also examined only 2 cow rumen and used the rumen of old cows which may have impacted findings. However, the results are still useful for indicating the upper bounds of AT safety for ruminants and it highlights potential problems of high AT dosage.

The impact of these halogenated compounds on human health in **cow products** is also a concern. Multiple studies have reported increased bromine and iodine concentrations in cows fed red alga (Antaya et al., 2015; Stefenoni et al., 2021). Stefanoni et al. (2021) reported a 5-fold increase in iodine and 8-fold increase in iodine and bromide concentrations in the milk of AT-fed cows compared with a control. The Muizelaar et al. (2021) study detected notable residues of bromoform in cow milk after introduction of AT at rates of 6.5% of diet. However, this milk bromoform concentration decreased significantly after detection in the first hour after the first dose. This suggests that following exposure, the cow modifies how it metabolizes the bromoform and excretes it via urine rather than via milk. It should also be noted that the Roque et al. (2019) study, which used more realistic doses (0.5%) and feeding conditions, detected levels of bromoform less than 500 times lower than the maximum standard set by the U.S. EPA for bromoform levels acceptable in drinking water. Overall, the potential for harmful compounds to be transmitted into dairy products poses a potential risk to the commercialization of AT.

5.2.1.2 High specifications to meet

In order to satisty customers, VG must work hard to prove the safety of their product. In terms of official regulations, AT is currently on the accepted list of EU feed materials for substances that can be fed to cows. An application is filed for its use in the U.S.A.. The high levels of cow-product safety required in order for retailers to accept AT means that the '*evidence [on AT] risks such as iodine] need to be well set up and robust* '(Respondent E17). The evidence required is also **country specific**, increasing the amount of work VG must do to reach client acceptance for their final product. According to a Swedish cow-feed-additive company, '*You need to go through each and every country to convince them that it is working. This is a huge barrier* '(Respondent E15) This notion is supported by Cherry et al. (2019) who describe the lack of harmonization between national food safety regulatory frameworks. Unfortunately, VG is also at a disadvantage here compared to DSM who, '*have trials planned in Norway, Denmark and so on. They invest time and money to convince people and organizations [of the safety of 3-NOP]* '(Respondent E15). Therefore, a barrier to VG success is linked to the **high safety requirements** for their final product. The investment in product safety research already untaken by VG, for example the monitoring of milk iodine content, will need to continue in order to provide convincing evidence to clients.

In terms of client acceptance, there is also **caution in the dairy industry** with respect to new feed additives. This is despite the hundreds of years of cows have been eating seaweed for. Almost all actors in the dairy value chain interviewed for this research raised potential concerns about the safety of this product for human and animal. A specific example would be from an LRF representative who commented that their concerns included, '*Animal health, welfare, milk quality. A lack of general awareness about other potential risks*' (Respondent E2). The general feeling of the dairy industry is summed up by Respondent E17 who commented, '*Dairy producers are very careful with this technology…more research is needed.*' It appears that before commercial clients will accept this product, a **larger amount of research** is required. The feeling of this need for greater research is noted by a farm advisor, '*If you want farmers to start using additives, and want us advisers to recommend it, we must have good research-results that these additives really work well, and this research must be done in Sweden under Swedish conditions*' (Respondent E4). This research also must be read by the relevant parties: communication of research results can be challenging. Despite the large community working on this, the requirement for more trials and tests, particularly long-term ones, is a barrier for VG.

5.2.2 Potential amelioration of risk barrier

There are two major risk mitigants that should be noted. These are the **high quantity of research** being done on AT and the ability to control **human health risks** from AT-fed cow products through either a) a focus on beef rather than dairy products or b) changing methods of AT production or processing.

More research on AT risks has the potential to prove that there is no hazard to either humans or animals by using this compound. Bromoform itself is not considered a hazard, provided safe limits are kept to. The bromoform within AT is within these limits (Respondent T3). The consistent usage of AT as a human and animal food stuff through history (Abbott & Williamson, 1974) is also evidence that its toxicity should not be of large concern. The VG team is waiting for '*the official status that [the bromine level in milk] is harmless*' (Respondent T2) from the scientific community, given that there are no current EU levels set. However, this team member notes that trials have generally shown that a litre of milk has, '*roughly the same levels of bromine as in a fish*.' If indeed this is the case, the growing number of trials and tests run with AT-fed cows should be able to provide evidence that can enable more widespread commercial acceptance of this additive. There is great potential for rapid advancement of research, both on the safety of cow products and investigation of AT bromoform. This is because of collaboration between AT companies and 'free' academic research on the compound (Chapter 6). In terms of the bromoform risk, CH_4 Global, one of the other AT producers, already announced that "*trade secret handling ensures that the stored bromoform is not released until it is eaten by the cow*" (CH_4 Global, 2021). This indicates that there certainly are mechanisms by which the risks from bromoform release can be mitigated. There is therefore high potential that this research will lead to amelioration of the barrier related to AT risks.

There are also methods by which VG can subvert the current risks, or at least lack of evidence on, the safety of dairy products. One option, which they are currently pursuing, is to focus on **beef**. Even the controversial Muizelaar et al. (2021) trial indicated that neither iodine or bromine posed issues for beef production as the chemicals are rapidly excreted with bodily fluids. The two other published trials on beef (Kinley et al., 2020; Roque et al., 2021) also indicate no impact of AT on meat taste or chemical residues in the final carcass. This finding is supported by the examination of cows fed VG's AT. In these cows, there were no areas of the rumen with loss of papillae (Respondent T3). Additional benefits of focusing on beef production include an improved average daily weight gain when feeding AT, with the Kinley et al. (2020) trial finding weight gain improved by 51% for cows fed AT at 0.1% of their organic matter intake. This weight gain improvement is seen much more consistently in beef cattle than any productivity improvements for dairy cows. In addition, mixing of AT-fed cow with non-AT-fed-cow milk remains a viable option for **reducing milk iodine content** (Respondent T3). Finally, it is worth commenting that milk-drinking humans in some parts of the world suffer from iodine shortage, including in Sweden. To compensate for this, Jordbruksverket (the Swedish board of Agriculture) doubled the maximum iodine limited allowed in cow feed in Sweden from 5 mg / kg DMI to 10 mg /kg DMI. It is therefore possible that this high iodine milk may have benefits as it can transform milk into a functional product enriched with organic iodine (Respondent T3). In summary, the current potential risks associated with bromine and iodine levels in milk seem unlikely to be severe enough barriers to limit the commercialization of this product.

5.2.3 Summary

AT has been consumed by humans and animals for generations, with **no noted harmful side effects**. However, the manipulation of the cow rumen is a complex process. With VG and other AT companies looking to maximize the proportion of bioactive compounds in their AT, it is increasingly important for them to be able to comprehensively demonstrate the safety of their product to clients. More research on the seaweed is essential for its commercial success. The **negative public perception** of bromoform poses a challenge to VG in terms of persuading investors, clients and other influential persons to support their product. Bromoform is toxic at high doses, but like many things, its toxicity is **dose dependent**. This dose-dependent relationship has been proven with bromoform in every single animal trial done to date. This toxicity/ dose dependent relationship can be challenging to communicate to clients, especially given the bad reputation of bromoform. Comprehensive and convincing scientific evidence will have an important role in mitigating this negative perception.

5.3 Competition

5.3.1 Understanding the competitiveness of *Asparagopsis taxiformis*

The assessment of AT competition is based upon the process described in Section 4.6. Section **Error! Reference source not found.** identifies AT competitors and the reasons for considering them a competitive threat. These are classified in Section **Error! Reference source not found.**. Section **Error! Reference source not found.** discusses the outcome of in-depth analysis of the major competitor.

5.3.1.1 Identifying *Asparagopsis taxiformis* competitors

5.3.1.1.1 Methane-reducing additive companies

There are over **90 MRA** that have been shown to have potential for methane-reduction in ruminants. The 5 deemed to have the greatest potential for commercial viability (Section **Error! Reference source not found.**) are AT, 3-NOP, Mootral, Agolin and Yea-Sacc. These are assessed fully in Section 5.3.1.3, but a summary of the reasons for the threat status of these additives is given below.

Reasons for high threat:

1) Lower cost: the 4 other MRA are available at a lower cost than AT
2) Fewer risks: there are less production and use risks with these 4 MRA
3) Scale-up: the 4 other MRA are more cheaply and easily produced
4) Established companies: some MRA (Agolin, Yea-Sacc, 3-NOP) are produced by established companies with market experience
5) Geographic region: some MRA (Agolin, Yea-Sacc, probably 3-NOP) are competing in the same marker at AT.
6) Co-benefits: some MRA (Agolin, Yea-Sacc, probably 3-NOP, possibly Mootral) are associated with productivity or health benefits for the cow.

Reasons for low threat:

1) Methane reduction: other MRA display significantly lower enteric methane reduction than AT
2) Popular support: other MRA experience less popular and academic support than AT

5.3.1.1.2 Asparagopsis taxiformis producing additive companies

This research identified four companies actively commercializing AT (CH_4 Global, Symbrosia, Blue Ocean Barns and Sea Forest), and two more involved in the commercialization process. These are FutureFeed who are the license holders for the AT technology and Greener Grazing who are developing the knowledge to farm AT at scale. Table 5-2 summarizes vital information on these potential competitors

Table 5-2 Summary of companies currently commercialising Asparagopsis taxiformis.

Company	Location	Status of commercialization	Production of algae
FutureFeed (2019)	Queensland, Australia	Holders of key patents on AT use. Works to support the growth of the AT value chain.	No production
Greener Grazing (2018)	Texas, U.S.A. Aquaculture in Vietnam	Project by Australis Aquaculture. Developing foundational knowledge for scalable ocean-based AT production.	Marine cultivation. Have developed methods to produce, recover, and seed spores essential to ocean-based cultivation.
CH4 Global (2018)	HQ in U.S.A. Aquaculture sites in New Zealand and Australia.	Licensed technology from FF. Secured a buyer for its first output, which they say would feed 10,000 cows	Tank and marine cultivation. >800 ha of marine water space leased. 1 ha trial cultivation sites in operation. Planned: 20 ha marine cultivation, 2 ha land-based hatchery cultivation.
Sea Forest (2019)	Tasmania, Australia	Commercial trials with a wool producer and a dairy cooperative (Fonterra).	Marine cultivation. 1800 ha marine water space leased. Facility aims to produce 7,000 tonnes AT annually.

Blue Ocean Barns (2019)	California, U.S.A. Aquaculture site in Hawaii.	N/a	Outdoor land-based tank.
Symbrosia (2018)	Hawaii, U.S.A..	Selling carbon credit subscriptions. Carbon credits are funding a commercial trial in Washington, U.S. (4 cows)	Outdoor land-based tanks (similar to spirulina production). Bioremediate waste from fish farms.

Data sourced from: FutureFeed 2021; Greener Grazing 2021; CH4 Global 2021; Sea Forest 2021; Blue Ocean Barns 2021; Symbrosia 2021; Thompson, 2021; Morais et al., 2020.

Reasons for high threat:

1) Production method: AT producers are cultivating the same product as VG, using a more established and less resource-intensive method of production.
2) Political environment: the supporting environment of other firms is more favourable. The U.S. provides more reliable start-up support. Both Australia and the state of California include agricultural emissions in emission reduction fund or cap-and-trade schemes.
3) Current progress: Sea Forest appears much closer to commercial success than VG. They have large-scale production, successful commercial trials with a large dairy company (Fonterra) and have received over $34 million from investors (Palmer-Derrien, 2021).

Reasons for low threat:

1) Geographic location: AT producers are headquartered in either the U.S.A. or Australia, with an initial production focus in these regions. Therefore, there is no current competition with VG for the Swedish market.
2) Production method: AT producers are using outdoor tank-based or marine cultivation rather than the factory-based system used by VG. If successful, VG have a first mover advantage and the possibly of owning intellectual property on this production method. Recent papers have advocated the requirement for ‘controlled environmental conditions’ for production of AT (Zhu et al., 2021). This is to the advantage of VG and other land-based systems.

5.3.1.1.3 Alternative enteric methane-reduction project companies

This research identified 3 major mechanisms in addition to MRA for reducing enteric methane. These are manipulation of rumen diet, breeding programs, and a methane vaccine. (Hristov et al., 2013; Kumar et al., 2014).

Manipulation of **ruminant diet** has been identified as one of the most acceptable and applicable measures by which to reduce enteric methane (McCauley et al., 2020). Methane emissions are lower when ruminants ferment starch, as comapared to fibre. Feeding a higher starch diet also lowers ruminal pH which inhibitis methanogens. Therefore, feeding higher quality feed, with a greater proportion of concentrates results in a lower intenstiy of methane emission. Aguerre et al. (2011) found that increasing the dietry concentrate: forage ratio reduced the methane yield of cows by an average of 13%. As is well known in the beef and dairy industries, increased levels of concentrates also lead to **higher animal producitvity**. Indeed, in the Arndt et al. (2021 review, milk yield was found to increase by an average of 17% with a higher concentrate diet. However, despite the methane reduction and co-benefits there are concerns with this method of enteric methane reduction. Firstly with regards to animal welfare, overfeeding of grain-based concentrate can trigger subacute ruminal acidosis (Arndt et al., 2021). Secondly, when considered from a life-cycle analysis, the benefits are substantially reduced: ruminant feed production promotes degradation of natural carbon sinks (McCauley et al., 2020). Thirdly, and particuarly relevant within Sweden, feeding of concentrates is not always practical (McCauley et al., 2020). In Sweden, cows are legally obligated to be out grazing for a certain portion of the year, thus (at least for this time) forage will constitute their sole diet.

Observation of more efficeint ruminants has lead to support for replacing regular cows with the **lower-methane genotype**. Amongst others Wallace et al. (2019) found that cow efficiency is related to genetic traits and thus heritable. Proponents of the idea of breeding for methane-reducing genetic improvement note the benefits to both ruminant economy and environment. More efficient ruminants tend to have more beneficial microbial communities that increase productivity per unit feed (Ortega et al., 2021). However, breeding for effiicient cows depends upon the selective pressure placed upon this trait. Black et al. (2021) used selection models to estimate that cow methane could be reduced by 20 to 26% in 10 years, but only alongside a 6 to 18% decrease in genetic gains for prodcution traits. Alternative models suggest the maximum methane emissions possible, whilst maintaining improvement in milk production, would be 3% (Pryce & Bell, 2017). Whilst breeding programs promoting efficent ruminants through gathering genetic resources are already in place, this process is slow and expensive and establishment of a particular genotype can take decades.

A potential, albeit scientifically challengeing, option to reduce enteric methane is **vaccination.** The idea is that vaccinated cows would develop an immune response to methanogens, thus inhibiting their activity (Subharat et al., 2015). This solution is still at a realtively early phase, with ongoing research in New Zealand aiming to identify possible antigens. On the plus side, scientific trials have shown vaccinated cows exhibit methane reduction of up to 69%. However, methane increases of 20% have also been seen, and half the attempted experiements have been unsuccessful (Baca-González et al., 2020).

Reasons for high threat:

1) Cost: any of these mechanisms may be able to produce lower cost methane reduction.
2) Maintenance: some enteric methane reduction schemes (vaccination; breeding programs) would not require constant input, thus minimising both cost and farmer workload.
3) Geographic region: enteric methane reduction schemes are competing (breeding programs; feed manipulation) or are likely to compete (vaccination) in the same geographic market at AT.

Reasons for low threat:

1) Competitive status: the literature and multiple interviewees highlighted the necessity of investing into and trialling multiple methods of reducing enteric methane.
2) Methane reduction: these schemes show lower enteric methane reduction than AT.
3) Experimental status: some enteric-methane-reduction schemes (vaccination) are still unproven technologies.
4) Time to impact: some enteric-methane-reduction schemes (breeding programs) will take years to have impact.

5.3.1.2 Classifying *Asparagopsis taxiformis* competitors

VG's competitive field can be mapped according to competitors' market commonality and resource similarity with the focal firm (Figure 5-1). The most direct competitors to VG (other MRA) can be found in the northeast corner of the grid where there is high similarity between market commonality and resource similarity. Other MRA producing firms have extremely high ability for their product to substitute for AT in the same geographic region (market commonality). They also have high resource similarity (i.e. capabilities, assets and knowledge of the market), albeit not quite as high as other AT producers. Other MRA therefore constitute a direct threat to VG. Potential entrants to VG's market (other AT producers) can be seen in the southeast corner, where firms possess similar resources, but currently serve different customer needs. These firms have extremely high resource similarity (similar assets, information, and strategies), but are currently meeting different segments of customer need due to their different geographic distribution. Finally, the firms on the southwest corner (methane reduction schemes), score low on both market commonality and resource similarity. These comprise the indirect competition or possible substitutions. According to this mapping. as well as other gathered evidence (Section 5.3.1.1.1), MRA constitute the most direct threat to VG.

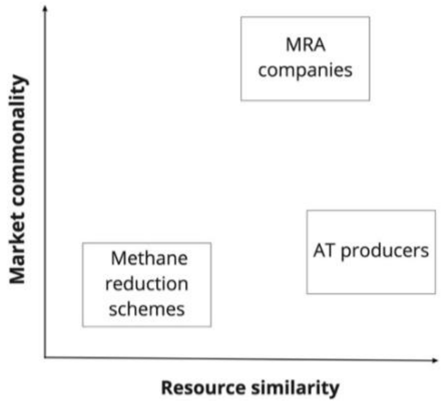


Figure 5-1 Mapping the competitive field for focal firm Volta Greentech according to a customer-needs based analysis Own illustration, based on concepts from (Bergen & Peteraf, 2002).

5.3.1.3 In-depth analysis of major competitor

Within the list of high potential MRA, 4 high potential options were selected for deeper analysis, alongside AT. The process for assessing these is described in (Section 4.6). These MRA were assessed based on the **foundational scientific evidence** underpinning the use of this additive (Table 5-3), the **production** of this additive (Table 5-4), and aspects relating to the **use** of this additive (Table 5-5). Appendix 2: Comparison of foundational research on 5 methane-reducing additivesincludes a summary and references for the evidence compiled for grading this matrix.

Table 5-3 Hotspot assessment of the foundational scientific research underpinning the five most promising methane-reducing additives for cows. Own assessment based on evidence compiled in Appendix 2.

		Enteric methane mitigation	Understanding of additive mechanism	Animal performance	Human food safety	Animal safety	Palatability and intake
AT	Research findings						
	Strength of evidence		n/a		n/a	n/a	
3-NOP	Research findings						
	Strength of evidence		n/a		n/a	n/a	
Mootral	Research findings						
	Strength of evidence		n/a		n/a	n/a	
Agolin	Research findings						
	Strength of evidence		n/a		n/a	n/a	
Yea-Sacc	Research findings						
	Strength of evidence		n/a		n/a	n/a	

	Criterion 1	Criterion 2	Criterion 3
Research findings	Evidence is promising for commercializing this MRA for the purpose of reducing enteric methane	Minor issues to be resolved before commercializing this MRA for the purpose of reducing enteric methane	Major issues to be resolved before commercializing this MRA for the purpose of reducing enteric methane
Strength of evidence	≥ 10 relevant studies	3-9 relevant studies	≤ 2 relevant studies

AT generally performs well on research findings, although there is a lack of sufficient scientific evidence to prove these. The 6 published *in vivo* trials measuring enteric methane reduction show a range of **26-98% reduction** compared to controls. There is a requirement for **long-term trials** into methane reduction and under varying dietary conditions. Bromoform is understood to be the major active compound, but the effect of other bioactive compounds present is less well understood. The suggested high mineral content of AT is thought to be beneficial and there is suggestion of milk yield increase on supplementation. 3 studies on AT-fed cow milk indicate that **raised iodine, bromine and possibly bromoform levels** may constitute a threat to human food safety. Seaweeds such as AT have been eaten by cows for eons and pose no threat to their safety. Studies on palatability and intake are conflicting, with 4 studies indicating reduced feed intake, and 1 indicating no impact. Respondent E3 noted that successful ways have been developed of improving palatability. The greatest difficulty here revolves around how to feed this supplement to grazing cattle.

3-NOP performs well across almost all categories of foundational scientific research. Only human food safety is potentially problematic, based on the fact this additive is still awaiting approval by EU food agencies. It has, however, passed tests related to mutagenicity and genotoxicity. The slow process for approval is due to this being a **synthetic molecule**. The strength of evidence on 3-NOP is extremely high, with **over 10,000 cows tested** under varying conditions and time-periods. This comprehensive evidence base will be useful for DSM as it means their product is likely to be approved as a methane-reducer under diverse conditions. The only concerning research finding is the requirement for continuous delivery of 3-NOP to ensure methane reduction. This would not be practical for grazing cattle. DSM report that there is research ongoing into this issue, with a new 3-NOP prototype likely available shortly.

Mootral is another natural compound, which is showing promising results albeit with an extremely low level of evidence. Results have also been contradictory with methane reductions reported from **no significant impact to 38%.** There appears to be a need for cow acclimatisation to the additive, however conclusions are hard to come by with only 2 *in vivo* trials. Results from Mootral studies can be somewhat supported by previous trials into the methane reducing effects of garlic and citrus extracts, which are constituents of the additive. These previous results are also useful in supporting the proposed **animal performance benefits** of Mootral which include improved milk yield and reduced somatic cell counts (indicating healthier cows). Given that Mootral is a natural compound, it faces no problems on either animal or human safety criteria. 1 study indicated non-total consumption of Mootral pellets by cows suggesting potential palatability issues.

Agolin is a **well-established** feed additive provided by Agolin Ruminant to improve ruminant productivity. Although the mechanism by which this additive reduces methane is poorly understood, there is growing evidence that long-term supplementation results in methane reduction of ~10%. This additive is confirmed as methane reducing by the Carbon Trust. There is a large amount of evidence indicating **animal performance improvement** on feeding Agolin. This includes improved feed efficiency (+4.4%) and milk yield (+3.6%). The additive has been on the market since 2008, and there are no safety concerns. A limitation of feeding is that the additive is typically given in pellet form and therefore usage is restricted to intensive farming.

Yea-Sacc is another **commercially available** additive, introduced by Alltech for optimizing ruminant productivity. It is a particular culture of *Saccharomyces cerevisiae* yeast that creates a healthier ruminant microbiome. Scientific findings indicate either low or no direct impact of the yeast culture on enteric methane production (0-10%). There are an extremely low number of *in vivo* Yea-Sacc trials, however over 50 have been conducted on *Saccharomyces cerevisiae* yeast. A meta-analytic review of these indicated there was no significant impact of the yeast on methane production. However, the additive has been certified as methane-reducing by the Carbon Trust based on its ability to increase milk yield and therefore **reduce the methane intensity** of milk products. Feeding Yea-Sacc typically results in feed efficiency improvements of around 8%, with milk yield being improved by 1.6 litres daily. Use of the yeast is deemed safe by all appropriate authorities, and it is available in multiple forms that have been found to be easily palatable by cows.

Table 5-4 Hotspot assessment of the production methods for the five most promising methane-reducing additives for cows. Own assessment based on evidence compiled in Appendix 3: Comparison of the production of 5 methane-reducing additives.

	Ability to scale production	Raw material availability	Environmentally friendly production	Conversion to transportable/ storable feedstock
AT				
3-NOP				N/a
Mootral				
Agolin				
Yea-Sacc				

	Criterion 1	Criterion 2	Criterion 3
Research findings	Evidence is promising for commercializing this MRA <u>for the purpose</u> of reducing enteric methane	Minor issues to be resolved before commercializing this MRA <u>for the purpose</u> of reducing enteric methane	Major issues to be resolved before commercializing this MRA <u>for the purpose</u> of reducing enteric methane

There are large barriers relating to the production of AT. Multiple sources highlight the **scale-up** of AT production as an issue of major concern. This is based on the difficulty of farming this seaweed: more research and experimentation will be required to domesticate the species. Currently no AT aquaculture has reported to being able to close the life cycle of this algae. Both marine and factory production of AT present potential environmental problems. Large scale marine farming can lower the ocean pH, cause marine mammal entanglement and potential invasion of a non-native species. Factory or tank-based production requires energy and chemical inputs, as well as significant infrastructure. In terms of the specific VG factory, this is aiming to be carbon neutral, but there is still work to be done in achieving this. Finally, the **processing and long-term storage** of AT is a major issue. This is mostly due to the loss of bioactive compound. This loss is problematic in terms of the reduced effectiveness of the algae.

3-NOP is a synthetic molecule, produced from 1,3-propanediol and nitric acid. These chemicals are **readily available**, and the molecule is therefore easily produced in large quantities. The infrastructural, knowledge-related, and commercial resources of DSM will assist effective upscaling of this product, once approved. LCA's have been conducted on the 3-NOP production process, which indicate a minimal environmental impact (47.9 kg CO_2e /kg 3-NOP). No information is available on compound shelf-life.

Mootral currently has a lab scale production facility in Wales, UK, but no commercial facility yet. This lack means investment would be required prior to mass upscaling of Mootral production. The raw materials for Mootral, primarily garlic and citrus extract, are easily available and the company will be able to **tap into existing supply chains**. Although infrastructural facilities are required, ingredients for Mootral can be sourced locally, and the company plans to set up local production sites and ensure a low carbon footprint. Therefore, production is likely to be **environmentally friendly**. Although there have been no studies investigating the long-term storage of Mootral, there has been research into the stability of organosulfur compounds from garlic, one of the active Mootral compounds. The stability of this compound was found to be limited and to impact its practical use, thereby indicating the shelf life of Mootral may be small.

Agolin is produced on a large scale, with around **1.5 million cows already fed this additive**. The company indicated that capacity is not an issue, and they would be rapidly capable of increasing production by 3-5 fold (Respondent E9). Agolin is a blend of essential oils. The oils (raw materials) used to prepare this blend are highly concentrated extracts from herbs which are readily available. Although the company exports most of their product, their production is still deemed environmentally friendly based on the extremely low environmental impact and carbon footprint of production, calculated as 0.000108 kg CO_2e /kg Agolin (Respondent E9). The compound is easily processed and maintains activity for around 18 months when stored.

Yea-Sacc is also a commercial product. The commercializing company, Alltech, have over 6000 employees and indicate they would be able to **expand production easily** with demand. The yeast product is produced by batch fermentation in a typical industrial medium based on molasses and mineral salt. These are both easily available raw materials, and the process has minimal environmental impact. Yea-Sacc is regulated to a certain amount of live activity, with research data indicating shelf life is at least 12 months.

Table 5-5 Hotspot assessment of the aspects relating to the use of the five most promising methane-reducing additives for cows. Own assessment based on evidence compiled in Appendix 4: Comparison of the usage of 5 methane-reducing additives

	Cost	Approval by authorities	Political/ external support	Time to commercialisation	End-of-chain interest
AT					
3-NOP	Unknown				
Mootral					
Agolin					
Yea-Sacc					

	Criterion 1	Criterion 2	Criterion 3
Research findings	Evidence is promising for commercializing this MRA <u>for the purpose</u> of reducing enteric methane	Minor issues to be resolved before commercializing this MRA <u>for the purpose</u> of reducing enteric methane	Major issues to be resolved before commercializing this MRA <u>for the purpose</u> of reducing enteric methane

The **cost** of AT is a major prohibitive factor. Personal calculations for this thesis indicated a cost of €230 /tCO_2e reduced (Appendix 4), based on a daily additive cost of 15 SEK/cow. The high cost of this additive is due mostly to the expensive production cost, but also increased by licensing fees and constant R&D. AT is a natural product and, on the EU Safe List for feed additives currently. It is still awaiting approval from the FDA in the U.S.A.. Given concerns about iodine and bromine concentrations in milk, **more research is needed** before AT-fed dairy products are widely accepted by farmers and retailers. Both globally and in Sweden, AT production has been receiving significant external support. Both the New Zealand and Australian governments are **directly funding** research into AT production, and there is discussion of inclusion of AT in Australian carbon markets. In Sweden, VG has received funding from government grants including Almi. Commercial trials of AT are running, for example Sea Forest with Fonterra and Sybrosia with Midnight Farm, however the low levels of production are limiting large scale commercialization. The most successful AT producer, Sea Forest, will reportedly be able to produce **7,000 tons of AT** from their current marine lease (Palmer-Derrien, 2021). There is significant end-of-chain interest in AT with various major retailers both in Sweden (IKEA, Coop, Lantmannen) and globally (Burger King, Darigold, Fonterra) indicating their interest in the product.

DSM is yet to release a price for 3-NOP. Although the compound is cheaply produced, the extensive amount of research trials needed to prove and develop the product will likely be a large contribution to the final cost. The approval process for this additive is more complicated than others given that it is a synthetic molecule. The EU approval process is currently underway, with New Zealand and Latin America next on the list. U.S. approval is expected in 2024. The compound is produced in-house by DSM and there has therefore been minimal external support utilised thus far. Time to commercialisation is limited by the **long regulatory process**, however when the compound is approved, DSM's vast amount of research trials mean the compound should be able to be used for methane reduction across diverse ruminant conditions. There is also extensive end-of-chain support for 3-NOP: DSM have been working with both governments and large dairy corporations including Fonterra.

Personal calculations indicate a rough cost for Mootral as €100 /tCO_2e (Appendix 4), which is in the **medium-cost range** of effective additives. Their cost may be more viable given than the company is also developing an alternative business model to fund the feeding of this additive. This model is based on businesses purchasing 'cow credits' to offset emissions. Mootral use natural, food-grade quality ingredients and therefore experience no regulatory issues. The company have received financial support, including from the Swiss Climate Foundation, and this product is also verified by the Carbon Trust. The company plans to expand production to reach 300,000 cows in 2021, however their limited commercial infrastructure is likely to make this goal unrealistic. There has been minimal indication of high end-of-chain interest.

The cost of Agolin is low, with personal calculations indicating a rough cost as €48 /tCO_2e (Appendix 5), based on a daily cost of €0.04 /cow. The increase in cow productivity should more than compensate this cost. The additive has been approved since market inception in 2008 and experiences political support in that it is recognised as a carbon offset methodology in both the EU and U.S.A.. It has also been recognised by the Solar Impulse Foundation as a **'profitable' solution** to climate change. Time to commercialisation is zero, and there is high interest in this additive. It is fed to 1.5 million cows already and Agolin Ruminant is collaborating with major clients including Nestle and Barry Callebaut.

Yea-Sacc is also found to be in the **low price bracket**, with a daily cost of €0.06 /cow. Personal calculations in this thesis are based on tCO_2e reduced directly, and as Yea-Sacc only reduces the methane intensity of milk, this calculation is not appropriate. Further research is needed to provide a broader range of relevant calculations. However, the cost of this compound should also be more than compensated by cow productivity improvements. This yeast culture has been commercial for over 30 years and is supported by its certification by the Carbon Trust.

5.3.2 Potential amelioration of competitiveness barrier

AT also has unique features that distinguish it from competition. These features could enable VG to access specific opportunities. The opportunities for AT discussed in Chapter 6 are useful in terms of resolving product barriers, but also offer additional potential competitive advantage over other MRA. Table 5-6 provides evidence of distinguishing features of AT that distinguish it, and thus may contribute to overcoming the competitiveness barrier. Symbiotic production is excluded: this opportunity is useful only in resolving VG's production-related issue.

Table 5-6 Overcoming the competitiveness barrier: why Volta Greentech may be able to use the identified opportunities to gain a competitive advantage.

Opportunity	Reason AT is distinguished from other MRA	Evidence	Link to other MRA
Funding mechanism	High marketability and high methane reduction	Respondent E17: *[The AT] story is easy to pack up. People want it to work.*	Other MRA exhibit lower methane reduction and marketability → not worthy of a differentiation label.
	High levels of media and/or celebrity support	See Section 6.2	Other MRA have lower press coverage (possibly excluding 3-NOP) → unable to generate awareness and trust in scheme
Media and celebrity endorsement	High current level of media attention	See Section 6.2	Other MRA (possibly excluding 3-NOP) have lower current press coverage → future media endorsement is likely to be lower
	High current level of celebrity attention	See Section 6.2	Other MRA have lower levels of celebrity support → future celebrity endorsement is likely to be lower
	Ethical and interesting features of AT product/ VG team	Respondent E17: *[The AT] story is easy to pack up. People want it to work.*	Other MRA firms are less interesting and/or purpose-driven → free marketing is less likely
	New technology	Agolin and Yea-Sacc have both been commercial products for > 15 years	Agolin and Yea-Sacc are more established → celebrity endorsement is less effective for better established products
Collaboration	There are multiple AT producing companies	Table 5-2	Other MRA companies are typically the sole producer of an additive → no ability to collaborate on production or commercialisation opportunities.
	There are multiple algae networks	Section 6.3	Other MRA (excluding yeast) do not exist within a well-defined product group → AT better able to access 'free' research (e.g. Cawthron), gain and hire experts and share resources.
	AT is an organic compound	AT is a naturally available alga	Other MRA are trademarked mixes or chemical products that academia is less free to experiment upon → AT is an organic compound thereby more available for academic research
Political support	High methane reduction	See Appendix 2.	Other MRA have lower methane reduction → VG has greater potential to dent GHG emission with their product
	Innovative/ radical venture	Section 7.2.1	Other MRA companies are less radical → VG may be able to gain specific high risk/ high reward venture funding
	Swedish company	VG is headquartered in Sweden and aiming to sell to the Swedish market	Other MRA are headquartered outside Sweden →VG will be more likely to access Sweden-specific political support (especially in terms of early investment in development)
	Swedish trials	VG is conducting trials with cows under Swedish conditions	Other MRA (Mootral and 3-NOP) have not been testing their product under Swedish conditions → VG product more likely to be used as they can prove the

			methane reduction of their product under Swedish conditions.
Alternative uses of AT	Healthy human food stuff/historical usage as food	AT has been consumed for generations e.g. (Abbott & Williamson, 1974; Bonin & Hawkes, 1987; McDermid et al., 2019)	Other MRA are not used for human consumption → AT has an additional, high value market
	Anti-microbial / anti-oxidant activity of compounds	Compounds extracted from AT have been found to have properties that enable their use in the development of pharmacological drugs (Vedhagiri et al., 2009; Neethu et al., 2017)	Other MRA (excluding the garlic fraction in Mootral) have not exhibited anti-microbial properties → AT has valuable components that may provide future high value markets

VG may be able to succeed commercially despite strong competition from other MRA. Effective solutions to GHG emission sources, such as enteric methane, are needed urgently. Public and governmental support may be available for **multiple options**. Therefore, even though VG appears at a disadvantage compared to other additives on certain criteria, it may still be a commercially viable enterprise.

5.3.3 Summary of competitiveness barrier

The analysis conducted identified VG's competitors as **other MRA companies, AT producers and various enteric-methane schemes**. Other MRA companies constitute the greatest competitive threat to VG. These companies have similar resources and seek to serve the same market. VG faces multiple disadvantages in terms of competition with other MRA companies. AT is more expensive, has a more complicated production process and experiences more unresolved challenges related to product risk than any other MRA. From either a client or political point of view, it may appear unwise to invest in an additive that has such large associated barriers and costs more per tonne of CO_2e reduced. However, AT is unique in the extremely high methane reduction it offers. One respondent even referred to other MRA as 'distractions' compared to the potential environmental impact of AT (Respondent E17). VG also has the potential to gain extra revenue through accessing high-value markets that other MRA cannot. This may be able to support their true purpose of supporting the reduction of enteric methane. In addition, the competitive field may be less of a threat to VG than for traditional firms due to widespread support for GHG mitigating measures.

6 Opportunities: the stakeholder perspective

This section discusses the 6 short-term opportunities found to be facing VG. These are a **methane-reduction label**: VG could market their product through a 'methane-reduced' label on the final dairy product. **Celebrity endorsement:** VG could invest time and resources into increased media and celebrity attention to publicise their cause. **Collaboration:** VG could develop relationships and share learning with other relevant algae experts. **Political support:** VG could push politicians to provide greater support for this alga. **Symbiotic production:** VG could use symbiotic techniques to enhance the environmental and economic profile of their production mechanism.. **Alternative uses for AT:** VG could exploit other high-value commercial uses for AT.

6.1 Methane-reduction label

6.1.1 Benefits of a methane-reduction label for *Asparagopsis taxiformis*

This opportunity refers to the ability of VG to potentially market their product through use of a 'methane-reduced' label on cow products. This label would signify the lower methane emissions of the product. Consumers would be expected to pay an **extra premium** for these labelled products. This premium would be returned to VG and used to cover the costs of seaweed production. This business model would enable the farmers to be given the additives free of charge. The proposed reduced-methane label is in essence a new form of **eco-labelling**. Eco-labelling here is defined as "*the practice of marking products with a distinctive label so that consumers know that their manufacture conforms to recognized environmental standards*" (Oxford Dictionary, 2014). Reduced-methane labelling is also a similar concept to carbon footprint labelling schemes which aim to compare the footprint various consumer products.

Use of this methane-reduced label would enable VG to utilize a different business model to its competitors. Multiple data sources indicated the difficulty of ensuring **fair financial flow** up the dairy value chain. LRF commented, '*A challenge is that value added is produced on the farm, by the farmer and cow and that value added has to follow milk through processing chain'* (Respondent E6). Clearly a working model is needed to fairly reward methane reduction by farmers: a way by which the farmers do not end up paying for this reduced enteric methane. A researcher from SLU noted '*How should it work – in terms of financial flow down the chain? … We need a way for the producer to get paid – without needing to think about price from slaughterhouse'* (Respondent E3). If this funding mechanism were to work, VG would create a model by which producers could be treated fairly. This model would enable farmers to be **freely provided** with an MRA, thus differentiating them from other enteric methane reduction schemes which are typically paid by the farmer. Normally with premium products, the retailer benefits rather than the farmer. This was a concern for LRF about MRA, '*It's the retailer that makes the money – this is where the profit comes to.'* A label which enables funding to be provided directly to VG, and thus provision of free MRA to farmers would satisfy this concern. Although unproven, it appears likely that there will be cow-productivity benefits associated with AT (Appendix 2), which would provide an incentive for farmers to use this freely supplied product. Overall, this label provides the potential for VG to operate an **alternative business model** that would support the demand for fair financial returns in the Swedish dairy value chain.

This type of product label may increase **retailer interest** in VG products. It provides ready-provided marketing in the form of a clear communication tool for environmentally minded consumers. Product labels, whether classic ecolabels or reduced methane, have been widely recognized as an **effective communication tool** for enabling consumers to recognize production or processing methods that do not end up impacting the final product (D'Souza, 2004). These methods (for example responsibly sourced timber or methane-reduced milk) are imperceptible, and the benefit of labels is that consumers need only glance at them to understand the environmental impact of products. Ecolabels have been demonstrated to help consumers save time and effort when attempting to make sustainable choices (Grunert and

Principle	Explanation
Transparency	All information on the label and labelling process available to stakeholders
Appropriateness	The available information should be relevant and useable for stakeholders
Credibility	Communication is presented in a format that enables stakeholders to ensure its trustworthiness.
Responsiveness	Information is provided in an easy-to-access and timely manner.
Clarity	Information is easy to understand

Wills 2007). In a globalized world where expansive supply chains obscure the impacts of production from shoppers, labels are a proven means by which VG can communicate the green credentials of their product. Labelling products in this way has been done since the 1990s and therefore provides an established communication channels that both consumers and companies understand. Thus, this label is a way to utilise a clear communication method to generate additional client interest in VG's product.

6.1.2 What are the potential problems with a methane-reduction label?

There are a high number of environmental labels on the market and thus a reduced-methane label may struggle to stand out. Choice paradox theory, the idea that humans can easily be cognitively overloaded by too much choice and thus revert to the simplest option implies that the cowfunding label may just be extra noise in the **busy ecolabelling marketplace**. Lierre and Thidell (2005) found that the overload of labels has led to "inadequate information" being cited as a major factor hindering green purchases. Whilst ecolabels are viewed as a key differential tool, the sheer number of them can mean that any new label (such as cow-methane-reduced) would struggle to differentiate itself from the already formed masses. There is a high trust in and understanding of certain ecolabels in Sweden (Lefébure & Rosales Muñoz, 2011). However, this may end up working against cowfunding. The **market domination** of these trusted regional ecolabels (KRAV, Bra Miljöval and Nordic Swan) may make differentiation even more challenging and enhance the difficulty of penetrating this market. Confusion is particularly high with respect to the newer labelling schemes such as carbon-footprinting. Boardman (2008) found that 89% of UK shoppers were found to be confused about carbon-footprint labelling. The cow-methane-reduced labels would also be a new labelling formats, that would likely generate **higher confusion rates** amongst consumers. To sum up, the large numbers of eco-labels on the market may mean VG struggles to differentiate itself in this field.

Cow product retailers (such as ICA and Coop) have **complicated procedures** related to labelling schemes and certification. The team notes that for any funding mechanism, '*Our system of counting must work with their system*' (Respondent T1). When it comes to measuring enteric methane, the retailers have a variety of counting systems. *'There is not one system that everyone is using. Maybe this will never exist'* (Respondent T1). Thus, both VG and the retailer may face challenges with the **logistical challenge** of implementing a new label in retail stores. For VG, the challenge would be around adaptation of this label to meet the requirements of retailers. For retailers, there would likely be additional complications involved in the extra data processing. Therefore, a barrier to the adoption of this label would be the reluctance of retailers to stock it because of complicated integration processes.

Meeting the requirements for a trustworthy label would require time and money from VG. There are five main principles described by ISO (Lefébure & Rosales Muñoz, 2011) for enabling effective environmental communication (

). These would likely constitute a large logistical and financial burden. One particularly large cost to ensure credibility would be the requirement for **third party verification**, which VG expects would be done by large accounting firms. "B*ig accounting companies – they will lead this. They will do revision on any climate declarations that have been done…. They could give stamp of approval that the way*

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[VG] calculated was correct' (Respondent T1). The high cost and technical considerations, such as internal human resources and external technical support, of meeting these principles often provide large barriers to adoption of ecolabels by SMEs. Indeed, very few labelling schemes have succeeded in overcoming these challenges and integrating SMEs. Therefore, as a small company VG may be unable to develop or adopt a trustworthy and thus successful label for their product.

Table 6-1 The requirements the Volta Greentech label would need to fulfil the ISO criteria.

To add to this challenge, Thorgersen et al. (2009) demonstrated that adoption of eco-labels is a **slow process**: consumers typically require repeated exposure to the label before they commit to purchasing a labelled product. This is backed up by the vast majority of ecolabelling literature which cites the considerable time and investment costs to companies of successful labelling schemes (Lefébure & Rosales Muñoz, 2011). Thus, a long-time horizon may be needed before the labelling idea kicks off with the public. VG is a small company with limited resources: they may not have this time available before financial constraints (and the need to make profit) kick in.

Even with this funding mechanism, VG would struggle with logistical issues related to directly tracing their impact on enteric methane. Imagine a milk product from a seaweed-fed cow that later ends its life as beef. How should VG split the methane-reduction between these products? This logistical problem was discussed in the SLU report on the economic feasibility of feeding AT (Jardstedt & Holmström, 2021). The author of the report commented in an interview that the '*Carbon footprint for beef is much higher than for the calf born to a dairy cow'* (Respondent E3). **Justifying the green premium** connected to a label on dairy products, and the clarity of communication in the label, will therefore be a complicated issue for VG to resolve.

6.1.3 Summary and suggestions

Overall, a label provides a clear communication tool, but the significant complications involved with implementing a labelling scheme suggest that this is not a project VG should embark on alone. Retailers are generally aware of the cost-benefit of implementing a label and consequently any judgment on product labelling may be better left in their hands. The literature indicates the importance of retailers in stimulating demand for ecolabelled products through information campaigns, special offers and co-marketing (Iraldo et al., 2020). Large retailers have the budget to educate consumers and entice them to understand, recognize and accept various labelling schemes (Testa et al., 2015). The following suggestions indicate which retailers may be good targets and recommendations for implementation of the label by these retailers.

There is **high environmental drive** amongst Swedish retailers. Commitment levels are evidenced in the membership of certain companies in sustainability related initiatives such as the Hagainitiativet (Haga Initiative) and Hållbar Livsmedelskedja (Sustainable Food Chain

Alliance). A representative from Haga noted, '*The companies pay to be members – even that is commitment.*' The companies involved in Hagainitiativet (including Coca-Cola, McDonalds Sweden and HKScan Sweden) set climate targets of at least 40% CO_2e reduction by 2020 and net-zero by 2030 (Hagainitiativet 2021). The Sustainable Food Chain is an initiative of fifteen food companies (including Martin and Servera, Axfood and Arla) aiming to restructure the food chain to increase sustainability by 2030 (WWF, 2020). These sustainability-driven initiatives offer **good potential targets** for VG product stocking and labelling discussions.

The label may prove more successful if initially limited to **smaller geographical areas**. This claim is made by noting that Swedish consumers have a higher awareness and understanding of Swedish or Scandinavian ecolabels. Indeed, the difference in consumer understanding of the Swedish/Scandinavian labels compared to regional ones is larger than 30% (Lefébure & Rosales Muñoz, 2011). This has been linked to various factors including greater exposure to these labels, a better understanding of Swedish companies for their own markets and marketing strategy from the labels that are specifically designed for the country. These findings provide a clear case for the methane-reduced label to focus initially on only the Swedish market. It could also be extrapolated to suggest that the label success may be greater if initially applied at only a local level. Given the early-stage limitation on the number of cows able to be fed algae (Section 5.1.1), focusing on one smaller geographical region would enable greater exposure of local customers to the label. In addition, the local markets tend to be quite specific and linked to one cooperative (Respondent E5). If VG were to focus efforts on one region only, they could adapt their marketing strategy to the region. They could also utilise the awareness of producers (the cooperatives) or retailers for their region to determine how best to communicate to potential dairy consumers. The considerable variation across Sweden, particularly in terms of climate and consequently agricultural conditions, means there is a lot of scope to **adapt marketing messages**. A regional focus is therefore one means by which VG or retailers may be able to promote uptake of this labelling scheme.

The retailers of reduced-methane-labelled products should have a strong role in stimulating consumer interest for labelled products. There is a cited need for stronger communication to fuel the ecolabelled product market, and retailers are in a perfect position to provide this push (Iraldo et al., 2020). When retailers are enticing customers to buy green, Testa et al. (2015) indicate that **point-of-sale communication** is most effective for ecolabels and thus should be focused on when promoting these methane-reduced products. A store environment that motivates customers to buy eco-friendly (for example, through placing these products on a more accessible shelf) could play a large role in enticing consumers to consider seaweed-fed cow dairy products. Overall, most of the marketing of any methane reduced label should be done by retailers, and in the store environment.

Finally, there will be the opportunity for this labelling scheme to learn from other institutions currently tracing and certifying GHG reduction efforts on farms. Danish Crown's 'Klimavejen' or 'Climate Path' scheme is one example (Danish Crown, 2021). As part of their efforts to become reduce climate impact by 50% by 2030, Danish Crown introduced a certification scheme for pork farmers than enables them to track and certify a series of measures related to reducing pig related GHG emissions. The mechanism to track, trace and certify may be able to be replicated in this scheme. In addition, food additive tracking companies are already developing mechanisms by which to **measure and report enteric methane emissions**. The CEO of a Swedish ruminant feed additive company indicated that they were prepared to include the impact of 3-NOP of cattle emissions. '*We are prepared to handle this. We will include these additives and their proven effect*' (Respondent E15). The general upwards trend of the industry towards understanding emissions was also noted by him. '*The last 12 months – we can see different standards* *from feed industry have been published so we know how to solve [problems].'* This indicates that the mechanisms for accounting for enteric methane production is developing fast. The proficiency of these potential collaborative partners in tracking and reporting GHG emissions may be of help in enabling VG to meet ISO requirements and deal with complex methane-reduction traceability problems. The caveat to this would be that many trials of AT would be required to inform these calculations (Respondent E17). However, in summary, these opportunities for collaboration offer VG access to expertise that may enable them to develop an effective and trustworthy label.

6.2 Celebrity endorsement

6.2.1 Benefits of celebrity endorsement of Volta Greentech

This opportunity refers to the ability of VG to seek greater publicity via endorsement by celebrities or any other media channel. This discussion will use the McCracken (1989, p8) definition of celebrity endorser as, "*any individual who enjoys public recognition and who uses this recognition on behalf of a consumer good by appearing with it in an advertisement*." Endorsement, whether by a celebrity or other news/media professional will be broadcast by media which can be understood in terms of both conventional channels (e.g., radio, television, newspaper) and more modern channels (e.g., social media, blogs, influencers).

The ethical and interesting features of both the AT product and VG team make it a prime target for '**free marketing**.' There is a high-level awareness and interest in finding climate change solutions in Sweden (Lefébure & Rosales Muñoz, 2011). This increases the probability that the media, celebrities, and other influential sources such as sustainability influencers, will play a role in 'free' advertising of VG. As the lead scientist at Cawthon notes, '*People want [AT] to work*' (Respondent E17). Thus, **influential platforms** may well promote this product for reasons related to their own moral or climate-change-related concerns. In addition to the ethical side, the VG team are perfect media material. They are unique in both their product and their personal story which features three young founders and a CEO who dropped out of university to start this company. Media outlets or celebrities looking for a 'scoop' are therefore more likely to be interested in promoting their work. Therefore, VG has a relatively high probability of receiving free marketing attention.

Celebrity endorsement is a promotion tool and is likely to be an effective means by which to differentiate the VG product or service from others in the enteric-methane reduction field. As noted by Jordbruksverket, '*Researchers, farmers, retailers, consumers and the media also have important roles when it comes to supporting low emission food products and promoting technologies that might work'* (Respondent E21). Kalra & Goodstein (1998) demonstrated how promotion of a product by celebrities lowers consumers price sensitivity making them more willing to pay for an endorsed product. Similarly, where celebrities are used to promote branding, an enhanced sense of brand awareness has been noted among the consumer base (Tanner & Maeng, 2012). Therefore, these endorsement mechanisms may **raise consumer willingness** to pay the green premium associated with AT-fed dairy. In a marketplace increasingly saturated by products and marketing strategies, celebrity or media endorsement has been proven as one way to improve the willingness of the public to engage with brands and products (Lefébure & Rosales Muñoz, 2011). This could be seen as particularly important for the VG dairy products: the milk market has been recognized as one of the most competitive in the food domain (Tacken et al., 2008). Human phycological studies demonstrate we place a trust in the figures we 'interact' with regularly, including those figures on tv or in newspapers (Tanner & Maeng, 2012). Provided the marketing message of these persons is perceived as authentic, there is a trust 'spill over' where perceived brand credibility (and brand purchase intention) is improved because of these endorsements. Linking this to the endorsement of 'methane-reduced' cow products, it can be suggested that celebrity endorsement would be an effective strategy for improving consumer trust in the seaweed-feeding concept. This would likely generate higher sales. Research by Ambroise et al. (2014) demonstrated that a stronger effect of celebrity endorsement on unfamiliar compared to familiar brands: this bodes well for involving celebrities early during the introduction of methane -reduced products. Overall, celebrities have the potential to increase consumers trust in, and willingness to pay for, VG's product.

Media or celebrities are a particularly important communication channel for environmental causes. In Knoll and Matthes (2016) meta-analysis of celebrity endorsements, it was found that such endorsements generally enhanced the public's intention to support a charitable cause or to volunteer. This suggests that this style of endorsements is particularly effective when related to ethical issues. This bodes well for the promotion of AT as a 'climate-solution' by celebrities. The importance of this channel for reaching the public on sustainability-related issues is evidenced by the growing celebrity support for environmental causes since the 1990s, with a corresponding increase of attention in the literature. The elite status of celebrities enables their supported organization access to key individuals, groups, and events, as well as increased general publicity (Olmedo et al., 2020). Celebrity involvement has ranged from endorsing NGO campaigns (Jackie Chan and Wild Aid), creation of celebrities' own institutions (Jane Goodall Institute), participation in high level forums (Leonardo DiCaprio at UN summit 2014). Many environmental organizations now use celebrities as 'strategic assets' (Turner 2016). As an example of the widespread nature of this, **almost all UK conservation organizations use celebrities** to a greater or lesser extent in marketing or fund-raising work (Duthie et al. 2017). This suggests for that celebrity or media endorsement is an appropriate, perhaps even necessary, channel by which VG can raise awareness of this environmental project. The myriad of other environmental issues that are raised to high levels of attention by celebrities means VG may have to employ similar tactics for their environmental issue (methane emissions by cows) to be noticed. Therefore, evidence from other environmentally endorsed projects suggests this is an effective means by which to raise awareness. It also suggests that without access to publicity, VG may struggle to compete in the well-publicized sustainability field

Endorsement is likely to increase the public understanding of the enteric methane problem and **reduce GMO-style fears**. Celebrities often have well-developed communication skills and so can make distant issues relevant to the public and distil complex topics into an engaging format. Through this, they can draw the public's attention to issues they otherwise would not pay attention to (Doyle et al. 2017). Given that one of the challenges of reducing methane in the dairy and beef industry is a poor understanding amongst consumers as to the environmental impact of cows, celebrities may prove a powerful tool for raising base-level awareness of this problem. Another potential problem highlighted in interviews were public wariness over GMO-style fears related to AT (Respondent E19). Celebrities' talent in communicating effectively could also be useful in allaying these fears. Thus, if endorsement is performed by talented communicators, it offers potential to increase both client awareness of enteric methane issues and their trust in the AT product.

6.2.2 What are the potential problems with celebrity endorsement?

The broad span of areas this solution covers (climate change, agriculture, animal welfare, food safety and so on) will make selection of a celebrity with relevant expertise challenging. There is significant evidence to suggest that without expertise on a promoted subject, celebrity endorsement can have minimal to negative impact (Till and Busler 2000). Clearly then, the choice of celebrity or media channel can impact the effectiveness of the message communicated. An inappropriate choice risks, at worst, VG losing credibility and, at best, a waste of time and money.

There is mixed evidence on the impact of celebrity endorsement on conative effects (i.e. changed behaviour). Knoll and Matthes (2016) meta-analysis of celebrity endorsements, found that celebrity endorsers had minimal effects on brand choice or intention to share information on the product or to inform oneself further. This is concerning, given that the purpose of celebrity endorsement in this case is primarily to change behaviour such as the purchase of methane-reduced products. If celebrity endorsements cannot cause companies or customers to choose VG branded products over non-methane reduced options, there is little purpose in investing in them. Given that the **cost of celebrity endorsers is high** and often beyond the means of small start-ups (Popescu 2014), pursuing celebrity or media endorsement is thus a potentially hazardous strategy.

The **unresolved AT risks** may disincentivize celebrity attention, and even result in bad media press. Celebrities may be unwilling to put their reputation on the line when it comes to an unproven and potentially risky product. The Muizelaar et al. (2021) report on AT risks is evidence that the media or celebrities may use to conclude that this product is too risky to support. The controversy that sprung up around this paper and resulting blogs and discussions are indicative of media interest in 'bad' press (Bryne, 2021). Media stories often capitalize on negative findings and therefore may choose to portray the potential hazards of AT, thus harming the reputation of the company. These risks may therefore pose a threat to celebrity involvement in promotion and to VG reputation because of negative media endorsement.

6.2.3 Summary and suggestions

The effectiveness of celebrity endorsement for other environmental causes is a good indication of its potential importance for VG. Although the cost of involving celebrities is high, and likely unworthy of VG investment, the **purpose-driven nature** of the company mean they may have access to free endorsement. Given the reliance of VG on investors, and on client interest in their product, they would stand to gain significantly from **an improved public awareness** of their company's mission. Greater investment in endorsement mechanisms has the potential to support the upscaling of this company.

In terms of celebrity endorsement, the celebrity chosen will impact the effectiveness of the message communicated. The literature advises **considerable market research** prior to selection. In selecting celebrities to represent this cause, AT producers must be careful to select credible and persuasive spokespersons. According to Kenton (1989), this demands four dimensions to be fulfilled: good will and fairness, prestige, expertise, and self-presentation. The marketing industry has extensive experience in selecting appropriate celebrities, having spent six decades investigating the most effective attributes for spokespersons. The 'source credibility model' and 'product match-up hypothesis' are often employed (Duthie et al., 2017). The first posits that knowledgeable and trustworthy celebrities positively impact the effectiveness of a campaign, the second that the success of a campaign will increase if there is a clear link between celebrity and product (Kamins, 1990). This match-up idea is supported by Schema Theory which suggests that if celebrity schemas match product schemas, the attributes of the celebrities can be integrated more easily with their message thus improving trustworthiness (Lynch & Schuler, 1994). Thus, when selecting an appropriate spokesperson, AT producers should look for someone who can be trusted on **climate-related issues**. As noted, the broad span of areas this solution covers means there may be few total experts available. VG should however attempt to find a celebrity who matches up with as many criteria as possible. In the absence of full expertise, other criteria for trustworthiness may be useful to employ. In a meta-analysis of celebrity endorsements, Knoll and Matthes (2016) found the most positive attitudinal effect was for male actors matching well with an implicitly endorsed object. The impact of actors as spokespersons has been found to be particularly large due to the stronger relationship of consumers with them. Consumers are audio-visually exposed to actors over multiple encounters which creates a deeper connection and more trust. Actors may thus prove appropriate communication channels for this message.

6.3 Collaboration

6.3.1 Benefits of collaboration with seaweed experts

This opportunity refers to the ability of VG to develop learning or share information with other algae experts in the field. This collaboration is already happening to a mild extent, however the premise behind this section is that this could be broadened significantly.

Collaboration is possible between the multiple AT producing companies. These potential collaborators have similar expertise and can work together on **various, mutually beneficial projects.** Multiple sources note the need for more AT research trials to investigate animal safety and productivity, as well as the effectiveness of methane reduction under different circumstances. More unity between seaweed companies and researchers can **lower research costs** for individual companies and is of benefit to all concerned. Literature on AT has noted a lack of comprehensive framework in AT research (Vijn et al., 2020), something that was confirmed in data collection for this thesis. Greater collaborative efforts between those requesting the trials would enable the building of a , *'unified dossier on product safety and efficiency,'* as well as a '*summary of the state of the art… with the constant research updates'* (Respondent T1). These research outputs are noted to be *'needed frequently.'* There is also apparent high motivation for collaboration between the companies on aspects including product safety. VG's CEO notes, '*Collaboration is needed between animal scientists and seaweed companies…this is in the interest of all commercial companie*s' (Respondent T1). This motivation for collaboration goes arguably beyond that of firms such as DSM. The purpose-driven nature of the AT companies (reducing enteric methane from cows to mitigate GHG emissions) likely increases their willingness to collaborate and **their smaller size enables greater flexibility and risk-taking**. The ability to share information, and the costs of research, between VG and other AT companies has a large potential benefit. Whilst production challenges differ between companies, all are faced with challenges related to the risks and economic competitiveness of this seaweed. Therefore, collaborating with other AT producers is both viable and offers benefits that would support the successful commercialisation of AT.

AT is an alga and there is a **large and growing network of algae producing companies** that could provide useful expertise. Even within the immediate geographic radius of VG, there are at least two alga firms that indicated interest in collaboration (Respondent E12 and E24). Despite the differences in algal species, Swedish Algae factory CEO commented, '*there are learnings we can do together*' (Respondent E24) These learnings may include collaborative work on symbiotic production (Section 6.5) or even accessing grants. Start-ups in the algal industry require support, but the **novelty of this industry** mean funding can be poorly targeted. Swedish Algae Factory CEO commented, '*Algae is new industry, so it is hard for people to know how to support it, how to design support*' (Respondent E24). Collaborative efforts may enable companies to support each other in accessing appropriate support and preparing applications or even reporting back to political agencies on the best mechanisms for support. More generally, VG may be able to tap into a **broader network of algae experts** who can provide knowledge transference that is of use to AT production. Incorporation into networks proved helpful for algae-growing neighbour Nordic SeaFarm who commented that, '*We are part of a network….Ulbar production is working all over Europe. There are big European projects (e.g. seaweed for Europe). These are good*' (Respondent E15). VG can join similar networks, perhaps even organising conferences that bring together macroalgae experts. Overall, there is relevant expertise available in VG's field that may help them address company barriers. Interviews conducted indicate that there is potential for collaboration with local business or in broader networks.

Greater collaboration with the academic community offers VG easier access to the large amounts of AT research currently being conducted. The high potential of AT (and possibly the enticing story behind it) has generated high interest from researchers and grant providers. SLU, for example, have already run an economic analysis of AT production based on various scenarios (Jardstedt & Holmström, 2021). This research is of high value to VG. Other current research projects are also investigating exactly the problems that VG faces. For example, Cawthon Institute *'already work with a range of commercial partners to optimize the growth of healthy algae strains for successful aquaculture'* (Respondent E17). **Industry-academic collaboration** of this type is beneficial for both partners: VG gain access to cutting edge research and academics can provide real-world context for their research. Such collaborative efforts can be expanded. An SLU researcher noted that there are an '*increasing number of grants'* related to AT (Respondent E3). One example of these grants is provision of $100,000 from the New Zealand government's Sustainable Food and Fibre Futures fund to Cawthron to support the development of the production systems needed to produce AT at scale (Cawthron, 2021). VG can capitalize on this by **partnering with relevant, funded teams** or even encouraging academia to investigate and gain funding for various production challenges including AT domestication. Greater company publicity will support this push (Section 6.2). In addition, VG could better benefit from this research by having systems, or even a hired person, to ensure they keep track of the rapidly developing research. The large amounts of free research available, and willingness of research institutes to collaborate with mean there are significant benefits to VG investing time or personnel into collaborative efforts.

6.3.2 What are the potential problems of collaboration with seaweed experts?

The amount of information that can be shared between VG and other AT or algae producing companies is limited. One limitation is **investor requirements**. Investors in the AT companies require that their firm has a competitive advantage which prevents the firms from freely sharing processing techniques or seaweed production methods, for example. VG CEO commented, '*[we are] not interested in sharing information on the production of seaweed, this is a private recipe'* (Respondent T1). The different statuses of the algae producers, and the possibility of new ones appearing, also complicates 'fair' information exchange capability. After all, an experienced company does not want to lose its advantage by providing detailed seaweed knowledge to new start-ups. One algae commercializing company noted that a barrier to collaboration was, '*Companies popping up in Sweden when it comes to cultivation of algae- any new companies could steal the knowledge'* (Respondent E15). The literature also notes **the lack of absorptive capacity** of small, private companies: only so much information can be taken in and utilized. This is certainly the case within the small, 6-person, VG team. However useful the potential research is, the team members each have their own responsibilities within the firm and cannot spend all their days pursuing collaborative efforts. Overall, the willingness and ability of VG to share and absorb information is limited which hinders the potential of collaborative efforts.

There is also mismatch of information gathering style between academia and business. The VG team needs rapid development of research and development and notes that, '*Academia is very slow'* (Respondent T1). This concept is supported by the literature which identifies **asymmetry of motives** between universities and private firms (Cunningham and Gök, 2016). The universities are driven to create new knowledge, through a rigorous and time-consuming process whereas industries attempt to capture useful knowledge for the purposes of gaining a competitive advantage. It is understandable that the VG team believes there, '*needs to be a cleverer way of collaborating without slowing down'* (Respondent T1). This mismatch, as well as the belief that '*[academia-AT producer] collaboration is not effective*,' (Respondent T1). This is concerning given the need for academic research into the two major barriers facing VG: production and AT-related risks. In contrast to scientific experts at DSM or Agolin, for example, there is a lack of experience on the AT producer side. The lack of expertise within AT producing companies suggests some form of academic collaboration will be required: they may have to contend with this time-consuming approach. In summary, the different research styles between academia and industry hinder collaborative efforts.

6.3.3 Summary and suggestions

The benefits of academic collaboration indicate that it would be worth greater investment in by VG. This is supported both by the literature and data collected in this research. VG, and all AT producing companies, are closely tied to academia. '*Companies that work with seaweed are mostly academia. Seaweed companies have been built from academia'* (Respondent T1). A substantial amount of the expertise that VG may need to draw on therefore exists within the academic field. Collaboration here is therefore worthy of VG's limited time and finances. The CEO of successful clean-tech company Genius Food also highlights the important role academic collaboration played in complex processes. She was particularly grateful for academic input in, '*becoming meticulous over the scientific approach to our products (e.g. gluten free bakery)*' (Respondent W2-1). This is indicative that, despite the time-consuming nature, the **rigorous approach** used in academia may be fundamental in the success of a company dependent on a complex process. VG certainly falls within this 'complex process' category. In addition, comments from Genius Foods CEO highlighted the benefits of partnering directly with professors, rather than merely accessing published research (Respondent W2-1). If used in this way, the expertise of professors can be applied to a particular problem faced by a company. VG may therefore benefit from a **direct collaborative effort** with an appropriate academic team or expert. One example of this would be to involve (more) masters or PhD students with relevant expertise. Overall, the close ties of VG's product to academia and the requirement for rigorous research indicate that more investment in this type of collaboration is worthwhile.

VG is also far from alone in the expertise they are developing and could therefore benefit from greater B2B collaborative efforts. AT producers are the obvious partners. While information sharing with these companies is limited by investor and IP concerns, there is a clear potential to work together on mutually beneficial projects. All AT producers experience issues related to AT production and risks and would benefit from a **more organised and comprehensive set of research trials.** Otherwise, whilst VG is very much involved in 'learning as they do,' there may well be other algae companies available where useful knowledge transfer is possible. This is particularly the case with local companies or those cultivating similar species to AT. Local companies are likely particularly useful for offering guidance on seeking appropriate funding/support, whist companies producing *Asparagopsis armata* or other red seaweeds will have the most relevant expertise. Involvement in a network of businesses, rather than just single collaboration, would reduce the time required for information dissemination.

The small capability of VG to absorb information means they must be tactical with their collaborative efforts. In academic terms, the largest benefits of collaboration will be linking up with **prestigious, well respected universities** or those with domain specific knowledge. Respondent E15 noted that SLU, VG's current major research partner, is perhaps not the most beneficial. '*I would go for a bigger research centre – [SLU] are not known even in the middle of Sweden.'* It is worth commenting that SLU are agriculture specific and VG's involvement with them is beneficial on these terms. However, in terms of broadening VG's academic network related to the engineering/production requirements of the company (their major barrier), VG may do better to form links with the top Swedish engineering institutes: The Royal Institute (Stockholm), Chalmers University of Technology (Gothenburg) or Lund University. Professors, as well as masters or PhD students in engineering from these universities may be able to provide the expertise to enable VG to upscale more rapidly. Therefore, through focusing on more prestigious or engineering-specific academic collaborations, VG can optimize the potential benefits of these efforts.

Successful collaborative efforts from VG require **network competence**. This refers to the ability of the company to develop and utilize relationships with external stakeholders including academic institutions, industry and government bodies (Walter et al., 2002). Particularly with respect to industry-academia collaboration, network competence is found to be a vital asset in SME success. This network competence runs through all aspects of communication and collaboration including aspects such as website design. This has been highlighted as a potential limiting factor for VG collaborative success. *'If I would enter VG homepage – it's a completely different set of vibes to [our additive company]. This may distance them from professors and the research community'* (Respondent E15). Therefore, it could be said that focusing on improving the network competence of the VG, for example through designing their website to maximise helpful traffic, would enhance their ability to collaborate effectively. One potential means to achieve this would be via hiring an information broker. This person would be responsible for developing and maintaining VG relationships and knowledge exchange. In summary, VG can enhance collaboration through a focus on network competence, with an information broker being one means to achieve this.

6.4 Political support

6.4.1 Benefits of political support for Volta Greentech

This section focuses on extending political support for AT as an MRA. Table 6-2 summarises relevant current commitments or policies made by the Swedish government or EU.

Table 6-2 Swedish political commitments relevant to enteric methane production. Information source: Klimatpolitiska Rådet (2021).

Commitments	Relevant aspects of program
EU: Farm to Fork strategy	Program includes: - 10 billion on research and development linked to food, bio-economy, agriculture etc. - Reform of CAP envisaged
EU: Landsbygds-programmet/ rural development program (part of CAP)	Program includes: - Targeted environmental grants - Landsbygdsnätverk (the rural network) which brings together actors in the rural, marine and fisheries industries.
EU: Methane strategy	Program includes: - Setting up an expert group to analyse life-cycle methane emissions. - Developing an inventory of best practice with a particular focus on enteric methane reduction - Promotion of dietary changes through Farm to Fork Strategy
Sweden: Greppa Naringen	Greppa Naringen provides a free advisory service to farmers. The advice focuses on how to reduce the climate impact of agriculture, particularly with respect to methane and nitrous oxide.
Sweden: Klimatklivet	Klimatklivet provides investment support for reduction of GHG emissions at a local and regional level. Since 2019, there is prioritization on agricultural investment.
Sweden: Klimatkollegium	Klimatkollegium works to achieve the governments climate goals and implement the climate policy action plan.
Sweden: Livsmedelsstrategi	Livsmedelsstrategi forms the basis of food-related policy until 2030. It aims to create a long-term sustainable and competitive food chain in Sweden.
Sweden: Fossil free Sweden	Program includes: - Dagligvaruindustrins färdplan (grocery industry roadmap). This roadmap includes a plan for reduced emissions from primary production (e.g. rewarding selected brands for carbon dioxide emissions).

Political support for AT has the potential to tackle the 3 major barriers that VG face, primarily through provision of funding. Interviews and literature research have highlighted three major avenues by which the political environment could be made to support the commercialization of AT as a feed additive.

Create demand:

a) Subsidies to farmers: reward farmers for emission reduction compared to a standard or based on use of the use of a technology (Respondent T1; E17; E22)

Create (safe) supply:

a) Innovation and development support (Respondent E17; E19; E24)
b) Funding product safety and animal trials for AT (Respondent T1; T2; E3; E17; E19)

Innovation and development support may be crucial for the success of large-scale AT deployment. This support type is understood as services that facilitate the efficient and successful development of an innovation process, whether in terms of technological shifts, business development or organisational evolution (RISE, 2021). The literature supports the importance of this support, with consequent calls from the OECD (2005) for national innovation strategies to form stronger linkages with entrepreneurship and increase the horizontality, coordination and integration of innovation and other policy domains. Interviewees also noted the importance of political intervention in VG's case, given the **innovative nature of the company**. '*Governments have an important role to fund the initial stage of innovation, this is widely recognized*' (Respondent E19). This case can be understood by examining the importance of political support in the development of wind and solar power. If AT is politically supported in the same way wind power was, there is potential for **sharp cost reductions and productivity improvements**. '*[Governmental funding of innovation] is what happened when wind power came around. Wind power wouldn't be where it is without support from government*' (Respondent E19). The literature supports this idea (e.g. Burke & Stephens, 2018). Respondent E19 argues that policies largely drove the expansion of these renewables through **attracting investment and creating markets**. This is indicative of the importance of political involvement in green technology. If AT or other methane-reducing additives are to reach the economies of scale and supported technological enhancement that so significantly brought down the price of solar and wind, investment in technology improvement and market certainty is required. Appropriate policy can create both things. Overall, it can be said that shifts towards greener technologies often require significant political investment to succeed on a large-scale commercially.

In addition, funding from the government may be required to enable the large-scale testing of animals needed for commercial viability of AT. A political science researcher argues that '*this testing program {the trials for AT} must be paid by the government otherwise it won't happen*' (Respondent E19). The **high cost of these trials**, in combination with the requirement for more and longer-term studies prior to AT acceptance is likely beyond VG's means (Respondent E19). Although academia is funding some trials, provision of government funding would enable faster, and perhaps more comprehensive, proof of AT safety.

Political support can create demand for AT through including this additive in subsidy schemes. In the case of renewables, the role of feed-in tariffs, which guaranteed markets for solar and wind energy, is seen as one of the **biggest drivers of investment** in this area (Söderholm & Klaassen, 2007). Government subsidies, through CAP or an equivalent scheme, could provide a similar **guaranteed market for AT**. The bottom-up, technological abatement subsidies offered in CAP would be an appropriate means by which to support farmers feeding AT. The possibility of this inclusion is recognized both internally and externally to VG. Jordbruksverket for example notes, '*If [AT] is proven to work, and if support could stimulate the use of additives, [AT] is* *one example of measures that could get support within for example the Rural Development Program'* (Respondent E21). The framework for CAP is already in place, with widespread farmer acceptance and understanding of the payment mechanism (Respondent E6). Although inclusion of AT (or other MRA) in the framework adds complexity to a scheme already noted for its impenetrability (Respondent E6), such subsidies would remain voluntary. This would reduce discontent in the dairy industry. It would provide guaranteed funding for farmers and, as an LRF spokesperson comments, '*If there is a business case – the farmer will be willing to change'* (Respondent E6). The less direct nature of CAP funding (funds come from the EU) would also take some of the heat off Swedish politicians, who may be concerned about their involvement in high risk/high reward ventures. Therefore, inclusion of AT in subsidy schemes is one viable means of long-term support for AT that may take some of the commercializing pressure of VG.

6.4.2 What are the potential problems of political support?

The difficulty, time and high-cost requirements of influencing policy or politicians means VG has, thus far, not been active in this area (Respondent T2). Given the high potential impact of political support for VG, this section provides reasons why it is unlikely that politicians/policy will support this measure. If these arguments are taken to be convincing, it would be a strong case for discouraging VG from any further attempt to work with policy.

Climate policy experts tend to be from the energy or industry sector, leading to minimal engagement with agricultural issues or solutions. A professor with expertise in Swedish climate politics noted, '*Traditionally the climate problem has been an energy problem and a lot of the expertise and knowledge comes from the energy sector. There is inertia from tradition*' (Respondent E19). Indeed, an official report from the Swedish Climate Policy Council describes the major reason for poor projected emission reduction in the agricultural sector as 'lack of solutions' (Kåberger et al., 2020). This thesis demonstrates that this is not the case: the **climate experts merely are unaware** of these possible solutions. Without awareness, however, or strict climate policy for agriculture, these experts and politicians are unlikely to act upon and invest in new innovative solutions. The lack of expertise is likely to hinder the engagement of politicians in this domain: greater effort will be required to convince them to support such a climate change solution.

Agriculture is a politically sensitive topic within Sweden and politicians may therefore be unwilling to impose new policy that has implications for farmers. Interviewees overwhelmingly commented about the perceived need for agricultural support from politics. '*If we compare dairy production in Sweden to other countries - huge challenges with profitability,'* and therefore, *'with farmers there is this feeling -we need to support them'* (Respondent E19). Whether because of this public perception or other reasons, **agriculture is an important topic in Swedish politics**. '*Almost all political parties [in Sweden] are pro-agriculture. Agriculture has an oversized influence in politics compared to economic importance'* (Respondent E19). One force that is linked to the dominance of agriculture in Swedish political circles is LRF. This is a union of farmers that dedicates significant resources to lobbying. *'You can't enforce things on Swedish farmers without consequence. [It is a] consequence of big dairy in Sweden – strong pressure.'* (Respondent E19). It would therefore clearly be beneficial to have LRF behind any proposed support for AT. In addition to their influence, LRFs concerns are generally perceived as being valid, given the **profitability challenges** faced by Swedish farmers (Respondent E19). Therefore, it is concerning that they seem to have a negative perception of political support for AT. LRF explained how early political support for AT may lead to later enforcement of AT usage, and consequent economic loss for farmers. *'Any political decision to support additives – it's risky for the farmer…. what if farmers are put in a position where they are dependent on a product'* (Respondent E6). Such reasoning is likely to lead the organisation to push against any political support for AT. Whilst the political decision in neighbouring Denmark to implement a carbon neutral agriculture target for 2050 could be seen as promising, the political scientist noted the difference between LF, the dairy representation organization in Denmark and LRF.

'In Denmark, the equivalent is LF and they commissioned this report. LF seems to be more… LRF is more lobby' (Respondent E19). Therefore, there is strong evidence that VG would have to work hard in Sweden to influence dairy-related policy.

Beyond just upsetting farmers, food production in Sweden is suggested to be a **sensitive area** with people potentially being wary of additives such as AT. *'People have a strange idea that agriculture should be something natural – adding strange substances to cows'* (Respondent E19). This is an extra reasons why Swedish politicians may be extremely cautious to implement any new regulations that promote the uptake of AT, especially in its early stages. Overall, agricultural concerns amongst the broader public mean politicians may be hesitant to introduce support for any new additive.

6.4.3 Summary and suggestions

The political support for other GHG mitigation schemes in Sweden, including the Pump Act (2005) which mandates filling stations to supply renewable fuel, indicate there is hope for political support of AT. This support has the potential to resolve AT supply barriers, as well as create markets for the product. However, the sensitivity of this agricultural sector will mean that any new policy will be challenging to introduce and large amounts of supporting evidence are likely to be required. A potential best mechanism for political support that VG could pursue is discussed below.

Combining a bottom-up approach (such as CAP subsidies), with top-down support (innovation and development support/ funding trials) would be beneficial in getting AT towards large-scale uptake more rapidly. The top-down approach would enable more rapid development of, and trust in, AT technology, whilst the bottom-up approach creates the markets. Such an approach has been described by Baker (2021) as the best way to promote MRA economies of scale.

The potential capacity of VG factory 1 is currently sufficient only to feed 500-1000 cows (Respondent T1), and thus more investment is needed in **production improvement and scale-up**. Additional top-down support is required in scientific trials. There is, for example, a cited need to investigate the long-term methane reduction effect, health benefits to cows, bromoform risks and so on. Provision of state-funded grants, such as Almi, go some way to providing funds for research. However, the scale of these funds is not sufficient for large-scale farm trials, and they are currently used to support in-house research only (Respondent T2). Top-down governmental investment may therefore be required: the scale of funds involved may prove too much for a small company or even supporting academic institutions.

In addition to these top-down mechanisms of support, there must be a **clear market** for VG products. Political support to create the market was deemed to be possible by Jordbruksverket who discussed two possible bottom-up funding mechanisms. '*The two main forms of support that I would think could work are as an investment support (that you get paid for the extra costs associated with [AT] use… or if applied at a larger scale it would be possible to include as an eco-scheme [within CAP]'* (Respondent E21). Creation of a market through bottom-up support would relieve pressure on VG to market their product. It could also provide additional incentive for external investment: there is more guarantee of firm success if the market is proven to exist. In terms of a mechanism for creating bottom-up support, inclusion of AT in CAP seems a viable option, worth VG pushing for. As noted previously, there is general support for the CAP payments even if they are deemed to be too complicated. If a simple mechanism can be designed by which farmers can opt into or out of methane-reduction schemes, this may avoid any violation of dairy industry concerns. The 2022 EU review of CAP payments (European Commission, 2020) provides a perfect opportunity for integration of (simple) methane-reducing payments into the scheme. In summary, support for VG is needed at different levels to best support upscaling of the company.

6.5 Symbiotic production

6.5.1 Benefits of symbiotic production

VG could enhance their production mechanism through symbiotic production mechanisms. In nature, symbiotic exchange is relationship between two individuals of different species where both individuals benefit. In industry, symbiosis refers to the usage of a waste or by-product of one industry becoming a resource for another. This mutually beneficial process tends to increase both the profitability and resource productivity of companies (Karlsson & Wolf, 2008). As an example of symbiotic systems, VG are already using **waste heat from the a local refinery** to heat their factory (Respondent T2). The major future symbiotic opportunity identified involves **utilisation of fish farm effluent to grow algae**. VG is aiming for their production be climate-neutral and environmental-friendly (Respondent T2). For this reason, as well as reduced costs, these symbiosis opportunities are appropriate.

AT require high nutrient input to maximise growth (Respondent T4) which can be proved in a natural form by fish effluent. This would reduce costs for supplying nutrients, as well as subvert potential difficulties with inputting and disposing of large quantities of chemicals into the VG factory (Respondent T4). This potential of fish farm effluent for promoting algae-growth was highlighted by fellow seaweed-production business Nordic Seafarm, '*Water from fish farms is used to cultivate our ulbar*' (Respondent E12). The Swedish Algae Factory also use fish effluent to provide nutrients and CO_2 to their algae noting this was a '*more stable system…how nature designed it*' (Respondent E24). This company also reported additional benefits including reduced costs of water heating due to the effluent being at the required temperature. This symbiosis was noted to be a '*win-win collaboration [for both partners] from both a financial and environmental standpoint*' (Respondent E24). Fish farms benefit as they have reduced costs and environmental impact. '*[Fish farms'] critical issue is to get rid of nutrients…they can build a treatment plant and deal with these nutrients as with sewage water, but this is costly and wasteful*' (Respondent E23). This suggests that a symbiosis collaboration could be a **beneficial option for both VG and fish farm partners**, thus reducing any difficulties involved with recruiting partners. Fish farm-algae symbiosis is apparently widespread, and the benefits are well supported by the literature (Enwereuzoh et al., 2021). In terms of AT production specifically, the integrated production of AT with a commercial fish farm in Portugal was found to be successful by da Mata (2008). This research even supplies information on optimum conditions, including optimum supply rate of effluent and pH of the culture. In addition to the da Mata (2008) study, bioremediation of fish waste by AT has been adopted by Hawaiian AT producer, Symbrosia (Symbrosia, 2021). Therefore, this production technique should be appropriate for VG seaweed and there is already some information available on conditions required and potential for collaboration to gain further expertise.

The VG team are geographically well-placed for succeeding in symbiotic production methods. They are in the vicinity of a symbiosis centre that can offer **testbeds** for experimenting with this technology (Respondent E18), and there are plans for a large salmon factory to open in their neighbourhood in upcoming years. The symbiosis centre, located 45 minutes' drive from the VG factory, already have experience in algae-fish testbeds. They receive EU and municipality funding for such testbed projects, thereby minimising the funding needed from local companies wishing to test ideas. If wanted, VG should be able to capitalize on this opportunity and determine the viability of fish farm/ factory-produced AT symbiosis on a small scale before having to design their factory around it. If proven successful, the opening of a 100,000-ton salmon factory in Sotenäs in late 2022 (Respondent E18) should provide plenty of effluent for VG use. This will be to the benefit of the fish farm, who may even provide small amounts of funding for free waste disposal. Overall, the current location of the VG factory favours their inclusion in symbiosis projects.

The VG team are also currently financially and collaboratively well-placed for optimizing their production to be environmentally friendly. Much of the funding VG is receiving currently is dedicated to enabling VG to develop a **scalable method of production** (Respondent T2). This access to funding means that VG currently have the financial capability to invest into experimentation in sustainable methods. In addition, potential collaborative partners including the Cawthron Institute and Symbrosia are also investigating sustainable AT production (Respondent E17; Symbrosia 2021). Symbiosis institutions such as Wa3rm also have experience working with algae and fish farms and have expressed interest in working with the VG team in future (Respondent E23). This high-level interest across various academic and institutional bodies indicates there is **high potential for further research and development** in this area. Overall, VG has the potential to make symbiosis work in their factory through investing whilst funds are available and capitalizing on collaborative opportunities.

Seizing symbiotic production opportunities in this way will enable VG to work towards their aim of **climate-neutral, environmentally friendly production**. As an environmental firm, VG has a reputation that is at risk of being lost if their environmental impact is deemed harmful. The importance of this reputation was apparent in multiple interviews, where the sustainability aspect of VG production was questioned. For example, a representative from HKScan noted, '*The seaweed must be produced in a responsible way. No negative impact*' (Respondent E14). If VG were to release nutrient-saturated wastewater into the Skagerrak and/or utilise vast amounts of electricity to maximise algae growth, they would risk losing popular support (including possibility the opportunity of political support and celebrity endorsement). In contrast, symbiotic projects such as bioremediation of fish waste and use of waste heat from Preem are likely to strengthen VG's environmental profile. Overall, investment into environmentally production methods seems wise to ensure client support.

6.5.2 What are the potential problems of symbiotic production?

Improving the sustainability of VG production through symbiotic production requires experimentation. This experimentation will be a **risky, time-consuming, and costly business.** There are multiple questions to be answered if this will work on a large-scale, as indicated in Table 6-3. VG are in the process of building up their pilot factory with an aim for, '*50% built by end of spring*' (Respondent T2). They therefore cannot afford (either timewise or financially) to be constantly investigating symbiosis opportunities. In terms of connecting algae infrastructure to fish farms a later time, Wa3rm's CEO noted, '*Its pretty set when built,*' (Respondent E23). indicating that any changes should be performed early in the building process. Of course, this is the demo plant and future factories may be better able to incorporate symbiotic methods. However, the earlier VG start to trial symbiotic mechanisms such as these, the more refined and likely to work they are. Therefore, the limitation of this production style is that, whilst wise to invest now, the company lacks some of the time and finance resources to fully investigate it.

Table 6-3 An indication of the resources required to investigate the symbiotic production mechanism. Information based on Observation 2.

Question to be answered	**Work/resources needed to answer question**
Is this worth trying?	Research the potential of using fish farm effluent; research the best type of effluent.
Does it work on a small scale?	Conduct lab level experiments; conduct (and fund) testbed research.
Does it work on a large scale?	Create factory infrastructure able to deliver effluent to AT; ensure stable provision of effluent from fish farm; ensuring and monitor safety of effluent.

Does it work commercially?	Prove the effluent is safe for uptake in animal feed; relieve any public perception concerns.
What are the legal concerns?	Investigate rules and regulations on effluent usage; negotiate contracts/ terms of agreement with fish farms.

There are also potential risks for VG in associating with a fish farm. This symbiosis would imply some dependence of VG on provision of the fish effluent which could be problematic if the fish farm were to go bust or encounter production problems, such as parasites. During the experiment run by da Mata (2008), optimum conditions involved regular fish effluent input (thrice hourly). If VG were to operate under similar optimums, this would imply **minimal temporal flexibility** if the fish system were to encounter problems. Therefore, if opting for this symbiosis, VG runs the risk of encountering AT production declines and even crashes as a result of their dependence on their fish-farm partner.

6.5.3 Summary and suggestions

The reported success of symbiotic production between algae producers and fish farms indicates this is a viable method of production for VG, and one that is likely to suit the environmental profile of the firm. The difficulty in adapting built factory infrastructure indicates VG would do well to run **comprehensive experiments** first to investigate the viability of this mechanism for their particular alga and production mechanism. There are testing facilities available for this, for example at the nearby Sotenäs Symbioscentrum, that can offer expertise and low-cost experimentation. Expertise may also be able to be gained from other algae firms attempting this symbiosis, such as the Swedish algae factory and Nordic Seafarm or from previous experiments such as those run by da Mata (2008).

The risks associated with symbiotic partnerships may be alleviated by good back-up systems and technology. Use of smart sensors or other monitoring software (Section 5.1.2), could ensure the fish effluent is high quality. If it is not, automated programs should be able to switch to an alternative system. This concept is utilised by Swedish Algae Factory who have, '*automation to make a cut from [fish farm] operations fast if necessary*' (Respondent E24). This indicates that such technology is available for VG's use, and the nearby Swedish Algae Factory may be able to share expertise on their symbiosis experience. Therefore, through good technology, and potential collaboration with neighbours, VG should be able to subvert any possible risks associated with this production mechanism.

6.6 Alternative uses for Asparagopsis taxiformis

6.6.1 Benefits of alternative uses for *Asparagopsis taxiformis*

This section explains how VG can exploit other commercial uses for AT. The compound has commercial potential for **cosmetics, human foodstuff, and health-related purposes**. These higher value uses may increase the commercial viability of factory-produced AT.

AT is suitable for human consumption and is in places regarded as a delicacy. In Hawaii the species is highly valued as a food condiment and has been described as the "most favoured and most expensive seaweed food of [people] of Hawaiian ethnicity" (Abbott 1999). In modern Hawaiian cuisine, AT is regularly consumed in poké bowls, a type of raw fish salad (Mickelson, 2013). AT is not only safe for human consumption, but also beneficial. The high concentration of halogenated metabolites gives the alga **antibacterial and antiviral properties** (McDermid et al., 2019). In addition, analysis of one specimen of AT found that it contained 9.4% total protein and 44% total dietary fibre content per gram dry weight (McDermid et al., 2005). This fibre content is higher even than wheat bran's 42.7%. Overall, both the health characteristics and 'delicacy' status of AT imply that there may be market potential for the alga as human foodstuff.

VG can capitalize on the higher price paid for AT as a human food compared to as a cow MRA. Human consumption of seaweed sits as the **top of the seaweed value pyramid**, and therefore has the potential to bring in higher revenues for the company. Nordic Seafarm are already capitalizing on this (Respondent E12). To be viable, this seaweed business is selling their product to the customers are the top: Michelin star restaurants. If high-class restaurants are willing to buy pliers, why not the Hawaiian delicacy of Asparagopsis? The cost of AT in Hawaii is currently US$55-60 kg^{-1},(~ €45-50 kg^{-1}) (McDermid et al., 2019) which compares favourably to the estimated cost of VG produced AT as 150-200 SEK kg^{-1} (~€15-20 kg^{-1}) (Jardstedt & Holmström, 2021). Despite low seaweed consumption in Sweden (Respondent E17), consultation with a restaurant local to the VG factory indicated there is potential interest (Observation 2). There are also currently ongoing research projects aiming to investigate how to entice Swedes to eat algae (Respondent E12). Both indicate there may be a **future market for AT as a human food**. The aim of VG is to reduce enteric methane in cows. However, if they were able to break into an additional human market for their product, the higher margins may enhance VG's potential for commercial success.

There are other high value uses of AT, including for cosmetics and health. These additional uses are already being investigated by researchers. '*We already work with a range of commercial partners to… identify algal species, like Asparagopsis, with the potential to produce high-value products.'* (Respondent E17). The halogenated compounds in the seaweed can be extracted for use as natural preservatives in cosmetics formulations (da Mata, 2008). In addition, compounds extracted from AT tetrasporophytes (the life-stage cultivated by VG) were plated with antibiotic resistant pathogens in an Indian trial (Manilal et al., 2009). This trial found that the compounds showed **promising antimicrobial properties.** Although more research is needed, these two examples should demonstrate the unique and potentially valuable properties of this red alga. Therefore, cultivation and sales of this alga could provide an important source of bioactive compounds for the industries such as cosmetics and health, and an important source of income for VG.

If AT were to be utilised as a human foodstuff, clever marketing may help undermine client concerns about the safety of AT for cows. This research indicated that multiple industry actors are concerned about health aspects related to AT consumption. However, if AT were to be marketed as foodstuff for both cows and humans, the dairy industry would be hard pressed to make safety concerns stick.

6.6.2 What are the potential problems associated with alternative uses?

There is a lack of market for seaweed foodstuff in Europe. This was noted as a barrier by multiple interviewees, for example, *'[before commercializing algae foodstuff] we need to get the Swedish population to accept it as food'* (Respondent E12). A potential way around this problem would be to export the seaweed to high paying customers in Hawaii. However, the purpose-driven nature and reputation of VG would likely suffer if it were to transport AT these long distances. In addition, there would be challenges associated the uptake of non-local AT in Hawaii. This is supported by the high price of AT in Hawaii despite its availability in China for $5kg/ dry weight (Respondent E17). There may well be niche users of AT in Sweden (as supported by Observation 2), however the demand from the general public is likely to be low.

Creating a market for alternative uses of AT is going to take time. The antimicrobial properties of the *Asparagopsis sp.* are still under investigation (Pinteus et al., 2020) and there is a patent on cosmetics-related uses of the algae (Ogawa, 2003) which limits the freedom of new companies to experiment commercially. Incoming funding from these alternative uses is likely to be slow and therefore unable to help VG out of a potential 'valley of death.'

6.6.3 Summary and suggestions

There are multiple high-value uses of AT that mean VG may be able to circumvent commercialisation barriers related to the high cost of their product. Whilst health and cosmetics applications may be limited by the need for greater research, VG is already able to pursue opportunities related to AT as a human foodstuff. The health benefits of AT and success of other companies in seeking **premium buyers** for their seaweed are both promising in terms of finding a market.

The purpose-driven nature of VG may support its success as a provider of AT as a human foodstuff. VG's focus is reduction of ruminant enteric methane. They should not (and likely would not) give this up to pursue alternative markets. However, if VG were to highlight this purpose, even as they enter other markets, it could work to their success. The purpose-driven shoe brand Toms, which donated one pair of shoes for every one sold proved popular with customers and a commercial success (Apadula & Predamore, 2019). Similarly, the purpose-driven nature of VG's enteric methane reduction may encourage AT food customers to support this product. To sum up, VG's should use their ethical purpose to support sales in alternative markets.

AT is a high value product but only in specific places and VG should adapt to this. As a small company, VG are unlikely to be able to have any large impact on Swedish consumer preference. They could follow the Nordic Seafarm trajectory of supplying their seaweed to **high class, even Michelin star, restaurants**. As the sole supplier of AT in Sweden, VG would have minimal competition provided they can persuade restaurants to stock this product. The purpose-drive nature of the firm and the potential high marketability of associating with VG may work in the company's favour. The 'delicacy' status of this seaweed in Hawaii also suggests VG would do best to contact Hawaiian suppliers or restaurants. Through adaptation to high class restaurant interests and requirements, VG may be able to generate additional useful income for the same product.

Prior to AT usage in health-related fields, there is a need for extra research. VG may be able to incentivize this by developing their network competence. More academic contacts, for example through association with PhD students, would increase **academic awareness of this product** and its potential health-related applications. In addition, researchers may be specifically interested in the new, more bioactive AT produced by the company. VG could contact relevant researchers in the field and offer to supply their AT. Therefore, whilst the applicability of AT in sectors such as health is limited, VG may be able to support development of this opportunity through engaging with the academic community.

7 Broader applicability and conclusions

This section provides an overview of the findings of this research and its broader application. Section 7.1 discusses the implication of the findings for the commercial viability of factory AT production in Sweden. Section 7.2 considers the applicability of these findings for other innovative green-tech companies, and lessons that can be learnt from this case. Finally, section 7.3 comments on the research technique itself, its benefits and limitations and its future potential assessing commercial viability. Section 7.4 presents a final conclusion on this topic.

7.1 Findings from research: the commercial viability of factory *Asparagopsis taxiformis* production

7.1.1 Volta Greentech represents the commercial viability of factory-produced *Asparagopsis taxiformis*

Findings relating to the commercial viability of factory-produced AT from this investigation are only valid if VG can be taken to be representative. There are three reasons that support the representativeness of VG: their position at the forefront of factory-produced AT research; their position as a first mover and the conclusive evidence of commercial viability that VG's success would entail, even if failure does not comprehensively indicate lack of viability. The main reasons supporting the non-representativeness of VG are the inexperienced team; the unfavourable environment they operate in and their ability to pivot their focus away from factory production of AT.

If factory-produced AT commercialization is to succeed, VG is in a good place to make it happen. Therefore, the success or failure of VG could be seen as representative of the success or failure of factory-produced AT. As explored in Chapter 6, a considerable number of exploited or still to be exploited opportunities are available to VG including academic research collaborations and funding grants. The team have one of the top AT growers in their team (Respondent E17), as well as a CEO that many interviewees (E15; E23; E26) noted to be well respected. This is particularly promising given that Respondent E26 described the proficiency of the CEO as one of the most important factors in firm success. In addition, the start-up itself has been listed as one of the top ten Swedish start-ups to watch in 2021 (EU Start-Ups 2021). Therefore, the firm itself is clearly highly capable. Whilst the barriers faced by VG are certainly large (Chapter 5), it could be argued that if this firm cannot address them then perhaps the whole concept of factory-produced AT is unviable.

VG are first movers in the factory-produced AT-for-cows space. Therefore, they can provide a useful perspective on the commercial potential of factory-produced AT, if only because there is little other information to go on. Prior to their commercialization efforts, there was very little evidence of the possibility of this mechanism of production. VG have already indicated that the *idea* has potential through gaining extensive amounts of funding (from both investors and grants) and winning various competitions (Volta Greentech 2021). Through the rapid R&D and experimentation on AT done by the company, there is also a significant bundle of evidence growing that can be used to examine the previously poorly understood concept of 'factory-produced AT commercialization.' Both the (proven) potential of VG's idea and the growing evidence to understand the viability of their product are thus useful to investigate to better understand the commercial potential of factory-produced AT.

Long term commercial success for VG would convincingly indicate the viability of factory-produced AT. This is the case even though failure would not comprehensively disprove the viability factory-produced AT. Therefore, the case study is useful as a representation. If this case succeeds: it can be taken as proof that factory-produced AT is viable. If the case fails: it is evidence (not proof) that the product *may* not be commercially viable.

VG is not a 100% accurate representation of factory-produced AT commercialization as the company can (and is willing to) pivot towards other opportunities if this proves necessary. As respondent T2 noted, '*There are a lot of improvement to be made. Possible future options: even outdoor or sea-based premises*.' Rather than a disadvantage, this ability of a company to pivot or adapt, whilst maintaining their vision, has been noted as an important factor for commercial success. For example, advice from the CEO of Ocado (one of the most successful transport logistics businesses) was to, '*have the vision but recognize when to pivot…looking back on Ocado's history, we have been willing to change how we deliver on that vision. Be aware of the environment and adapt*' (Respondent W2-6). Therefore, in the quest for commercial viability, the opportunities available to VG and their growing expertise may at some point be pivoted towards alternative methods for reducing cow enteric methane. Thus, even if the odds are saying that VG will succeed, this is not necessarily tied to the success of factory-produced AT production.

The viability of a product is highly dependent on the environment in which the firm and its market operate. This research has highlighted that there are other global regions where VG would experience greater levels of support, whether this be related to climate targets (Denmark has a Climate Neutral Agriculture by 2050 target); on the production side (the Australian Government funds AT production research) or on the demand side (agriculture is included in the emission reduction fund in Australia). If VG were to be operating in these environments, the commercial viability of factory-produced AT would be judged differently. A serious limitation of this assessment of AT viability is then that it is highly context dependent: not only on the company commercialising it, but also on the surrounding environment. For this reason, VG could be deemed an inaccurate representation of factory AT production.

In summary, the context-dependence this case and the ability of VG to pivot towards other methods for enteric methane reduction offer good critique for why VG should not be accepted as the perfect model by which to judge commercial viability. That is not to say the case is useless, however. Firstly, it is providing evidence from the only case study currently available for factory-based AT production. It is also not by any means a hopeless commercial case. VG are in a good position to make this additive viable. This evidence to understand factory-produced AT viability is constantly growing as VG develops their expertise. The company is currently a major actor in the commercialization of AT and therefore studying them is one of the most useful tools to develop this judgement. As a final note, VG have currently chosen <u>not</u> to pivot from factory-produced AT (despite their willingness and ability to do so if necessary). This choice is important: it indicates that the team, of reportedly high capability, believe in the commercial viability of this product.

7.1.2 Evidence from this case study that factory-produced *Asparagopsis taxiformis* has minimal commercial potential

The barriers that VG are facing (Chapter 5) are large. The product is not viable if firstly VG cannot scale this product up fast enough and at a low enough cost and if they cannot scientifically prove the safety of the intracellular bromoform. Competition poses a large threat too, albeit one that VG may be able to survive despite.

In terms of production, there is a lack of successful historical precedent for mass cultivation of factory produced AT, and even minimal precedent for marine or land-based cultivation of AT. This lack of precedent means that cultivation of this type, at the levels of productivity required for commercial success, may not even be feasible. The difficulty of cultivating red seaweeds supports this. Even if AT were able to be successfully domesticated, evidence from the mussel and salmon industries indicates this is an extremely long-term process. VG is not likely to be viable if it must wait even 10 years (the lower end of the domestication time frame) to produce commercial quantities of this algae. Similarly, there is no guarantee that bromoform from AT will be found to be acceptable to clients. Even if it is, the funds and time required to prove this may present a serious barrier to AT commercialisation.

The unfavourable environment that VG is innovating within may result in company failure. This study examined perceptions of AT within the Swedish dairy value chain. Actors within this chain were found to be both disproportionately powerful and very cautious about the use of this product. This extreme caution is likely to have a large impact on the commercialising of AT: dairy actors may be able to use their influence in politics to prevent widespread political support arising. Other unfavourable features include the lack of any mandated need for GHG reduction in the Swedish agricultural sector. Without any political support, such as inclusion in subsidies, the 'green premium' for VG products will most likely fall to the consumer. Although Swedish environmental awareness is high, multiple studies reveal a lack of enthusiasm to pay more for environmental goods (Lefébure & Rosales Muñoz, 2011), as well as a distrust of any new labelling schemes for these products. In summary, the lack of external support for VG and potential lack of consumer willingness to pay a premium may result in failed uptake of their final product and thus commercial failure.

7.1.3 Evidence from this case study that *Asparagopsis taxiformis* has commercial potential

Enthusiasm for AT is high across most sectors interviewed for this thesis. These sectors include academics, algae experts, start-ups, political actors and the media. This is a unique and interesting product, with extremely high potential to mitigate GHG emissions and to top it off it is being commercialised by a unique and interesting team. Returning to a quote from Respondent E17, '*People want it to work*.' This interest itself is valuable. CEO of successful greentech firm Genius Foods commented, '*If there is purpose in the business and people are interested in purpose, it isn't as difficult as you may think to turn this idea into a commercial entity*' (Respondent W2-1). VG have already seen the benefits of their purpose-driven firm, for example in the angel investors and high levels of academic support. Governments are being pushed to meet climate targets, and the growing public awareness of AT may also generate political support for VG or more general AT research. Thus, this enthusiasm and interest may be sufficient to ensure VG has the support it needs to succeed commercially.

Though the barriers facing factory-produced AT commercialisation are major, research gathered for this thesis indicates they are modifiable. The major solution appears to be more research, and the high levels of AT interest and enthusiasm indicate that this research is likely. Two of the most recent publications on AT (May and June 2021) both recommended growth of AT under 'controlled environmental conditions' (Searchinger et al., 2021; Zhu et al., 2021). This is opposed to growth in the marine or open land-based systems used by other AT producers. This recommendation was based mostly on the ability of controlled facilities to maximise productivity and internal bromoform content whilst minimising external release. This growing awareness and support for controlled-environment production indicates its perceived viability by experts. In addition, academic support for factory-produced AT increases the likelihood of continued research, which will assist the chance of VG commercial viability.

6 major opportunities for factory-produced AT commercialization in Sweden have been identified. These opportunities all enhance the possibility of commercial success for VG. In addition to support from individual opportunities, these opportunities are also likely to mutually reinforce each other. For example, increased celebrity attention is likely to increase the viability of a new funding mechanism. Therefore, there is the potential for kickstarting a virtuous cycle, which may generate rapid commercial success for the company. Whilst some or even all of these opportunities may not come to fruition, AT is fairly unique amongst its competition in being able to exploit these (Section 5.3.2) and therefore has at least a potential competitive advantage.

In summary, AT is fortunate in the mutually reinforcing opportunities it has access to, which may help kick-start the commercial success of the company.

7.2 Findings from research: supporting innovative green tech firms

It has become abundantly clear in the process of this research that VG is not a traditional business. The literature was useful for identifying this firm as potentially 'market driving' (Kumar et al., 2014). In essence, rather than being based on traditional market research, market driven firms tend to be vision driven. They take 'leaps' into new commercial space, whilst traditional firms take much smaller steps. Therefore, it could be asked how lessons from this innovative green firm could be applied to others in the same bracket. This is considered outside of the Swedish context.

7.2.1 Volta Greentech is an innovative firm

Strong evidence can be given of the innovative nature of VG in terms of team, product and the production process. VG was founded by three young and relatively inexperienced people. One respondent even described the team (affectionately) as, '*kids*' (Respondent E17). There is significant bravery required for young, inexperienced founders to take on a commercial venture of this novelty and magnitude. This bravery and innovative venturing may be a result of the youth of the founders. It may also act as an asset. Kuckertz & Wagner (2010) found that inexperienced ventures of a sustainability-orientation are often more successful. Greater resourceful and creativity is one explaining factor. Evidence of the innovative nature of the VG product include the lack of previous successful AT commercialization, the poor understanding of the AT production mechanism and the multiple barriers revolving around the safety of the product. More traditional businesses would have been likely to stand back and let academia resolve these issues before attempting commercialization. Innovative companies, such as VG, seize these new, poorly understood products. VG's factory production process also shows innovation. The attempt to mass-cultivate AT in a factory environment is the first of its kind. The VG team are innovative in selecting this production method and are forced to be innovative in designing their process. There is no historical precedent to refer to. Observation 2 highlighted how the firm were forced into 'making it up as they went along' in designing their process. As an example, no firm previously has experimented with increasing the bromoform content of AT under factory conditions. This requirement for learning and doing in production is echoed by fellow innovative firm Swedish Algae Factory who commented, '*We are still learning as we are doing…we had an idea and started to work around it*' (Respondent E24). Both this team and VG are responsible for combining any relevant studies with their own expertise to design new processes. Therefore, their production mechanism inherently requires innovative thinking. In summary, team, product and production method do not correspond to traditional business practice. It can therefore be safely concluded that VG is an innovative firm.

7.2.2 The agricultural sector requires innovative green firms

The lack of politically recognised technologies for mitigating climate change in the agricultural sector indicates a need for innovative firms. Various governmental reports describe the lack of technical solutions in the agricultural sector for emission reduction (Kåberger et al., 2020). This is particularly the case for mitigating enteric methane emissions. As Respondent E19 notes, '*We need technologies. This is a key area that has been lacking. There hasn't been a lot of progress for substances reducing enteric methane.*' The small steps that constitute the traditional 'research to innovation' process are unlikely to produce the results needed in the timeframe designated by various climate agreements (Searchinger et al., 2021). Thus, rapid innovation is needed here. Interestingly in BBC Radio 4's '39 Ways to Save the Planet,' (Heap and Edwards, 2021) almost all ideas were innovative: bamboo for housing construction; UV paint to discourage barnacles on ships and so on. This is supportive of this idea that innovative thinking is needed to meet the challenge posed by our changing climate. In sum, the gap between current mitigation technologies in the agricultural sector and required emission cuts implies innovation is needed rapidly.

Private sector action is more appropriate than academic research for finding solutions to agricultural sector GHG emissions. This research highlighted the slowness of academic research, which stands in contrast to the rapid knowledge development and knowledge utilisation by VG. This can be understood in terms of the different drive of academia and business: academia is meticulously creating information; private ventures find a way to gain a competitive advantage using information. Creating the right incentives to encourage private firms to solve problems such as enteric methane emissions in the agricultural sector therefore seems to hold much greater promise of fast results. Thus, green-focused private firms in this domain are more likely to generate the mitigation technologies required to rapidly cut emissions.

7.2.3 Innovative green firms require support

This research highlighted the long-term nature of support that VG will require to scale up. VG is reliant on grants and investors and will likely be for some time to come. Factory production mechanisms for AT are poorly understood and will require extensive amounts of research, infrastructure development and the training of new experts to become commercially viable. These facts make both entrepreneurs and investors wary of commitment to such schemes, even when they have high potential. Incentives are needed to push the private sector towards investing in such high-risk schemes. Respondent E19's view was that these incentives should be political. '*[Governments] need to be involved as timescales are too long otherwise and vested interests might block these.*' Unlike the commercialization of software, for example, serious time and investment is needed to run experiments and create the infrastructure needed for physical products such as AT. This will take time, during which period VG will likely be reliant on grants and investors. This reliance could prove problematic if grant committees wane in interest. This need for long-term support is common amongst green tech firms (Respondent E19; E26; W2-1). The need is particularly great amongst innovative businesses as they often struggle to get constant, large-scale funding for their 'wild' ideas. In summary, without appropriate long-term support, innovative firms such as VG are unlikely to be able to get their ideas to market.

7.2.4 What kind of support should be offered?

The current innovation system is programmed to mostly support low risk ventures, taking small steps towards solving problems. This is important, but high-risk ventures with high potential are needed. As an example of challenges involved in obtaining climate-related support for unproven innovative technology, VG CEO commented, '*Klimatklivet [a major Swedish climate change solution funding agency] said to only apply when there are more numbers*,' (Respondent T1) i.e. when the research is further down the line and 'safer'. But how many radical, high potential ideas will for mitigating climate change be lost before they ever get to this stage? As advocated by Harford (2011), the best solutions to a problem emerge when a pluralism of businesses is enabled to test innovative, high potential ideas. This is the case <u>even though</u> a lot of them fail. To properly test out AT, however, significant funds are needed to trial different ways of producing or commercializing the product. One example of a 'high risk' funding agency that will enable the testing (and failing) of high potential ideas is the UK's Advanced Research and Invention Agency (Department for Business, Energy & Industrial Strategy UK, 2021). Announced in February 2021, this extra-governmental agency will deliver funding to turn potentially 'transformative' ideas into products and services. Visionary researchers will oversee the selection of these visionary ideas, rather than relying on tick box mechanisms. This mode of high risk/ high reward investing could go a long way to supporting innovative green ventures such as VG. Overall, the current system should be more enabling of the testing of innovative, transformative business ideas, such as VG's.

The success of innovative business will not be the result of one good idea: it will be a continuous process of trying and failing. This can be seen in VG's current strategy. VG are currently using their pilot plant to test out optimum production conditions for AT, in a way that enables regular failure and learning. The plant is not fully built out to enable the firm to make improvements according to experimental results. Other algae factories have employed similar techniques, using testbeds for algae and fish to determine if symbiotic production is viable. As noted, '*Science works with grams, symbiosis with kilograms and commercialization with tons*' (Respondent E18). Testbeds or pilot studies provide a safe place in between basic research and large-scale commercialization: a place in which innovative companies can test their wild ideas before risking all. These pilot studies thus make failure safe. In conclusion, support must be given to businesses to enable this process of trial and error. This could be in the form of specific funding for pilot studies, advisory services, or provision of industrial symbiosis centres such as Sotenäs.

Support for innovative businesses such as VG should be offered over a consistent, long-term basis. It should also not be based on immediate provision of results. Without long term funding, many high risk/high reward ideas will die before they have been fully trialled. Using AT as an example, the commercialization process will require seaweed experts to be trained, research into the bromoform pathways in AT and more long-term *in vivo* animal trials. Funding must be there consistently to avoid firm bankruptcy. The novel nature of AT, and other innovative products, means there will be a constant influx of problems to deal with. For VG it will take time to create meaningful progress or 'results' as there is a lack of AT expertise available. One particular problem for radical firms is regulation which is often unprepared for such innovations. A report from the World Resources Institute described how complicated regulatory process is discouraging private innovators (Searchinger et al., 2021). Overcoming obstacles, such as complex regulation requirements, requires time and funding and thus, as the executive chairman of the UK Business Growth fund commented, *'support must be there from the start to the end of scaling (and even then) –it must be continuous'* (Respondent W1-1). Supporters of these innovative green tech firms must be aware that the time from idea conception to commercial results is a long one, possibly with slow progress of results provision. They should account for this when providing support.

Innovative green businesses can benefit from being involved in a supportive collaborative ecosystem. VG has been lucky in gaining advice from angel investors, which has proved important in the firm's success so far (Respondent T2). Interviews for this research highlighted there was much greater potential collaborative support available though, both in the AT-specific and more generic algae-industries. Interactions between firms can help break bubbles of group think and provide access to new expertise and resources. The CEO of innovative green tech firm Genius Foods highlighted the importance of early work with external scientists to nail problems with their gluten free selection (Respondent W2-1). However, this opportunity can be a hard one for small start-ups to seize as they have limited capacity to initiate or maintain collaborations. This is supported by the limited of uptake of available collaborations by VG. Therefore, support could be well aimed if it were to enable such collaborations. One example could be governmental funding of PhD positions within innovative green companies. These researchers would provide a definitive link between academia and business and develop the network competence of firms.

7.3 Findings from research: usefulness of this research style

7.3.1 Benefits of this research style

The breadth of stakeholders consulted in this research resulted in a widespread awareness of relevant barriers and opportunities. This research process included mapping the dairy value chain, as well as mapping actors related to the production and usage of AT. Through consultation of this range of actors with extremely different vested interests, the research was able to provide a balanced overview of AT's commercial chances. Regular team consultation ensured that these consultation findings were relevant. Although one threat of consultation of a diverse range of actors could be a lack of emergent patterns because of such widespread concerns. This was not found to be the case in this research. Out of consultation with 26 external and 7 team-member stakeholders, only data from 2 interviews was deemed unworthy of inclusion in the patterns or codes that form this paper. This indicates how relevant information can be gathered by consulting broadly. Overall, this broad consultation provided a breadth of data that would have been impossible through more focused interviewing. This breath of data proved translatable into clear patterns and meaningful results.

The inductive approach enabled prioritisation of the opinions of experienced stakeholders. Rather than the researcher proscriptively prescribing barriers or opportunities, this research evolved around concerns raised by knowledgeable stakeholders. In this way, the research was able to utilise relevant expertise to develop a clearer overview of VG barriers and opportunities. This research method was one way subvert issues related to a lack of researcher expertise across all the relevant fields related to AT commercialisation. Indeed, the broad range of sectors covered meant overarching researcher expertise is likely impossible. Through a combination of expert consultation and data triangulation with the literature, this research approach aimed to prevent denigration into any particular concern, and thus present a more holistic appreciation of VG's viability. In sum, this bottom-up approach utilised expertise in the field to provide a more representative overview of VG's commercial chances.

The exploratory case-based nature of this research accounted for the importance of contextual factors. By specifically targeting VG as a representation of factory-produced AT, this research acknowledged the complexity of understanding commercial viability. This complexity was proved correct by data findings indicating the specificity of VG's case. The focal firm were influenced by factors ranging from their innovative, radical nature to the unique dairy value chain in Sweden. Taking a broader approach to assessing commercial viability would have risked missing these nuances and therefore gaining a generic, but ultimately fairly useless overview. This appreciation of contextual factors is noted by Flyvbjerg (2006) as being one reason why case study findings are often more valuable for practitioners than generic insights. Overall, focusing specifically on VG enabled an in-depth understanding of a complex problem. Insights obtained from a more generic overview would likely have proved a less useful.

This research also has benefits for the focal firm. This research was pivoted towards understanding and investigating VG, thus results gathered from stakeholders are likely to provide useful insights to the company, as well as expanding their network. The importance of corporations accounting for stakeholder opinion (Section 3.2), means that such stakeholder insights should be of high importance and relevance to the company. This thesis research may also expand VG's useful network. The requirement to map out relevant stakeholders prior to consultation, as well as use of snowball interviewing techniques, meant the research exposed contacts previously unknown to VG (Respondent T1). This improved awareness of network is likely to have positive corporate implications. In essence, this research improved the network competence of VG, an important opportunity highlighted earlier in the research. Through engagement with a master student the firm can access free research and an expansion of contacts. Therefore, through pivoting towards VG and consulting major stakeholders of the firm, this research style provided useful external insights on the firm's viability.

7.3.2 Limitations of this research style

This research style is limited by its subjective nature. The information gathering process centres around stakeholder consultation. At every stage of data collection and processing, researcher or stakeholder bias can enter and potentially cloud the results. The choice of stakeholders may implicitly reflect researcher bias. An example would be how mapping of the dairy value chain to include advisors may be the result of the high importance the researcher assigns to these services. The design and conduction of the interviews, although based on social science and grounded theory principles (Timonen et al., 2018), may also bias the collected results. Greater interviewer enthusiasm for discussing opportunities, for example, rather than barriers may result in more data collected on opportunities or barrier amelioration and thus apparent minimisation of the challenges facing VG. The processing of the data into codes is also an entirely subjective process. Researcher bias or expertise in a certain area may result in greater weighting of certain issues. For example, a researcher with an engineering background may focus in on production infrastructure challenges. Throughout the research process, the wide-ranging issues emerging (from algal breeding to fluid dynamics in this thesis) mean the researcher will lack expertise in multiple areas covered. This leaves them open to influence from stakeholder interviews. These stakeholders may themselves have vested interests or biases that result in a non-representative portrayal of VG. Overall, the subjective research style means stakeholder and researcher bias will likely enter the data, potentially distorting the results towards unrepresentativeness.

The pivoting of the research towards VG may limit the useful outcomes of this thesis. Whilst the specificity of the contextual factors was a prime reason for case-based research, it also limits the applicability of results. Many of the identified opportunities open to VG, for example local symbiosis opportunities, or the firm's competitive field, are extremely specific to the firm. If the firm were to go bust, the results of this research may appear useless. This is exaggerated by Chapter 5 and 6 including recommendations for possible actions that VG could take. There are also multiple other stakeholders who would be able to act on suggestions, and such broader recommendations may have results in more generic and applicable results. Thus, the in-depth analysis of a specific case study may limit the broader applicability of the results of this research approach.

The use of grounded theory as a methodology for data collection and analysis in this thesis also has its limitations. Grounded theory enables identification of patterns and theory from any collected data. This method involves risks of missing important data or processing it inappropriately. The opportunities available to VG are incredibly open-ended and therefore missing one key stakeholder may have meant an important opportunity was entirely lost from the discussion. In this thesis, time-constraints also posed a difficulty to this research methodology: interesting opportunities such as alternative uses of AT only emerged at the end of the research process which led to a minimal ability to develop these categories. Consequently, the amount of data supporting this opportunity is less than for earlier identified opportunities or barriers. Overall, the lack of set framework in grounded theory means there are risks of missing key data or only identifying it at a late stage.

7.3.3 Potential applicability of research structure

There may be future academic applicability of the combined use of grounded theory and stakeholder theory to elicit the opportunities and barriers facing a case study firm. There is minimal evidence in the literature of such a process being used to assess commercial viability previously. Therefore, if the results of this thesis are deemed useful, the technique may be a viable one by which future academics can investigate commercial opportunities and barriers. This thesis provides a clear generic structure by which this can be achieved (Figure 7-1). Within this structure, this research used specific techniques to gather information. These information-gathering techniques, including a workshop, regular consultation with team members and company observation were found to be extremely helpful for developing researcher understanding. In addition, the information storage and communication techniques, for example the constantly evolving mind maps of the opportunities and barriers may prove equally applicable. These techniques may be adapted and applied to future case-study research. In summary, both the general and more specific structural elements of this research style may prove applicable for later academic case study work.

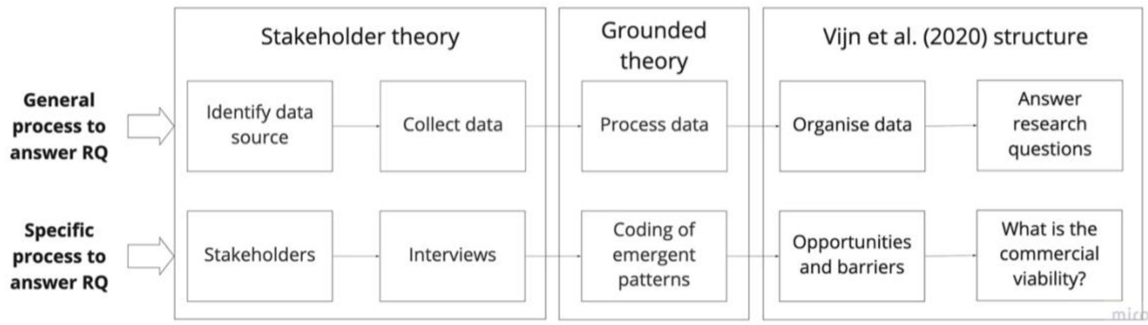

Figure 7-1 Overview of the research process and the theoretical perspectives used to guide it.

In addition to academic uses, other commercial actors may be interested in applying this structure and process to determine their own major barriers and opportunities. Investigation by an external party appears to offer additional benefits, especially improved network competence. Given this, other corporations may be interested in engaging PhD or Masters' students to investigate their commercial viability in this fashion. Thus, this thesis may also be able to provide a structure for future research students to help support academia-industry collaboration.

The framework presented to assess the five most promising MRA may also prove to have broader applications. This research discovered a lack of comprehensive frameworks for MRA assessment in the literature. This first attempt to synchronise and organise research findings on five of the most promising additives may provide a structural basis on which future academics can expand. The condensed findings in the assessment also provide an easy-to-understand comparison. In clearly summarizing and assessing the most viable additives, this framework may prove a useful tool for decision-makers including politicians, investors, and client of any type of MRA. Jordbruksverket, for example, highlighted how they may be interested in including MRA in advisory programs (Respondent E21). This comparison framework may be useful for comparing between options for this governmental organisation to support. Therefore, the structured and easily accessible format of this comparative assessment means it may provide a useful basis for future comparison and decision making.

7.4 Overall conclusion

The opportunities and barriers identified in this research do not provide a definitive assessment of AT commercial viability. The barriers highlight the high-risk nature of this enterprise. The opportunities highlight the advantages open to VG because of potential high rewards. This high risk/high reward nature of VG indicates it is an innovative, potentially market driving, business. This research highlighted that there are opportunities available that VG can seize, however these opportunities are all dependent on some form of external support. Therefore, this case study can be used to identify reasons why such radical firms should be supported and mechanisms by which this can be achieved. As a final one sentence summary: the commercial viability of factory-produced AT in Sweden is unknown but should be supported anyway. Radical and innovate companies such as VG offer hope in the struggle to mitigate climate change.

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Appendix 1: Respondent list

Observation list

Observation number	Locations	Date
1	Stockholm	2-5 March 2021
2	Lysekil (factory)	28-30 April 2021

Team member consultation list

Interview number	Role/ position	Date	Form of interview
T1	Chief Executive Officer	Regular	In person interview, regular calls.
T2	Chief Commercialising Officer	Regular	In person interview, regular calls.
T3	Chief of Science	March and April 2021	In person
T4	Senior Research Engineer	March 2021	In person
T5	Marine Biologist	April 2021	In person
T6	Chief of Technology	April 2021	In person
T7	Chief Marketing Officer (now left position)	Pre-thesis	Regular calls and zoom

External stakeholder interview list

Interview number	Role/ position	Date	Form of interview
E1	CEO, Agroväst	Early stage	Phone
E2	Dairy product researcher, SLU	Early stage	Zoom
E3	Ruminant nutrition researcher, SLU	Early stage	Zoom
E4	Advisor, Hushållningssallskapet	Early stage	Phone
E5	Animal science expert, Norrmejerier	Early stage	Phone
E6	Sustainability specialist, LRF Mjolk	Early stage	Phone
E7	Sustainability ambassador, LRF	Early stage	Phone
E8	Ruminant Manger, Alltech	Early stage	Phone
E9	Employee, Agolin Ruminant	Early stage	Phone
E10	Research Scientist and Consultant, Aquabiota	Mid stage	Phone
E11	Researcher, Tjärno Marine Laboratory	Mid stage	Phone
E12	Co-founder, Nordic Seafarm	Mid stage	Phone
E13	Executive Director, Haga initiative	Mid stage	Phone
E14	Corporate Responsibility Manager, HKScan Sweden	Mid stage	Phone

E15	CEO, Swedish feed additive company	Mid stage	Phone
E16	Sustainability Officer, Swedish food distribution company	Mid stage	Phone
E17	Algae and Bioactives Science Lead, Cawthron Institute	Late stage	Phone
E18	Development Manager, Sotenäs Symbioscentrum	Late stage	Zoom
E19	Professor of Environmental and Resource Assessments of Agriculture, Chalmers University	Late stage	Phone
E20	Shareholder, CarbonCloud	Late stage	Phone
E21	Environmental Objectives Coordinator, Jordbruksverket	Late stage	Phone
E22	Trade Policy Investigator, Jordbruksverket	Late stage	Email
E23	CEO, WA3RM	Late stage	In person
E24	CEO, Swedish Algae Factory	Late stage	Phone
E25	CEO, FutureFeed	Late stage	Phone
E26	Board member, Almi Greentech and CEO, Loudspring (retired)	Late stage	In person

Webinar attendance list

Speaker number	**Speakers**	**Webinar**	**Organisation responsible**	**Date**
W1-1	Stephen Welton (Executive Chairman, BGF)	Navigating the journey to net zero: how growing businesses will play their part	Business Growth Fund, Scaleup Institute, HM Government UK	18 May 2021
W1-2	The Baroness Brown of Cambridge (Chair, Climate Change Committee's Adaptation sub-committee)			
W1-3	Solange Chamberlain (COO, NatWest)			
W1-4	Paul Hayes (CEO, Seasalt)			
W1-5	Jo-jo Hubbard (CEO, Electron)			
W1-6	Dr Emily Shuckburgh (Director, Cambridge Zero)			
W2-1	Lucinda Bruce-Gardy (CEO, Genius Foods)	Unlocking Ingenuity: how to create fertile conditions for innovation	Business Growth Fund, Scaleup Institute, HM Government UK	19 May 2021
W2-2	Martin Murphy (CEO, Syncona)			
W2-3	Ottoline Lyser (Chief Executive, UK Research and Innovation)			
W2-4	Gerard Grech (CEO, Tech nation)			
W2-5	Amanda Solloway (Member of Parliament, Derby North)			
W2-6	Alex Harvey (Chief of Advanced Technology, Ocado)			

Appendix 2: Comparison of foundational research on 5 methane-reducing additives

Asparagopsis taxiformis

	Enteric methane mitigation	Understanding of additive mechanism	Animal performance	Human food safety	Animal safety	Palatability and intake
Research findings	**Enteric methane reduction in vitro:** Methane production almost entirely inhibited at 2% organic matter (Kinley et al. 2016a; Kinley et al. 2016b; Machado et al. 2018). **Methane production reduction in vivo:** Methane production range between 26% (Roque et al. 2019) to 98 % (Kinley et al. 2020). Methane production found to decrease linearly with increasing dose of AT (9%, 38% and 98% lower for the animals receiving 0.05%,0.10% and 0.20% red algae respectively, compared with the control group (Kinley et al. 2020). **Methane reduction yield or per kg milk:** Roque et al. 2019 found 18% (0.5% OM) and 60% (1% OM)	**Enteric methane reduction in vitro:** Methane production almost entirely inhibited at 2% organic matter (Kinley et al. 2016a; Kinley et al. 2016b; Machado et al. 2018). **Methane production reduction in vivo:** Methane production range between 26% (Roque et al. 2019) to 98 % (Kinley et al. 2020). Methane production found to decrease linearly with increasing dose of AT (9%, 38% and 98% lower for the animals receiving 0.05%,0.10% and 0.20% red algae respectively, compared with the control group (Kinley et al. 2020). **Methane reduction yield or per kg milk:** Roque et al. 2019 found 18% (0.5% OM) and 60% (1% OM)	**Feed efficiency:** Increase in feed efficiency noted in beef trials for combined red/ brown seaweed (average efficiency increase of 0.41 +/- 0.22 kg per kg) but not studied in dairy cows. Sharma and Datt (2020) found supplementation of red seaweed powder (not AT) had no effect on feed conversion efficiency in dairy cows. **Milk yield:** Roque et al. 2019 found 0.95kg milk higher per kg TS intake for AT. Significant increase in milk yield (weighted mean difference of 1.35 kg/ day) for results across closely related seaweeds (Lean et al. 2021). No significant differences noted for milk fat or protein (Lean et al. 2021).	**Natural/ unnatural:** Natural compound. **Potential risks:** Bromoform is listed as a probable human carcinogen by the EPA, but not the IARC. Bromoform residues found in milk, but only at potentially hazardous concentrations in the controversial Muizelaar et al. (2021) trial. High iodine levels found in seaweed-fed cow milk (Antaya et al. 2015; Stefenoni et al. 2021) and raised bromine (Stefenoni et al. 2021). There may be risks associated with producing or using the high bromoform seaweed. No harmful residues found in beef. **Risk mitigation:** milk may be mixed to reduce iodine/bromine concentrations. Algae	**Notes:** Proven safe for livestock consumption, long historical precedent of ruminant seaweed and AT consumption. (Makkar et al. 2016). AT is also safe for human consumption (Gribble, 2000).	**Taste/ DMI change:** The majority of published studies (Roque 2019; Roque 2021; Muizelaar et al. 2021; Stefenoni et al. 2021) indicate reduced feed intake by cows when they are feed AT, especially at high % AT inclusion. One study (Kinley et al. 2020) indicates minimal impact. There is a cited need to improve palatability in some papers (Vijn et al. 2020), but others note that taste and aroma are easy to mask and not an obstacle in practice (Jardstedt and Holmström 2021). A recent Lantmännen research facility trial (unpublished) found that cows seem to be unaffected by taste. **Delivery:** uncertainty on

	reduction in methane per kg milk. **Effect of diet:** proportion of roughage/ roughage quality in diet seems to impact methane reduction. Higher roughage linked to less methane reduction (Roque et al. 2021).	reduction in methane per kg milk. **Effect of diet:** proportion of roughage/ roughage quality in diet seems to impact methane reduction. Higher roughage linked to less methane reduction (Roque et al. 2021).		may have to be processed to remove some minerals before feeding, special growing conditions to minimise iodine uptake, short-term focus on beef production		whether algae need to be given continuously; no current mechanism for feeding to grass-fed cows (Abbott et al. 2020).
Strength of evidence	4 published in vivo studies on AT for cattle (Kinley et al., 2020; Roque et al., 2021; Stefenoni et al., 2021; Muizelaar et al. 2021). Roque et al. 2019 investigated *Asparagopsis armata*; Li et al. 2018 investigated AT impact in sheep.	n/a	3 published in vivo studies on AT and dairy cow performance (Roque et al. 2019, Stefenoni et al. 2021; Muizelaar et al. 2021). 14 published papers on closely related seaweed species (Lean et al. 2021).	5 published studies on chemical residues in milk as a result of feeding AT (Stefenoni et al. 2021; Muizelaar et al. 2021). Roque et al. 2019 studied *Asparagopsis Armata*. 3 published studies investigated bromine/ iodine concentration in beef (Li et al. 2018; Kinley et al. 2020; Roque et al. 2021).	n/a	5 published studies (Roque 2019; Roque 2021; Kinley et al. 2020; Muizelaar et al. 2021; Stefenoni et al. 2021).

3-NOP

	Enteric methane mitigation	Understanding of additive mechanism	Animal performance	Human food safety	Animal safety	Palatability and intake
Research findings	**Enteric methane reduction in vitro:** complete inhibition of methanogenesis observed (Duin et al. 2016). **Methane production reduction in vivo:** Meta-analysis indicated average mitigation effect of 39% in dairy cattle (Dijkstra et al 2018). Range of CH4 production decrease of 7 % (Reynonlds et al. 2014) to 84% (Vyas et al. 2016). Significant linear decrease in methane production (g/kg DMI) with increasing 3-NOP supplementation (Jayanegara et al. 2018). **Effect of diet:** Greater methane reduction for dairy rather than beef cattle, possibly due to higher DMI (Dijkstra et al. 2018). Dijikstra et al. (2018) also found a decreased methane production with higher feed concentration of neutral detergent fibre.	**Known:** Mechanism of effect known (Duin et al. 2016). 3-NOP is structurally analogous to a co-enzyme involved in the final step of methanogenesis. It inactivates MCR. **Unknown:** Interactions between rumen microbes and 3-NOP in relation to rumen feed fermentation.	**Feed efficiency:** Multiple studies show FE is not affected in dairy cows. (Haisan et al. 2016, Schilde et al. 2021, Pitta et al. 2018 meta-analysis indicated small decrease in FE with increasing 3-NOP. **Milk yield:** minimal change (Pitta 2021, Schilde et al. 2021, Jayanegara et al. 2017.)	**Natural/ unnatural:** Unnatural compound. **Potential risks:** Potential carry-over of chemically synthesis molecule into animal products. **Risk mitigation:** Mutagenicity and genotoxicity tested, and no flags raised (Thiel et al. 2019).	**Notes:** the low concentrations of 3-NOP required to inhibit methanogenesis has been proven as non-toxic to animals (Hristov et al. 2015). It is known that 3-NOP is reduced to nitrite and 1,3-propanediol (naturally found molecules) by rumen bacteria.	**Taste/ DMI change:** Meta-analytic review found 3-NOP does not compromise feed intake (Jayanegara et al. 2017). **Delivery:** Need for continuous delivery of 3-NOP to cows as the pulse dose effect is transient (Hristov et al. 2015). Research is ongoing into alternative forms to enable sustained release for grazing systems. An initial prototype has been able to extend methane reduction by 6-8 hours from feeding (DSM 2021).

	However, 3-NOP is still effective for both basal and concentrate diet, and can decrease emission by ~20% regardless of type of feed (Van Wesemael et al. 2019).					
Strength of evidence	More than 15 published in vivo studies on 3-NOP for cattle. 10,000 cows tested.	n/a	14 published in vivo studies on AT and dairy cow performance; 5 on AT and beef cow performance (Jayanegara et al. 2018).	?	n/a	More than 15 published studies looking at DMI (Jayanegara et al. 2018).

Mootral

	Enteric methane mitigation	Understanding of additive mechanism	Animal performance	Human food safety	Animal safety	Palatability and intake
Research findings	**Enteric methane reduction in vitro:** Nearly complete inhibition of methane production in vitro at 2g Mootral /day (Eger et al. 2018). **Methane production reduction range in vivo**: between no significant change (Roque et al. 2019) -38 % (Vranken et al. 2019). Methane reduction appears to increase over time with minimal reduction at start of supplementation but increasing to 23% at week 12 (Roque et al. 2019). Average methane reduction taken as 17% (VERRA). **Effect of diet:** needs investigation.	**Known:** The garlic component in Mootral targets methanogenic archaea populations and protozoal communities in the rumen. There is suppression of the methane producing *Methanobrevibater. Sp.*. (Castro-Montoya 2015) **Unknown:** The exact mechanism by which essential oils operate have not been linked to any sole factor and there are several competing hypothesises for the anti-methanogenic effect of essential oils such as Mootral. These include the inhibition of certain rumen bacteria, methanogenic archaea, or protozoa (Castro-Montoya 2015).	**Feed efficiency:** Remained similar to control in Roque et al. (2019) study. Vranken et al. (2019) showed a 13% FE increase. **Milk yield:** Vranken et al. 2019 found increase in milk yield by 5% (Jersey cows) and 7.8% (HF cows).	**Natural/ unnatural:** Natural compound. Mootral is synthesised from natural products including garlic- and flavonoid-containing citrus extract. **Potential risks:** none	**Notes:** Vranken et al. (2019) showed significant decrease in somatic cell counts (healthier cows). This has also been reported for other garlic supplements. Dietary addition possibly linked to reduced susceptibility to acidosis	**Taste/ DMI change:** non-total consumption of pellets in Roque et al. 2019 trial, full consumption in Vranken et al. (2019) trial. **Delivery:** pellets (3% Mootral), incorporated into TMR (Mootral 2021).
Strength of evidence	2 published in vivo studies on Mootral for cattle (Roque et al. 2019; Vranken et al. 2019). >10 studies on impact of garlic compounds on	n/a	1 published in vivo study on Mootral for dairy cattle (Vranken et al. 2019); Roque et al. 2019 investigated beef cattle.	n/a	n/a	2 published in vivo studies (Roque et al. 2019; Vranken et al. 2019).

	methanogenesis (Eger et al. 2018).					

Agolin

	Enteric methane mitigation	Understanding of additive mechanism	Animal performance	Human food safety	Animal safety	Palatability and intake
Research findings	**Enteric methane reduction in vitro:** No specific in vitro Agolin experiments. In vitro studies with blended essential oils show high concentrations are needed to inhibit methanogenesis (Belanche et al. 2020). **Methane production reduction in vivo:** ranges from 0 % (Klop et al. 2017, Castro-Montoya et al. 2015) to 20% (Hart et al. 2019). Carbon Trust takes 8.8%. Short term treatment shows low and inconsistent methane reduction (~2.3%). Larger decreases for longer term treatment. CH4 production (−8.8%), CH4 yield (−12.9%) and CH4 intensity (−9.9%) (Belanche et al. 2020). **Effect of diet:** the effect of diet on essential oil impact is thought to be diet dependent based on differences in volatile	**Known:** Essential oils are known have a broad antimicrobial effect. This antimicrobial nature likely implies a capacity to modify rumen fermentation (Belanche et al. 2020). The essential oil impact is likely to be due to a combination of mechanisms (Helander et al. 1998). **Unknown:** The exact mechanism by which Agolin or other EO operate has not been linked to any sole factor and there are several competing hypothesises for their anti-methanogenic effect. These include the inhibition of certain rumen bacteria, methanogenic archaea or protozoa (Castro-Montoya 2015).	**Feed efficiency:** Agolin specific meta-analysis (Belanche et al. 2020) shows increased FE (+4.4%) for dairy cows. Essential oil blends typically result in a greater FE (Elcoso et al. 2019). **Milk yield:** Meta-analysis indicates Agolin increases the average milk yield (+3.6%) and fat and protein corrected milk yield (+4.1%) (Belanche et al. 2020). EO typically demonstrates a higher production of energy-corrected milk yield in dairy cattle (Elcoso et al. 2019).	**Natural/ unnatural:** Natural compound; a blend of eugenol, geranyl acetate and coriander essential oils. **Potential risks:** none	**Notes:** safe for animal consumption commercially.	**Taste/ DMI change:** DMI unaffected by Agolin supplementation and all pellets consumed across studies (Belanche et al. 2020). **Delivery mechanism:** mixed into compound feeds, used only in intensive farming (Agolin 2021).

	fatty acid concentrations for different feeds (Belanche et al. 2020).					
Strength of evidence	8 published in vivo studies on Agolin for cattle (Belanche et al. 2020).		19 published in vivo studies on Agolin and dairy cow performance (Belanche et al. 2020).			16 published in vivo studies (Belanche et al. 2020)

Yea-Sacc

	Enteric methane mitigation	Understanding of additive mechanism	Animal performance	Human food safety	Animal safety	Palatability and intake
Research findings	**Enteric methane reduction in vitro:** no direct Yea-Sacc studies. Contradictory for *Saccharomyces cerevisiae sp.*. Most studies show no significant decrease (Darabighane et al. 2019). **Methane production reduction range in vivo:** Methane production reduction for Yea-Sacc yeast between 0% (Ashworth et al.. 2016) and 4% (Tristant and Moran 2015). Yea-Sacc is a *Saccharomyces cerevisiae* species which have demonstrated methane reduction potential of up to 10 % (Mutsvangwa et al. 1992). Darabighane et al. (2019) indicated effect size of *Saccharomyces cerevisiae* yeast on methane production is not significant (Darabighane et al 2019). **Effect of diet:** effect for *Saccharomyces cerevisiae* yeast consistent across all diets tested.	**Known:** Yea-Sacc stimulates fibre digesting and lactic acid utilising bacteria which optimises fibre digestions and nutrient utilisation (Tristant and Moran 2015). **Unknown:** if there is a mechanism by which Yea-Sacc decreases methane. It is suggested that Yea-Sacc might stimulate acetogenic bacteria which could use metabolic hydrogen in the rumen (Darabighane et al. 2019). This would prevent the hydrogen being used for methanogenesis.	**Feed efficiency:** 8% FE improvement for dairy cows fed Yea-Sacc (Respondent E8). Yeast increasingly used in ruminant diets to improve performance. Feeding *Saccharomyces cerevisiae* yeast improves nitrogen uptake through improved ruminal bacteria (Darabighane et al. 2019). **Milk yield:** *Saccharomyces cerevisiae* yeasts shown to increase milk yield, milk fat and milk protein content (Darabighane et al. 2019). Yea-Sacc improves milk production by 1.6 litre/cow/day (Respondent E8).	**Natural/ unnatural:** Natural compound. **Potential risks:** No risks in food products. Both commercial forms of Yea-Sacc are highly proteinaceous and considered as potential respiratory sensitisers. **Risk mitigation:** Yea-Sacc is designed to reduce dustiness and no significant exposure of users is to be expected for this form.	**Notes:** *Saccharomyces cerevisiae* authorised by European Food Safety Authority (EFSA) as an animal feed.	**Taste/ DMI change:** Small DMI increase in meta-analysis (Darabighane et al. 2019). Fed in various ways - added into compound feed, included in mineral premix, farm pack Yea-Sacc sprinkled on top of feed. **Delivery:** Grass fed dairy cows can be fed Yea-Sacc with pellets in milking parlour.

Strength of evidence	2 published in vivo studies on Yea-Sacc for cattle (Ashworth et al. 2016; Tristant and Moran, 2015). ~50 published papers on *Saccharomyces cerevisiae* or other yeast.	n/a	7 published papers on Yea-Sacc and dairy cow performance; >100 papers on impact of *Saccharomyces cerevisiae* yeast on cow performance (Darabighane et al. 2019).	n/a	n/a	2 published papers on Yea-Sacc. DMI/delivery mechanism considered to be equivalent to *Saccharomyces cerevisiae* yeast (~50 published papers).

Appendix 3: Comparison of the production of 5 methane-reducing additives

Asparagopsis taxiformis

Raw material availability	Environmentally friendly production	Facilities available for large-scale production	Conversion to a transportable/ storable feedstock
Aquaculture of *Asparagopsis sp.* limited by current inability to close lifecycle (Zhu et al. 2021), and a consequent requirement for harvesting juveniles. Research is ongoing into this (e.g. Greener Grazing) and practical protocols are being established for wild species collection (Mickelson 2013). AT is a tropical/sub-tropical species.	Dependent on production type. Land-based system have high input requirements (energy and nutrients), although some land-based growers are aiming for carbon neutrality (Volta Greentech). Marine-based systems may lower ocean pH, cause marine mammal entanglement and impact larval transport (Abbott et al. 2020), but have benefits including creation of habitats, carbon sequestering and excess nutrient removal.	This is a poorly domesticated and hard to farm species (Zhu et al. 2021). There is no successful historical precedent for large-scale AT production (Respondent E17). Estimated requirement of 100ha marine space to feed 1mil cows (land-based unknown). Sea Forest are the most advanced producers with an active trial cultivation site of 1ha (Sea Forest 2021). Sea Forest are reportedly aiming for 7000 tonnes annual production (Palmer-Derrien, 2021).	The bioactive compound in AT is highly volatile. Appropriate processing to maintain this bioactive compound (freeze-drying) is expensive and energy intensive (Respondent T4). Even with this processing, bioactive compound degrades rapidly within months. Oil immersion processing offers possibilities for long-term storage but is expensive (patented) and largely impractical for farm use (Respondent E17).

3-NOP

Raw material availability	Environmentally friendly production	Facilities available for large-scale production	Conversion to a transportable/ storable feedstock
3-NOP synthesized from 1,3-propanediol and nitric acid, both readily available (DSM, 2020).	Non-energy intensive manufacture process. 47.9 kg CO2e/kg 3-NOP produced (Alvarez-Hess et al., 2019).	Yes	n/a

Mootral

Raw material availability	Environmentally friendly production	Facilities available for large-scale production	Conversion to a transportable/ storable feedstock
Raw materials (garlic; citrus extract) readily available and can tap into existing supply chains.	Mootral aiming to set up local production sites to ensure low carbon footprint (Mootral, 2021).	Lab scale production facility in Wales but no commercial factory yet (Mootral, 2021).	The stability of organosulphur compounds from garlic in liquid formulations is limited and impacts practical use (Putnoky et al., 2013)

Agolin

Raw material availability	Environmentally friendly production	Facilities available for large-scale production	Conversion to a transportable/ storable feedstock
Raw materials (extracts) readily available. Agolin Ruminant create synergies (Agolin, 2021).	Yes. Extracts bought and mixed (Agolin, 2021).	Yes. Capacity not an issue, can easily enlarge actual production 3-5-fold (Respondent E9).	Maintains activity for around 18 months when stored (Agolin, 2021).

Yea-Sacc

Raw material availability	Environmentally friendly production	Facilities available for large-scale production	Conversion to a transportable/ storable feedstock
Yeast cells are produced by batch fermentation in a typical industrial medium based on molasses and mineral salts. These raw materials are readily available (Alltech, 2021).	Low energy intensive manufacture process (Respondent E8).	Privately owned company with offices in 128 countries, 6000 employees. Able to expand as demand surges (Respondent E8)	Yes. The yeast product is regulated to certain amount of live activity. Data supports a shelf life of at least 12 months, over which time losses were less than a one log compared to counts made at the start of the experiment (Alltech, 2021).

Appendix 4: Comparison of the usage of 5 methane-reducing additives

Asparagopsis taxiformis

Cost	Approval by authorities	Political/ external support	Time to commercialization	End-of-chain interest
Calculations indicate ~ €230 /tCO_2e reduced. *	FutureFeed (the AT license holder) is working on approvals from food regulators in Europe (FutureFeed, 2021). U.S. and other jurisdictions. More extensive research needed to meet FDA standards.	Possible ability to access carbon or ecosystem service markets. FutureFeed in talks with Australian Clean Energy Regulator about inclusion of AT in emission reduction fund (Palmer-Derrien, 2021). Both the New Zealand and Australian governments are directly funding research into AT production (Respondent E17).	CH4 Global and Sea Forest have launched commercial trials (Palmer-Derrien, 2021).	Displayed interest from major retailers. For example: VG: Coop, ICA, Lantmännen (Respondent T7). Symbrosia: Burger King, Darigold (Symbrosia, 2021). Sea Forest have signed an agreement with Fonterra (Palmer-Derrien, 2021).

3-NOP

Cost	Approval by authorities	Political/ external support	Time to commercialization	End-of-chain interest
Unknown cost of supplement. LCA study found the breakeven cost of 3-NOP under the Australian Emission Reduction Fund is $30/kg (beef) and $51/kg dairy (Alvarez-Hess et al., 2019)	Complicated approval process given it is a synthetic molecule. EU approval process underway. New Zealand and Latin America next. US approval expected in 2024 (DSM, 2021).	DSM conducting research in-house.	Expect approval in 2021 and ready with commercialisation shortly after (DSM, 2021).	Working with governments as well as dairy and beef companies. Dairy cooperative Fonterra have already signed collaboration (DSM, 2021).

Mootral

Cost	Approval by authorities	Political/ external support	Time to commercialization	End-of-chain interest
Calculations indicate ~ €100 /tCO_2e reduced. *	Natural compound, no need for regulatory approval.	Certified by Verra (2019) and UK Carbon Trust (Mootral, 2021).	Mootral is aiming to feed 300,000 cows in 2021 (Mootral 2021).	Working with Brades farm (who are selling methane reduced milk

				to commercial baristas (Vrancken et al., 2019)

Agolin

Cost	Approval by authorities	Political/ external support	Time to commercialization	End-of-chain interest
Calculations indicate ~ €48 /tCO_2e reduced. *	Commercially available.	Certified by UK Carbon Trust. Recognized by solar impulse foundation as a profitable solution to climate change (Agolin, 2021).	On market since 2008 as a milk production booster.	Fed to ~1.5 million cows already. More than 100 industrial clients worldwide and a network of 25 distributors (Agolin, 2021).

Yea-Sacc

Cost	Approval by authorities	Political/ external support	Time to commercialization	End-of-chain interest
n/a	Commercially available.	Certified by UK Carbon Trust. (Alltech, 2021).	Commercially available for over 30 years as registered yeast culture.	Successful commercial company for 30 years.

Cost Calculations

Cost of additive per tonne of CO_2e reduced= cost of additive per cow per day *1000/ (methane produced daily by cow in kg * methane conversion factor * % methane reduction by additive)

	Values used in calculations
Methane produced daily per cow /kg	0.33 (K. A. Johnson & Johnson, 1995)
Methane emission conversion factor	25 (IPCC, 2019)
Methane reduction by additive	AT 0.80; 3-NOP 0.39; Mootral 0.17; Agolin 0.1; Yea-Sacc n/a
Cost of additive /€ per cow per day	AT 1.5; 3-NOP n/a; Mootral 0.14; Agolin 0.04 (Agolin 2021); Yea-Sacc 0.06 (Yea-Sacc 2021).

This calculation is taken to be indicative only. Multiple factors will affect the cost of additive /tCO_2e reduced. Cost for the different MRA is based on the following sources:

AT: 100g of AT fed to cows daily at 150 SEK/kg AT (Jardstedt & Holmström, 2021)

Mootral: $60 for a years worth of Mootral per cow (Palmer 2021)

Agolin: Costs 0.04 € per cow per day (Agolin 2021)

Yea-Sacc: Costs $0.07 per cow per day (Yea-Sacc 2021)

Appendix 5: Mind-maps of the barriers and opportunities facing Volta Greentech

Barriers first draft

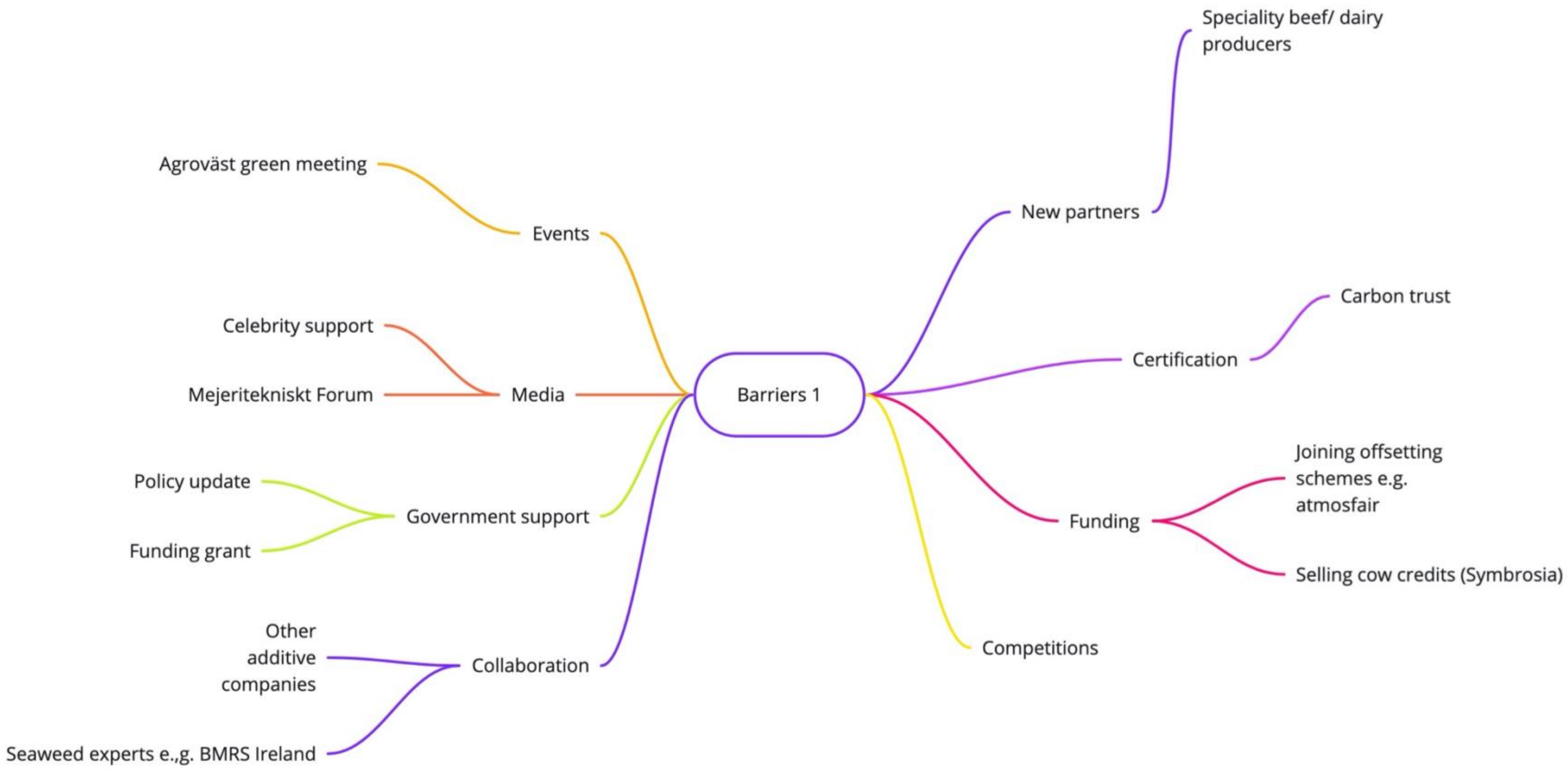

Figure A3-1 Volta Greentech barriers elicited from the literature and early-stage stakeholder consultation

Barriers second draft

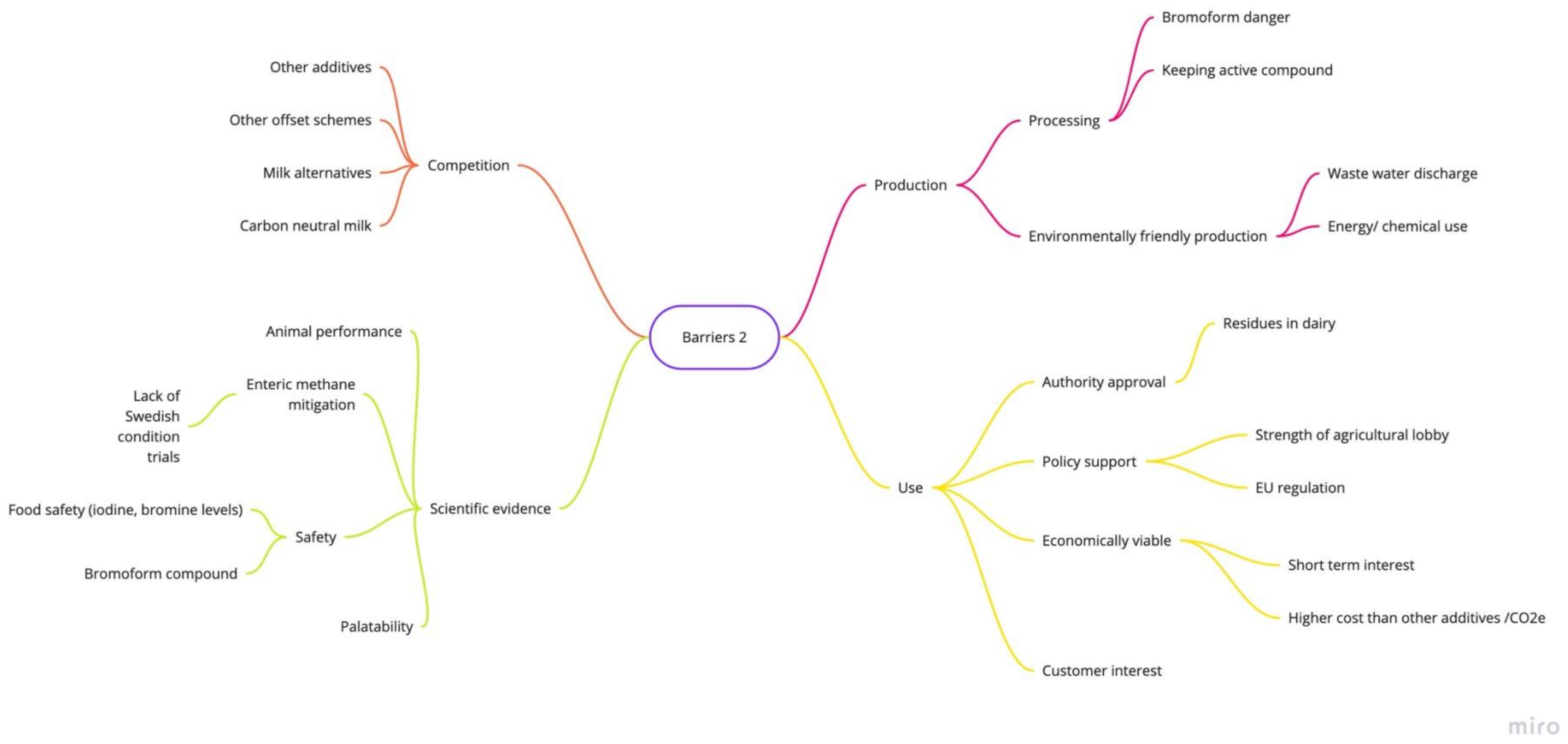

Figure A3-2 Volta Greentech barriers elicited from the workshop

Barriers third draft

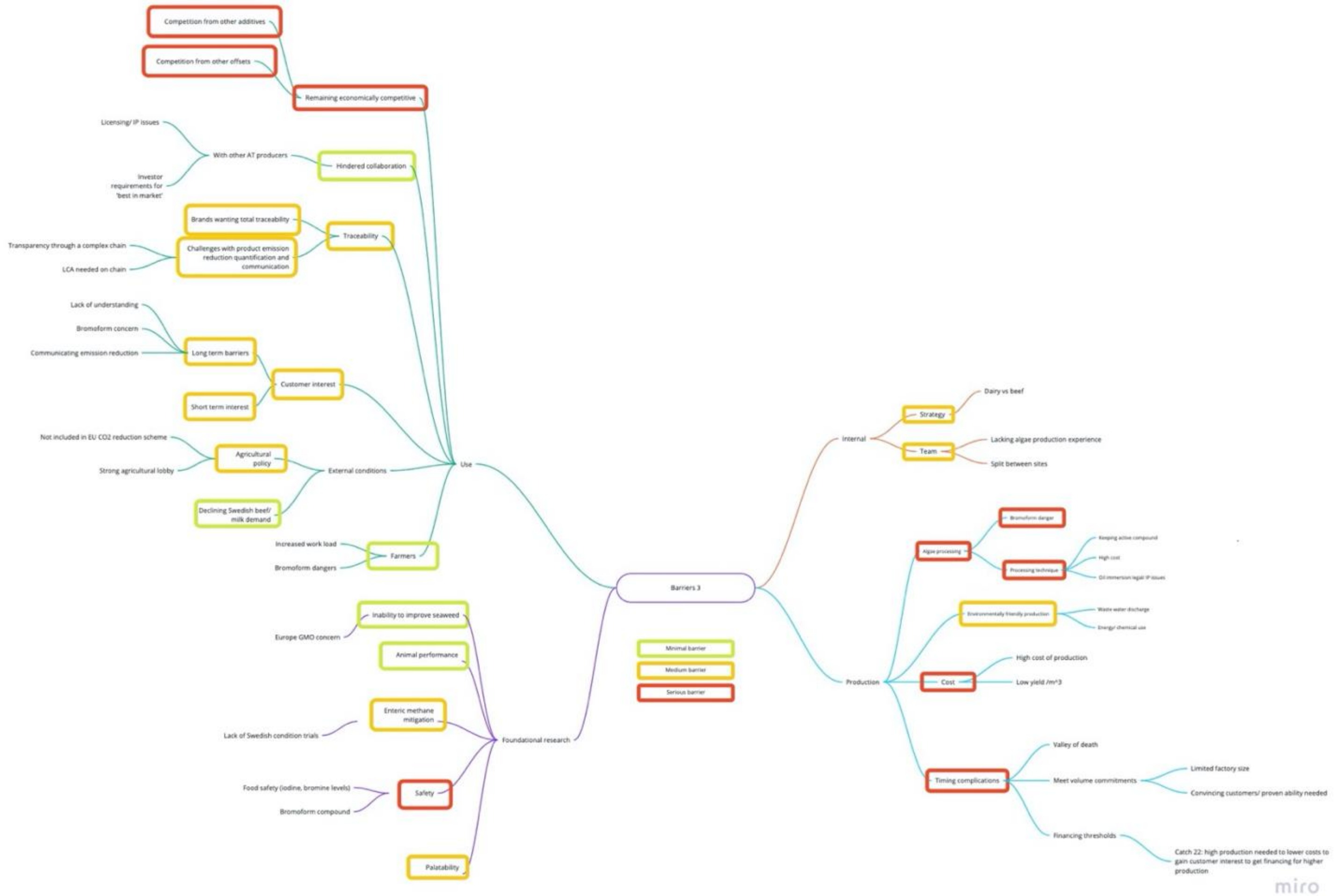

Figure A3-3 Volta Greentech barriers elicited from the workshop and stakeholder consultation and then categorized by severity.

Opportunities first draft

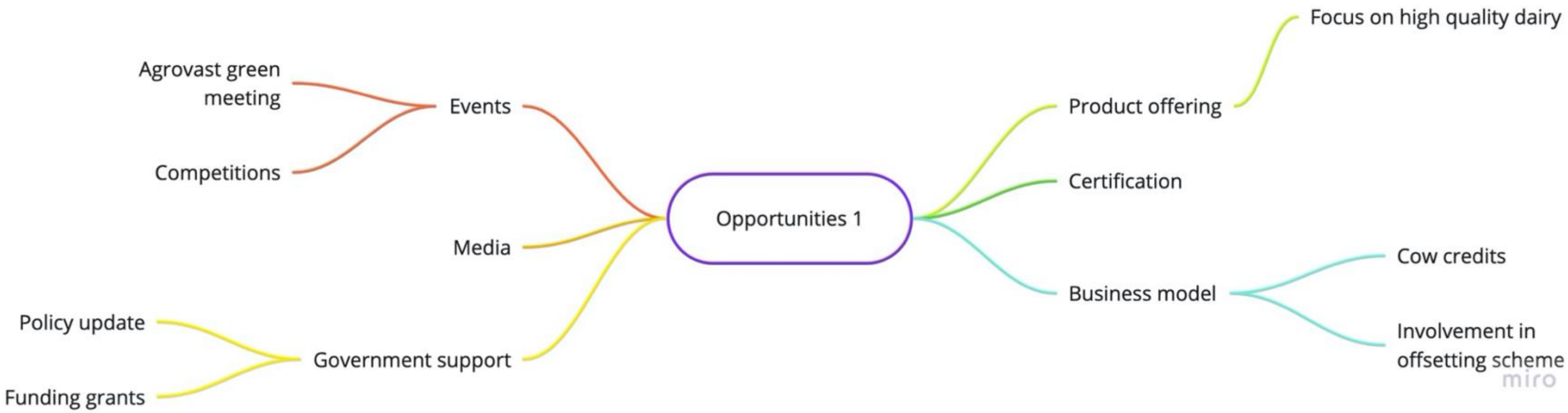

Figure A3-4 Volta Greentech opportunities elicited from the literature and early-stage stakeholder consultation

Opportunities second draft

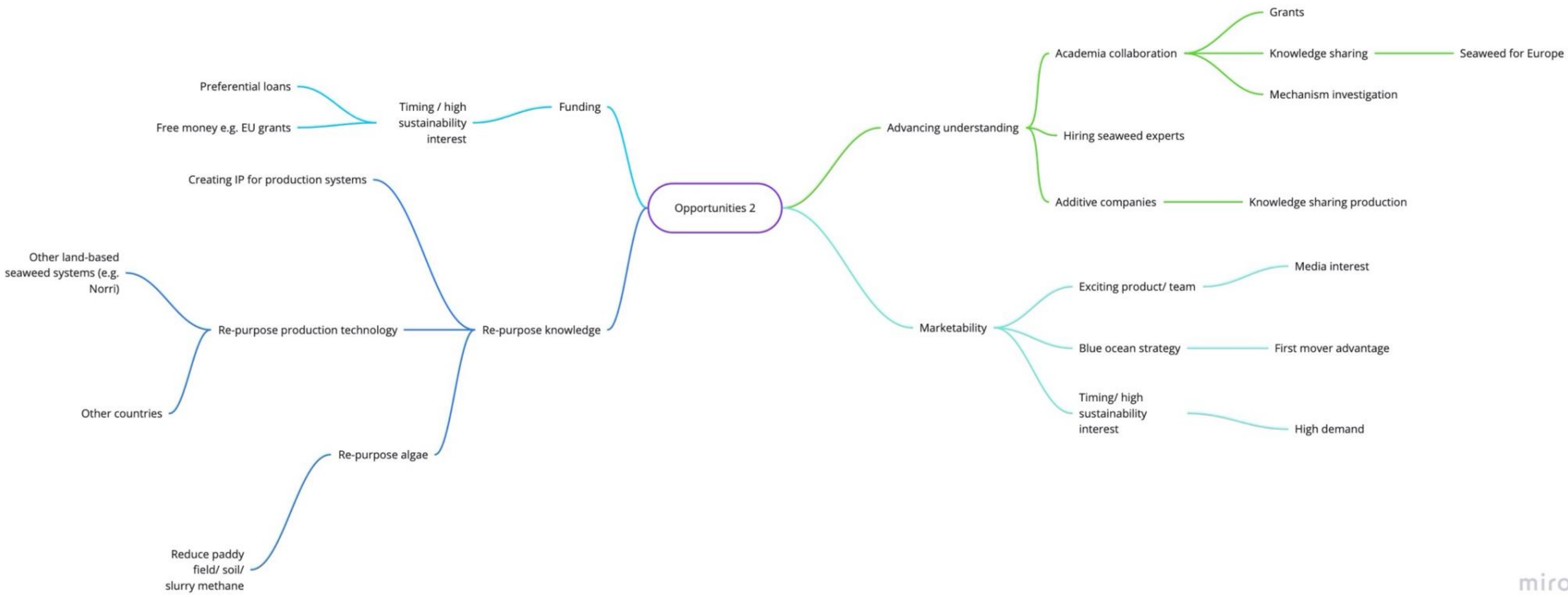

Figure A3-5 Volta Greentech opportunities elicited from the workshop

Opportunities third draft

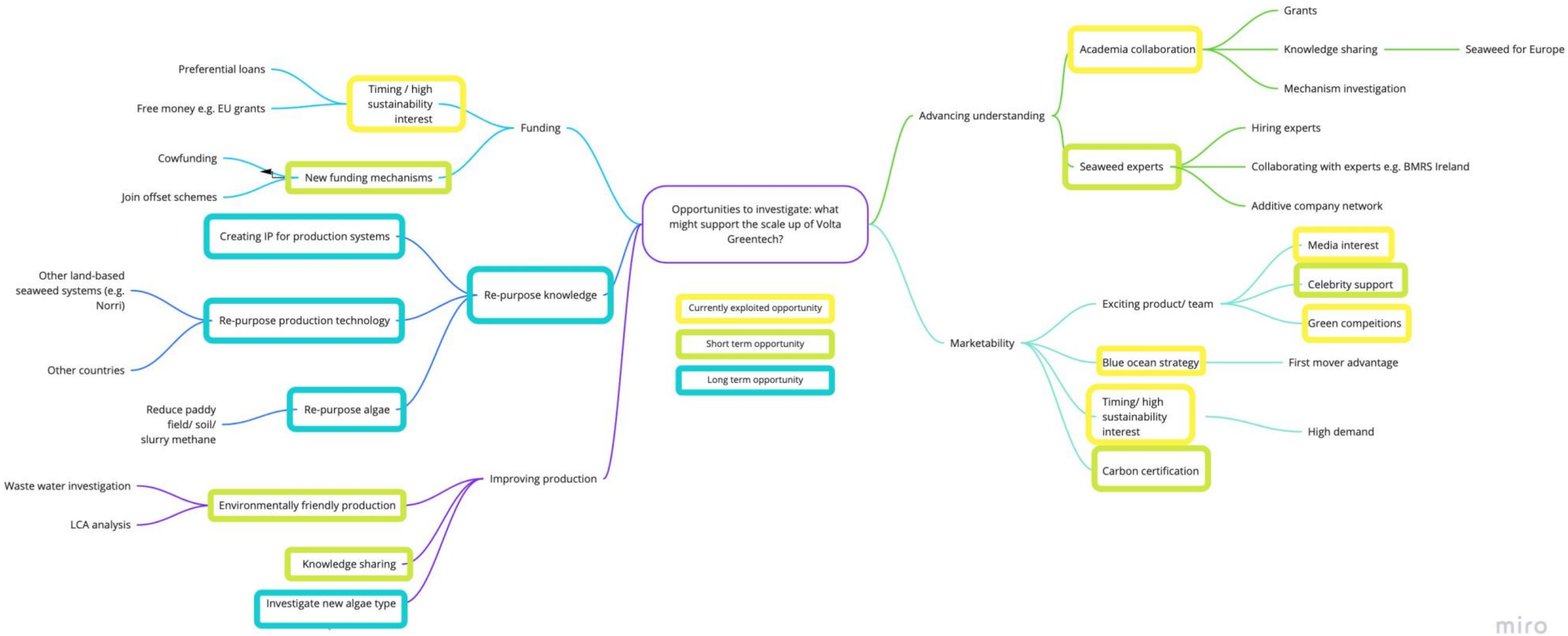

Figure A3-6 Volta Greentech opportunities elicited from the workshop and stakeholder consultation and then categorized by time frame.

Appendix 6: Pre-thesis research

Summary of research

In Autumn 2020, the researcher carried out consultancy work for Volta Greentech whilst volunteering at 180 Degrees Consulting. During this work, the researcher coordinated 2 focus groups (14 people) and conducted a survey in combination with Hoppipolla café, Lund.

The focus groups were both conducted on November 15th 2020, and lasted 1 hour. Participants were asked to discuss their perceptions on VG milk.

The café survey was conducted in mid-November 2020. Servers at Hoppipolla café asked 130 customers directly if they would be willing to pay 10% extra for a milk-based coffee. For example, would a customer pay 44 SEK for a latte normally sold for 40 SEK. A tick sheet was provided to mark customer response and a small information sheet was provided for interested customers. The test was conducted over an 8-day period.

Results of café survey

	Yes	No	% daily
Thursday	15	2	88
Friday	19	4	83
Saturday	13	1	93
Sunday	9	4	69
Monday	15	5	75
Tuesday	12	2	86
Wednesday	9	1	90
Thursday	16	3	84
Total	108	22	83