NOTTINGHAM TRENT UNIVERSITY

THE IMPACT OF CLEAN MEAT ON GLOBAL FOOD SECURITY: A QUALITATIVE STUDY

by

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Dissertation submitted in partial fulfilment of the
MSc '*Global Food Security and Development'* degree

2019

Abstract

Over 800 million people are currently suffering from hunger with the issue only exacerbating with the consequences of climate change and declining resources. Neither the current system of industrialised agriculture nor more sustainable agro-ecological farming practices are estimated to be able to feed a growing population, making technological innovations a necessity. One technology praised for its potential to address food insecurity by meeting the rising demand for meat without the severe exploitation of limited resources is 'clean meat'.

Whether its impact will indeed be positive has not yet been thoroughly investigated, since food security is often overlooked in the clean meat space. Considering the importance to evaluate the impact of a technology before its prevalence on the market, this study aims to assess the potential impact of clean meat on global food security and ways to design it in a positive way.

By using a qualitative approach, the still limited amount of literature concerned with the social and structural impacts of clean meat was reviewed, while new data was gathered through conducting semi-structured interviews with four experts from either a clean meat or food security background.

Opinions on the potential impact of clean meat on global food security were divided. While it could possibly be beneficial to availability and utilisation, similar to previous agricultural technologies this depends on how power over the technology will be distributed and whether the industry will be prepared for its potential disruption. Potential solutions to designing the impact in a positive way were suggested.

By demonstrating its relevance to food security, this study aims to fill the gap in research on clean meat, that is so far mostly restricted to assessing its effects on farm animals, the environment, climate change mitigation and public health. Its findings can assist both the public and private sector in preparing for and preventing scenarios in which the technology might be harmful to global food security.

Acknowledgements

I want to thank my supervisor, my friends and family for constant encouragement and helpful comments and my interview partners for giving me their time and interesting insights.

Disclaimer

This dissertation is submitted in part-fulfilment of the requirements of the MSc Global Food Security and Development at Nottingham Trent University. In submitting it the author undertakes that it is the result of their own endeavour except where indicated through references. All other help, material, or argument used is fully acknowledged in the text.

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1. Introduction

While feeding the world is often equated with producing a sufficient amount of food, food production and its market availability are only part of one of the four dimensions of food security. As a matter of fact, oftentimes countries with a high prevalence of food insecurity record food surpluses (McMichael P. , 2000; Otero, 2012). Therefore, if food availability is met, whether a household goes food insecure is still a question of access; it needs the physical and economic ability to acquire food. However, even though food might be available and accessible, it might still not fulfil people's nutritional requirements. The realisation of the dimension of utilisation depends on dietary diversity as well as micro- and macronutrient intake which might be endangered by contaminated food or drinking water and untreated disease such as HIV/AIDS and which can lead to malnutrition (FAO, 2018). Finally, food security is only accomplished when the stability of the system is fulfilled, meaning that the dimensions of availability, access and utilisation need to be stable in the long-term. It is thus commonly defined as being achieved "when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 1996).

With currently over 800 million people suffering from undernutrition and one in three from some sort of malnutrition, including over two billion being overweight or obese, the state of the world's food security is alarming. Tackling food insecurity requires addressing its complex and interacting causes, the most prominent of which are climate change, poverty and conflict (FAO, 2018). Already one of the most pressing issues of today, food insecurity will in all likelihood only exacerbate in the future as food production will be endangered

by climate variability and extremes, combined with natural resource scarcity and rapid population growth (FAO, 2018).

Part of the issue are the prevailing conventional farming practices, due to relying on vast amounts of resources such as land and water as well as fossil fuels and agrochemicals which "contribute to soil depletion and erosion, water contamination and runoff, ecological dead zones, increased greenhouse gases, and global warming" (Besthorn, 2013). Even though more sustainable farming practices such as agroecological approaches are already utilised and further promoted by organisations such as La Via Campesina, an international alliance of peasants, or the Food and Agriculture Organisation of the United Nations (FAO), projections expect that "even with the best efforts at sustainable land use, there is simply not enough land available to meet the world's growing food needs" (Besthorn, 2013). An additional area of Brazil would be needed to provide food for an expected population of nine billion in 2050, meaning production would have to double by then compared to 2012 (FAO, 2017). Therefore, while food availability is not in jeopardy today, it will most probably be in the future, calling for technological innovations to ensure future food security.

One technological innovation which is argued to have the potential to benefit future food security is Cellular Agriculture (Goodwin & Shoulders, 2013; Hocquette, 2016; Stephens, et al., 2018). The technology includes the removal of animal agriculture from the process of producing animal products, such as meat, milk or leather, and instead growing them from cells in a laboratory (Waschulin & Specht, 2018). Whether this technology actually has the potential to benefit global food security or whether it might be harmful, has not yet been thoroughly investigated.

Since it is crucial to understand the implications of a technology before it is prevalent (Stephens, et al., 2018), this paper aims to fill this gap in research. Considering the limited scope of the paper, it will solely focus on the cellular agriculture technology of producing meat from cells, Clean Meat, since it not only receives the biggest media coverage but is also most relevant to food security, as will be more closely depicted in the following chapter. This paper therefore aims to answer the two related research questions:

What is the potential impact of clean meat on global food security?

How can this impact be designed to be positive?

The structure of the paper will be as follows. The subsequent chapter will offer information on animal agriculture and clean meat as its alternative. Chapter three will provide a theoretical background on how (agricultural) technologies have impacted global food security in the past. Chapter four will describe the methods used to analyse the research questions. Since clean meat is not yet prevalent on the market, no data can so far be analysed, demonstrating the need to conduct primary research. Therefore, several qualitative interviews with stakeholders with either a background in clean meat or food security have been conducted. The interview guide is based on the literature review in chapter three. The results of the interviews as well as of a document review on the research questions will be shown in chapter five. They will be discussed in chapter six, followed by a conclusion in the final chapter.

2. Background: Conventional Animal Agriculture and Clean Meat

2.1 Conventional Animal Agriculture

Conventional animal agriculture, meaning the production, slaughter and consumption of over 150,000,000,000 animals annually (FAOSTAT 2019), leads to enormous and intertwined environmental and social issues.

Livestock production is responsible for approximately 18% of greenhouse gas emissions, mostly due to deforestation to make land available for grazing and growing animal feed as well as "nitrous oxide releases from the use of nitrogenous fertilisers, and gases from animal manure (especially methane) and enteric fermentation" (McMichael, Powles, Butler, & Uauy, 2007) as also demonstrated in Figure 1.

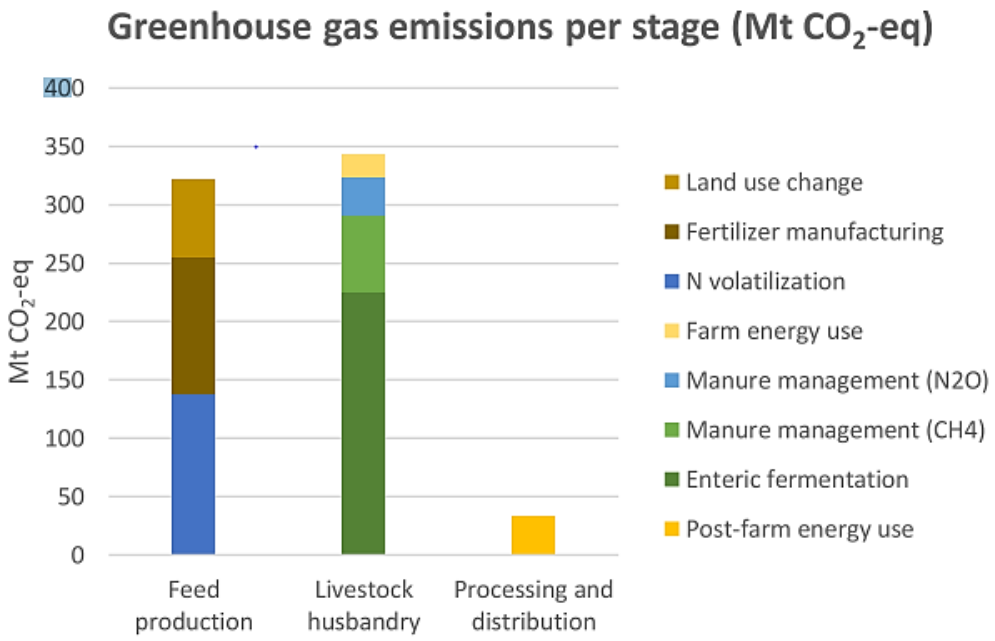

Figure 1: Total GHG emissions from the animal industry in 2010 (aan den Toorn, et al., 2018)

This makes it a key driver of climate change and exacerbates the devastating effect it already has on the environment, with livestock production being estimated to account for a third of global biodiversity loss due to pollution from fertiliser run-off, "deforestation and land conversion, overgrazing and degradation of grasslands, and desertification" (Bailey, Froggatt, & Wellesley, 2014).

The animal industry uses up a vast amount of resources, not only using three quarters of the earth's agricultural land as pasture and for growing animal feed, but also relying on an extensive amount of water resources as it is estimated that beef production, for instance, uses around nine times the amount of water than cereals on a per kilo basis (Bailey, Froggatt, & Wellesley, 2014). Industrialised meat production, therefore, is a tremendously inefficient way of resource use, especially considering it "currently relies on feeding 34% of human-edible crop calories to animals globally" (Berners-Lee, Kennelly, Watson, & Hewitt, 2018), practically leading to humans competing with livestock for food as well as to an increase in international food prices, thereby reducing poor people's financial access to food and exacerbating global food insecurity (Bailey, Froggatt, & Wellesley, 2014).

Furthermore, the average meat consumption has risen to an unhealthy amount, being associated with an increased risk of suffering from "non-communicable diseases such as heart disease, diabetes and several forms of cancer" (Bailey, Froggatt, & Wellesley, 2014; McMichael, Powles, Butler, & Uauy, 2007). Human health is similarly compromised through the widespread distribution of antibiotics to livestock, which has been shown to increase antibiotic resistance and thus affect the medicine's efficiency in treating humans (Bailey, Froggatt, & Wellesley, 2014).

With an ever-growing demand for meat – an estimated growth of 73% in 2050 compared to levels in 2010 (Gerber, 2013) – much of which takes place in developing countries

(Bryant, Szejda, Parekh, Desphande, & Tse, 2019), the previously mentioned issues will only intensify in the future. Researchers, environmental organisations and international bodies alike have therefore been calling for a reduction in meat consumption (Bickett & Koll, 2018; Schiermeier, 2019). Even though awareness for the topic is growing, so is the global meat market (OECD/FAO, 2016). As long as demand shapes the market, supplying people with meat in a more sustainable way seems the best option (Stephens, et al., 2018). A promising technology to both satisfy people's desire for meat and address the issues raised is cellular agriculture or, more specifically, clean meat.

2.2 Clean Meat

Clean meat is "artificial muscle protein" (Hocquette, 2016) produced through tissue engineering, whereby cells, sourced from an animal with a biopsy and then propagated millionfold are – with the help of a growth media - grown to be flesh biologically indistinguishable from that grown within an animal; many research papers offer a more detailed description of the process (Khan, 2019; Stephens, et al., 2018; Waschulin & Specht, 2018). For now, the clean meat space, consisting of dozens of start-ups in the process of producing various types of meat including chicken by JUST, steak by Aleph Farms, beef by Meatable and pork by New Age Meats (Cameron & O'Neill, 2019) as well as of non-profit organisations that function as their lobby such as The Good Food Institute or The Cellular Agriculture Society, are faced with numerous challenges.

The first challenge is overcoming several technological barriers that have so far kept clean meat from entering the market (Hocquette, 2016). These include developing bioreactors to produce products on an industrial scale, producing more technically complicated meats with various layers of proteins and fats such as steak, developing methods for cell sourcing and cell line creation and finally, creating "a serum-free, chemically defined medium that

optimizes for factors such as viscosity and pH while greatly reducing media cost" (Saavoss, 2019). Although these difficulties are significant, they do not "hinge upon technological breakthroughs" (Specht, 2019), meaning they will most likely be solved in the near future.

Another major challenge is of regulatory nature (Stephens, et al., 2018). While the European Commission is in charge of regulating novel foods in the European Union (EU), in the United States (US), the US Department of Agriculture and the Food and Drug Administration take joint responsibility to guarantee clean meat's safety. The regulation procedure is complicated by cases aimed at hindering the success of clean meat products such as the US Cattlemen's Association petitioning the US Department of Agriculture "to narrow the definition of meat to exclude anything that does not come from a slaughtered animal" (Khan, 2019). However, with the largest American meat and poultry producers Tyson Foods and Cargill investing in clean meat start-up Memphis Meats arises the possibility of support from the conventional meat industry which could simplify regulation (Khan, 2019).

Additionally, there is still the question of cost. Over the last few years the clean meat space was able to secure many million dollars in venture capital, which led to gradual progress in the development of products and a reduction of price from 325,000$ for a burger patty in 2013 to 11$ in 2019 (Le, 2018). While it would not be price competitive with conventional meat yet, a study on future production costs found it "likely that cell-based meat can achieve price parity with mainstream conventional meat once produced at industrial scale" (Specht, 2019).

Finally, the question of consumer acceptance remains: will people eat clean meat? (Hocquette, 2016). Research shows that people are worried about its unnaturalness, taste, texture and appearance, safety and experience a 'yuck'-factor, especially when asked about

the terms lab-grown or in-vitro meat (Bryant & Barnett, 2018; Stephens, et al., 2018). However, a US study not only found that 65.3% of consumers would be willing to try clean meat but 32.6% of them would eat it regularly (Bryant & Barnett, 2018). A more recent comparative study similarly suggests that a majority of consumers from both developed countries and emerging economies would be willing to try clean meat or even eat it on a regular basis if it had the same taste, quality and price as conventional alternatives – with 76.4% being likely to purchase clean meat in the US, 93.2% in China and 86.4% in India (Bryant, Szejda, Parekh, Desphande, & Tse, 2019). It was also shown that consumer acceptance rises when people are familiar with the technology (Saavoss, 2019; Stephens, et al., 2018) or informed about the benefits of clean meat, with the benefits of public health, environment and animal welfare being especially useful (Bryant & Barnett, 2018). Clean meat is expected to be especially well-received by consumers if it enters the market after other cellular agriculture products such as leather which will be easier for consumers to accept and thus eases the way for the acceptance of food products (Stephens, et al., 2018; Shapiro, 2018).

As could be shown, the clean meat space will most likely succeed in bringing its product to the market, if it can appropriately react to the previously mentioned challenges. This would potentially come with a number of benefits, reaching from animal welfare and human health to freeing up resources and drastically reducing the animal industry's negative impact on the environment and climate (Gasteratos, 90 Reasons to Consider Cellular Agriculture, 2019; Waschulin & Specht, 2018).

Comparisons between conventional and clean meat production highlight environmental and climate benefits of clean meat. A study on European meat production found that it results in 78–96% less greenhouse gas (GHG) emissions, 99% less land use, 82–96% less water

use, and 7–45% less energy use compared to conventional animal agriculture, with the numbers varying for different kinds of meat and different possible ways of production and emissions potentially being even lower when relying on renewable energy (Tuomisto & Teixeira de Mattos, 2011). More conservative numbers assert 76% less GHG emissions, 80% less land use and 94% less water use with estimations once again varying between types of meat (Gasteratos, 2017). Other benefits include the end of pollution and water contamination by 1.75 billion tons of animal waste as well as pesticides used in animal agriculture (Gasteratos, 2019). It has substantially lower eutrophication potential than conventional beef and pork (although a comparable amount to poultry) and results in a higher energy return on investment than conventional livestock products (Saavoss, 2019). As mentioned in section 2.1, rainforest deforestation is a key driver of biodiversity loss and global warming and is primarily caused by the animal industry – approximately 90% of the deforestation of the Amazon rainforest is due to livestock (Margulis, 2004) – which highlights the potential of clean meat for saving the rainforest.

Eliminating farm animals from meat production would not only come with various benefits for humans and the environment, but, most notably, for the billions of animals themselves, who currently suffer from cruel conditions prevalent in factory farming. With a technology managing to mimic meat, animal welfare cannot be overruled by consumer preferences anymore, which makes it necessary for live meat producers to prove farm animals benefit from living productive lives (Driessen & Korthals, 2012).

The consumption of clean meat would also come with public health benefits. While "tailored production could contribute to improved nutrition, health and wellbeing" (Stephens, et al., 2018), for instance by replacing saturated fats with unsaturated ones, standardised production could decrease the risk of antibiotic resistance and disease since

no antibiotics are required and there is no contamination from faecal material without the use of live animals (Saavoss, 2019).

The uptake of clean meat could come with numerous economic benefits. It could not only likely be competitive with conventional meat products as soon as it is produced on a large scale (Specht, 2019), but also create new jobs, create less waste and be independent from weather and climate which would ensure constant production, all of which would pose economic gains (Gasteratos, 2019).

It is also argued to be beneficial to global food security or even to be one solution to the global food crisis (Goodwin & Shoulders, 2013), increasing availability as the rising demand for meat can be met while preserving resources that can be used to grow other food (Hocquette, 2016), access as cheaper products will increase the poor's access to nutritious animal products and "enable more of the global population to have consistent access to protein" (Stephens, et al., 2018), and utilisation as the products can be made healthier, thus decreasing people's risk of non-communicable disease associated with meat consumption (Saavoss, 2019).

However, in opposition to the other assumed benefits of clean meat, which are based on empirical data for instance through Lifecycle Assessments of its environmental impact (Driessen & Korthals, 2012; Stephens, et al., 2018), its consequences for global food security are merely based on assumption. This research gap on clean meat's potential social and political consequences has been recognised within literature on clean meat, for instance by Stephens et al 2018 who then go on to argue that through "critical engagement with cellular agriculture and its ramifications, a more nuanced set of understandings will emerge leading to more robust socio-technical responses to these challenges and opportunities"

(Stephens, et al., 2018). It is therefore critical to further examine clean meat's potential impact on global food security in order to be able to design it in a positive way.

3. Theoretical Framework: Technology and Global Food Security

In order to analyse the way clean meat will impact global food security, it is crucial to determine in what ways other (agricultural) technologies have influenced global food security in the past. The interview guide will be based on this literature review.

The literature is divided when it comes to the question of whether technology has benefited or has the potential to benefit global food security. On the one hand, proponents of the *Green Revolution* have argued that the uptake of mechanisation and biotechnology has prevented famines and improved food security in developing countries, such as Mexico where it originated (Pingali, 2012). However, opponents counter that not only did its success in raising food production occur largely due to increased irrigation, but it also resulted in a tremendously unsustainable farming system increasingly dominated by few large transnational corporations (TNCs) (Shiva, 2016). They instead propose for power to return to the hands of smallholder farmers with a sustainable and holistic approach to farming (Rosset & Martínez-Torres, 2014). This dichotomy between the domination of TNCs and the food sovereignty movement is thoroughly expounded in *Food Regime Theory*.

A food regime describes where, how and by whom (what) food is produced and consumed in the international capitalistic economy and which effects this has ecologically and socially in a certain time frame. The current *corporate* or *neoliberal* food regime is characterised by the previously mentioned large TNCs dominating the world food system (Bernstein, 2016). By industrialising agricultural production, it leads to environmental destruction due to its reliance on fossil fuels and chemical fertiliser, its accountability for approximately one third of greenhouse gas emissions, soil degradation and its threat to biodiversity

(McMichael P. , 2009). Its key features among being located "within the general dynamic of liberalisation (of markets) and privatisation (of formerly public functions and services) at the core of neoliberal globalisation" (Bernstein, 2016) and food being produced far from where it is consumed, are mechanisation, *chemicalisation* and the *neoliberalisation of nature;* describing the way corporations pursue private property rights of the genetic qualities of seeds and animals (Bernstein, 2016). Thus, numerous negative consequences of the use of technology for food security become apparent.

Mechanisation

As a consequence of mechanisation, millions of cheap labourers lose their jobs in both developed and developing countries, with expectations of a "world without farmers" (Rifkin, 1996) within the next few decades becoming apparent, as outdoor farming will be replaced by laboratory food production as already the case with sweeteners and vanilla. Developing countries are especially affected as many rely on only a few key export crops, whose replacement by laboratory products leads to mass unemployment of farmers. Even the retail sector is affected with restaurants becoming increasingly automated and thus reducing labour costs (Rifkin, 1996). While people will be able to create and find new jobs, not only is the transition period painful, but, "in the race against the machine, some are likely to win while many others lose" (Rotman, 2013). Considering unemployment oftentimes leads to poverty which in turn is one of the key drivers of food insecurity, it becomes apparent how mechanisation induced unemployment negatively affects food security.

Dispossession

Seventy percent of food is already produced by smallholders and it is estimate that even agroecological farming could meet the world's food needs, making large, industrial farms

unnecessary. However, smallholder farmers are marginalised by dispossessing them either directly by land grabbing (Bernstein, 2016) or indirectly through new policies and technologies that specialise on monocropping and make smallholder farms inefficient, effectively displacing 20-30 million peasants in the 1990s, leading them into migration or into poverty and food insecurity (Otero, 2012).

Health

Within the neoliberal or corporate food regime, the consumption of industrially produced food and fast food increased, leading to malnutrition for instance due to high levels of toxicity and low nutritional value thus contributing to obesity worldwide (Bernstein, 2016).

Power and Profit

Power is unequally distributed within the current food regime with shareholder capitalism prevailing in neoliberalism, making producers and consumers in developing countries dependent upon investment funds (Burch & Lawrence, 2009). Similarly, five agrochemical companies dominate the biotechnology market, with the state regulating it mainly to their advantage and the limited number of corporations dominating agricultural production limiting consumer options (Otero, 2012). Initially driven by venture capitalists and academics, agricultural biotechnology and genetic engineering in particular have been praised as tools for sustainable development, able to contribute to solving food insecurity and other social and ecological issues. However, since it was quickly overtaken by large companies, so far, the technology has primarily contributed to the corporations own profit (Otero, 2012), for instance by using transgenic crops as animal feed which is susceptible for higher pesticide use (McMichael P. , 2000).

Capitalism

The current food regime is characterised by its "immanent destructive force of capitalism, both ecological and social, manifested with ever-greater intensity in the practices (and ideologies) of industrialised agriculture and agribusiness" (Bernstein, 2016). In addition to the social consequences of a growth-based capitalist economy such as displacement, job loss and social inequality mentioned above, it is also responsible for the global ecological crisis since industrial growth-oriented activities are breaching planetary boundaries as well as leading to "destructive behaviour and attitudes" (Zink, 2019).

4. Methods

As introduced in the first chapter, this paper aims to provide an answer to the following research questions:

What is the potential impact of clean meat on global food security?

How can this impact be designed to be positive?

Considering clean meat is not yet on the market, empirical data regarding its impact on global food security does not yet exist. This paper therefore relies on an analysis of opinion on the questions. The first section of the results chapter presents perceptions from the limited literature on the topic while the second section summarises the perceptions from expert 30-70 minute-long interviews with four stakeholders with a background in either clean meat or food security listed on Table 1.

Table 1: Interviewee Overview

Expert	Expert 1	Expert 2	Expert 3	Expert 4
Continent	Asia	Europe	America	Asia
Background	Start-Up	Food Security NGO	Non-profit Lobby Organisation	Non-profit Lobby Organisation
Method	Skype	Telephone	Zoom	Zoom

They were semi-structured with the interview guide (Appendix 1) based on the literature review in chapter three of the way (agricultural) technology has influenced global food security in the past. Based on the literature review, five interlinked themes could be distinguished, namely mechanisation, dispossession, health, power and profit as well as

capitalism. They were incorporated into the interview guide and will be referenced to in the first section of chapter five.

5. Results

5.1 Literature Review

To determine clean meat's impact on global food security at times when its market implications are still uncertain (Saavoss, 2019), it is crucial to assess its potential influence on the existing livestock industry (Stephens, et al., 2018), or – more specifically – whether it will be a disruptive technology or rather a niche market.

A part of the literature views clean meat as only one solution for a more sustainable food system by putting forward that we not only raise livestock to produce meat but also for land management purposes and by arguing that "livestock will remain of fundamental importance" while clean meat's relevance will increase nevertheless (Ford). This could go alongside the so-called 'addition effect', whereby conventional meat consumption is not reduced, but overall meat consumption increases as it is already anticipated. However, the introduction of clean meat could just as well lead to a 'substitution effect', namely a decline in the consumption of conventional meat due to it being replaced by clean meat, and thus a disruption of the market (Stephens, et al., 2018).

This would "not only affect cattle farmers but also other jobs in the meat supply chain such as feedlot workers, transporters, beef processors and butchers" (Le, 2018) as well as potentially lead to a "global-scale shift in livelihoods, practices and supply chains across multiple sectors beyond just agriculture (e.g. steel and transport)" (Stephens, et al., 2018) as did other examples of mechanisation mentioned in chapter 3. A disruption of the industry has two possible outcomes; while it could cause a drop in employment with "evidence of societal concerns relating to the end of traditional animal agriculture" (Bryant & Barnett, 2018), it could also create "the need for a workforce with a range of skills and knowledge

levels […] for example […] chemists, cell biologists, material scientists, chemical engineers, skeletal muscle scientists, technicians, meat scientists and food technologists" (Stephens, et al., 2018). It could even create new jobs since "the combination of traditional agriculture and new technologies will enable a circular economy as the majority of waste products (heat, metabolites) from cultured meat production can be upgraded for use on a farm or sold" (Stephens, et al., 2018). Since not all farmers and communities historically relying on livestock farming who might be affected by a decrease in demand for traditional animal products can be retrained for jobs in demand by the clean meat space, they need different income sources. These could include investing in cellular agriculture companies as insurance against decreased demand and specialising in different products for instance by repurposing equipment to brew beer or to produce mushrooms (Saavoss, 2019; Stephens, et al., 2018).

While the conventional meat industry might experience change due to the introduction of clean meat, its consequences for global food security also depend on the way power over the technology will be distributed. The question of power is for instance raised by large meat companies such as Tyson Foods or Cargill already preparing for the potential success of clean meat by including these novel products within their investment portfolio, which accelerates progress in the development (Saavoss, 2019) while at the same time raising concerns. These include the idea that clean meat production – due to the probability of being in the hands of big Western companies - "will only reinforce the power of multinational food companies as it was the case for GMO production" and "may also reinforce the domination of northern countries over the poorer southern countries further aggravating the difference between rich and poor countries" (Hocquette, 2016; Stephens, et al., 2018). Although the current clean meat space is highly morally motivated, there is

the risk of future producers being more profit-oriented, neglecting the many benefits which are not necessarily inherent to the technology (Stephens, et al., 2018), further attaching importance to the question of power.

More optimistic authors envision a shift to a new form of (the traditional) decentralised production with kitchen appliances for clean meat cultivation (Driessen & Korthals, 2012), sometimes combined with the 'pig in the backyard' scenario fostering the animal-human relationship by having companion animals serve communities with their cells (Stephens, et al., 2018; Van der Weele & Tramper, 2014).

5.2 Qualitative Study

Benefits, Drawbacks and Challenges

While the interviewees were mostly in agreement when asked about the benefits of clean meat, their replies about its drawbacks and challenges differed (Appendix 2-4).

Each expert declared environmental benefits of freeing natural resources and decreasing pollution and climate benefits of reducing GHG emissions and energy consumption. Other environmental and climate benefits stated were increasing biodiversity, preventing ecological disaster and increasing climate resilience by growing food in deserts. Everyone mentioned benefits to animal welfare with Regev especially stressing the point by regretting that factory farming was not discussed enough in media although it put a huge blight on humans and was a societal ill which clean meat could address by saving billions of animals from being slaughtered. While the food security expert did not address economic benefits, stakeholders from the clean meat space highlighted that its costs would decrease with technological progress, allowing for cost-competitiveness with conventional meat and a quicker and thus more effective production process. Mentioned social benefits were all

concerned with public health, emphasising the potential to guarantee meat's safety by eliminating the risk of antibiotic resistance as well as disease originating from the "direct contact between humans and animals raised in terrible conditions" (Expert 4). Although Expert 4 believed plant-based to be healthier, considering he could not observe a global movement towards plant-based diets he highlighted the potential to provide people with healthier meat, just like other experts who underlined the possibility of increasing meat's nutritional value for instance by reducing its fat content. Other benefits include a more transparent supply chain, producing more output with less input and the reference to an article providing '90 reasons to consider cellular agriculture'. Expert 2 and Expert 3 also mentioned possible benefits to food security such as clean meat's ability to strengthen food security by addressing animal agriculture issues as well to feed people despite the rising demand for meat, which would otherwise not be deemed possible.

While Expert 1 did not specify any drawbacks to clean meat, albeit referring to various challenges as listed in the following section, the other interviewees from the clean meat space mentioned different problems. Expert 3 on the one hand indicated the economic drawback that not every product will be available right away, the social issue of increased unemployment as well as the possible risk of contamination of the cell supply through aimed attacks. Expert 4 on the other hand focused on the technology's inefficiency in resource in- and output compared to plants, again emphasising the advantages of plant-based diets concerning the environment, as well as on clean meat not being proven economically feasible yet as he argued that it would otherwise at least be sold as an high-end product in restaurants, thereby highlighting idealised scale-up analyses meant to attract investors. Expert 2, from a food security background, declared a number of drawbacks of the technology. While she argued that it would only be beneficial to the climate if its energy

consumption could be reduced or if renewable energy was used, she concretely saw how the technology might negatively affect the environment since it could not only increase agricultural industrialisation but also neglect the fact that ecological farming relies on animals. Due to its high production costs and production being highly technical, it would likely stay in developed countries, possibly negatively affecting developing and emerging economies who could not compete. This unequal competition and increased industrialisation could then increase unemployment. She also recognised the risk of the technology increasing the animal-human divide and concluded with stating that it could only address symptoms, but not root causes of food security.

The interviewees were also aware of various challenges for clean meat, ranging from technological over consumer acceptance to regulatory and cost issues. Technological challenges included the difficulty in mimicking meat, the remaining technological problem with large-scale production since the first huge facility was only planned for 2040 and the fear that start-ups who promise a lower price than Perfect Day[1] are behind in their development. There was also the challenge of economic feasibility which Expert 1 believed to be addressed with large-scale production. He also mentioned regulatory issues such as legislation barriers and finally the issue of consumer acceptance which was similarly addressed by the other experts. However, while Expert 2 saw a trend to less industrial and more natural foods, Expert 3 believed that people would buy the product if it would be their best option. In summary, the prevailing opinion of stakeholders seems to be that while there are drawbacks and challenges and we should not rely on clean meat as the solution to all

[1] Cow-less dairy start-up Perfect day launched ice cream for 20$ per pint plus shipping in July 2019 and sold out within hours: https://about.bgov.com/news/move-over-fake-meat-cow-less-milk-and-cheese-are-on-the-way/ [accessed: September 7th, 2019]

problems, it does come with many benefits, some of which we can hardly abstain from if we aim for a sustainable future.

Global Food Security

Experts had different opinions on clean meat's impact on global food security (Appendix 5). Expert 1 found it an important aspect which was sometimes overlooked in the clean meat space, thereby highlighting its relevance. Expert 4 called clean meat a "double-edged sword" as it was both expected to be beneficial and to be harmful to global food security, while its exact consequences were said to be yet unclear; an opinion shared by Expert 3 who nevertheless thought the benefits to outweigh the risks. Expert 2 held a contrary opinion, not only stating that the technology would likely not be beneficial, but in fact even harmful to food security. In order to benefit it, which it is deemed not to be able to, she suggested strict regulations to be applied and risks to be assessed, the reasons for which will be become clear in the following results on food security and in the later section on industry and power. The results on food security are sorted according to its different pillars as defined in the introduction.

In regard to availability, clean meat's potential to preserve resources otherwise used for producing animal products which could then be used to grow crops for feeding people was highlighted by Expert 1, Expert 2 and Expert 4. Expert 3 also mentioned the benefit of increasing the availability of meat through large-scale production all-year round while Expert 4 emphasised the possibility of addressing waste inherent with animal agriculture. Expert 2, in case the energy problem was addressed, as well as Expert 4 revealed a link to climate change mitigation, due to increased deserts leading to worse conditions for agriculture and the technology benefiting the climate. Additionally, Expert 4 viewed a chance for climate change adaptation, since clean meat could be grown anywhere as long

as the isolation from the outside heat is guaranteed, which he admitted could be a cost and infrastructure problem in remote areas. Similar to the remark by Expert 4, Expert 2 saw the issue that production would probably take place in developed countries and thereby increase dependencies.

When asked about the pillar of access, the views of Expert 1 differed from those of the other stakeholders. He highlighted benefits to both financial access as he believed it to be one day cheaper than conventional meat and physical access as meat could be produced anywhere. Expert 2, Expert 3 and Expert 4 all emphasised that food security is not as much a problem of resources, but a problem of resource allocation or distribution, which would not be addressed with clean meat, as it for instance could not address food waste.

"One technology is not sufficient in addressing global food insecurity." (Expert 2)

Regarding utilisation, listed benefits include healthier meat and increased food safety as well as that the lack of animal protein for undernourished people could be addressed. However, Expert 2 worried that the prevalence of clean meat could increase overall meat consumption, which would again be harmful, while Expert 1 argued that the goal is only to replace unhealthy meat and not to increase overall consumption. Expert 4 finally mentioned the issue of overnutrition as a food security issue which clean meat could hardly address.

Concerning the stability of the pillars and the impact of the technology in the long-term, opinions again differed. While Expert 2 feared that it could increase power inequalities between the North and South as well as in-between countries and Expert 3 found it important that other food security were similarly addressed, Expert 1 and Expert 4 argued clean meat to be a sustainable solution under certain conditions. While Expert 1 said it to

be one of many solutions if a strong vision could be kept, Expert 4 highlighted the need to address certain problems the technology could cause politically, in order for it to be a sustainable solution. These problems are further depicted in the following section on industry and power.

Industry and Power

The response to the question of whether clean meat was going to be a disruptive technology was divided (Appendix 6) While Expert 2 and Expert 4 found it hard to predict, Expert 3 stated that it will 99% be disruptive, even imagining a transformation from smallholder farms to cell-based farms as technology can change drastically (especially when keeping in mind technologies such as fusion or artificial intelligence).

"[Our] products will reach the market within the next three to four years." (Expert 1)

In opposition, Expert 4 and Expert 1 both doubted that the technology will be disruptive, although for different reasons. While Expert 1 believed it to be an innovation that integrates into the current industry by offering a better alternative and only aims to replace industrial farming, Expert 4 was rather pessimistic considering promises for its uptake were already broken. [2] He also specified that it would mostly be relevant for cities in developed countries considering they produce most of the emissions linked to animal agriculture, have the biggest population and the biggest demand for meat, while remote areas would most likely be unaffected since clean meat would hardly be available in self-sustained communities.

[2] The clean meat start-up JUST teased its launch of chicken by the end of 2018, but never launched: https://www.plantbasednews.org/lifestyle/chicken-will-be-first-clean-meat-to-hit-market-this-year [accessed: September 7th, 2019]

The interviewees mentioned both positive and negative industry impacts (Appendix 6). Expert 2 argued that big investment in the technology should rather be used for causes such as investing in rural areas, mechanisation, water security, health access and education on gender equality, as these issues affect the poor in developing countries. While Expert 3 thought it to be a better system, he admitted it to not necessarily be perfect as it would realistically involve job loss. However, he highlighted that there would be opportunity for farmers to get involved and to prepare, especially with start-up companies wanting to help the transformation for instance by promoting growing crops for media supply for income generation. Expert 1 noted that farmers could instead produce grass-fed organic meat, while Expert 4 relied on political solutions - due to farmers supplying food for the entire country being affected by the rising competition - such as free job retraining (similar to other industries such as coal mining), job guarantees or green job programs that could include jobs where skills previously used in agriculture could be transferred, like building solar or wind farms, planting trees or cleaning up the environment.

Finally, interviewees were asked on their opinion on the question of power (Appendix 6). While Expert 1 was convinced that it would remain with the start-ups despite TNC's investing, Expert 2, Expert 3 and Expert 4 were each opposed to that. Expert 2 expected developed countries and large corporations such as Cargill to be in charge since they would continue to buy start-ups and are correspondingly already dominating the market from production to the consumer by setting prices. Expert 4 similarly mentioned large meat companies without ethical motivations to be in charge, considering they are needed for funding as progress through public research was slower than demanded by the political situation. He however argued that while it was debatable whether the monopoly of large

TNC's was inherently bad, even if the situation was unethical, it was deemed a necessary evil.

"Traditional meat companies will be in charge of the technology."

(Expert 3)

Expert 3 views differed in that regard. While he also believed traditional meat companies who are already supporting plant-based meat would be in charge as they do not only have financial capabilities but also already gained the public's trust, he thought the idea to be strong enough to withstand the unethical nature of meat companies.

6. Discussion

Different views on whether clean meat will be a disruptive technology emerged from both the literature review and expert interviews. It is therefore still hard to predict whether an addition effect, a substitution effect or an integration into the current industry will take place. Most common ground can likely be found in the prediction that – if certain challenges can successfully be addressed – once reaching cost-competitiveness clean meat could potentially one day replace factory farming, however not the production of grass-fed organic meat or land management through farming animals.

This could still lead to a shift in global livelihoods in either direction since it could on the one hand lead to unemployment and increase inequality and dependencies, but on the other hand create new jobs with innovative examples including producing crops as growth media or transferring skills from agriculture to other projects concerned with the environment within green job programs. To guarantee job safety, support from both politics and the clean meat space is needed.

Another factor influencing clean meat's potential future impact is the way power is exerted. While pig in the backyard-scenarios were mentioned in literature, the prevalent expectation among researchers and interviewees is large meat companies being in charge of the technology considering they are already investing in start-ups. Interestingly, the assumed consequences of this development differ. While researchers and the food security expert expect this development to reinforce the control of TNC's over the food system and increase inequality between North and South and call for strict regulation, stakeholders from the clean meat space either disregard the issue or believe in the idea withstanding the unethical nature of meat companies.

While the future impact of clean meat partly depends on the interrelated questions of whether it will disrupt the industry and who will be in charge, a few conclusions can be drawn regarding global food security.

Not only have researchers and interviewees from both a food security and clean meat background recognised its relevance for food security but agree that it could be one solution for a more sustainable food system, as long as certain issues are addressed. However, other food security issues such as overnutrition, the lack of access and food waste desperately need to be solved accordingly, as one solution cannot solve food insecurity.

Considering rural areas and self-sustained communities would most likely not be negatively impacted as the technology is primarily aimed at urban areas where most of the demand for meat occurs, its direct benefits of access and utilisation are deemed restricted to cities as well. Rural areas could still benefit from preserved resources, especially with a rising demand for meat which is threatening resources and could not be sustained without technological solutions such as clean meat, as well as from its potential for climate change mitigation.

7. Conclusion

The impact of clean meat on global food security will differ for urban and rural areas. As production will primarily take place in cities, urban consumers will likely benefit from increased access to a healthy alternative to conventional meat while rural areas could benefit from clean meat's potential to mitigate climate change and preserve resources that could be used for producing crops to feed humans. This however depends on whether clean meat will disrupt the industry and who will be in charge. Recommendations to ensure a positive impact of the technology include strict regulation as well as political solutions aimed at preventing unemployment due to a possible disruption of the industry, which could include green job programs, job guarantees or retraining.

While both the literature on potential social and structural impacts of clean meat as well as the number of interviews were very limited, the study was nevertheless able to fill the gap in research on the potential impact of clean meat on global food security, which can contribute to raising awareness to the relevance of food security and beyond that encourage stakeholders to find sustainable solutions, on which further research is needed.

"If there is not substantial change, our world is going to change in some irreparable ways. Clean meat would buy us time to develop an even better solution in the future." (Expert 4)

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9. Appendix

Appendix 1: Interview Guide

INTRODUCTION

What is your job? What does it entail?

1. What do you think are the benefits of clean meat?
2. What do you think are its drawbacks?
3. What are problems for its uptake?
    i. How can be dealt with those?

FOOD SECURITY

4. How relevant is clean meat for food security?
5. What could be its positive impacts on food security?
6. What could be its negative impacts on food security?
    i. Livestock production is central to the economy of developing countries. What does clean meat implicate for food sovereignty?

POWER

7. Who will be "in charge" of the technology? What are the implications of this for food security?
8. Large meat companies are investing in clean meat start-ups. What are the implications of this trend for food security?

THE FUTURE

10. Will clean meat be a disruptive technology?
11. How can policies and practices be designed in a way that the technology is beneficial global food security?

CONCLUSION

12. What else should we talk about regarding this topic? Have we missed something you believe is important?

Appendix 2: Benefits of Clean Meat

Benefits	Expert 1	Expert 2	Expert 3	Expert 4
Environmental	Frees natural resources	Frees natural resources that would otherwise be used to grow soy as animal feed	Mentioned	Decreases resource usage (land and water), pollution, deforestation
	Decreases pollution			Increases biodiversity
				Prevents ecological disaster
Climate	Fewer GHG emissions	Saves CO^2	More possibilities with additional technological progress such as fusion	Fewer GHG emissions
	Increased climate resilience by growing food in deserts			Lower energy consumption
Animal Welfare	Mentioned	Mentioned	Mentioned	Saves billions of animals from being slaughtered
				Factory farming is not discussed enough in media and puts a huge blight on humans as it is a huge societal ill
Economic	Costs will decrease	/	Costs will decrease with technological progress	Mentioned
	Quicker production process			
Social	Higher nutritional value	Higher nutritional value through less fat	Mentioned	No antibiotic resistance
	Food safety			Health benefits due to lack of direct contact between humans and animals in terrible conditions
				Option for healthy meat (since there is no global movement to plant-based, which would be healthier)
Other	Transparent supply chain	Feed people despite rising demand for meat (otherwise impossible)	Ability to strengthen food security by addressing animal agriculture issues	It is a good way and while there might be a better way in the future, it would buy us time to develop a better solution.
	Less input, more output		Wrote article on 90 reasons to consider cellular agriculture	"If there's not substantial change […] our world is going to change in some irreparable ways."

Appendix 3: Drawbacks of Clean Meat

Drawbacks	Expert 1	Expert 2	Expert 3	Expert 4
Environmental	/	Ecological farming depends on animals Technology would increase agricultural industrialisation	/	Not as good as growing plants which makes plant-based diets better Inefficiency in resource in- and output
Climate	/	Only beneficial if energy consumption is reduced or renewable energy is used	/	/
Animal Welfare	/	/	/	/
Economic	/	High production costs, highly technical Production would likely stay in developed countries	Not every product will be available right away	Not proven economically feasible as it's not sold yet, not even as a high-end product in restaurants (due to an idealised scale-up analysis which attracts investors)
Social	/	Increased unemploy-ment due to increased unequal competition and increased industrialisation	Increased unemployment	/
Other	/	Only addresses symptoms, not root causes It could increase animal-human divide	Possible risk of contamination of cell supply (through aimed attacks)	/

Appendix 4: Challenges for Clean Meat

Challenges	Expert 1	Expert 2	Expert 3	Expert 4
Technological	Difficulty in mimicking meat	/	Technological problem with large-scale production (first huge facility planned for 2040)	If Perfect Day's clean ice cream sold for such a high price, companies that promise a lower price must be lying which implicates they are behind in their development
Consumer Acceptance	Mentioned	Trend to less industrial, non GMO and more natural foods	Issue, however, if it is the best option, people will buy it	/
Regulatory	Legislation barriers	/	/	/
Cost	Large-scale production will decrease costs	/	/	Economic feasibility

Appendix 5: Clean Meat and Food Security

Food Security	Expert 1	Expert 2	Expert 3	Expert 4
Relevance	Important aspect, sometimes overlooked in clean meat space	Not beneficial, possibly even harmful	Risks and benefits	Double-edged sword for food security
		To benefit global food security, which it is deemed not to be able to, strict regulations need to be applied and risks need to be assessed	Impact yet unclear but probably more beneficial	
Availability	Preserving resources which can be used to grow crops	Preserving and using less resources	Increase availability of meat through large-scale production all-year round	Conserves resources otherwise used for animal products and frees resources for starving people
		Climate benefits when energy problem is addressed		Link to climate change mitigation: increased deserts lead to bad conditions for growing crops and clean meat benefits the climate
		Will probably be produced in developed countries and increase dependencies		Link to climate change adaptation: you can grow clean meat anywhere as long as the isolation from the outside heat is guaranteed (cost and infrastructure problem in remote areas)
				Could address waste inherent with animal agriculture
Access	Financial: will be cheaper than conventional meat	The poor lack access to food in general, which would not be addressed with clean meat	The poor lack access due to a distributional problem	Not as much a problem of resources but a problem of resource allocation (if there was a will to solve it, we could)
	Physical: producing meat anywhere			It would not address food waste
Utilisation	Healthier meat	Healthier meat	Food safety benefits	Issue of overnutrition which clean meat can hardly address
	Goal is replacing unhealthy meat, not increasing consumption	Lack of animal protein for undernourished people can be addressed		
		Could increase overall consumption which would be harmful		
Stability	One of many sustainable solutions, if strong vision can be kept	Could increase power inequality between North & South and in between countries	Other food security problems need to be addressed	Sustainable solution if problems are addressed politically by taxing TNC's and investing in green jobs program

Appendix 6: Industry and Power

Industry & Power	Expert 1	Expert 2	Expert 3	Expert 4
Disruptive Technology	Not a disruptive technology, innovation that integrates into current industry and offers better alternative	Whether it will be disruptive depends on consumers	It will 99% be disruptive	Although a prediction is hard to make, clean meat will not be disruptive, considering promises are already broken
	Aims to replace industrial farming	If it is, it might be harmful to food security if other solutions are not conquered	There might be a transformation from smallholder farms to cell-based farms as technology changes drastically (keeping in mind technologies like AI or fusion)	Mostly relevant for cities in developed countries as they produce most of the emissions linked to animal agriculture, have the biggest population and the biggest demand for meat, while remote areas would most likely be unaffected since clean meat would hardly be available in self-sustained communities
Positive Impact on Industry	Many farmers can produce grass-fed, organic meat instead	/	There will be opportunity for farmers to get involved and to prepare Start-up companies want to help the transformation (for instance by promoting growing crops for media supply for income)	Solutions could include free job retraining (similar to other industries such as coal mining), job guarantees or green job programs with skill transfer
Negative Impact on Industry	/	Big investment in this technology could be used better for causes such as investment in rural areas, mechanisation, water security, health access and education on gender equality	It will realistically involve job loss, however there is opportunity It's a better system, but not necessarily perfect	Farmers supplying food for the entire country would be affected by the rising competition, making political solutions necessary
Power	Will remain with start-ups, with TNC's investing	Developed countries and large corporations such as Cargill will be in charge since they will buy start-ups and are already dominating the market from production to the consumer and set prices	Traditional meat companies (who are already supporting plant-based meat) will be in charge (for financial and public trust reasons)	Large meat companies without ethical motivations will most likely be in charge, since they are needed for funding; although public research was funded initially, progress was slower than demanded by the political situation
			Idea is strong enough to withstand unethical nature of meat companies	Debatable whether the monopoly of large TNC's is inherently bad; even if it is unethical, it is deemed necessary