UNIVERSITY
OF TWENTE.

Sustainability Transitions in Milk Production

How Livestock-Based, Socio-Technical Systems can Transition to Plant-Based Production Methods

Jerfy H.B. ter Bekke

Faculty of Behavioural, Management & Social Sciences

Philosophy of Science, Technology & Society

P.O. Box 217, 7500 AE, Enschede, The Netherlands

25 April 2019

Master Thesis (30 EC)

First supervisor Prof. dr. ir. Fokko Jan Dijksterhuis

Second supervisor Dr. Kornelia Konrad

ABSTRACT

The animal agriculture industry is among the main causes of climate change, deforestation, and depletion of arable land. However, a plant-based diet offers multiple potential benefits in terms of health, sustainability, and animal well-being. In recent years, developed countries have seen a rapid increase in the number of people adopting a plant-based diet. The milk industry is feeling the impact of these changes in consumer behavior, thus forcing adaptation. This thesis explores the following research question: when viewing the milk industry as a socio-technical system, what are the potential pathways for a transition from dairy-based to plant-based milk production? The Multi-Level Perspective is used to map the socio-technical system of the milk industry, after which various transition pathways are discussed. Meanwhile, a case study (a company that switched from dairy-based to plant-based milk production) is used to contrast theory with practice. Two transition pathways in particular are likely to occur, each mainly depending on the (state of) development of niche technologies. Another observation is that a radical overhaul in production methods can initially be accomplished by regime actors without significant changes or support to the socio-technical landscape. The thesis finishes with recommendations on how a sustainability transition of this sort can be stimulated and supported by companies, government, and consumers.

ACKNOWLEDGEMENTS

The completion of this project has surely taken its sweet time, but it would have been far longer without the amazing help and support that I received from the people around me. First and foremost, I am very grateful for my supervisors. Robert-Jan, Fokko Jan, and Kornelia: you all provided clarity and challenges in exactly the right amount. Thank you for the insights you shared and the growth you enabled. Secondly, the unconditional support from my parents, sister, and other family members and friends provided me with the space and motivation to finish this project. Thank you for your patience and everything you've done. Thirdly, I'm thankful for the PSTS graduates that were friendly (and arguably crazy) enough to read this thesis multiple times to provide me some much-needed feedback. So, Jonathan and Alice in particular, thank you for your efforts; it made a difference.

As much as I'd love to write down the names of everyone who helped me at any point during this journey and how they contributed, that would unfortunately mean I'd probably be writing indefinitely. So, I close simply by saying: thank you to everyone who helped and supported me in any way, shape, or form. If you feel like that might include you, it does. I am very happy to be surrounded by such an amazing group of people.

TABLE OF CONTENTS

PREFACE

As a child I've always wondered how it's possible to produce and consume as much as we do. I never heard anyone mention that things might run out; as if the resources on this planet are infinite. Being a child, I passed this off as "I probably just don't know enough; the adults know what they're doing". As I grew up, this naive notion faded. As I delved more deeply into how we, as humanity, are using this planet and to what ends, it became clear that there is a long road ahead of us.

I started eating plant-based more than half a decade ago and I noticed how easy it was (compared to how difficult I thought it would be). From there started a journey into learning more about the various factors related to food production and consumption, including health, sustainability, animal wellbeing, and more. This thesis is an attempt at a deeper understanding of the role that technology plays, as well as an exploration into how we can change the current systems of food production.

Thankfully, this attempt at a deeper understanding has been quite successful, both widening and deepening my knowledge and insights on these issues. Along the way I started recognizing what I wrote about. It is difficult to verbalize specifically what I picked up from this exploration, but I can confidently say I learned more than I expected to learn, and it will certainly shape the activities I engage in in the future.

1. INTRODUCTION

The food industry is the largest industry in the world and is likely to maintain its dominant position due to a growing and increasingly wealthy global population (Murray, 2007). Oftentimes, this additional wealth is accompanied by an increased consumption of processed foods and animal products such as meat and dairy; as poor countries grow economically, their consumption patterns usually start to mimic those of wealthier nations (Msangi et al., 2014). Some of the main downsides of Western consumption patterns may therefore also be exacerbated. For example, animal agriculture is among the leading causes of climate change (FAO, 2006a; Goodland & Anhang, 2009) and environmental degradation in general (Oppenlander, 2013). The Food and Agriculture Organization (FAO) of the United Nations predicts that the growing global demand for meat will increase by 68% and the global demand for dairy will increase by 57% between 2000 and 2030 (FAO, 2006b). The animal agriculture industry accounts for approximately 80% of all greenhouse gas emissions of the total agricultural sector (the latter containing both crops and livestock) (FAO, 2006a). Given the serious consequences of climate change and an ever-increasing world population, more emphasis needs to be placed on the environmental impact of the foods we choose to consume. Long-term health and sustainability are essential considerations for any food production system that will have to support the whole of humanity.

A plant-based diet may yield significant benefits in multiple areas such as health, climate change, and animal well-being. Furthermore, environmental issues such as depletion of soil, deforestation, ocean dead zones, and the exhaustion of fresh water resources will also likely have more positive outcomes when switching to an increasingly, and preferably complete, plant-based diet (Oppenlander, 2013). Such a transition will not solve any of these issues on its own, but it will be a significant step towards solving them. Moreover, none of these issues can be resolved without making changes to food production and diet. A societal and industrial transition away from animal products and towards plant-based foods is a promising and necessary discussion to have in the context of creating healthier and more sustainable food.

The onus for such a change is not on any single actor, but necessitates a collective effort. A transition away from animal products requires changes in consumption patterns, production processes, and legislation related to stimulating and supporting such a transition. This raises questions regarding what such a transition looks like, what it requires, who and what the relevant (f)actors are, and what the consequences might be. Research and reports from different fields focus on various aspects of this topic, for example: policy-oriented advice for governments on diet (RLI, 2018), marketing activities and responsibilities pertaining to (a plant-based) diet (Beverland, 2014), or consumer perceptions of a plant-based diet (Lea, Crawford, & Worsley, 2006).

This thesis employs a multi-level perspective (MLP) on large socio-technical systems in order to explore how the milk industry can shift away from animal products and instead move towards plant-based products. Some disciplines (e.g. economics, marketing, or sociology) blackbox the role that technology plays. Research on socio-technical systems aims to explore the role of technology beyond its technical aspects by focusing on how it is composed of and influenced by, for example: materials, rules, users and producers, and hardware and software. Social and technological domains co-shape each other, thereby indicating a link between economics and technological innovation and development. The MLP is uniquely qualified to help to understand the transition from dairy to plant-based alternatives on the level of socio-technical systems. Furthermore, the type of technological transition at the core of this thesis is a sustainability transition. Such transitions are highly complex, long-term processes, since they require systemic changes across large parts of the overall configuration of technologies, consumer practices, knowledge, infrastructure, and policies (Elzen, Geels, & Green, 2004) and the MLP as a framework was created specifically for such analyses (Geels, 2004).

To ensure that this exploration is not purely theoretical, a case study is used. Some companies have already started to shift away from animal products and can therefore provide a more practice-based perspective to complement the theoretical perspective. One such company is Elmhurst, which was originally completely dairy-oriented and has recently successfully transitioned to producing and selling plant-based milks as an alternative to dairy products. Elmhurst's re-orientation can help to shed light on how such technological transitions can be made effectively which will help ground and supplement the theoretical framework by exploring what happens in practice.

The socio-technical system central to this thesis is that of milk production. Plant-based milk substitutes are largely used in the same way as dairy milk. Declining dairy sales and increasing sales of plant-based alternatives indicate that there is a growing consumer preference for one type of milk production over another (i.e. plant-based rather than animal-based production) (Garfield, 2017; Hancox, 2018). Therefore, this thesis concerns itself with how the milk production industry, which is currently predominantly animal-based, can transition to making plants the main resource for milk (substitutes). Elmhurst is still a company that produces and sells milk, but it changed its production process and the basic resources it bases its products on. If the current trend of people adopting a plant-based diet continues, there will be an increasing amount of companies looking to offer plant-based alternatives to animal products. If sales of animal products keep decreasing, then transitions away from livestock-based food production will likely become more commonplace. Hence, the research question is: when viewing the milk industry as a socio-technical system, what are the potential pathways for a transition from dairy-based to plant-based milk production?

A relevant distinction to keep in mind throughout the thesis is that "milk industry" refers to that section of the overall market that focuses on producing milk. For the purposes of this thesis, the dairy industry is considered to be a sub-section of the milk industry, namely the animal-based milk producers. Plant-based milk producers are the other sub-section of the overall milk industry. Also, since milk production is done by companies, the analysis focuses on how companies operate and how they might change their production process.

1.1. Thesis Contents and Contributions

After outlining the contents of this thesis and its methodology, I introduce and describe the role that Elmhurst will play throughout this thesis as a case study. I subsequently move on to clarify why I focus on a switch to plant-based alternatives to animal products, along with an exploration of plant-based food trends in the developed world.

Chapter two introduces the main theoretical framework of this thesis. Since socio-technical systems are taken as the central perspective through which to explore the possibilities for a technological transition, a brief overview of the history of this field is given. Afterwards, the main model (the MLP) and its accompanying analytical distinctions used in subsequent chapters will be introduced, along with reasons for why the MLP is relevant for this particular exploration. The MLP revolves around mapping socio-technical systems and how innovations are integrated into these systems. It does so by first creating a network that uses hubs of human activity (e.g. education, production, distribution) and mapping how these are linked to each other. The second step involves exploring the various rules and practices that add dynamics to the sector. The third part of the overall model relates to how transitions are brought about and how these transition processes work. I then go on to discuss some of the main criticisms leveled at the MLP and some of the issues that are raised by applying this model to the topic of dietary transitions. Lastly, I will present some of the main difficulties involved in sustainability transitions and some of the work that has been done in this area.

Chapter three conceptualizes the milk industry as a socio-technical system. There are several sub-questions that will help answer the main research question, starting with the following two sub-questions: (1) What is the socio-technical system of dairy production? (2) What is the socio-technical system of plant-based milk production? The first section of this chapter aims to answer these questions by mapping the core activities, elements, stakeholders, and technologies that play a significant role in the production of dairy products and their plant-based alternatives. Understandably, this sector does not exist in a vacuum, but is entrenched and interconnected with other sectors as well. Given that the case study is an American former dairy company that shifted to produce alternatives to dairy, the socio-technical system will focus on reflecting the American dairy industry.

The answers to the previously mentioned sub-questions provide a comprehensive picture of the milk industry's socio-technical system. Subsequent sections of this third chapter take these answers as a starting point to explore transition pathways in the milk industry. Elmhurst's shift from one production method to another is analyzed, as well as the ways in which dairy-based milk production can switch over to plant-based milk production in the overall sector. The last portions of this chapter concern the feasibility of Elmhurst's type of transition for similar companies, and how sustainability transitions such as the one described in this thesis can be stimulated and supported.

The fourth and final chapter answers the main research question. I combine all the various answers and analyses to form a more coherent and comprehensive picture of the (so far) separately discussed aspects of (1) the socio-technical systems of milk production, (2) how technological transitions take place, and (3) which transition pathways are most likely to take into consideration. I also explore what the perspective of socio-technical systems has offered in terms of insights and I offer some suggestions for future research on this topic. I conclude the thesis with a summary.

The primary aim of this thesis is to explore how a harmful production method can be supplanted with a more sustainable one. This is done by analyzing the milk industry as a socio-technical system, thereby taking into consideration the multiplicity of factors and roles that are involved with technological practices. With an ever-growing number of people on the planet and facing the undesirable reality of climate change, there is an increased necessity for sustainable food production. The identification of potential pathways for a technological sustainability transition can contribute to that field. Specifically, this is done by exploring how companies and industries that currently produce animal products can transition effectively towards producing plant-based alternatives.

1.2. Transitioning to Plant-Based Products: a Case Study

As mentioned, some companies are already making changes in their production system to accommodate an increased demand for plant-based alternatives to animal products. Since the transitions that this thesis discusses are already starting to happen, some of these companies may provide useful insights as a case study. The real-world transitions and the analytical frameworks can be compared and contrasted in this way.

In this thesis I will use Elmhurst as a case study of a successful shift of animal-based to plant-based foods. Elmhurst is close to a century old and used to be a dairy company, primarily engaged with selling milk. Over the past two years they have transitioned to producing and selling various plant-based milks, including oat, cashew, almond, and hazelnut milk. The main reason for this shift was a decline in dairy consumption and sales, making it increasingly difficult to remain competitive (Garfield, 2017). By bringing in food scientists, Elmhurst developed their own method of producing plant-based milks that would appeal to consumers, focusing on nutritional content, taste and texture, price, and sustainability. Now, with a revised production system, Elmhurst seems to thrive as it is already selling significantly more than they initially expected (Fox, 2017).

In order to best describe Elmhurst's new production process and exploring how it compares to dairy-based milk production, I contacted Elmhurst for further clarification. Unfortunately this was not very fruitful, so descriptions of Elmhurst's new socio-technical organization are largely based on the contents of their website as well as various news articles. Given this restriction, attempts at maintaining accuracy and avoiding speculation necessitated more general descriptions. However, for some of these descriptions this is not an issue, since some parts of Elmhurst's overall organization are unlikely to have changed much.

By extension, the limited contact with Elmhurst also complicated accurate descriptions of the dairy-based production system. While more information is available for that portion of the analysis (since dairy-based milk production is far more common), that information is more descriptive of the overall dairy industry. Given the variations that can exist between companies, even those producing the same products, that information does not do much to clarify some of the issues or changes that Elmhurst experienced when they switched to plant-based milk production.

Elmhurst is a company that has successfully made the move from animal-based foods to plant-based alternatives to those foods. These successful companies may help to provide insights and raise questions that may not come up when simply relying on theoretical frameworks. Therefore, Elmhurst will be used alongside the theoretical model throughout the thesis as a continuous link between theory and practice.

Strictly speaking, Elmhurst's shift was not a sustainability transition from their perspective. They transitioned primarily due to market demands, rather than environmental concerns. Nevertheless, with the arguments and evidence supporting a move towards a plant-based diet, their transition can be considered a sustainability transition from the outsider's perspective, hence Elmhurst's inclusion as an example of such a transition. Furthermore, a transition away from animal products towards plants is the kind of transition that is required for more sustainable food production, so ideally there would be more companies making a similar change in the future, be it for sustainability-related reasons or otherwise.

Another noteworthy caveat is that Elmhurst, as a company, is not a socio-technical regime. Regimes are much larger than any individual company and span industries and sectors that contain a multitude of companies and other organizations (Geels, 2004). Nevertheless, large-scale, regime-wide transitions are also reflected in the goings-on of its smaller constituents, which is what makes Elmhurst a relevant and worthwhile case study.

Lastly, because Elmhurst, or any other company, is not a regime in and of itself, there may also be some confusion further on in the thesis regarding the use of terms like socio-technical systems or transitions. To avoid this, from here on I will refer to Elmhurst's socio-technical system as their (socio-technical) organization. Likewise, the word "transition" will primarily be used to talk about regime-level developments, which makes its use confusing when applied to Elmhurst, since Elmhurst is not a regime, but a part of it. I will refer to the change that Elmhurst went through as a "shift", which is a term I will also use when describing technological transitions of single companies, be it Elmhurst or otherwise. Not every use of the words "shift" and "organization" will concern the meanings I described above (though most of the time it will), but the semantic context will be clear enough to interpret these words correctly.

1.3. Moving Away from Animal Products

When assessing the desirability of a diet, two primary concerns are healthfulness and sustainability. If a diet is not healthy, it will likely lead to people getting sick, thus lowering their quality of life, and increased health care costs, for example. If a diet is not sustainable regarding food production, it cannot be kept up indefinitely, since the environmental damage will, at some point take, its toll on food production. Since the growing world population is predicted to move more towards a Western diet (centered around meat, dairy, eggs, fish, refined grains, sugar, and oils), this diet will be used as a contrast to a plant-based diet. The term "plant-based diet" will refer to a diet consisting of (largely) unrefined plant foods, including vegetables, fruits, legumes, grains, mushrooms, nuts, and seeds.

When it comes to health, a standard Western diet that centers largely around animal products and processed foods has been shown to contribute significantly to heart disease and strokes (Ornish et al., 1998; Esselstyn, 2010), common types of cancer (Ornish et al., 2005; Campbell & Campbell, 2006), Alzheimer's disease (Barnard et al., 2014), chronic obstructive pulmonary disease (COPD) (Jiang, Paik, Hankinson, & Barr, 2007; Varraso et al., 2007), diabetes (Fraser, 2009), obesity (Tonstad, Butler, Yan & Fraser, 2009), and high blood pressure (Le & Sabaté, 2014). These diseases are among the most common causes of death and disability in the developed world. Diet is the number one cause of premature death as well as the number one cause of disability in the U.S., followed by smoking at number two (Murray et al., 2013). Diseases such as heart disease, cancer, and chronic lung disease are primarily the result of lifestyle (Murphy, Kochanek, Xu, & Arias, 2014). Interventional trials on the health effects of plant-based diets show that these prevalent diseases can largely either be prevented or reversed by adopting a plant-based diet (Greger & Stone, 2015).

Regarding the environment, animal agriculture has been found to be either the number one (Goodland & Anhang, 2009) or number two (FAO, 2006a) cause of climate change, with the primary differences in the outcomes of these studies being due to research methodology. Globally, livestock accounts for eighty percent of all greenhouse gas emissions from the total agricultural sector (including both crops and livestock) (FAO, 2006a). Cows in particular produce significant amounts of methane, a greenhouse gas that is 25 to 72 times more potent than CO_2 at warming up the planet (Forster et al., 2007). Since the dairy industry consists of cows, for the most part, this industry alone is already a significant contributor to climate change. Aside from livestock's impact on climate change, it also leads to deforestation. Globally, large amounts of forest are cleared only to be replaced with more animal agriculture or crops to feed them. Over the course of fifty years, the amount of land surface covered by rain forests has dropped from fifteen percent to less than two percent (Oppenlander, 2012), thereby replacing an effective carbon sink with something that accelerates climate change. In the U.S. alone, close to eighty percent of all agricultural land is directly or indirectly used for growing livestock (FAO, 2006a). Looking at food production for human consumption, any given acre of (arable) land can yield twelve to twenty times the amount of vegetables, fruit, and grain (in weight) as it can in animal products (Robbins, 2001). Growing plants also requires far less fresh water; over half of all fresh water resources are estimated to be given directly or indirectly to the production of animal products (Turner et al., 2004). Producing one pound of meat can take 250 to 500 times more fresh water than is required to produce one pound of vegetables, pulses, grains, or fruit (Pimentel & Pimentel, 2003). Taking required resources, negative impact on the quality of ecosystems, and negative impact to human health all together, a plant-based diet is almost seven times less damaging than a standard Western diet, and about three times less damaging than a far more moderate version of a Western diet (Baroni, Cenci, Tettamanti, & Berati, 2007).

In the case of animal agriculture, two nested biotic chains can be identified. A biotic chain refers to a cycle of food production (e.g. through photosynthesis), consumption, and decomposition (breaking down chemicals from producers and consumers into more basic elements that can be reused). The first biotic chain is grain (and other animal feed) production, relying on water, nutrients, and arable land as its resources. The second chain is animal products, relying in large part on grain and other feed crops (Lintsen, Veraart, Smits, & Grin, 2018). Overall, of all the calories and nutrients in animal feed, approximately seven percent remains in the final product (meat, dairy, or eggs) (Shepon, Eshel, Noor, & Milo, 2016), instead of feeding those plants to 3.5 billion humans for example (Cassidy, West, Gerber, & Foley, 2013). Such a large loss of nutrients (and therefore resources) is impossible to overcome technologically, since this is simply what is required for animals to live and grow. This underlines a core issue of any specific part of the livestock sector: the majority of the unsustainability of animal agriculture stems from the animals, not the technological practices. So a technological fix that successfully makes the livestock industry sustainable is an unlikely scenario, although technology can play a role in the context of transitioning to plant-based alternatives. Therefore, in order to be sustainable, food practices must focus primarily, if not entirely, on the production and consumption of plants.

Below is a comparison between dairy milk and two of the most often used plant-based milks, namely almond milk and soy milk. These products are compared based on the emissions, land use, and fresh water use associated with producing one glass (200ml) of milk.

For dairy milk, this works out to be about 0.64kg of CO_2eq (equivalent) emissions, 1.8 square miles of land use, and 126 liters of water (Poore & Nemecek, 2018). A glass of almond milk has, on average, 0.15kg of CO_2eq emissions, requires 0.11 square miles of land use, and requires 78 liters of water (ibid). Lastly, for 200ml of soy milk, 0.2kg of CO_2eq are emitted, 0.14 square miles of land are used, and 6 liters of water (ibid).

Understandably, such a brief discussion on the effects of food choice on human health and the environment does not include many studies that are also relevant to mention. Unfortunately, going into these topics more deeply is not the main goal of this thesis and would take up too much space. Therefore, a longer and more thorough outline of the various arguments and studies related to these topics can be found in appendix A. Likewise, questions can be raised regarding what can be considered as “sustainable”, which is a matter I will explore more deeply in chapter 2.6, where I discuss sustainability transitions.

1.4. Current Developments towards Plant-Based Diets

As mentioned earlier, in 2006 the global demand for meat was predicted to increase by 68% and dairy by 57% between 2000 and 2030. Largely, this is due to growth of the global human population and developing countries growing their wealth (FAO, 2006b). The predicted growth does not account for differences between different parts of the world, though, but only global trends. In many developed countries, though, a contrary trend is occurring. Adopting a plant-based diet was predicted to be the biggest food trend in 2018, with sharp rises in number of vegans occurring throughout many developed countries (Hancox, 2018). For example, in the U.S. the number of consumers describing themselves as vegan went up from one percent in 2014 to six percent in 2017, primarily including people up to 34 years of age (GlobalData, 2017). This development presents significant issues for animal-based companies going forward, as well as new business opportunities. In 2016 a group of investment funds (Fairr: Farm Animal Investment Risk & Return) totaling $1.25 trillion dollars worth publicly urged major food producers and retailers (including Unilever, Walmart, Tesco, Kraft Heinz, and Nestlé) to develop and sell plant-based alternatives to animal products (Hancox, 2018). Various types of companies are actively catering more to vegans by, for example, adding more vegan options to restaurant menus or creating plant-based alternatives to supplement their main product range. In the case of Elmhurst, this involved transitioning entirely to plant-based products.

It is certainly possible for people to adopt a plant-based diet without consuming plant-based alternatives to meat, dairy, or eggs, by simply relying on vegetables, fruit, grains, nuts, seeds, mushrooms, and legumes. However, plant-based substitutes to animal products do play a significant role in making such a dietary change. The more a new behavior fits within people’s current behavioral patterns, the easier it is to adopt the new behavior. This helps to close the gap between *intentions* to create better habits and actually engaging in those positive actions. A plant-based diet, specifically, may be more challenging than other pro-sustainability behaviors. For example, utilizing electric cars and renewable energy sources may have a smaller gap between attitude and actual adoption. As long as a vehicle gets people from one place to another reliably and comfortably, the power source is not particularly important. Similarly, as long as the lamps, computer, refrigerator, and television work, the source of electricity (e.g. solar panels or coal), so long as it is affordable, is not very relevant. Electric vehicles and renewable energy sources, therefore, require fewer actual changes to people's behaviors and habits. A dietary change, however, does require such changes, which makes the adoption of healthier and/or more sustainable consumption patterns more challenging. Aside from anticipating a growing trend, this is also why it is worth exploring how (animal-based) companies can switch to producing plant-based alternatives, since these alternatives offer people an opportunity to largely maintain the same behaviors, but consuming products that have significant benefits for human health and environmental sustainability.

Furthermore, even if people had the money to purchase solar panels and electric vehicles, as well as the willingness to spend that money on these things, it would take many years before enough of these products have been produced to meet such a demand. A switch to a plant-based diet involves spending money that people are already spending, only now on different products. Theoretically, one could adopt a (more) plant-based diet as early as their next meal. This makes such a change especially interesting, since there is no need to wait several years to work towards more sustainable options in this area; these options are largely already available.

Arguably, since the adoption of, for example, renewable energy sources does not require much of a behavioral change, there may also be less of a need for an attitudinal change beforehand. A long-lasting shift in dietary patterns, however, is unlikely to manifest without a positive attitude towards such a change. This makes a sustainability transition of this kind more unique and more challenging. Moreover, this aspect raises questions regarding how suitable the MLP is for dealing with such complexities. I will explore these concerns more deeply in chapter 2.5, when I discuss various caveats and criticisms pertaining to the MLP.

2. THEORETICAL FRAMEWORK

In this chapter, I clarify the theoretical framework that I apply in subsequent chapters, as well as other related analytical distinctions. I start by giving a brief overview of the models that the multi-level perspective aims to improve upon. Subsequently, I explore how the MLP aims to answer three main questions: (1) What is the structure of a socio-technical system? (2) How does a socio-technical system function? (3) How do technological transitions occur? I then go on to address some criticisms against the MLP and I close with a discussion on sustainability transitions and some of the literature regarding this field.

2.1. Introduction to Socio-Technical Systems

The study of socio-technical systems shows that the social and technological aspects of our environment continuously influence each other. Technologies are not neutral means to an end and technological development is not determined by just technology itself, nor solely by its producers. Innovation processes are multi-faceted phenomena that require the various social and technological factors to be taken into consideration. Various models have been created to enable a comprehensive discussion on these various factors and dynamics. Below, I briefly explore some of these earlier models that ended up providing the basis for the MLP.

Innovation studies describe innovation as a systemic process. An early framework within this field was that *sectoral systems of innovation*, which can be described as: a system or group of firms that are active in developing and producing a sector's products and creating and using that sector's technologies. This group of firms is related in two principle ways, namely through processes of interaction and cooperation, and through competition (Breschi & Malerba, 1997). There are two main issues with this definition: Firstly, it takes firms as its main actors, thereby not taking into consideration, for example, government organizations. Secondly, it looks at the selection of innovation primarily from the viewpoint of the actors that create and use these products and technologies, thereby not including the influence on the selection process that users (i.e. customers) have (Geels, 2004).

An approach attempting to overcome the previous limitations was that of *technological systems*, which can be described as networks of agents acting within a particular institutional infrastructure to generate, diffuse, and utilize a specific technology. These technological systems are defined in terms of the flow of knowledge and competence, rather than the flow of goods and services (Carlsson & Stankiewicz, 1991). While this approach more clearly emphasizes the role of diffusion and use of a technology, rather than just its creation, it is also narrowed down to social systems. This still leaves room for the influence of the material aspects of technology, yet these are not specifically taken into consideration in this particular approach (Geels, 2004).

However, the material aspects of technologies and systems are taken as a central focus in the *Large Technical Systems* approach. This approach takes into consideration the physical artefacts within a system, but also organizations, natural resources, science, education, and policy (Hughes, 1987). Actors within this system navigate between multiple domains (e.g. political, scientific, economic), thereby creating a dynamic web of activities that collectively function as a whole.

Frank Geels' (2002, 2004) suggestion is to combine the multi-actor and multi-level aspects of innovation to create a heuristic device focused on helping to understand emergent (technological) processes. The vast scope and complexity of large-scale technological transitions complicate the creation of an ontologically accurate model, but a model that takes into account some of the key factors can be useful in examining such complex shifts.

The main lessons to take away from the three earlier described models is that all three approaches (1) describe innovation as a co-evolutionary process and (2) emphasize the interconnectedness of the various elements within the system (Geels, 2004). A third factor that Geels adds, based on the work of Rip and Kemp (1998), is that of levels: micro (niche), meso (regime), and macro (landscape). The MLP primarily focuses on the meso-level (the regime), since transitions are defined as changes from one regime to another. The other two levels, niche and landscape, are therefore considered 'derived terms', because they derive their definition from their relation to the regime. The framework overall combines insights and concepts from science and technology studies, evolutionary economics, neo-institutional theory, and structuration theory (Geels, 2011). Transitions are considered a non-linear process that are the result of an interplay of actions and contexts of human actors, technologies, and rules leading to developments across niches and regimes set within the broader socio-technical landscape (Rip & Kemp, 1998; Geels, 2002, 2011). The pathway of various developments in between one dynamically stable state of affairs for a regime to the next stable state is the transition; it is the response to counter destabilizing pressures.

Beyond technology-based shaping forces, there is also the influence of the meaning of certain key terms and how these meanings may clash with the interests of established regimes. The domains that need to become more sustainable the most include transportation, (animal) agriculture, and energy, since these are the primary drivers of climate change (FAO, 2006a). The (large) companies within these domains often have such extensive socio-technical organizations that a major change to that organization will likely be met with resistance. Manufacturing facilities, distribution channels, technologies, researchers, and other elements and actors in their network give these companies both a strong position when it comes to influence, and a vested interest in maintaining the system as it is now (Rothaermel, 2001; Geels, 2011). In the quest for more sustainable animal husbandry systems, the multifaceted nature of these large systems poses analytical challenges that complicate the discussion. The political, economic, and socio-cultural components in this type of discussion lead to conflicting interests which further leads to different definitions on what, for example, sustainability means for any particular group or individual (Bos et al., 2008). In the case of animal agriculture, the definition of sustainability used in this thesis calls for a significant extensification of the livestock sector. Such a transition poses significant issues for companies that depend on livestock for their existence, so a less strict definition of sustainability would be greatly preferred (from their point of view) since it requires far fewer modifications to their overall sector and production processes.

As used so far, the basic building blocks of a socio-technical system are called elements, and Geels distinguishes three particular types of elements: (1) systems (e.g. materials, resources), (2) actors that maintain and change the system (e.g. firms, government institutions, individuals), and (3) rules and institutions (e.g. policies, standards, regulations). The model he proposes for this type of exploration is primarily intended to be used as a heuristic tool to describe the dynamic factors that enable and explain innovation processes and the use of artefacts.

Socio-technical systems are understood in terms of societal functions (e.g. food production, housing, transportation, communication). So, beyond a focus on innovation, there is also a focus on how technologies perform and how they are used in practice. Therefore, both the production and the consumption sides are to be taken into account (Geels, 2004). The sub-chapters below delve more deeply into the various distinctions that are required to successfully map a socio-technical system, along with an analysis of how change takes place within this system.

2.2. Mapping Socio-Technical Systems

Many earlier approaches to mapping innovation systems focused primarily on the production side, which is where innovations often emerge. However, the demand or user side also plays a role in the selection, adoption, and utilization of innovations. The MLP is an attempt at integrating production and consumption activities. Figure 2.1 represents a schematic visualization of the basic elements and resources commonly present within socio-technical systems. As can be seen in the figure 2.1, the production, distribution, and actual use of artefacts is central and is divided amongst the production and use side overall. Each of these two sides contains elements and resources that are (1) necessary for the processes of production and use, and (2) that influence the production and use of artefacts (Geels, 2004). In order to produce any particular artefact, tools and machines are necessary, as well as natural resources, and sources of funding. Labor or human resources are also required. These do not simply come about, but generally rely on prior education in order to have specialized skills and knowledge that can be applied within a particular socio-technical system. The design of particular technologies within the system is another factor that the production of artefacts depends on. The role of scientific knowledge is one that supports the creation and design of the relevant technologies as well as serving as a source of knowledge for further education.

Since artefacts are often not used where they are produced, there is a system of distribution to get these artefacts to the (end) users. For example, food producers rely on various means of transportation, supermarkets, and restaurants to distribute their products. Subsequently, the use of artefacts is influenced by their cultural meaning (e.g. trends, items that symbolize status), which is often related to media sources. Facilities for repair or maintenance (e.g. auto repair shops) and complementary artefacts (e.g. in the example of food: barbecues, kitchenware, recipes, microwaves) also influence the use of artefacts.

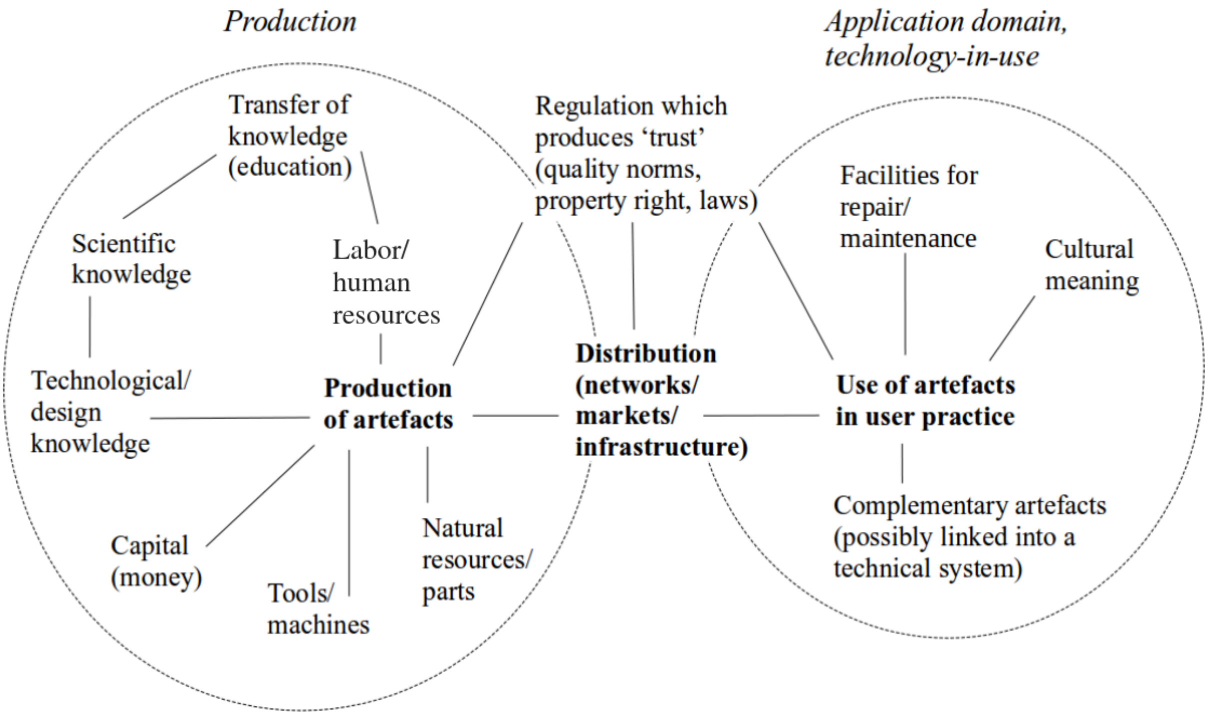

Figure 2.1: The basic resources and elements of a socio-technical system (Geels, 2004).

Regulations and laws influence the production, distribution, and use of artefacts. Regulations that deal with, for example, quality norms, property rights, and consumer protection help to establish trust with consumers, since it reduces the chances of them buying something unsafe or deceptive. This in turn influences which innovations can (lawfully) be produced and distributed to which parties, and how artefacts can be used in practice.

Important to note is that this schematic representation of a socio-technical system only brings to the fore the main elements that are related to the production, distribution, and use of a particular artefact or (homogeneous) group of artefacts. Universities play a role in this system primarily through their contributions in scientific research and education. The tools, machines, and other technologies that are utilized by the producers of an artefact have their own socio-technical system. In their system, the producers that are central in figure 2.1 can be part of the user side. A socio-technical system, as described here and shown in figure 2.1, is porous and interconnected with many others, rather than being completely self-contained or shut off from other systems.

2.3. Dynamics in Socio-Technical Systems

This section aims to explore how socio-technical systems function, both internally as well as in their wider context. As described earlier, the elements of the socio-technical system can be categorized as (1) systems, (2) social actors, or (3) rules and institutions[1] (Geels, 2004). Although these categories are analytically distinct, they refer to various aspects of an otherwise congruent and cohesive whole. For example: a worker uses a certain tool in a facility, another employee receives some extra training, and products get a different label because a new regulation has come into effect that mandates additional information on the packaging. The various aspects surrounding (in the previous examples just) the production of artefacts seamlessly co-exist and co-shape each other. These aspects are referred to and seen as dimensions. Each of these three analytical dimensions interacts with the others, leading to six types of interactions. Figure 2.2 is a visual representation of the three dimensions and their interactions.

The dimension of socio-technical systems refers to the basic web of elements and resources that have been discussed in the previous section. This is largely comprised of material and socio-economic necessities, including natural resources and technologies. However, this does not yet sufficiently take into consideration the perceptions and behaviors of social actors within the system, which is why human actors, organizations, and social groups are included as a separate dimension. The perceptions and behaviors of actors in the socio-technical system influence how technologies are used and which actions are prioritized, all of which influences the process of innovation and potential technological transitions. Another influence on actions taken within the socio-technical system are related to rules and institutions. Rules and institutions, in this context, have a particular meaning. Rather than referring to public or private organizations, laws, regulations, or policies, instead they refer to the coordination and structuration of activities. This does include laws and regulations, but can also include unwritten rules of engagement and interaction between various actors. Socio-technical systems, rules and institutions, and human actors all taken together constitute the broader term of socio-technical regime.

1. The subsequent discussion has shortened names of each dimension for the sake of brevity: socio-technical systems are referred to as *systems*; rules and institutions are simply called *rules*; and human actors, organizations, and social groups are combined as *actors*.

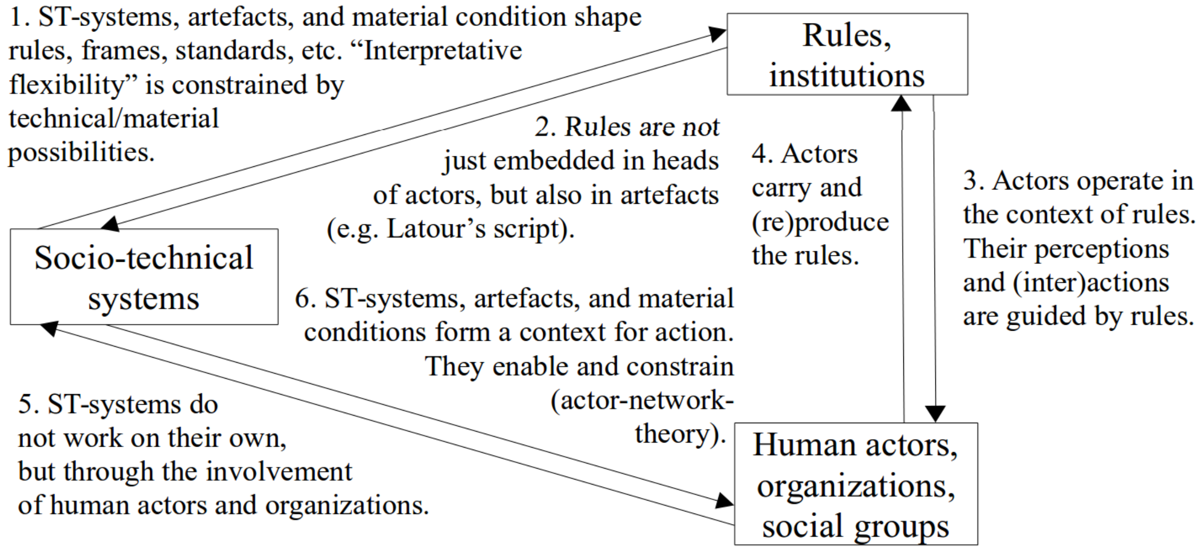

Figure 2.2: Three interrelated analytic dimensions and their interactions with each other (Geels, 2004).

1. On the influence of systems on rules: due to their (often) material nature, technologies have a certain hardness or persistence. This also has to do with their economic aspects (e.g. sunk costs and investments). The 'hardness' of technologies and other material arrangements means there is a persistence in their presence that is hard to change (Geels, 2004). It is difficult to change the composition of a material or technology at will, or how they function in conjunction with other technologies, and firms or other organizations often do not have the financial means to replace materials and technologies regularly. Once a technology has been purchased (especially costlier ones), it will likely remain an integral aspect of the overall workings of an organization. While artefacts may have a level of interpretive flexibility (finding new applications for an artefact, or altering it to fit a new function (Bijker, 1995; Pinch & Bijker, 1987)), there are technological and scientific limits to this flexibility. However, rules and institutions may offer a level of flexibility that is greater than the hardness of materials and technologies allows for, so the coordination and structuration of activities may be more easily changed through changes to the rules and institutions than the materials and technologies these activities revolve around. In short: if the technologies cannot be sufficiently changed to achieve a certain goal or adhere to certain rules, then changing the goal or the rules may be an easier solution.
2. On the influence of rules on systems: a famous example within the field of philosophy of technology is that of Moses' bridges. Robert Moses designed bridges over the New

York to Long Island parkway that were so low that large buses could not pass underneath. He thereby limited access to Jones Beach to poor people and minorities that relied on public transportation such as buses to travel there (Winner, 1980). Discriminatory 'rules' were effectively inscribed into the technology (i.e. the bridges). The notion of 'script' was introduced by actor-network theorists to describe how technological artefacts enable and constrain human relations amongst each other, but also relations between humans and objects (Latour, 1992). Similar to film scripts, the technological artefacts themselves provide a framework of action for those interacting with the artefacts. The actors find themselves acting according to the possibilities and limitations offered by the objects (Akrich, 1992).

3. On the influence of rules on actors: rules and institutions provide constraining and enabling context for actors within the socio-technical system (e.g. individuals, organizations, social groups). The behaviors, perceptions, and interactions of actors and organization are structured by these rules (Geels, 2004). This places a limit on the degree of freedom actors have. Rules and institutions that provide this structuring context include, but are not limited to, written sources (e.g. laws, policies, regulations, contracts), verbal agreements, or and unspoken rules of engagement (e.g. in social contexts or business settings).
4. On the influence of actors on rules: through their activities, actors also (re)produce the rules and institutions that constrain and enable them (Geels, 2004). New developments may lead to new activities, which in turn may spur changes in rules. In this way, the actors exert influence on the rules and institutions that guide their activities.
5. On the influence of actors on systems: socio-technical systems do not function autonomously, but through the activities of individuals and organizations. Their activities (re)produce the elements and the connections between these elements, since these connections are not only technological or material linkages. Human actions bridge the gaps between, for example, companies and investment firms or consultancies. These social groups subsequently influence the design, setup, and application of technologies. The approaches of actor-network theory (Latour, 1992) and the social construction of technology (Bijker, 1995; Pinch & Bijker, 1987) underline this point.
6. On the influence of systems on actors: human beings largely function within a highly technological environment, including buildings, cars, roads, electrical appliances, and

much more. These technologies shape our perceptions (Verbeek, 2008)) and behaviors (Latour, 1992; Strum & Latour, 1999). The design of artefacts enables, constrains, nudges, limits, or otherwise influences the behaviors that one can engage in. Rules and values that govern and guide certain aspects of people's lives are also reflected in the (design of) technologies that people are surrounded by. This means that socio-technical systems form a structured and structuring context for human behaviors and perceptions.

2.4. Transition Theory

Even though socio-technical systems consist of many different moving parts, they are 'dynamically stable' (Geels, 2002; 2004), referring to the fact that there is continued change within and between elements, though the overall system is relatively stable and not prone to radical transformations in short amounts of time. This section explores how transitions take place within this dynamically stable system. The MLP distinguishes between three different levels, namely the niche (micro), regime (meso), and landscape (macro). These levels are found on a spectrum of structurization, ranging from low (niche) to high (landscape). There are no clear boundaries between where a niche turns into a regime, or where a regime turns into the landscape; these terms are relational. Regarding transitions, the MLP explores how the developments on the niche and landscape levels lead to changes on the regime level (the socio-technical system) (Geels, 2004).

The niche level contains various actors that often work towards solving problems of existing regimes. These niche actors aim for their novelties or innovations to be integrated into the current regime, either alongside existing technologies and practices or as a replacement. Niche actors produce many different innovations, each of which may also be linked together. The more innovations match up with regime-level technologies and practices, the more likely these innovations become a standard fixture in the regime (Geels, 2004). However, regimes partly derive their stability from the fine-tuned integration between all of its various technologies. This indicates a high chance of there being a mismatch between novel technologies and the existing regime (Freeman & Perez, 1988). Since there is such a rapid rate of development and experimentation, the niche level is highly dynamic. It does not have the degree of stability that regimes have, though it is more flexible, thereby making it more responsive (and susceptible) to external pressures.

The landscape level refers to aspects of the wider context which socio-technical regimes are a part of. Every regime has its own particular technologies, rules, and actors, but some of these factors are not limited to any particular socio-technical system. Economic issues, the material and spatial arrangements of cities and energy infrastructure, socio-cultural beliefs, symbols, and values, political developments, and more constitute the breadth of the socio-technical landscape (Geels, 2004). The landscape level is slow in its developments; it takes a considerable amount of time for cultural values or large infrastructures to change significantly, for example.

The way innovations break through from the niche-level into the regime happens due to changes that occur on the landscape level. Developments in the landscape exert pressure on the regime, which can then allow for windows of opportunity for innovations to break into the regime and become an integrated part of the whole. The same pressures from the landscape can also cause some (connections between) elements to disappear or be substituted (Burns & Flam, 1987; Geels, 2006). Although the socio-technical regime itself is relatively stable, it is also in constant flux. Activities within the regime itself continuously bring about both stabilization and change. The pressure from the landscape level forces adaptation from the regime, which presents an opportunity for novelty to be introduced. In a similar fashion, the landscape-level also puts pressure on the niche level, thereby also forcing adaptations in that domain.

If landscape pressures to the regime create a window of opportunity for niche innovations to break through, and these innovations are adequate at helping the regime to adapt to the landscape pressures, then these innovations become a part of the regime. Once an innovation has broken through into the regime, the regime has to adjust for further accommodation and integration. Subsequently, the regime itself, due to these changes, also exerts influence on the landscape. This cyclical, dynamic process then begins anew, with the changes to the landscape exerting new pressures on the regime (Geels, 2004). Figure 2.3 offers a visual representation of the various occurrences that take place in the process of changes in the landscape putting enough pressure on the regime for novelties to find a chance to break through.

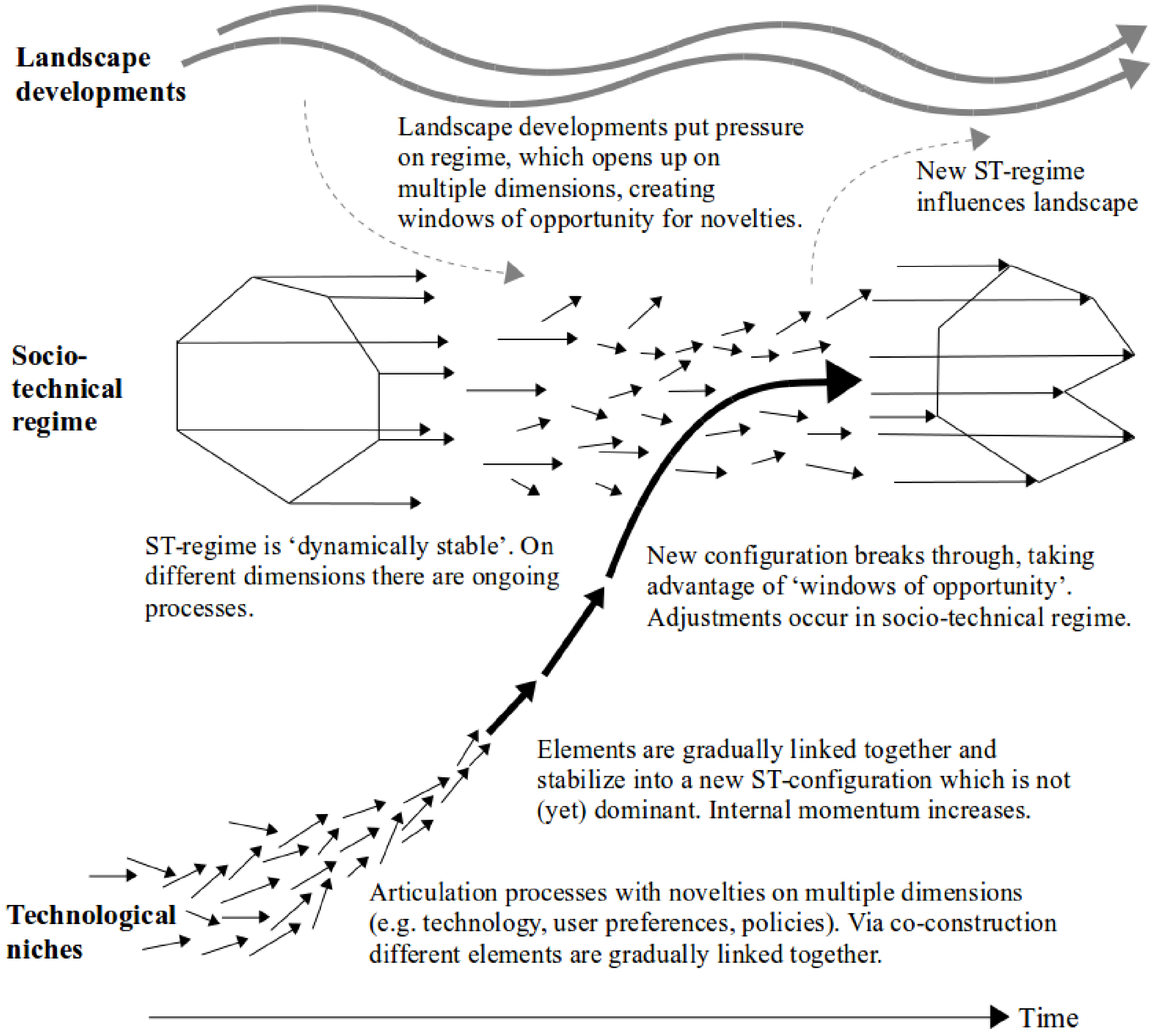

Figure 2.3: A dynamic multi-level perspective on ST-system innovations (Geels, 2002; Geels, 2004)

Not every technological transition undergoes the same process, due to differences in timing, types of landscape pressures, and technological developments. Geels et al. distinguish between four types of transition pathways: transformation, reconfiguration, technological substitution, and de-alignment and re-alignment (Geels & Kemp, 2007; Geels & Schot, 2007). Each of these transition pathways has its own criteria for occurring (Smith, Stirling, & Berkhout, 2005; Geels & Schot, 2007). Since there is a large amount of variety when it comes to combinations of external and internal pressures and available innovations, there are also multiple different potential transition pathways. Transitions do not simply happen out of nowhere and are generally the result of shocks (i.e. pressures) to the regime. Four types of shocks can be identified: hyperturbulence, specific shock, disruptive, and avalanche (Suarez

& Oliva, 2005). I will first expand upon these types of shocks, after which I will describe the various types of transition pathways and how these are related to shocks.

Every type of shock has a combination of low/high-values on the attributes of (1) frequency: number of environmental disturbances in a certain time frame, (2) amplitude: how much the disturbance deviates from the initial conditions, (3) speed: rate of change, and (4) scope: the number of environmental dimensions that are affected by the disturbance(s) (Suarez & Oliva, 2005). Regular or baseline change corresponds to low values across all attributes, so low frequency, low amplitude, low speed, and low scope.

Hyperturbulence can be observed in environments that have a high frequency of high speed changes along one dimension. The intensity, however, is modest. An example of this could be that of hypercompetition. Fast, time-based competition can cause rapid and continuous changes to the environment in an effort to stay ahead of competitors.

Specific shock refers to environmental changes that high in amplitude and speed, but low in frequency and scope. Sudden (de)regulation of an industry can cause such a shock. The significant adaptation it forces occurs over a relatively short amount of time and occurs on one or very few dimensions.

Disruptive change corresponds to changes to the environment that happen infrequently, gradually, and have a high-intensity effect. Usually, though, these changes emerge in a limited part of the environment, so the scope is rather low. An example of this type of change are disruptive technologies that slowly but surely play an increasingly bigger role in organizations or societies.

The most extreme form of change is avalanche change, occurring infrequently, but having a high amplitude, high speed, and large scope. Avalanche change causes permanent changes to the environment (Geels & Schot, 2007) and can be seen in, for example, developing countries that implement profound economic reforms. Slow deterioration turns into rapid growth (Suarez & Oliva, 2005).

The various types of landscape pressures forcing regimes to adapt can influence the transition pathway that regimes undergo depending on timing and the nature of these pressures. If niche-innovations are not sufficiently developed, for example, a regime will likely adapt in different ways than if innovations were fully developed. The landscape pressures on the regime create windows of opportunity for niche actors and that window may close again in time, when the regime has stabilized again (Geels & Schot, 2007). The nature of landscape and niche developments refers to whether they have reinforcing or disruptive relationships to the regime. Reinforcing relationships stabilize the regime, whereas disruptive developments exert pressure that may lead to transitions. Niche-innovations may be either competitive towards the regime and aim to replace it, or symbiotic and aim to enhance it. Below, I will describe four transition pathways as described by Geels and Schot (2007), keeping in mind the types of relations niche-innovations may have with a regime.

A transformation pathway occurs when moderate landscape pressure (particularly disruptive change) occurs when niche-innovations have not sufficiently been developed. The niche actors lose their window of opportunity and regime actors actively modify the direction of development paths and the necessary innovation activities. Outside scientists, engineers, or other professionals are brought in to develop ways of dealing with the pressure experienced by the regime. In other words: regime actors take charge of research and developments to create the innovation they need in order to adapt to the landscape pressure they face.

A reconfiguration pathway is a relatively slow and low-impact pathway, focused on symbiotic niche-innovations that are initially integrated into the existing regime to deal with local issues. After this initial phase, these innovations trigger further adjustments throughout the broader regime architecture. The niche-innovations, if symbiotic, can function as add-ons or replacements while leaving most of the regime unchanged. Over time and with continuous landscape pressures, sequences of innovations being integrated can add up to far reaching reconfigurations to the overall regime.

In the case of technological substitution, various types of landscape pressures (specific shock, disruptive change, or avalanche change) occur at a moment when niche-innovations have sufficiently been developed, breaking through and replacing the existing regime. This pathway does assume that radical innovations have been developed, but that the stability of regimes has not yet provided the opportunity for these innovations to break through. The regime actors pay little attention to what happens in niche areas, so that when sufficient shocks happen that destabilize the regime, the niche-innovations are in a position to replace the existing regime. The niche-innovations, in the time that regime actors were largely ignoring them, stabilized and gained internal momentum, thus putting them in a strong position to become mainstream when the environment changes enough.

The last pathway to discuss is that of de-alignment and re-alignment. Avalanche change leads to increasing regime problems, causing regime actors to lose faith and reducing R&D investments. This leads to de-alignment of the regime. Without sufficiently developed niche-innovations to substitute the failing elements in the regime, multiple niche-innovations are developed that co-exist and compete for attention. Eventually, one innovation becomes dominant and will form the core of regime re-alignment and stabilization.

The amount of moving parts in any socio-technical regime give rise to a level of diversity and complexity that may describe other types of transitions as well. A sequence of transitions may also occur, given enough time. For example, with enough disruptive change, a regime may first experience transformation, then reconfiguration, followed by substitution or de-alignment and re-alignment (Geels & Schot, 2007).

The analyses and explorations described in the current and previous sub-chapters will be applied in the context of the milk industry, starting in the next chapter. Animal-based production will be contrasted with plant-based production. Given the fact that plant-based milk production is still quite a niche activity, Elmhurst is used as a case study. Furthermore, Elmhurst does not simply produce plant-based milks, but shifted to that type of production after nine decades of animal-based milk production. The way Elmhurst changed its socio-technical organization may provide insights on transitions on the regime level.

2.5. A Closer Look at the Multi-Level Perspective

This thesis utilizes the MLP to explore a sustainability transition from animal-based products to plant-based substitutes in the milk industry. Given the vast complexity of technological transitions, it is useful to get acquainted with the MLP's limitations. Particularly, in the context of socio-technical systems engineering it may be useful to identify potential issues that stand in the way of applying these types of frameworks more regularly in practice (Baxter & Sommerville, 2011). For this, a more thorough understanding is first needed regarding the context that the MLP provides.

Various criticisms have been leveled towards the MLP and discussing these concerns will provide a more complete picture of the capabilities and limitations of the framework.

Below, I will go into some of the main points as well as Geels' responses. The first points relate to how the MLP is more of a heuristic device rather than an accurate, empirical representation of how complex processes such as transitions occur. This may limit its usefulness (Genus & Coles, 2008). The benefit, however, of a heuristic device instead of a "truth machine" is that it can provide a context of analysis that prompts relevant questions and insights (Porter, 1991). Another benefit of more open-ended frameworks such as the MLP is that it facilitates the integration of auxiliary theories (Geels, 2011). This allows, for example, for the inclusion of theories from social science to help explore the influence of social groups. A related point was raised regarding how the MLP has so far only been used illustratively, rather than systematically with the aim of empirically accurate results (Genus & Coles, 2008). Geels (2011) accepts this point and argues that this is due to the heuristic nature of the framework. Rigorous attempts at making the framework more suitable for empirical research would likely narrow down its usefulness as a heuristic tool. The formulation of the research question of this thesis takes this into account, as the primary aim is to identify potential obstacles and opportunities in transitions from animal-based foods to plant-based alternatives, rather than creating a representation of how such a transition occurs. The central aim of both this thesis and the MLP is not about accurately describing how these transitions happen, though accuracy is still a priority.

The second collection of criticisms of the framework have to do with its hierarchical categories of niche, regime, and landscape. It remains unclear how these levels ought to be operationalized (Berkhout, Smith, & Stirling, 2004). An example that illustrates this issue involves the matter of scale. Significant organizational shifts for oil and gas companies may barely even register when looking at the overarching regime of energy production and distribution. Both of the mentioned systems can justifiably be viewed as regimes, leaving questions regarding how these conceptual levels should be applied. Geels' (2011) response is that the researcher should simply demarcate their object of analysis first and then go on to apply the framework. The MLP does not delineate these sorts of distinctions, so that is a task for the researcher. This thesis takes the above critiques into account by clearly formulating the regime in question as being the (American) milk industry. Apart from criticism on the operationalization of the regime level, the landscape level has also been criticized for lacking specificity and largely just being a residual category that is considered the locus of various influences and pressures. Geels (2011) agrees that this category requires further theorization, for example, by differentiating between landscape dynamics (Van Driel & Schot, 2005), exploring landscape developments that stabilize regimes (Geels, 2011), or delving into how regime transitions affect the landscape (Perez, 2002; Berkhout, Angel, & Wieczorek, 2009).

Aside from other authors' critiques, I raise the issue of the MLP's black-boxing of (societal) norms and values in sustainability transitions. The field of philosophy of technology describes in multiple ways how people's ((un)conscious) norms and values can make it into the design of a technology, thereby affecting its adoption and use. One of the more well-known examples of values influencing design and subsequent outcomes is that of Moses' bridges; an architect's discriminatory beliefs informed his design of certain bridges, which ultimately had a discriminatory effect on New York's poor and African-American communities (Winner, 1980). The norms and values of actors can be inscribed into the technology's design and influence people that way. Likewise, a technology's design can influence people's norms and values (Verbeek, 2008). So, in discussing technology-centered sustainability transitions, norms and values also need to be taken into account.

The transition in this thesis, one from animal-based over to plant-based milk production, is particularly value-laden. A plant-based diet is not only significantly more sustainable, but also has significant potential health benefits, and has a very direct impact on the well-being of a great many animals. Each of these factors (human health, climate and the environment, and animal wellbeing) justifies careful deliberation regarding the ethical consequences of the technology transitions that are to be supported and how they ought to take place.

As it stands, the MLP takes norms and values as a given; they are (largely external) factors that aid in describing why and how certain transitions take place. As explained by Geels (2004) and as described in the previous sub-chapter, the landscape level contains those factors that go beyond the influence of any particular regime, including socio-cultural beliefs, values, and symbols. Changes in values can (lead to other changes that can) be experienced as external pressures by a regime. However, this interpretation of the role of values is not helpful when discussing sustainability transitions, which are developments that inherently encourage the pursuit of a specific set of values. Therefore, discussions pertaining to sustainability transitions need to open up the black box of values, which the MLP does not do well enough for a framework that is specifically intended to aid in the discussion of sustainability transitions.

While the MLP currently does not really support discussions of the type mentioned above, I will attempt to apply these insights pertaining to values and sustainability transitions in further chapters as I explore transition pathways more deeply.

2.6. Sustainability Transitions and Agriculture

Before discussing sustainability transitions, I will first discuss sustainability and what this term means, at the very least in the context of this thesis. Feeding billions of people all across the world, now and in the future, will have an impact on the world. When it comes to exploring sustainability transitions through the lens of the MLP, it is worth noting that the MLP itself does not have any specific criteria for what sustainability is. So, theoretically, any purposeful transition under the guise of sustainability would qualify, even when the suggested transition only has minor benefits. Some improvement is of course better than no improvement, but ideally words like sustainability refer to "good" rather than "less bad". The United Nations (specifically the World Commission on Environment and Development) linked sustainability to well-being by defining it as: "sustainable development is development that meets the needs of the present, without compromising the ability of future generations to meet their own needs, here or in other parts of the world" (WCEN, 1987). A just distribution of well-being and of the resources required to generate well-being is central to this notion of sustainability. Well-being is inherently linked to the 'here and now', but also to the dimensions of elsewhere and later. In other words: developments in one part of the world should not negatively impact the ability of future generations to maintain or increase their level of well-being, nor the ability to do so of people elsewhere in the world (Lintsen et al., 2018).

Another noteworthy point is that sustainability is not just conceived as an ecological issue, but also as an economic and societal issue. Likewise, the capital that enables well-being is not merely financial or economic capital, but also human capital (e.g. health, knowledge, skills), social capital (e.g. social networks, institutions, and relations), and natural capital (e.g. the environment, climate, natural resources) (Lintsen et al., 2018). Arguably, natural capital can be seen as the most important one since it is foundational to everything else. Keeping in mind the above notions of sustainability and well-being, talking about sustainability in a pure sense (e.g. these practices have practically no negative impact on the environment and can therefore be maintained indefinitely, barring some external catastrophic events) could be too strict and to the point of being unattainable, so it may be more prudent to talk about relative sustainability (Oppenlander, 2012). This concept revolves around questions like: How can we best utilize available resources? Which foods have the least negative impact on the world? Which foods best promote health and longevity?

Many historical transitions simply ‘emerged’ (e.g. business owners exploring new markets with new products) while sustainability transitions are generally more goal-oriented and purposive (Smith, Stirling, & Berkhout, 2005). To address sustainability-related problems requires significant structural changes in various technological systems, including energy, agriculture, transportation, housing, and other systems and infrastructures (Elzen, Geels, & Green, 2004). Aside from the technological aspects, sustainability transitions also require significant changes in consumer practices, knowledge, and policies (Geels, 2004). Therefore, these transitions are highly complex, long-term processes. So, rather than being market driven, as is usually the case, sustainability transitions require more than market dynamics.

For private actors, sustainability transitions may not be rewarding enough to focus on due to the additional cost, effort, and knowledge that is required to produce a competitive product; the main benefit is for the greater good, rather than the private actors. In a similar fashion, many sustainable solutions do not offer clear user-oriented benefits, due to sustainability primarily being oriented at benefits for the greater good (Geels, 2011). Taxes and subsidies may offer economic benefits for sustainable products through pricing, but even in those cases the benefits of a product for the user are not directly related to sustainability.

Another issue related to sustainability transitions is that the most effective results are realized when large organizations change their system of operation (Geels, 2004). A rather small company changing its production process may not accomplish much overall; the impact of large companies is simply greater, whether these function in a sustainable or unsustainable way.

The unique characteristics of sustainability transitions underline why the use of the MLP as described in this chapter is important and valid. There are many moving parts that need to come together to work towards the collective benefit of improved sustainability, ranging from analytical distinctions to technological capabilities. This needs to happen in a context where single end users and private actors will not be the main benefactors of the envisioned sustainable practices and products. Moreover, although significant changes are necessary, there are many actors with a vested interest in maintaining the current system.

Sustainability transitions in various sectors all overlap in some areas. For example: they all concern themselves with climate change and the environment to some extent. However, such transitions in the livestock sector have several more unique characteristics. Since it concerns nutrition, there is a more direct relation to human health to take into consideration. There is also the effect the industry has on animals that are directly under human care. Lastly, as mentioned earlier, food plays a much more direct role in people's lives than energy production or a vehicle's power source. Such factors increase the complexity of discussing sustainability transitions in the (animal) agriculture sector.

One of the most direct applications of the MLP to the (animal) agriculture sector concerned pig husbandry systems (Elzen, Geels, Leeuwis, & Van Mierlo, 2011). In the article, the authors compared the results of various special-interest groups (regime outsiders) that put normative pressures on pig farming operations, specifically regarding pregnant sows and pig fattening practices. Analyzing the two case studies, it was found that the NGO's and scientists pushing for better living conditions for the pregnant sows were successful. Normative contestations led to about half the pig farmers converting the pig's living conditions by 2009, with the other half soon following suit given the new standards would be legally enforced starting in 2013. The groups demanding better living conditions regarding pig fattening practices was less successful.

In Elzen et al. (2011), the MLP provided a way of exploring multiple types of streams (technological, regulatory, etc.) and seeing how they interact and collectively lead to an actual transition. The case of pregnant sows showed that significant transitions can occur when multiple pressures and developments coincide. Normative pressures were mounting and were subsequently complemented by market pressures, and the availability of technological and regulatory solutions set things in motion. Meanwhile, the case of pig fattening did not enjoy such serendipitous coinciding of pressures and developments. The normative and regulatory pressures were weaker, and market demands also did not add much pressure, since consumers did not translate moral concerns into purchasing decisions (Elzen et al., 2011).

Some of the main takeaways from Elzen et al.'s (2011) study are that the MLP as a framework can function as a lens through which one can explore, analyze, and contrast highly complex phenomena. Moreover, the study showed that the MLP can aid the discussion on transition pathways within the livestock industry. In a broader sense, that is what this thesis is doing, although the main deviation is that this thesis focuses on a radical shift in food production, rather than maintaining a certain production process and improving it.

3. TRANSITIONS IN THE MILK INDUSTRY

In this chapter I will be using the multi-level perspective to (1) map out the general socio-technical organization of both animal-based and plant-based milk production, (2) explore Elmhurst's shift more deeply, (3) discuss potential transition pathways in the milk industry, (4) analyze the role of the socio-technical landscape, (5) explore the viability and feasibility of Elmhurst's shift in the wider milk industry, and (6) discuss ways in which such sustainability transitions can be stimulated.

An important distinction to keep in mind is that the descriptions are a combination of qualitative and quantitative research. It is qualitative in the sense that I explore what the various commonalities, differences, and nuances are between the two methods of milk production. It is quantitative in the sense that the description of the dairy-based production system is derived from a great many companies, enough so to largely reflect the American industrialized dairy sector. The plant-based production system, however, is based mostly on one company. The former can be considered a socio-technical system, while the latter is too anecdotal in nature for that label. So, there are some significant differences regarding the epistemological weight of both descriptions, though for the purposes of this thesis, the comparison can still be insightful.

3.1. Mapping the Milk Industry

Animals need space, food, water, shelter, waste disposal, and medical care. While many of these things are provided on-site, some of them (e.g. food) often come from external sources. Before any animal products make it to the consumer, there are processing and packaging activities, along with inspections regarding, for example, product quality and safety. Workers in this sector also needs specialized knowledge and skills to successfully perform their jobs and to run the entire production process smoothly and efficiently. There is also the material or technological dimension: every farm, facility, and other type of organization relies on a network of technologies that each play a role in the larger process.

The socio-technical system of pig husbandry can be seen as operating on two different environments simultaneously (Elzen, Geels, Leeuwis, & Van Mierlo, 2011). Firstly, the task environment contains those social groups that concern themselves with the economic exchanges and transactions within the system (Oliver, 1997), which mostly covers the production process. Secondly, the institutional environment includes those social groups that affect the system in non-commercial ways, such as policy makers, media, social movements, or the general public (Suchman, 1995; Oliver, 1997). Elzen et al. (2011) represented the socio-technical system of pig husbandry with the inclusion of these two dimensions (see figure 3.1 for a visual representation).

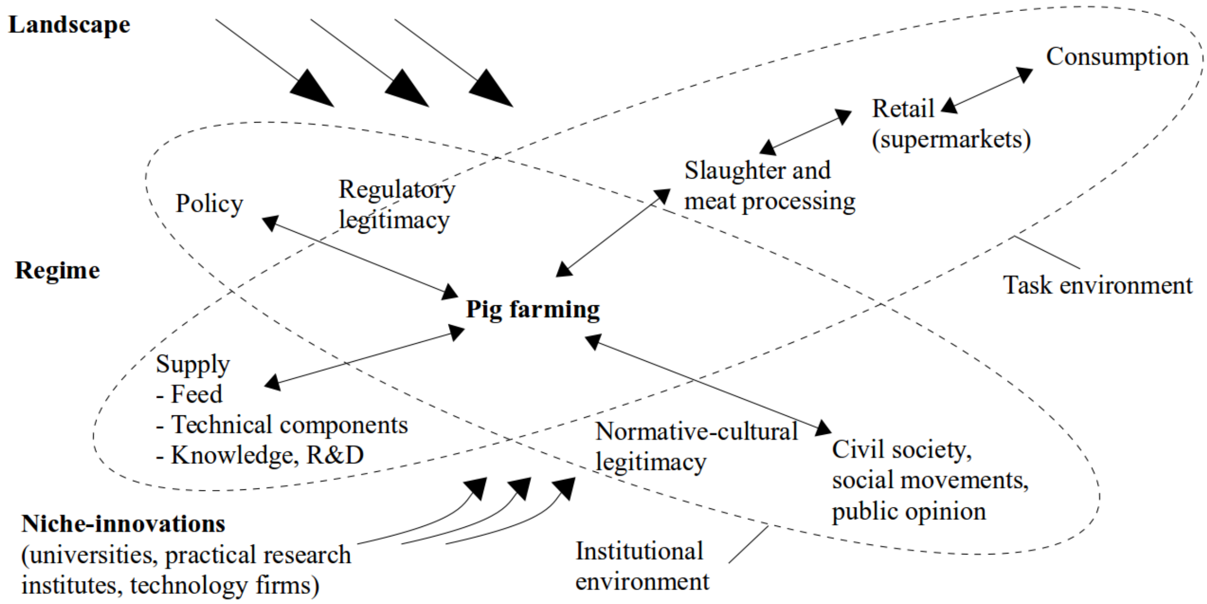

Figure 3.1: An embedded multi-level representation of pig farming (Elzen et al., 2011)

Within the task environment, various sources supply the farm with its resources, including food, technologies, and knowledge. From the farm onwards, there are processing and packaging activities, distribution and retail, and finally consumption. A similar process will be the case for dairy production, though naturally with some changes. The slaughter of animals takes place at facilities that are usually separate from the farms, meaning that the technologies and tools for those actions are not necessarily present on the farm. In the case of dairy farming, the animals are milked on the farm they live at, hence the technologies need to be on the farm.

The institutional environment contains elements that will also be present in the dairy sector, including policy makers, civil society, and the wider public. These various elements may be similar to pig husbandry in the case of dairy farming (e.g. concerns or policies regarding animal wellbeing), but could also be more specifically related to the dairy industry (e.g. normative pressures towards the dairy sector may be lower due to meat production, on the level of public opinion, being considered more cruel than dairy production).

The model that Geels (2004; 2011) created for mapping a socio-technical system did not explicitly include the distinction between the task environment and the institutional environment, though they are included in the part of the model that discusses dynamics in such systems (see chapter 2.3, figure 2.2). Geels' model, however, does provide enough opportunity for including some more peripheral elements. For example, task-specific education and research may not be central to the production of artefacts, but the knowledge and skills that such activities produce are certainly requirements for production. Furthermore, a transition to plant-based alternatives to animal products will also have to take into account how consumers currently use the animal products. To make plant-based products a worthwhile and competitive alternative one also has to take into account the general consumer environment and what roles the animal product plays (e.g. as ingredients in recipes or their role in social gatherings such as barbecues or holidays). The benefit of the explicit inclusion of the consumption side, or application domain, is that the influence of those elements can also be explored more comprehensively. Nevertheless, the representation of pig farming's socio-technical system displays multiple elements that are also present in dairy farming.

Below, I explore both the dairy-based and the plant-based methods of milk production. Elmhurst has successfully made a shift to producing plant-based milk, so a more thorough perspective on their current socio-technical organization may clarify how things have changed. I start by describing dairy first and contrasting it with Elmhurst's new production process. In the socio-technical system of milk companies, there is an overall division between production and consumption, both of which are linked together through systems of distribution and regulations that govern or influence both of these sides. I first explore all elements on the production side, after which I move on to distribution, and lastly the various elements on the consumption side.

Production of Artefacts

The central element on the production side is the production of artefacts/products, and includes the processing, refining, and packaging of foods. Dairy comes into the facility, where it is subsequently separated and re-mixed (cream and skim are separated and then mixed together again in predefined ratios), pasteurized, and homogenized (mechanical treatment to prevent cream from separating in the end product). After this, various treatments can occur to produce cheese for example. Once an end product has been produced, it is packaged, cooled, and shipped (Carbon Trust[2], 2011).

Elmhurst created their own process of producing plant-based milk. After the nuts are grown elsewhere and delivered to Elmhurst, they are rinsed and go through a cold milling process. This separates the nuts into oils, protein, fiber, and other such basic components. The ground nuts are then pressed and filtered, removing fiber, after which the liquid is bottled and sold (Elmhurst, 2017a).

The two types of production are significantly different, mostly due to the way the basic resources (either dairy or plants) need to be processed in order to produce milk. Dairy production necessitates heating and cooling procedures, while Elmhurst's process does not involve heating. Both types of production, however, do separate some of the basic components before remixing them back together; dairy production removes fat and Elmhurst's cold milling process breaks up the plant matter in its basic macro nutrients (proteins, fats, and carbohydrates) and ends up primarily removing fiber.

Resources

Dairy farms supply the majority of the basic resources that are required for producing dairy products. The dairy company (i.e. the processor, not the dairy farms) then process, refine, package, and distribute a homogenized end product. However, there are also other basic necessities, such as water, electricity, and cleaning products. Most notably, instead of relying on dairy, Elmhurst now relies on various nuts, grains, and seeds to produce their milks. Other resources, such as water and electricity, are still present in Elmhurst's new socio-technical organization. This means that such basic resources can still be gotten through the same systems (i.e. an electricity grid and running water infrastructure) and the primary changes to Elmhurst's new organization have to do with the plant-based product's production process.

2. Carbon Trust is a consultancy firm that, among other things, explored how dairy production can be made more sustainable; their first step was mapping the overall production system. Their analysis provided a basis for descriptions pertaining to the technological aspects of (dairy-based) milk production as outlined in this chapter.

Tools, Machines, and Technologies

For dairy, various technologies are utilized throughout the refinement process, including heating and cooling systems, centrifugal separators, sensors, pumps, and tanks and tubing (Carbon Trust, 2011). Elmhurst's production process involves cleaning systems to rinse the nuts, grains, and seeds, and involves other machines that help with pumping, filtration, and bottling (Elmhurst, 2017a). This element displays some significant differences, yet also similarities: technologies in the later stages of production (i.e. bottling, packaging, and the initial stages of distribution) are largely similar, while the beginning stages of production show the biggest differences in required technologies. On a different level, both systems also reveal a significant role for technological automation; attempts at the efficient maximization of product output fare well with automation processes instead of relying on human activities.

Capital

Investors, banks, and similar organizations supply companies with the means to make large investments for the required tools and machines for producing, processing, and packaging dairy. For Elmhurst, a significant investment was necessary to shift from one production process to another, requiring funds for the acquisition of all new technologies as well as the prior research and development. There is no indication where the capital for this change came from, but it could arguably have come from the same bank or firm that enabled such investments for Elmhurst in the past. Either way, since Elmhurst's proposed shift moved them away from a shrinking market and placed them into a growing one, it stands to reason that this positively affected their search for investors and funding.

Technological Design

The process of refining dairy involves a significant amount of energy, largely through heating and cooling down the milk. A constant push for more sustainable practices makes the technologies involved in this process a target for potential reductions in energy use, more reliance on renewable energy sources, and improvements in efficiency. Consultancies (e.g. Carbon Trust) and other such organizations help to improve various processes to limit waste and energy use, for example.

A deep-structural shift (i.e. large overhaul of their technological infrastructure) such as the one Elmhurst underwent requires significant knowledge and skills. There were no ready-made innovations available that Elmhurst either could or wanted to purchase and apply, so outside experts were brought in to aid in the development of an adequate technology. Most notably, dr. Cheryl Mitchell, a food technologist, was consulted to help develop the technologies and processes necessary to meet Elmhurst's needs and demands (Elmhurst, 2017b; Fox, 2017). The main contrast here is that the consultants that dairy companies needed were faced with issues that were likely to be well known. This is primarily due to the dairy industry being large enough to make it likely that other dairy companies have already faced similar issues and have formulated solutions. To deal with the challenges that Elmhurst faced, a new level of technological design and knowledge was required in order to successfully come up with a unique and effective solution. In the context of this challenge, Elmhurst took a more active role in acquiring and utilizing external knowledge and skills, rather than relying on previously mapped out responses.

Labor

Skilled and knowledgeable employees are necessary to maximize efficiency and output and to minimize downtime and risks. The prior description of tools and technologies already clarified that while the production process is new for Elmhurst, the bottling likely relies on similar technologies and processes. For employees, this means that some knowledge and skills can be applied in the changed organization as well, but there are also new activities and technologies to get used to. The level of automation present in both production processes may indicate that the primary tasks of workers concern the maintenance and monitoring of various technological processes. Although there are differences in both production processes, it is likely that knowledge and skills relating to technological upkeep are at least partially transferable from one process to the other.

Education

Universities and schools (of applied science) educate the people that will end up working in the dairy industry (or food production as a whole). Given the amount of automation involved in the production processes, it is likely that the educational background of someone working on dairy production would also be able to function reasonably well within Elmhurst's new production process. Many processes are handled entirely by machinery, with employees in more of a supervisory or maintenance position to ensure that everything runs efficiently and safely.

Research

Universities and other research institutes provide knowledge and insights that may aid in the education of workers, but can also inform consultancies on how some (part of a) process can be improved. The development of a new method of creating plant-based milks involved scientific knowledge (e.g. through the involvement of dr. Cheryl Mitchell) that was previously uncharted territory. Food-related science and technology was put to use to come up with a new method of turning a raw, basic resource (grains, nuts, seeds) into the desired end product.

Distribution

Once the end product has been made, it is distributed to supermarkets, restaurants and other eating establishments, and potentially even sold online. The distribution process transports the end product to the end users or consumers. The element of distribution did not change significantly, except for the following: Elmhurst shifted their production process from animal-based to plant-based in an effort to exploit the recent increased demand for plant-based alternatives. A similar update seems to have occurred regarding their distribution, given how currently there is a greater emphasis than before on online sales. While this may be a noteworthy difference, and it also sprang out of the overall shift, this is also the type of activity that can independently be shifted by any company, with or without other accompanying changes to the overall organization. Therefore, I will not go much deeper into this part of the overall shift.

Complementary Artefacts and Practices

Milk and other dairy products can be consumed on their own, but can also be an ingredient in cooking or baking. The specific characteristics of the product influence to what extent it is considered a suitable ingredient in certain recipes. Elmhurst's newly developed products also had to fit into what consumers were already used to. Perhaps more than others, this element shows how current or new innovations are beholden to demands that were created by older products and practices. The plant-based milks need to function well in existing recipes for cooking and baking. This element especially is a good example of how new products need to fit into the mold of the previous ones. While most milk is consumed simply as (a glass of) milk, it also plays a role in various recipes. So, the attributes of dairy milk that made it suitable for use in cooking or baking would ideally also be present in the plant-based substitutes. Unfortunately, there is no clear indication to what extent Elmhurst's revised product line also meets those demands, or to what extent it was even taken into consideration in the development of their new products. It does seem that their plant-based milks are primarily advertised for consumption as a plain glass of milk, or being used in combination with breakfast cereals.

Media

Television, radio, and Internet advertising all play a role in how a product is perceived by (potential) consumers. Marketing agencies focus on directly influencing purchasing behaviors of consumers. The recent dramatic increase in number of people identifying themselves as vegan does not go unnoticed. Multiple companies are trying to appeal to this growing group of consumers, leading to various advertising campaigns both online and offline. Likewise, this growing group of people wants other people to join in as well, leading to vegan-centered non-profits and other such organizations to share their message and calls to action more frequently as well. Admittedly, the points made about this element do not necessarily have to do with Elmhurst's shift specifically, but it is a media-centered response that originates from the same trends that forced Elmhurst to undergo a significant shift.

Regulations

An overarching element that influences the production, distribution, and consumption of products pertains to regulations. This includes quality norms, safety regulations, and sanitary standards (FDA, 2018). These help to ensure food safety and accessibility (e.g. through subsidies), thereby producing trust between companies, products, and consumers. Largely, the same or similar regulations apply to Elmhurst's new organization. Every food production system has to meet certain safety, health, and sanitary standards. Unfortunately, it is difficult to be precise regarding the specific differences in applicable regulations between the two systems. Since a new technological process was developed to produce Elmhurst's new products, the relevant rules and regulations will likely have already been integrated or taken into consideration. The differences in regulations between the pre- and post-shifted organization will to some extent be found in the technologies. Unfortunately, this does not provide any more specific information regarding what those specific regulations are, but their influence may, to some extent, be found in the new technologies.

Overall, various elements remain relatively unaffected, others are overhauled completely, and some are somewhere in between. Some of the most significant changes are found in the task environment and have to do with the material basis of the products. The resources (at the start of the production process) have changed almost completely in the shift from dairy to plant-based products. Then, as the production process goes along, the differences become less radical, and the two systems reveal some commonalities once production reaches the bottling stage and finally enters into distribution. Comparing the old and the new organizational structures reveals decreasing degrees of divergence between the two methods of production as one moves further down the production process. A similar pattern can be seen in knowledge and skill requirements, especially since these often relate to the technologies that employees work with.

The institutional environment has fewer changes on the policy side. However, social groups raising public awareness for certain issues will likely have changed. For example, Elmhurst no longer depends on animals for their revenue, so animal rights activists or other such special-interest groups are no longer a significant factor to take into consideration. Laws and regulations that deal with animal well-being are also no longer a concern.

3.2. Elmhurst's Shift

This section focuses on describing how Elmhurst changed their production process and subsequently exploring what this might show regarding a transition from animal-based to plant-based milk production. The question this section aims to answer is: how did Elmhurst shift to producing plant-based milks? Exploring this question helps to provide a basis for analysis in subsequent sections that deal with transition pathways in the milk industry as a whole.

So far, I have taken Elmhurst's changed production process as being an example of plant-based milk production. Of course, before this they were a dairy company and it is worth exploring what Elmhurst's position is in the milk industry before moving on to what can be learned regarding a transition in milk production processes.

Prior to their shift, Elmhurst's organization largely reflected that seen in the rest of the industrialized dairy sector (i.e. Elmhurst looked and functioned much like other dairy companies). Elmhurst's shift may be the first of more, thus potentially translating the combined effect of multiple dairy companies switching to plant-based substitutes to an actual regime-wide transition. The role of Elmhurst from that point of view is that of an early adopter.

Simultaneously, Elmhurst's new socio-technical context and activities arguably puts it in the category of a niche actor. The milk regime is currently dairy-based and various niche actors are actively trying to explore new ways of doing things and vying for attention. Their innovative activities can focus on improving the dairy-based system, or replace it. Market pressures stimulated Elmhurst to deploy niche activities in order to adapt successfully, involving the development of a new production process in order to create an alternative to dairy milk. Multiple other such technologies were already available, since there were other plant-based milk producers already, each with either their own or shared technological practices, yet Elmhurst still choose to engage in more innovation-centered activities.

Other characteristics of niche-level actors also apply to Elmhurst's new position. For example, regimes largely derive their stability from the strong connections between its various elements. Elmhurst has now broken or changed many of those stabilizing connections, making them both more susceptible to external pressures, but also more adaptable.

As described in chapter two, the landscape level refers to the larger context in which socio-technical regimes are situated. The socio-technical landscape includes the material and spatial arrangements of various infrastructures such as housing, cities, energy, and water supplies, socio-cultural beliefs, values, and symbols, economic issues, and politics. The niche level consists of various actors that generally work towards solving an issue of an existing regime with the aim of their innovations being integrated into that regime (Geels, 2004).

On the landscape level, there are various developments that exert pressure on the dairy industry. In many developed countries there is a decline in dairy consumption as well as an increased consumption of plant-based substitutes for dairy (Ledwith, 2017; Hancox, 2018). Globally, though, animal product consumption is predicted to rise (FAO, 2006b), primarily due to the increase in wealth in developing countries along with a growing population there (Msangi et al., 2014). Export is not always an option considering the limited expiry date of many fresh dairy products, thus forcing dairy producers to opt for more national or regional sales. In this limited market, a dwindling consumption rate leads to increased competition as companies attempt to maintain or even expand their consumer base.

On the niche level, one can see companies offering plant-based alternatives to animal products to cater to the growing number of people who purchase such foods. Various technological practices are being developed to produce a wide range of plant-based substitutes for meat, dairy, and eggs. While such replacements have existed for many years, the recent increase in popularity of these products has pushed many companies to create their own versions (Hancox, 2018). So, the niche level displays a growing number of actors seeking to enter the same market, which leads to increased innovation.

The socio-technical regime is subject to many different pressures from the landscape level, such as national and international policies concerning climate change, for example, pushing for more measures being taken regarding sustainability. Animal rights groups continue to demand better living conditions for livestock. The decline in dairy sales and increase in plant-based substitutes sales are likewise a source of destabilization of the regime. As a result of these various concerns and pressures, the regime is forced to change in order to regain stability. Smaller regional companies like Elmhurst choose to adapt in novel ways to remain competitive.

The two main factors that Elmhurst mentioned were declining sales while simultaneously noticing that their plant-based competitors were gaining momentum (Garfield, 2017). If Elmhurst would not have experienced a consistent decline in sales, there would likely not have been much reason to shift. Likewise, if sales trends of plant-based alternatives were not any better than that of dairy milk, then a shift to plant-based alternatives would, in all likelihood, simply not have been a viable option to deal with the pressure of declining sales figures. The situation Elmhurst found itself in highlighted the threat of continuing down their current path (i.e. selling dairy milk) and the opportunity of changing their target audience (i.e. consumers of plant-based milk).

The changes that food producers are noticing in their sales as a result of people increasingly opting for plant-based alternatives are very recent (only a few years), thus making it more difficult to accurately assess what type of shock or change this might be. For now, the best fit seems to be that of disruptive change, using the typology of Suarez & Oliva (2005). Specific shock generally refers to more sudden changes (e.g. a new regulation coming into effect), whereas the recent increases in number of vegans is more gradual. Likewise, avalanche change refers to a more extreme set of pressures from the landscape than is the case here. Disruptive change starts gradual, but it works up to have a high-intensity effect. It can initially be ignored, though over time starts playing a bigger and bigger role in organizations and societies. Elmhurst, as a smaller company, was one of the first to feel the effects of such changes, especially if they happen to be operating in an area where a higher than average amount of people are opting for plant-based alternatives.

In discussing transition pathways, it is important to keep in mind that Elmhurst did not transition, since the technological transitions the MLP helps to elucidate are vast, regime-wide changes and adaptations. Nevertheless, the characteristics that make up the descriptions of the various transition pathways that Geels and Schot (2007) identified can still be considered characteristics that can be identified in Elmhurst's shift. Regarding such pathways, I first mention those that do not fit Elmhurst's case.

De-alignment and re-alignment is largely the result of avalanche change, which cannot be said to be the case for Elmhurst. While there were some niche-innovations available (and in use for competitors), they did not meet the demands that Elmhurst set for their envisioned new product range. The avalanche change that would trigger a de-alignment and re-alignment scenario would also have influenced far more dairy companies than just Elmhurst.

The reconfiguration pathway also seems to be a poor description of the case study. This pathway is characterized by symbiotic relationships and incremental changes to the regime, starting with add-ons or replacements that slowly but surely trigger adjustments to the regime architecture. What Elmhurst experienced was closer to a wholesale replacement of vast portions of the technological infrastructure.

Technological substitution also does not quite fit Elmhurst's path, since it generally involves regime actors remaining stuck in their regime, assuming incremental innovations of their existing systems will provide an adequate response to landscape pressures. While this might describe the state of affairs prior to the actual shift to plant-based products, the substitution pathway also describes that niche-innovations have been sufficiently developed and stabilized to be able to push for adoption and integration into increasingly bigger markets. However, this was not the case for Elmhurst, as I will argue next.

The pathway that best describes Elmhurst's shift seems to be the transformation pathway. Moderate landscape pressure (disruptive change in particular) occurring at a moment when niche-innovations have not been developed sufficiently will cause regime actors to undertake their own research and development to come up with solutions. There were certainly niche-innovations available in general (competitors were clearly already producing various plant-based milk alternatives), none of them met the demands of Elmhurst. The company therefore undertook its own efforts into creating the technologies and processes it needed. Also of importance in the transformation pathway is the reliance of regime actors to involve outsiders with expert knowledge and skills that can help solve the problem at hand. In the case of Elmhurst, food scientists and engineers were brought in to help produce a new product (Fox, 2017; Garfield, 2017).

The sub-question of this section was: how did Elmhurst shift to producing plant-based milks? The landscape pressures Elmhurst faced describe disruptive change, which, in the absence of adequate niche-innovations, prompted organizational actors to engage in their own research and development. Their actions and subsequent shift best align with the transformation pathway.

3.3. Transition Pathways in the Milk Industry

The proposed type of transition central to this thesis (moving from an animal-centered diet to a plant-based diet) has good arguments and evidence at its core. Unfortunately, although in Western countries there is a measurable and significant change in consumer preferences, companies are slow to respond to these arguments and developments. The changes that are occurring so far do not constitute regime transitions yet, so this thesis focuses on how such transitions can be made in the future. Below, I first explore some of the factors that will play a role in the milk industry's transition pathway towards plant-based milk, after which I go into which transition pathways are (un)likely to occur.

Niche actors continue to improve their innovations, leading to changes in connections between various elements. Some of these linkages will disappear while others are newly created, and others are strengthened or weakened. Over time, as (dairy) companies decide to produce plant-based milk alternatives, the timing of that change will influence how a transition might occur. In times that niche innovations are adequately developed and ready to be adopted, there will not be much research and development spurred by regime actors, for example, since there is no need for them to make that investment. Landscape pressures may also change over time. The introduction of new regulations or of subsidies or taxes impacting the milk industry will bring specific shocks that force adaptations in a shorter time frame.

The roles of various elements in the socio-technical system (e.g. labor, education, resources, as shown in figure 2.1 in chapter 2) will change as well, depending on timing. For example, regime actors that wish to undertake their own niche activities (e.g. research and development for innovation) will rely more on what universities and other research institutions have to offer.

Much like the way Elmhurst underwent changes to their socio-technical organization, some pathways are unlikely to occur in the milk regime. The reconfiguration pathway centers around gradual augmentation and replacements of parts of the regime. As the previous chapter clarified, the production of plant-based milks involves vastly different resources and technologies than dairy milk does. A realistic shift from dairy to plant-based would therefore involve an initial large-scale overhaul of a company's production process, which might only afterwards continue to develop more gradually as it is being refined. So, the technological requirements involved in the various milk production methods necessitate significant changes that greatly reduce the chances of a reconfiguration pathway occurring.

De-alignment and re-alignment of regimes is generally the result of severe ("avalanche") shocks and pressures (Geels & Schot, 2007). The severity and suddenness of such shocks makes their anticipation very difficult. However, clearly there are already companies that feel enough pressure to produce plant-based milks, either by shifting (like Elmhurst) or by starting such a company from scratch. The steadily increasing market pressures are likely to continue at an anticipatory pace, thereby enabling companies to take action before avalanche shocks or de-alignment and re-alignment phenomena actually occur (if they do at all).

3.3.1. Transition Scenario: Transformation Pathway

If current market trends progress, particularly the decreased consumption of dairy milk and increased consumption of plant-based milks, then more dairy-based companies will experience financial pressures forcing adaptation. The dairy-based milk industry consists of various actors that will each feel the landscape pressures at different times and to different degrees. This can depend on, for example, the financial buffer they have or the location in which they operate. Economic pressures may fluctuate over time and they may also be more or less pronounced depending on the area.

Dairy companies may first respond by attempting to improve the efficiency of their production process (focusing on lowering costs in order to cope with lower revenue). Either simultaneously or later on, they may also want to get in on the plant-based milk trend.

Especially early on, when disruptive change is experienced as a moderate landscape pressure, regime actors may try to influence the direction of development paths and innovation activities (Geels & Schot, 2007). This means undertaking their own research and development into producing plant-based milks, possibly enlisting the help of outsider firms or individuals. The regime-in-transition (or parts thereof) will face a group of established plant-based milk producers. Conflict, contestations, and power struggles ensue and both sides (the changing dairy-based regime and the established plant-based milk producers) will vie for customer attention and market share.

The competing niche innovations (i.e. methods of plant-based milk production) eventually become more standardized, since some innovations will be outperformed. As the earlier mentioned disruptive change progressively adds more and more pressure to dairy companies, further adaptations of the dairy-based portion of the milk industry may start to resemble more of a technological substitution pathway (discussed below).

3.3.2. Transition Scenario: Substitution Pathway

Like the previous scenario, this discussion concerning the substitution pathway assumes that current market trends and pressures continue at roughly the same pace.

A key factor in the technological substitution pathway is a significant increase in landscape pressure, either through specific shock (e.g. a new regulation coming into effect), avalanche change, or the steadily increasing pressure of disruptive change reaching a level that forces many companies in the dairy regime to adapt at roughly the same time. So, this scenario is more concerned with rather abrupt changes happening in a relatively small amount of time, while the transformation pathway indicates more of a slow and steady transition.

As long as dairy producers are still able to deal with the landscape pressures without any large-scale transitions or adaptations, the actions of niche actors may not receive much attention. The niche actors are considered to be fringe actors or outsiders. As plant-based milks increase in popularity, existing plant-based milk producers may steadily increase their market share and become more established, leading figures. Competitive success will partially rely on the efficiency and effectiveness of a particular production process.

The advent of a significant amount of landscape pressure over a relatively short amount of time can lead to major regime tensions. This might be caused by the introduction of specific regulations or (the removal of) certain subsidies or taxes, sudden changes in public acceptance of certain practices, or market trends simply reaching a tipping point. If niche innovations have stabilized sufficiently and have gathered internal momentum, then such sudden landscape pressure may provide a window of opportunity to break through and become a (if not the) dominant means of production. The innovation ((some method of) plant-based milk production) enters mainstream markets, which will spur regime actors (dairy companies) to defend themselves, leading to increased market competition and power struggles (Geels & Schot, 2007).

If the innovation ends up becoming dominant, it likely also entails the downfall of incumbent firms. Once the niche innovations have taken over as the new regime, a reconfiguration pathway may follow up on this one. This would mostly entail niche developments aiming to solve local problems and working *with* the basic architecture of the regime, rather than aiming to replace it or compete with it.

An interesting question here (regarding both transition scenarios) will be about which factors make for a successful niche innovation. Though a transition to plant-based alternatives is arguably more sustainable, the primary motivators for adaptation were financial concerns. So, it may be the case that the niche innovations coming out on top and becoming the mainstay production process are those that appeal to consumers and that maximize output while minimizing costs. The main selection criteria may end up having little to do with sustainability concerns. While this will not necessarily indicate an unsustainable production process, it may leave room for improvement.

3.4. The Role of the Socio-Technical Landscape

Sustainability transitions are unique due to how goal-oriented they are and how many significant, structural changes it requires in the overall configuration of consumer practices, technologies, knowledge, politics, and infrastructure (Elzen, Geels, & Green, 2004; Geels, 2004). Elmhurst managed to make a change without too many changes happening to wider societal context in which it was situated. A change in consumer practices spurred their shift, but many of the other infrastructural systems (e.g. energy, housing, transportation, agriculture) did not change much, nor were they the primary motivators or obstacles. Politically there were not any significant changes either, at least in regards to the decision making process surrounding the shift. There was a need for new knowledge and technologies, but only within the confines of Elmhurst's direct zone of influence. So, looking at the various aspects of the landscape level at which significant changes have to occur to facilitate or enable sustainability transitions, there were seemingly only quite minor changes. Even the biggest change, that of consumer preferences in this case, was only relatively minor, considering this was a change of only a small percentage of the population altering their behavior as consumers. All of this makes sense given Elmhurst's role as a niche actor. Big changes to the socio-technical landscape are not required to accommodate such small actors; their focus is on finding a solution that works with the options at their disposal, not on changing the larger environment to accommodate their needs.

Elmhurst did feel pressures from the landscape, forcing adaptation, but the main way to deal with the pressures was through internal restructuring. A change in resources and most of the technologies and machines (so basically the task environment (Elzen et al., 2011; Oliver, 1997)) provided most of the things Elmhurst needed to successfully complete their shift. The institutional environment, including non-commercial groups that affect the organization such as policy makers or media (Suchman, 1995; Oliver, 1997), did not see many changes.

In Elmhurst's case, two types of landscape developments (or lack thereof) can be identified: (1) developments that are experienced as pressures, thus forcing adaptation, or (2) developments that enable or constrain transitions. The second type is especially relevant in sustainability transitions, given their goal-oriented nature. For Elmhurst in their position as a niche actor, this was not a significant issue, since they did not depend on any enabling changes or developments on the landscape level in order to successfully complete their shift. The same overall infrastructure that serves the rest of the dairy industry also enabled Elmhurst's shift. So, there's a difference between landscape developments that precipitate a transition (pressures) and those that enable, constrain, or otherwise shape transitions. A change in consumer behavior forced Elmhurst to adapt, but the adaptation itself did not require any further changes to the landscape in order to be successful.

The same may not necessarily hold true when discussing regime transitions, though it might in the case of animal agriculture. In the energy sector, for example, a sustainability transitions involving a move from coal plants to solar panels (or something similar) would mean a radical change in technologies and materials. Fossil fuel-powered energy production is usually centralized while renewable energy technologies such as solar panels and wind mills are more dispersed. There is also little overlap in the technologies and materials used in either method of energy production, nor is there much overlap in basic resources. Plant-based substitutes, however, usually require the same basic resources that are given to animals (i.e. grains, nuts, seeds). The technologies are distinctly different, but are still at centralized facilities and involve similar components (e.g. tubing, heating and cooling systems) and processes (e.g. processing, refining, packaging). It is the removal of one biotic chain.

3.5. Feasibility and Viability Beyond Elmhurst

The fact that Elmhurst has so far succeeded in shifting to plant-based milks does not automatically mean that other companies can do something similar. However, Elmhurst's shift can provide an indication in the area of feasibility. Below, I cover three reasons for why other milk producers can theoretically and realistically also shift to producing plant-based milks.

First, even though the landscape pressures Elmhurst faced were external, the solution was largely an internal affair. This point largely ties into the first point of the previous section, namely how there were relatively few changes to the greater infrastructure in which regimes are situated, yet a sustainability transition was still achieved successfully. This indicates that companies have a significant level of agency in attempting to deal with the pressures they face. Elmhurst displayed this by actively searching for and hiring outside experts.

Second, the transition in question is largely one on the level of resources, technologies, and other material aspects. Replacing the technologies involved in the production process (the task environment) comprised the biggest change to Elmhurst's overall organization. Rules and actor behaviors were less affected, meaning that the rest of the milk industry does not necessarily have to feel constrained by current sets of rules, knowledge, and skills.

A third reason for optimism regarding other companies making Elmhurst's type of shift is the very basic fact that it is a viable change to make. Elmhurst has shown that a shift can be made and that it positively affected their bottom line. If this shift turned out to not be worth the cost and effort from a financial point of view, such a shift is unlikely to materialize across larger sections of the overall regime.

Lastly, a fourth benefit of plant-based milk production is the greater variety. Dairy milk is mostly quite a homogeneous product. Plant-based milks, however, can be produced out of oats, cashews, almonds, rice, soy, flax seeds, and more, each providing unique characteristics. This diversity provides companies with the opportunity for distinguish themselves from other companies by specializing in their own types of milk. Interestingly, Elmhurst largely uses the same machinery and production methods to create multiple types of milks, indicating that there is enough of a (potential for) standardized technology to produce different variations of a product using the same machinery. If Elmhurst were to only produce one type of milk, it might mean that each type of milk requires its own unique production process. That would make production more expensive, and thus less competitive. Clearly though, this is not the case and the case study shows that one technological process enables a variety of products to be created. This can lower the threshold for companies to make a similar shift in the future, as well as making it more likely for similar technologies to be adopted.

The changed organization may also be more dynamic than the old one, both now and in the near future. Financially, the old organization was restrictive. A shrinking market led to increased competition and drove down product prices. In such situations, business as usual does not work, so adaptations are required, necessitating investments. With decreasing profit margins, every costly expenditure needs to have a good return on investment, since there is less room for mistakes. Alternatively, Elmhurst's changed organization caters to a growing market and the subsequent higher-than-expected revenue puts them in a more comfortable position financially. There is more room for investments in research and development, and further tinkering to the socio-technical organization. Arguably, both the old and the new organization have reasons to be more dynamic than usual. Landscape pressures in the form of decreased sales can force adaptations to the regime and thereby make it more dynamic. The changed organization, however, can be more dynamic due to a more comfortable financial position as well as due to the novelty of the new organization.

In short, a shift to producing plant-based milk substitutes is likely feasible as well as viable for other companies in the livestock-based portion of the milk production regime. Company agency, technology-centered changes, and economic opportunities are considerable enablers and motivators, thereby increasing the likelihood that other milk producers will also consider a shift.

3.6. Stimulating Sustainability Transitions in Food Production

In this sub-chapter I explore some options that private industry, governments, and consumers have to support sustainability transitions. I also touch upon (some of) the roles of science, media, and education.

One of the most poignant points of Elmhurst's case was that consumers have a significant influence. Consumers decreasing their purchases of dairy and opting for plant-based milks instead pushed Elmhurst towards a shift. A growing number of people are willing to change their habits and consumption behavior in favor of healthier, more sustainable, and/or more ethical products (Hancox, 2018). Increasing sales of good, proper alternatives to harmful products do not go unnoticed. But, of course those products should be available and affordable in the first place, which is where companies and governments come in. Governments can place (higher) taxes on demonstrably harmful products while subsidizing better alternatives. This can give companies an incentive to improve their product line. Companies can lobby for such supporting measures in order to help them make such changes successfully.

In large part, (more) sustainable behaviors can already be accomplished by changing habits. It takes time to transition to a completely plant-based diet, but once those habits take hold, there is little extra effort on the part of the individual; one still needs to eat and preferably by consuming tasty, easy, and affordable food. So the more sustainable way of eating needs to be supported in meaningful ways. Education is an important factor here, because before anyone changes their dietary pattern, they need to know that it is an option in the first place, as well as what the main benefits and drawbacks are. This goes for both their current diet and the diet that is under consideration. Aside from that, people may need to be educated on what a change in dietary patterns might look like in practice.

One way of bringing a more plant-based more to the foreground would be to make it the standard in health care organizations. Since a plant-based diet is more capable than other dietary patterns at preventing, and in some cases reversing, common chronic illnesses, it would make sense for that to be type of food that hospitals offer. Health care professionals, including general practitioners and other doctors could also benefit from additional knowledge on nutrition. Lifestyle-related changes could be the first way to deal with certain diseases, with medication and surgery taking less of a dominant position as a means of treating illnesses. This is especially worthwhile if changing dietary habits can achieve the same or better results than an operation or medication.

Companies and industries follow market trends as well as anticipate them or create them. Given people's daily exposure to messaging from various businesses, a more generalized and consistent emphasis from companies themselves to champion sustainability in weighing the value of products may also affect consumer behavior and attitudes. As much as there is a focus on offering the tastiest or most affordable products, there can be a focus on the most sustainable products. Coupled with governmental incentives, this could potentially put sustainability more front and center in societal awareness.

In the livestock industry, specifically, this may be even more relevant. More climate change will lead to more droughts, floods, and other extreme weather events that lead to more failed crops and therefore a decrease in the availability of certain foods. Eventually, it may even force people to decide between giving (plant-based) foods to animals (and only retain on average seven percent of the calories and nutrients given to the animals (Shepon, Eshel, Noor, & Milo, 2016)) or giving one hundred percent to humans instead. Given how much animal agriculture contributes to climate change (anywhere between 18% (FAO, 2006a) to 51% (Goodland & Anhang, 2009)), the livestock industry is its own threat (along with others such as energy production and transportation) and the food industry itself would do well to transition towards offering more sustainable products. Preferably, such sustainability transitions are made as early as possible, rather than waiting until it is forced. Proper government incentives could potentially stimulate companies to shift sooner.

Aside from facilitating the consumption of plant-based products, there are also things that can be done to facilitate its production, including supporting transitions from animal-based foods to plants. As more companies consider a transition to producing plant-based substitutes, the resource suppliers (in this case dairy farmers) will be in increasingly perilous positions. Their income and way of life is threatened by changing consumer preferences and these farmers may find themselves out of a job. As meaningful and valuable as livestock farmers may consider their work, it is very unsustainable and cannot be continued simply to retain jobs. This is an area where government assistance could potentially be of great help. Subsidies can help livestock farmers by subsidizing, for example, their own shift (e.g. growing crops instead of livestock) or education to work in related fields. If current trends continue and there is a transition in the milk industry, these are issues that will only become more pronounced as time goes on. Pro-active support on the part of the government can help to soften the blow to those who may lose their job and smoothen the changeover to another occupation.

Throughout each of the suggestions mentioned above, there is a role for governments to stimulate and support the transition process. Subsidies for plant-based substitutes or plant-based foods in general and subsidies for those companies or farmers looking to transition to plant-based alternatives could be such a form of stimulation and support. Removing subsidies or adding taxes from those foods that are harmful in their production or consumption can be another such measure. The economic benefits for governments would include savings in health care costs of more than one trillion dollars a year globally, with the U.S. saving the most at 250 billion dollars a year (Springmann, Godfray, Rayner, & Scarborough, 2016). Additional economic benefits could come from people being sick less often and therefore not being away from work for prolonged periods of time. Overall, insofar as a plant-based diet improves people's health, it may also increase people's quality of life.

4. REFLECTION

In this thesis, I explored and discussed how the milk industry functions and how it can potentially transition towards a more sustainable production system. This final chapter reflects on the analysis of the milk industry from the perspective of socio-technical systems. I first explore how the MLP helped in gaining insights regarding a sustainability transition in the milk industry. Then, I explore the added value that the MLP provided compared to other perspectives. I subsequently discuss potential further research into this topic. Lastly, I close with a summary of the overall thesis and its main conclusions.

4.1. On the STS Perspective and the MLP

Sustainability transitions are complex, multi-faceted activities that are influenced by political structures, economic pressures, technological possibilities and limitations, and social factors. In this thesis, the milk industry was considered as a socio-technical system and the MLP provided analytical distinctions with which various portions and aspects of the milk industry could be explored in a comprehensive way. Milk production (either animal- or plant-based) is a highly technological process. The analyses showed that a sustainability transition in the dairy industry is possible largely through a change in technologies. Moreover, the skills of workers dealing with these technologies are, at least partially, also the skills that are necessary in a new method of production. Beyond this, the MLP also helped show that companies themselves have quite a degree of freedom in engaging in niche-activities to form solutions to their issues, and that they are capable of finding suitable solutions within the current socio-cultural, political, and economic context. This means that the industry as a whole potentially has quite some flexibility to deal with its challenges without initially relying on (and thereby overtly alerting) external structures such as governments. So, on both the level of companies and the wider socio-technical context, the MLP provided insights into the goings-on of this kind of sustainability transition.

These insights also help to augment other fields of study. Below, I explore what the MLP adds to economy-based, engineering-based, and social science-based analyses of a sustainability transition in the milk industry.

The field of economics largely blackboxes technology and its influence. Throughout the thesis, economic considerations were a recurring factor. Market pressures put Elmhurst in a perilous position and market opportunities provided a way out. The MLP provided insights into the role of technology in this shift. The technological nature of milk production meant that technological capabilities (or lack thereof) would play a major role in Elmhurst's success. Integration into existing (parts of) systems, skill requirements of workers dealing with these technologies, and the capacity to produce a product that meets consumer demands were all factors that needed to be taken into consideration. Using the MLP to explore Elmhurst as a case study provided a more comprehensive picture of the role of technology in this type of transition.

Likewise, Elmhurst's case also helped show that engineering-wise, there are various options of integrating the plant-centered innovations into the wider socio-technical landscape. The production processes overall (when comparing dairy-based and plant-based production) show quite some overlap regarding some aspects of production, particularly in the later stages. This is also relevant given the human factor; workers still have to run the production processes and a higher degree of similarity means less of a need for retraining.

Building on the previous point: for policy makers, the STS perspective helped elucidate the fact that niche actors can adopt more sustainable technological processes without much external support. So, current efforts towards more sustainable practices, at the very least in the milk industry, are not necessarily impeded by limitations set by the wider infrastructure. Regime actors also have quite a degree of agency in making change happen. All of this means that the beginnings of a regime-wide (sustainability) transition can go relatively unnoticed for some time, since there will not be a great need for outside (governmental) support. Given the very significant effects a regime transition of the type discussed in this thesis can have, it is wise for lawmakers to anticipate these changes by adopting supporting measures, as well palliative ones (e.g. for dairy farmers finding themselves out of a job in increasingly large numbers).

Throughout the thesis, one of the most significant (though obvious) lessons has been that consumers have a considerable impact. Through their purchases, they either support an industry, or they force it to change. Fewer consumers purchasing animal-based products forces animal-based companies to switch to other production methods. The MLP was not necessary in getting to this particular insight, but it is worth emphasizing.

4.2. Further Research

The MLP has been a useful framework throughout the exploration of the topic at hand. Its use prompted questions that helped to make more sense of Elmhurst's shift and add more context to it. However, there are some limitations that arose that need to be addressed in the future.

Elmhurst was a company that made a wholesale shift from animal-based products to plant-based products, but there are also companies, both inside and outside of the food production industry, that use fewer animal products (mostly basing their products on plants). Examples are soap manufacturers, or producers of licorice (usually containing some amount of gelatin). Some of these companies also shifted to a fully plant-based product and they may be examples of more incremental change, thus aligning more with a reconfiguration pathway.

The limitations of the scope of this thesis resulted in a focus on industrialized milk production, yet there are many livestock-based dairy companies, both in developed and developing countries, that would not be considered industrialized. Differences in scale, technological sophistication, and societal context will make for a socio-technical environment that may face its own unique set of opportunities and obstacles that are unlike those discussed in this thesis. It is worth exploring other socio-technical regimes more closely as well, especially considering the fact that the current trend towards a plant-based diet in the West does not limit itself to the milk industry.

As mentioned in the second chapter, the MLP does not adequately take into consideration the influence of attitudes. Norms and values as well as the moral underpinnings of sustainability transitions are blackboxed by taking them as a given, rather than a factor that plays an active role in sustainability transitions. It would be helpful to open up this box and to explore how these factors play a role in such transitions.

Moving away from animal agriculture is a worthwhile transition for multiple reasons. However, there are factors that were beyond the scope of this thesis that are worth exploring further. For example, even though it is demonstrably more sustainable to produce plant-based foods than it is animal products, questions can be asked such as: Is the milk production facility running on renewable sources of electricity? Are the basic resources (i.e. grains, nuts, seeds) themselves produced in environmentally friendly ways, without pesticides or herbicides for example? Many such questions are still unanswered and each topic provides another opportunity for improvements to the sustainability of the overall system of food production. The shift to plant-based substitutes may have been successful even when there were not many structural changes to the landscape level, but when all the other topics are taken into account as well (e.g. energy or agricultural practices), there may be more of a need for more systemic changes.

More widespread changes to the landscape may also occur as a result of a sustainability transition, rather than being an enabler of such transitions. The opportunity cost from producing dairy instead of plant-based equivalents is 75%, meaning that dairy only provides 25% of the calories and nutrients that a plant-based substitute would have when relying on the same basic resources (Shepon, Eshel, Noor, & Milo, 2018). If, over time, a large portion of the dairy industry switches to plant-based milk production, this would have far-reaching consequences not just for the socio-technical regime itself, but also for the landscape level. When a significant portion of livestock-based companies switch to plant-based products, this will have far-reaching consequences regarding land use (reducing land requirements, thus facilitating crop rotation and diversification), greenhouse gas emissions, fresh water usage, societal attitudes, and more. A few companies changing their production process will not have a large effect, but a significant enough number of companies doing so will certainly affect the landscape level, at least nationally, but potentially globally. It will also change job requirements significantly. For example: dairy farmers and their workers will find themselves having to acquire new jobs, likely needing new knowledge and skills.

Furthermore, a change in consumer preferences in the area of milk may also come with changes in preferences regarding other products, such as meat or eggs, thereby also mimicking the struggles of the dairy industry in other sectors of animal agriculture. These changes and more will affect the socio-technical landscape significantly, but the more severe and widespread changes will likely start occurring after regimes themselves start changing internally first.

Lastly, the available information for the analysis portion of this thesis (particularly the third chapter) was rather general and would benefit from more specific descriptions. This would better bring into focus the various connections and dynamics that exist in a socio-technical system, as well as how these factors influenced the transition process.

4.3. Summary & Conclusions

This thesis began with clarifying the need for a change in food production and consumption practices. A plant-based diet has various worthwhile benefits that are especially relevant in the context of climate change and having to sustain a growing world population. In this thesis, I applied the MLP to map the milk production industry and used Elmhurst as a case study to contrast animal-based and plant-based milk production methods. The analysis shows that while there are significant differences between each system, it is primarily a technological shift that enabled Elmhurst to create a more sustainable product.

The main research question is: from the perspective of socio-technical systems, which obstacles and opportunities can be identified on a transition pathway from dairy products to plant-based substitutes? Elmhurst's shift followed a transformation pathway and both a transformation and a substitution pathway are possible and likely for the dairy industry if current market trends continue. During the early stages of such a transition there will still be some competition among niche actors, each trying to promote their particular innovation. Regime actors may decide, in the midst of this turmoil, that they want to create their own production process, thus leading to a transformation pathway. Later on, however, there may be a sufficient amount of innovations to choose from, thereby leading to more of a substitution pathway.

Regarding the opportunities: Elmhurst's case showed that their shift was possible without further changes to the current socio-technical landscape. While the landscape will keep changing, there are currently no major (landscape-based) limitations that would prevent other dairy-based companies from transitioning to plant-based milk substitute production. A majority of the required changes to a company's socio-technical organization take place within the task environment (i.e. those activities related to the production of artefacts). Another opportunity is the fact that there is a growing amount of niche-innovations that can support the production of plant-based milk substitutes. Elmhurst's innovation is yet another one that could be adopted by companies looking to make this sort of change. Lastly, the more companies shift, the more case studies there are to learn from, making a shift easier and less risky for the next company that elects to do so.

Regarding the obstacles: every regime has multiple reasons to maintain their current practices, unless and until external pressure forces adaptation. Any of these reasons, ranging from sunk costs to retraining requirements, can complicate a transition. Elmhurst was in a position to shift successfully, but Elmhurst's state of affairs prior to their shift may not be the starting point other companies have. Additionally, if a sustainability transition like the one discussed in this thesis is to be made sooner rather than later, there are considerable obstacles to overcome regarding societal perception of and attitude towards the livestock industry. If animal products are considered to be healthy or vital, or animal agriculture is considered to be necessary or acceptable, this can take away from supporting or enabling measures aiming to stimulate transitions away from livestock farming.

To conclude: this thesis has mapped what a sustainability transition towards a plant-based diet might look like and what some of the main considerations are that need to be kept in mind. There are still plenty of obstacles to overcome, but there is reason for optimism for the future. Not only is a transition away from animal products possible, it is also viable. If this kind of transition can be made successfully, it will make for a healthier society and a far more sustainable world.

REFERENCES

Akrich, M. (1992). *The description of technical objects*. In: Bijker, W. E. & Law, J. (Eds.), Shaping technology/building society: studies in sociotechnical change. The MIT Press, Cambridge, MA: pp. 205-224.

Barnard, N. D., Bush, A. I., Ceccarelli, A., Cooper, J., De Jager, C. A., … Squitti, R. (2014). Dietary and lifestyle guidelines for the prevention of Alzheimer's disease. *Neurobiology of Aging* 35(2), pp. S74-S78. Doi: 10.1016/j.neurobiolaging.2014.03.033

Baroni, L., Cenci, L., Tettamanti, M., & Berati, M. (2007). Evaluating the environmental impact of various patterns combined with different food production systems. *European Journal of Clinical Nutrition* (61), pp. 279-286.

Baxter, G. & Somerville, I. (2011). Socio-technical systems: from design methods to systems engineering. *Interacting with Computers* 23(1), pp. 4-17. doi: 10.1016/j.intcom.2010.07.003

Berkhout, F., Smith, A., & Stirling, A. (2004). *Socio-technological regimes and transition contexts*. In: Elzen, B., Geels, F. W., Green, K. (Eds.), System Innovation and the Transition to Sustainability: Theory, Evidence and Policy. Edward Elgar, Cheltenham, UK, pp. 48-75.

Berkhout, F., Angel, D., & Wieczorek, A. J. (2009). Asian development pathways and sustainable socio-technical regimes. *Technological Forecasting & Social Change* (76), pp. 218-228.

Beverland, M. B. (2014). Sustainable eating: mainstreaming plant-based diets in developed economies. *Journal of Macromarketing* 34(3), pp. 369-382. doi: 10.1177/0276146714526410

Bijker, W. E. (1995). *Of bicycles, bakelites, and bulbs: towards a theory of sociotechnical change*. The MIT Press, Cambridge, MA/London, England.

Bos, B., Groot Koerkmap, P., Gosselink, J., & Bokma, S. (2008, July). *Reflexive Interactive Design and its application in a project on sustainable dairy husbandry systems*. Symposium conducted at the 8th meeting of the International Farming Systems Association, Clermont-Ferrarand, France.

Breschi, S. & Malerba, F. (1997). *Sectoral innovation systems: technological regimes, Schumpterian dynamics, and spatial boundaries*. In: Edquist, C. (Ed.), Systems of Innovation: Technologies, Institutions and Organizations. Pinter, London/Washington: pp. 130-156.

Burns, T. R. & Flam, H. (1987). *The shaping of social organization: social rule system theory with applications*. Sage Publications, London.

Campbell, T. C. & Campbell, T. M. II (2006). *The China Study: the most comprehensive study of nutrition ever conducted and the startling implications for diet, weight loss, and long-term health*. Dallas, TX: BenBella Books, Inc. ISBN: 1-932100-38-5.

Carbon Trust (2011). Industrial energy efficiency accelerator: guide to the dairy sector. *Carbon Trust*. Retrieved on 5 July 2018, from: https://www.carbontrust.com/media/206472/ctg033-dairy-industrial-energy-efficiency.pdf

Carlsson, B. & Stankiewicz, R. (1991). On the nature, function and composition of technological systems. *Journal of Evolutionary Economics* (1), pp. 93-118.

Cassidy, E. S., West, P. W., Gerber, J. S., & Foley, J. A. (2013). Redefining agricultural yields: from tonnes to people nourished per hectare. *Environmental Research Letters* 8(3). doi: 10.1088/1748-9326/8/3/034015

Elmhurst Milked, LLC (2017a). *Our process*. Retrieved on 10 September 2018, from: htps://elmhurst1925.com/our-process

Elmhurst Milked, LLC (2017b). *Our story*. Retrieved on 12 September 2018, from: https://elmhurst1925.com/our-story

Elzen, B., Geels, F. W., & Green, K. (2004). *System innovation and the transition to sustainability: theory, evidence and policy*. Edward Elgar, Cheltenham, UK.

Elzen, B., Geels, F. W., Leeuwis, C., & Van Mierlo, B. (2011). Normative contestation in transitions 'in the making': animal welfare concerns and system innovation in pig husbandry. *Research Policy* (40), pp. 263-275. doi: 10.1016/j.respol.2010.09.018

Esselstyn, C. B. (2010). Is the present therapy for coronary artery disease the radical mastectomy of the twenty-first century? *American Journal of Cardiology* 106(6), pp. 902-904.

Food and Agriculture Organization (2006a). *Livestock's long shadow: environmental issues and options*. Eds.: Steinfeld, H., Food and Agriculture Organization of the United Nations., & Livestock, Environment and Development (Firm). Rome: Food and Agriculture Organization of the United Nations.

Food and Agriculture Organization (2006b). *World agriculture: towards 2030/2050*. Eds.: Bruinsma, J., Bödeker, G., Schmidhuber, J., Broca, S., Shetty, P., & Ottaviana, M. G. Food and Agriculture Organization of the United Nations: Global Perspective Studies Unit. Rome: Food and Agriculture Organization of the United Nations.

Food and Drug Administration (2018, February 23). Milk guidance documents and regulatory information. *U.S. Department of Health and Human Services*. Retrieved on 7 September 2018, from: https://www.fda.gov /Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/Milk/default.htm

Forster, P., Ramaswamy, V., Artaxo, P., Berntsen, T., Betts, R., Fahey, D. W., … & Van Dorland, R. (2007). *Changes in Atmospheric Constituents and in Radiative Forcing*. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Eds.: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M., & Miller, H. L. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Fox, K. (2017, October 17). Why this New York dairy ditched cows after 92 years and started making nut milks. *Forbes*. Retrieved on 30 June 2018, from: https://www.forbes.com/sites/katrinafox/2017/10/17/why-this-new-york-dairy-ditched-cows-after-92-years-and-starting-making-nut-milks/2/#2bcc91fb10aa

Fraser, G. E. (2009). Vegetarian diets: what do we know of their effects on common chronic diseases? *American Journal of Clinical Nutrition* 89(5), pp. 1607S-1612S. doi: 10.3945/acjn.2009.26736K

Freeman, C. & Perez, C. (1988). *Structural crisis of adjustments, business cycles and investment behaviour*. In: Dosi, G., Freeman, C., Nelson, R., Silverberg, G., & Soete, L. (Eds.), Technical change and economic theory. Pinter, London, pp. 38-66.

Garfield, L. (2017, April 22). A major dairy producer collapsed—now it's making nut milks and business is booming. *Business Insider*. Retrieved on 30 June 2018, from https://www.businessinsider.nl/dairy-farm-nut-milks-elmhurst-2017-4/?international=true&r=US

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy* 31(8-9), pp. 1257-1274. doi: 10.1016/S0048-7333(02)00062-8

Geels, F. W. (2004). From sectoral systems of innovation to socio-technical system: insights about dynamics and change from sociology and institutional theory. *Research Policy* (33), pp. 897-920.

Geels, F. W. (2006). The dynamics of transitions in socio-technical systems: a multi-level analysis of the transition pathway from horse-drawn carriages to automobiles (1860-1930). *Technology Analysis & Strategic Management* 17(4), pp. 445-476). doi: 10.1080/09537320500357319

Geels, F. W. & Kemp, R. (2007). Dynamics in socio-technical systems: typology of change processes and contrasting case studies. *Technology in Society* 29(4), pp. 441-455. doi: 10.1016/j.techsoc.2007.08.009

Geels, F. W. & Schot, J. (2007). Typology of sociotechnical transition pathways. *Research Policy* 36(3), pp. 399-417. doi: 10.1016/j.respol.2007.01.003

Genus, A. & Coles, A.-M. (2008). Rethinking the multi-level perspective of technological transitions. *Research Policy* (37), pp. 1436-1445.

GlobalData (2017). *Top trends in prepared foods 2017: exploring trends in meat, fish and seafood; pasta, noodles and rice; prepared meals; savory deli food; soup; and meat substitutes* (report code: CS1713CT). Retrieved on 30 June 2018, from: https://www.globaldata.com/store/report/cs1713ct--top-trends-in-prepared-foods-2017-exploring-trends-in-meat-fish-and-seafood-pasta-noodles-and-rice-prepared-meals-savory-deli-food-soup-and-meat-substitutes/

Goodland, R. & Anhang, J. (2009). Livestock and Climate Change: What if the key actors in climate change were pigs, chickens and cows? *Worldwatch*, November/December. Worldwatch Institute, pp. 10–19.

Greger, M. & Stone, G. (2015). *How not to die: discover the foods scientifically proven to prevent and reverse disease*. New York, NY: Flatiron Books. ISBN: 978-1-250-06611-4 (hardcover) / 978-1-250-06612-1 (e-book).

Hancox, D. (2018, April 1). The unstoppable rise of veganism: how a fringe movement went mainstream. *The Guardian*. Retrieved on 30 June 2018, from: https://www.theguardian.com/lifeandstyle/2018/apr/01/vegans-are-coming-millennials-health-climate-change-animal-welfare

Hughes, T. P. (1987). *The evolution of large technological systems*. In: Bijker, W. E., Hughes, T. P., Pinch, T. (Eds.), The social construction of technological systems: new directions in the sociology and history of technology. The MIT Press, Cambridge, Massachusetts, pp. 51-82.

Jiang, R., Paik, D. C., Hankinson, J. L., & Barr, R. G. (2007). Cured meat consumption, lung function, and chronic obstructive pulmonary disease among United States adults. *American Journal of Respiratory and Critical Care Medicine* 175(8), pp. 798-804. doi: 10.1164/rccm.200607-969OC

Latour, B. (1992). *Society is technology made durable*. In: Law, J. (Ed.), A sociology of monsters, essays on power, technology and domination. Routledge, London, pp. 103-131.

Le, L. T. & Sabaté, J. (2014). Beyond meatless, the health effects of vegan diets: findings from the Adventist Cohorts. *Nutrients* 6(6), pp. 2131-2147. doi: 10.3390/nu6062131

Lea, E. J., Crawford, D., & Worsley, A. (2006). Public views of the benefits and barriers to the consumption of a plant-based diet. *European Journal of Clinical Nutrition* (60), pp. 828-837.

Ledwith, M. (2017, June 15). Soy milk? You can't call it milk, says the EU: order to rename dairy substitutes because they do not contain produce from an animal. *Daily Mail*. Retrieved on 12 July 2018, from: http://www.dailymail.co.uk/news/article-4605566/Soy-milk-t-call-milk-says-EU-court-justice.html

Lintsen, H., Veraart, F., Smits, J.-P., & Grin, J. (2018). *Well-being, sustainability and social development: The Netherlands 1850-2050*. Cham, Switzerland: Springer International Publishing. ISBN: 978-3-319-76695-9 / 978-3-319-76696-6 (e-book). doi: 10.1007/978-3-319-76696-6

Msangi, S., Enahoro, D., Herrero, M., Magnan, N., Havlik, P., Notenbaert, A., & Nelgen, S. (2014). Integrating livestock feeds and production systems into agricultural multi-market models: the example of IMPACT. *Food Policy* (49), pp. 365-377.

Murphy, S. L., Kochanek, K. D., Xu, J., & Arias, E. (2014). *Mortality in the United States*. NCHS Data Brief (229), pp. 178.

Murray, C. J., Atkinson, C., Bhalla, K., Birbeck, G., Burstein, R., Chou, D., … Wulf, S. (2013). The state of US health, 1990-2010: burden of diseases, injuries, and risk factors.

Murray, S. (2007, November 15). The world's biggest industry. *Forbes*. Retrieved on 12 August 2018, from https://www.forbes.com/2007/11/11/growth-agriculture-business-forbeslife-food07-cx_sm_1113 bigfood.html#7d6a57c9373e. Accessed on 26 June 2017.

Norman, D. W. (2002). *The farming systems approach: a historical perspective*. Presentation conducted at the 17th Symposium of the International Farming Systems Association in Lake Buena Vista, Florida, U.S.A. on 17-20 November 2002.

Oliver, C. (1997). The influence of institutional and task environment relationships on organizational performance: the Canadian construction industry. *Journal of Management Studies* (34), pp. 99-124.

Oppenlander, R. (2012). *Comfortably unaware: what we choose to eat is killing us and our planet*. New York, NY: Beaufort Books. ISBN: 978-0-8253-0686-0 (paper) / 978-0-8253-0622-8 (e-book).

Oppenlander, R. (2013). *Food choice and sustainability: why buying local, eating less meat, and taking baby steps won't work*. Minneapolis, MN: Langdon Street Press. ISBN-13: 978-1-62652-435-4.

Ornish, D., Scherwitz, L. W., Billings, J. H., Brown, S. E., Gould, K. L., Merritt, T. A., … Brand, R. J. (1998). Intensive lifestyle changes for reversal of coronary heart disease. *Journal of the American Medical Association* 280(23), pp. 2001-2007.

Ornish, D., Weidner, G., Fair, W. R., Marlin, R., Pettengill, E. B., Raisin, C. J., … Caroll, P. R. (2005). Intensive lifestyle changes may affect the progression of prostate cancer. *Journal of Urology* 174(3), pp. 1065-1069.

Perez, C. (2002). *Technological revolutions and financial capital: the dynamics of bubbles and golden ages.* Edward Elgar, Cheltenham.

Pimentel, D. & Pimentel, M. (2003). World population, food, natural resources, and survival. *The Journal of New Paradigm Research* 59(3-4), pp. 145-167. doi: 10.1080/02604020310124

Pinch, T. J. & Bijker, W. E. (1987). *The social construction of facts and artifacts: or how the sociology of science and the sociology of technology might benefit each other*. In: Bijker, W. E., Hughes, T. P., Pinch T. J. (Eds.), The social construction of technological systems: new directions in the sociology and history of technology. The MIT Press, Cambridge, MA, pp. 17-50.

Poore, J. & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. *Science* 360(6392), pp. 987-992. doi: 10.1126/science.aaq0216

Porter, M. (1991). Towards a dynamic theory of strategy. *Strategic Management Journal* (12), pp. 95-117. Winter Special Issue.

RLI (2018). *Duurzaam en gezond: samen naar een houdbaar voedselsysteem*. Eds.: M. Demmers, I. Y. R. Odegard, K. J. Poppe, M. E. Bouwman, N. W. M. van Buren, A. Koose-Verschoor, H. Koutstaal, & B. B. W. Thorborg. Raad voor de Leefomgeving en Infrastructuur, Report, March 2018.

Rip, A. & Kemp, R. (1998). *Technological change*. In: Rayner, S. & Malone, E. L. (Eds.), Human Choice and Climate Change, vol. 2. Battelle Press, Columbus, OH, pp. 327-399.

Robbins, J. (2001). *The food revolution: how your diet can help save your life and our world*. San Francisco, CA: Conari Press. ISBN: 9780-1-57324-487-9.

Rothaermel, F. T. (2001). Complementary assets, strategic alliances, and the incumbent's advantage: an empirical study of industry and firm effects in the biopharmaceutical industry. *Research Policy* 30, pp. 1235-1251.

Shepon, A., Eshel, G., Noor, E., & Milo, R. (2016). Energy and protein feed-to-food conversion efficiencies in the US and potential food security gains from dietary changes. *Environmental Research Letters* 11(10). doi: 10.1088/1748-9326/11/10/105002

Shepon, A., Eshel, G., Noor, E., & Milo, R. (2018). The opportunity cost of animal-based diets exceeds all food losses. *Proceedings of the National Academy of Sciences of the United States of America (PNAS)* 115(15), pp. 3804-3809. doi: 10.1073/pnas.1713820115

Smith, A., Stirling, A., & Berkhout, F. (2005). The governance of sustainable socio-technical transitions. *Research Policy* 34(10). doi: 10.1016/j.respol.2005.07.005

Springmann, M., Godfray, H. C. J., Rayner, M., & Scarborough, P. (2016). Analysis and valuation of the health and climate cobenefits of dietary change. *Proceedings of the National Academy of Science* 113(15), pp. 4146-4151. doi: 10.1073/pnas.1523119113

Strum, S. & Latour, B. (1999). *Redefining the social link: from baboons to humans*. In: MacKenzie, D., & Wacjman, J. (Eds.), The social shaping of technology, 2nd ed. Open University Press, Buckingham, Philadelphia, pp. 116-125.

Suarez, F. F. & Oliva, R. (2005). Environmental change and organizational transformation. *Industrial and Corporate Change* 14(6), pp. 1017-1041. doi: 10.1093/icc/dth078

Suchman, M. C. (1995). Managing legitimacy: strategic and institutional approaches. *Academy of Management Review* (20), pp. 571-611.

Tonstad, S., Butler, T., Yan, R., & Fraser, G. E. (2009). Type of vegetarian diet, body weight, and prevalence of type 2 diabetes. *Diabetes Care* 32(5), pp. 791-796. doi: 10.2337/dc08-1886

Turner, K., Georgiou, S., Clark, R., Brouwer, R., & Burke, J. (2004). *Economic valuation of water resources in agriculture: from the sectoral to a functional perspective of natural resource management*. FAO Water Reports. Rome, Italy: Food and Agriculture Organization of the United Nations.

Van Driel, H. & Schot, J. (2005). Radical innovation as a multi-level process: introducing floating grain elevators in the port of Rotterdam. *Technology & Culture* (46), pp. 51-76.

Varraso, R., Jiang, R., Barr, R. G., Willett, W. C., & Camargo, C. A. Jr. (2007). Prospective study of cured meats consumption and risk of chronic obstructive pulmonary disease in men. *American Journal of Epidemiology* 166(12), pp. 1438-1445. doi: 10.1093/aje/kwm235

Verbeek, P.-P. (2008). Obstetric ultrasound and the technological mediation of morality: a postphenomenological analysis. *Human Studies* 31(1), pp. 11-26. doi: 10.1007/s10746-007-9079-0

Winner, L. (1980). Do artefacts have politics. *Daedalus* 109(1), pp. 121-136.

APPENDIX A: THE CASE FOR A PLANT-BASED DIET

The text below is a more elaborate exploration of the various arguments pertaining to a transition towards a plant-based diet. It repeats some of the points made in the first chapter of this thesis, but includes vastly more research and sources. The main purpose of this appendix is to clarify and underline that the transition central in this thesis is not just theoretical. Animal agriculture, as normal as it is, is more destructive and harmful than most people realize. As such, this topic is worth exploring more deeply.

Food Choice and Health Outcomes

This section outlines the effects of various types of diets on human health. Particularly the Western diet will be explored due to its worldwide presence and that it is expected to become more uniformly adopted, with a growing number of nations trending towards it as they increase their wealth and accessibility to such a diet. One of the foremost examples of a country on such a diet is the United States. There are also a large number of empirical studies available on U.S. citizens' health and their diet. Another country to focus on is the Netherlands, mainly because the rest of this thesis will go more in-depth into Dutch socio-technological practices in animal agriculture, but also due to this thesis being written at a Dutch university by a Dutch author. The similarities in diet between the United States and the Netherlands will also enable drawing upon more research since the similarities in diet may likely also result in similar health outcomes. As a contrast to the Western diet, a plant-based diet and its effect on health will be examined. The main reason for this is due to its potential health benefits and its more sustainable food production practices.

There is not a precise definition for what constitutes a Western or plant-based diet. These definitions generally discuss emphasized or unique aspects of a given diet. For the purpose of this thesis, this is enough, though, since the emphasized characteristics of both diets are sufficiently different from each other. Regarding the Western diet, most would consider the United States to be an example of a country consuming such a diet, but even within the U.S. itself there are considerable differences in overall dietary behaviors. Therefore, in the remainder of this thesis, the term "Western diet" will simply refer to an overall dietary pattern that emphasizes the consumption of meat, fish, dairy, eggs, refined grains, sugar, and oils. For similar reasons, the term "plant-based diet" will refer to (largely) unrefined plant foods, including vegetables, fruits, legumes, grains, nuts, and seeds and the exclusion of animal-derived products.

Two main types of research will be used to explore the relation between diet and health. The first are observational studies. These studies take a proverbial snapshot in time and exemplify how several variables are correlated. For example, such a study could show that smoking is correlated to lung cancer. However, it cannot show causality and will therefore not be able to conclude whether smoking causes lung cancer, or whether people with a predisposition to smoking are simply more likely to smoke for whatever reason. The second type of study is interventional studies, which follow people throughout time as they are put in an experimental condition. For example, a group of people is randomly assigned to a non-smoking group, and another is randomly assigned to a smoking group. If in five, ten, or twenty years time the group of smokers develops significantly more lung cancer than the other group, then we could derive that smoking may cause lung cancer. Various other factors require consideration as well, though, to rule out other causes. For example, average weight, activity level, dietary patterns, and more variables may also be measured to act as a control. If there are no significant differences among these other variables and only the smoking comes out as the main difference, then that strengthens the conclusion of smoking being a causal factor for lung cancer. Similar trials are used in nutrition research. The main interventional studies used in this thesis will be randomized (participants randomly assigned to either the control or experimental group), single- or double-blind (respectively just the statistician or both the participants and statistician not knowing who belongs to which group), placebo-controlled trials, along with statistical controls for other potential relevant factors, such as age, weight, body mass index (BMI), gender, ethnicity, education level, income, and quantities of daily sleep, exercise, cigarette consumption, or alcohol consumption, among others. Ideally, one would use only double-blind trials so that even the participants are not sure whether they are in the control or experimental group, but in practice people tend to notice quite quickly whether they are in the group that includes or excludes certain products.

General Observations

Within the United States, most deaths have been found to be diet-related and preventable (Lenders et al., 2013). Diet has been shown to be the number one cause of premature death as well as the number one cause of disability (Murray et al., 2013). Back in 1900 in the United States, the main three causes of death were pneumonia, tuberculosis, and diarrheal disease; all three being infectious diseases (U.S. Centers for Disease Control and Prevention (CDC), n.d.). Nowadays, however, the killers are largely lifestyle diseases such as heart disease, cancer, and chronic lung disease (Murphy, Kochanek, Xu, & Arias, 2014). In the meantime, medicine has progressed, improvements in food production and distribution have supplied Western society with an abundance of food, we developed vaccines, and produced clean water. These factors are among the main reasons for a decreased overall mortality and increased lifespan as compared to the late 19th century. Citizens in the U.S. are now living longer than their previous generations, but those extra years are not necessarily healthy ones. Moreover, even though life expectancy has risen, the years one can expect to live without disease are fewer than before. Specifically, simply between 1998 and 2006 life expectancy has risen by about one year although an extra three years of that life are now with chronic disease (Crimmins & Beltrán-Sánchez, 2011). Effectively one step forward and three steps back in only eight years time.

With various rapidly industrializing societies across the world undergoing many simultaneous changes, why do we suspect the changes in diet specifically to be related to the increasing occurrence of certain diseases? Scientists engage in observational studies to track the eating habits and diseases of large groups of people over time. One example regarding meat comes from vegetarians who started to eat meat again at least once a week. Over the course of twelve years, this group experienced an increase in their chances of getting heart disease, stroke, and diabetes of 146%, 152%, and 166%, respectively, as well as a 231% increase in their odds of weight gain (Singh et al., 2014).

China may be one of the most well-studied examples. One of the most comprehensive studies ever conducted on nutrition is the “China Study”, focusing primarily on cancer rates (Campbell & Campbell, 2006). The reason China is an often-used example is due to its population sharing roughly the same genetic background, culture, and policies. Eating habits in the more industrialized parts of the country (mostly larger cities) do differ from the eating habits of people living in rural areas. The former group has adopted a more Western diet, consuming more meat, eggs, dairy, oils, sugar, sodas, and refined grains, while the latter retained the traditional plant-based diet (Popkin, 2006). Transitioning away from the traditional diet was accompanied by a sharp rise in chronic diseases such as heart disease, cancer, diabetes, and obesity (Zhai et al., 2009). The China Study found that cancers were largely geographically localized, with some areas having up to one hundred times higher rates than others (Campbell & Campbell, 2006). With the Chinese population not differing that much in terms of genetics, the main cause for this discrepancy was sought in environmental factors with diet being the foremost consideration. Worth noting here is that the areas with the highest cancer rates were most Westernized in their diet, and the lowest cancer rates were observed in rural areas where a (mostly) plant-based diet is the norm. In contrast to China and its considerable differences in the prevalence of cancer, the United States' statistics show the areas with the highest cancer rates have at most two to three times higher rates than the areas with the lowest rates. Part of these findings were explained by the fact that most of U.S. citizens eat roughly the same diet, while China displays much greater variety in dietary patterns. For example, animal protein consumption (as a marker for the amount of animal products consumed) in the U.S. was far higher than in rural China. The average U.S. citizen got about 15-16% of their calories from protein, with upwards of 80% coming from animal products. In contrast, rural Chinese citizens got only 9-10% of their calories from protein, with only 10% coming from animal products (Campbell & Campbell, 2006). Another trend the China Study checked for was whether increased animal product consumption also correlated to other "Western" diseases. It turned out that areas with higher animal product consumption did not simply have higher cancer rates, but also saw higher rates of obesity, cardiovascular disease, and diabetes among others (Campbell & Campbell, 2006).

Both in the United States and the Netherlands, cancer and heart disease top the list of main causes of death. Heart disease is the main cause of death in the U.S. (National Center for Health Statistics (NCHS), 2016), while in the Netherlands the main killer is cancer (Centraal Bureau voor de Statistiek (CBS), 2016). Both diseases combined account for about 46% (NCHS, 2016) and 57% (CBS, 2016) of all deaths in the U.S. and the Netherlands respectively. These high numbers are typical for many societies that follow a standard Western diet (i.e. including high amounts of meat, fish, dairy, eggs, refined grains, and sugars) (Campbell & Campbell, 2006). For this reason, I will go more deeply into how these two diseases and diet are related. Afterwards, I will also briefly touch upon obesity and diabetes, since these conditions are considered to be on the rise in nearly all Western countries. For example, it is expected that 42% the American population will be clinically obese (not to mention overweight in general) by 2030 (Finkelstein et al., 2012) and one third of Americans will be diabetic by the middle of the century (Boyle et al., 2010).

Heart Disease

The build-up of cholesterol-rich plaque inside the arteries is known as atherosclerosis. It hardens the arteries and narrows the path for blood flow. Over the years this plaque can build up, further restricting blood flow. If a part of this plaque ruptures, a blood clot can be formed that blocks off the artery. This is not a localized process, but happens throughout the body. In some places in the body these blood clots are more hazardous than others, though. For example, if this happens in a coronary artery (an artery that crowns the heart) it can cause a heart attack. Likewise, if this happens in a brain artery, it can cause a stroke (Greger & Stone, 2015).

In 1953, a study was published that radically altered the understanding of the progression of heart disease. Three hundred autopsies were done on American casualties of the Korean War and 77% of them apparently already showed visible signs of coronary atherosclerosis with some displaying arteries that were blocked off for 90% or more (Enos, Holmes, & Beyer, 1953). The casualties were young men averaging twenty-two in age. The startling conclusion here was that coronary heart disease (CHD) already starts decades before any symptoms may reveal themselves. Even more surprising results came from research done on American children that died from accidents. The autopsied victims were between the ages three and twenty-six and researchers found fatty streaks (the first stage of atherosclerosis) in just about all children by age ten (Voller & Strong, 1981). Subsequently, Italian researchers even found arterial lesions in the arteries of fetuses whose mothers' LDL cholesterol levels were high (Napoli et al., 1997).

LDL (low-density lipoprotein) cholesterol is often called the "bad" cholesterol, since it is the main cholesterol-depositing substance in our arteries. The amount of "bad" cholesterol in one's arteries been shown to be closely correlated to the amount of atherosclerotic buildup (McMahan et al., 2006). In order to reduce LDL cholesterol levels in the blood stream, one needs to reduce the intake of: 1) trans fats (found in processed food, meat, dairy), 2) saturated fat (found mostly in animal products and highly processed, low-nutrient foods (junk food)), and to a lesser extent 3) dietary cholesterol (found exclusively in animal products) (Trumbo &

Shimakawa, 2011). The (over)consumption of animal products and junk food likely explains why heart disease is so common in the West and so extremely rare in societies or communities that follow a plant-based diet.

Two separate studies were done in which researchers put patients with advanced heart disease on the type of plant-based diet followed by African or Asian populations that did not have a history of heart disease. The idea was that if this type of diet actually works, then the progression of heart disease in these patients would be stopped. However, instead of the heart disease either progressing or stagnating its progress, it started to reverse; the patients' arteries were unclogging (Esselstyn, 2010; Ornish et al., 1998). Most people in Western societies consume animal products and highly processed foods on a daily basis, thereby adding cholesterol and saturated fat to their bodies every day. It is not surprising then that this type of behavior leads to issues regarding arterial plaques over the course of several decades, even if the body does have the capacity to heal itself and attempts to do so. If one kicks their shin against a hard surface on a daily basis and experiences issues and discomfort from that, the solution is not to administer painkillers. The cause of the pain and discomfort was not a lack of pills or procedures. Instead, the issues and discomfort can be alleviated by stopping to kick one's shin against things. Given the proper conditions, the body will attempt to heal itself, which is a statement often regarded as the best kept secret in medicine (Kadoch, 2012). In the case of heart disease and various other common ailments in the West, a plant-based diet may provide such proper conditions.

Understandably, given such results, one might want to adopt a plant-based diet to prevent heart disease from becoming an issue in their life. However, considering how early it already starts (most children already display the first stages of atherosclerosis by age ten) it may be more of an issue of reversing the heart disease one likely already has.

Cancer

As was observed in the China study, there is a considerable discrepancy between the cancer rates in various regions. Furthermore, the difference in cancer rates largely overlapped with differences in dietary patterns with the more plant-based regions having lower rates of various cancers (Campbell & Campbell, 2006). Several studies have attempted to explain why plant foods seem to be protective and why animal products increase our chances of getting certain types of cancer. On a daily basis, roughly fifty billion cells in your body die and are replaced by new ones (Reed, 1999). As a child you start with fewer cells (adults have roughly four times as many cells as a child, totaling about forty trillion cells) and more cells are added than the amount that die (Greger & Stone, 2015). At the end of puberty, however, the number of cells that are added and the number that die levels out. One of the key regulators for cell growth is insulin-like growth factor 1 (IGF-1). In children this hormone is abundant, causing growth, but it diminishes in adulthood. If your IGF-1 levels remain high throughout adulthood, it will keep signaling your cells to keep growing and dividing, which axiomatically increases your risk of developing various cancers (Rowlands et al., 2009). Interestingly, Laron syndrome is a rare form of dwarfism caused by the inability to produce IGF-1. Individuals with this syndrome subsequently only grow to about a meter in height, but they also almost never contract cancer, in spite of having a life expectancy similar to the rest of the population (Guevara-Aguirre, J. et al., 2011). The consumption of animal products appears to be a trigger for the release of IGF-1 in the bloodstream (Allen et al., 2002). In almost any cancer, IGF-1 on its own is a key ingredient in the various stages of cancer cell growth, including its beginning, growth, and spread throughout the body (Greger & Stone, 2015). However, the body also produces IGF-1 binding proteins (IGF-1 BP), which binds to IGF-1 thereby rendering it harmless (Ngo et al., 2002). This mechanism may provide some protection against the risks of having high IGF-1 levels. The main downside, however, is that the consumption of animal products not only increases IGF-1 production, it also seems to decrease IGF-1 BP production, thereby adding risk and removing protection (Ngo et al, 2002). Meat is also not the only component that spurs such developments in the body, since vegetarians who include dairy and eggs in their daily diets have similar IGF-1 levels to those also consuming meat. Only men and women limiting their total intake of animal proteins appear to significantly reduce IGF-1 levels while raising IGF-1 BP levels (Allen et al, 2000; Allen et al., 2002).

Obesity & Diabetes

About twenty million Americans (~6.7% of the population) are diagnosed with diabetes (CDC, 2013) and over one million Dutch people are diagnosed (~6.5.% of the population) (Rijksinstituut voor Volksgezondheid & Milieu, n.d.). Diabetes is one of the leading causes of kidney failure, amputations of the lower extremities, adult-onset vision loss or blindness, and death (CDC, 2014). About five percent of all diabetes cases is type I, the kind that so far can only be treated (not cured) by injecting insulin, since the body has lost its ability to produce insulin on its own (CDC, 2014). The rest and thereby the great majority of cases is type II diabetes, which is characterized by insulin resistance in the muscles.

The intestinal tract dissolves and absorbs the food we eat and puts the various nutrients in our bloodstream. Included in this process is the conversion of various carbohydrates, like starches, into glucose, which in turn enters the bloodstream as blood sugar. An increase in blood sugar prompts the release of insulin, which functions like a key to open up various cells to take in glucose, thereby lowering the amount of sugar in the blood. However, in diabetics the insulin does not work as it should, the muscle cells become resistant to its effect; this is called insulin resistance (Greger & Stone, 2015). Why do cells become resistant to insulin? Intramyocellular lipids, the fat (lipids) inside (intra) muscle cells (myocellular), can build up and create toxic breakdown products that interfere with insulin sensitivity (Roden et al., 1996). Furthermore, if blood sugar cannot enter muscle cells, then blood sugar levels remain high, thereby damaging vital organs such as kidneys, eyes, nerves, and blood vessels (Tabák, Herder, Rathmann, Brunner, & Kivimäki, 2012).

Being overweight (Body Mass Index > 25) is considered to be the main risk factor for type II diabetes, with up to 90% of diabetics being overweight (Ginter & Simko, 2012). Various experiments have shown how adding fat to the bloodstream increases insulin resistance (Roden et al., 1999), as well as the opposite effect, lowering insulin resistance by removing fat from the bloodstream (Santomauro et al., 1999). This fat can come from both food and the body itself. Ones body does not create more fat cells during adulthood, so extra fat is simply stored in those existing cells, causing them to swell up. In overweight or obese individuals these fat cells can swell up enough for them to spill their contents back into the bloodstream (Spalding et al., 2008).

People consuming a plant-based diet generally have much lower rates of diabetes than those regularly consuming animal products. Taking daily meat-eaters as the baseline for comparison, flexitarians (occasional meat eaters) had 28% lower rates of diabetes, whereas pescotarians (vegetarian except for fish consumption) were 51% lower, vegetarians were 61% lower, and vegans had 78% lower rates of diabetes (Fraser, 2009). As more and more animal products were removed from the diet, the rates of diabetes dropped accordingly. Considering how weight-related the odds of getting diabetes are, it might not be the diet one adheres to, but rather the amount of excess weight they carry. However, even at the same weight and BMI as people on an omnivorous diet, vegans have less than half the risk of diabetes (Tonstad et al., 2013). Research showed that those consuming a plant-based diet have significantly better blood sugar levels, insulin levels, and insulin sensitivity as compared to those on an omnivorous diet (Gojda et al., 2013), and they had improved beta cell function (pancreatic cells that produce insulin) (Goff, Bell, So, Dornhorst, & Frost, 2005). Plant-based diets therefore appear to improve both insulin production and insulin sensitivity (the opposite of insulin resistance).

Given the strong correlation between obesity and diabetes one of the best preventative measures may be to ensure one that has a healthy weight, often indicated with a body mass index. Ideally, one wants to be between 18 and 25, indicating a healthy weight for ones height. In the largest comparison of obesity rates and various types of (vegetarian) diets in North America, encompassing over sixty thousand people, a strong correlation was found between average BMI and diet. Meat eaters were found to have an average BMI of 28.8, which is close to being obese. Flexitarians did slightly better with an average BMI of 27.3, pescotarians were at 26.3, and vegetarians averaged around 25.7. Only vegans were found to be in the healthy BMI range, coming in at 23.6 (Tonstad, Butler, Yan, & Fraser, 2009). As more and more animal products are removed from the diet, ones weight also drops accordingly.

Plant-based diets in and of themselves will not prevent or cure all cases of the most common diseases and causes of death in the West, but they will very likely prevent or reverse a significant number of them. Given the low prevalence of heart disease, various cancers, obesity, and diabetes (among others) in plant-based societies, a diet that can prevent or reverse some of the main killers and diseases in the West may be worth considering as a new standard.

Food Choice and the Environment

Regardless of what diet someone follows, the production of the required foods will have some sort of effect on the environment. Land and water is needed, transportation of foods, machines that help us harvest or process the crops, and more are all things that can have a considerable impact on the world. In selecting a preferential diet, these factors need to be taken into account, especially considering a growing world population. A higher demand for food emphasizes the need to be mindful and sustainable in our use of resources. In this section I will discuss the differences between resource use and environmental impact of a Western diet and a plant-based diet. First, I will discuss food production in relation to climate change while paying attention specifically to livestock. Second, I will discuss further environmental impacts of animal agriculture focusing primarily on soil degradation, deforestation, ocean deadzones, and overfishing. In both cases I will explore the alternative outcomes that adopting a plant-based diet may offer.

Arguably, there is a considerable difference in (negative) impact on the environment that is tied to a difference in scale of any food production practice. The agricultural practices discussed in this section will refer largely to intensive, industrial (animal) agriculture, rather than small family farms. This is primarily due to how much of our animal products comes from Concentrated Animal Feeding Operations (CAFO's) (in the U.S. 99% of farm animals are raised in factory farms (ASPCA, n.d.)) and the issues that such concentrated operations brings about. Furthermore, the next chapters of this thesis will focus more on the socio-technical aspects of such practices and CAFO's offer more material for analysis. Nevertheless, the negative effects of animal agriculture are likely to occur on a gradient, with fewer such results occurring in smaller farms and more negative impact being associated with large-scale enterprises. Most effects described below come from animal agriculture in general and factory farm-dominant or specific effects will be mentioned accordingly.

Climate Change

Greenhouse gases (GHG) have the potential to absorb and emit thermal infrared radiation, thereby effectively trapping heat in our atmosphere. The primary GHG in the Earth's atmosphere are carbon dioxide, methane, nitrous oxide, water vapor, and ozone. Of primary concern are the first three of these gases since humans play a substantial role in how much of those are emitted. Each GHG is given a global warming potential (GWP) value to compare which gases are most powerful at trapping heat. Given such values and the amount emitted into the atmosphere, one can assess which industries or human activities are in most need of (more) sustainable alternatives. Carbon dioxide (CO_2) is used as the reference gas, always having a GWP value of 1. Anything below a GWP value of 1 indicates that particular gas is less powerful than CO_2, while a value of 10 would indicate a ten-fold potency of heating up the atmosphere. All of this assumes the same amount of weight for these values, so one ton of CO_2 compared to one ton of another gas, for example. Not every gas has the same half life, though, so there may be different GWP values for each non-CO_2 gas depending on the time frame one uses. The most common and relevant time frames used within the context of GWP values and climate change are 20-year and 100-year time frames. With CO_2 retaining its reference value of 1, methane (CH_4) has a GWP of 72 and 25, while nitrous oxide (N_2O) has a GWP potential value of 289 and 298, with the first and second value of each gas respectively being the 20-year and 100-year time frame value (Forster et al., 2007). This means that, for example, over a period of 100 years, nitrous oxide will trap 298 times as much heat as CO_2.

The year 1750 is generally considered to be the start of the Industrial Revolution. Since 1750 atmospheric concentrations of CO_2 have increased by about 36%, methane concentrations are up by about 151%, and nitrous oxide increased by about 16% (Forster et al., 2007). Various reports came out to assess the GHG contributions per industry. In general, the energy sector comes out as (one of) the biggest, followed by agriculture and world-wide transportation making up the top three causes. A report by the Food and Agriculture Organization (FAO) of the United Nations calculated that livestock accounts for about 9% of anthropogenic CO_2 emissions, 65% of nitrous oxide emissions, and 37% of methane emissions (FAO, 2006). The report places animal agriculture as the second leading cause of global warming, contributing 18% of anthropogenic GHG emissions. Another study that assessed the contribution of animal agriculture to climate change concluded this number to be 51% (Goodland & Anhang, 2009). There are several reasons why there is such a large difference between the outcomes of both studies. The biggest factor is that the latter study used a 20-year time frame, rather than the FAO's 100-year time frame. This means that methane (with its shorter half life) plays a far greater role; methane has a GWP of 72 in a 20-year time frame instead of 25 for the 100-year time frame. Arguably, the 20-year figure is more relevant to use, since it offers stronger guidelines of how to mitigate impact short-term. Using a 100-year figure also loses some relevance when considering the fact that most global organizations (e.g. scientific communities and governments) agree that 2050 is the final year for humanity to reach neutrality on its GHG emissions; assessing the impact a century from now overshoots that deadline significantly. Goodland and Anhang's study also included livestock respiration as a source of CO_2 emissions, thereby also increasing livestock's total contribution to GHG emissions. Another major factor in the discrepancy is that the 2009 study did not assign data to various sectors the way the FAO report did. For example, raising, slaughtering, processing, packaging, transporting, (cooled or frozen) storage, and cooking could be allocated to separate sectors. This division of data can deflate the actual impact of a single product. Finally, the FAO also underreported various relevant figures, such as methane emissions, methane's GWP, and global number of livestock (Oppenlander, 2013). Regardless of the differences between these two often-cited studies, both results underline the impetus to revise our animal husbandry practices and their role in a sustainable society.

Aside from livestock's total contribution to climate change, the FAO report also stated that globally livestock accounts for 80% of all emissions from the total agricultural sector (including both crops and livestock). An average omnivorous consumer in the U.S. gets roughly 26% of their daily calories from (animal) products (Pimentel & Pimentel, 2003a). The U.S. also consumes more animal products per capita than is the case in other countries (Campbell & Campbell, 2006). This means that the 80% statistic would likely be higher if it were specifically calculated for the U.S. and this also means that 26% of most people's daily calories contributes to more than 80% of the GHG emissions of the agricultural sector. Alternatively, the other 74% of their consumed calories comes from (plant) products that contribute less than 20% of total agricultural GHG emissions.

The food production system in the U.S. uses about 17% of the fossil fuel energy used in the entire country (Pimentel & Pimentel, 2003b). Producing one calorie of plant (grain) protein requires an input of roughly 2.2 calories of fossil energy (Pimentel et al., 2002). In comparison, milk and pork production have a ratio of 14:1 (fourteen calories fossil fuel input for one calorie of protein output) and beef comes in at 40:1. The average fossil energy input for animal protein production in general is 25:1 (Pimentel & Pimentel, 2003a). Overall, the amount of grain fed to livestock in the U.S. is enough to feed approximately 840 million people following a plant-based diet (Pimentel, 2007). Total U.S. livestock thereby consumes seven times more grain than the U.S. population consumes directly (Pimentel & Pimentel, 2003a). This all comes down to animal products requiring vast amounts of fossil energy and plants (as livestock feed) in order to end up producing something that makes up a quarter of people's total caloric intake.

Environmental Impact

Worldwide land use for livestock is at least thirty percent of the total landmass (FAO, 2006). Less than two percent of livestock raised in the U.S. and roughly nine percent of animals raised worldwide graze for their food requirements. Therefore, shifting towards grassfed systems will likely worsen the demands placed on land occupation in a world that expects to double its meat and dairy production over the next ten years (Oppenlander, 2013). In 2011, there was a record worldwide yield of grain harvests (2.6 billion tons), which has been estimated to be enough to feed almost twice the amount of people currently living on this planet (Oppenlander, 2013). Instead, 43% of all grain was used as feed for livestock (FAO, 2006). In the U.S. alone, nearly eighty percent of all land used for agriculture is used for growing livestock, by either having livestock live directly on the land, or using it to grow crops to feed them (FAO, 2006). Looking at food production for human consumption, any given acre of (arable) land can yield twelve to twenty times the amount of vegetables, fruit, and grain (in weight) as it can in animal products (Robbins, 2001).

Apart from inefficient land use, there are also large amounts of land being created for livestock and livestock feed production by means of deforestation. Currently, over seventy percent of the Amazon rainforest has been cut down (Margulis, 2004), as well as 95% of the Brazilian rainforests bordering the Atlantic coast (Moran, 1993). These forests are cleared largely for cattle ranching and growing soy beans, over ninety percent of which is used as livestock feed (FAO, 2006). The largest consumer of Central and South American beef is the U.S. (Oppenlander, 2013). The rainforests have been destroyed at a rate of at least 30 million acres per year since the 1970s, even though they produce twenty percent of the world's oxygen while taking out tons of CO_2 (Oppenlander, 2013). So instead of functioning at full capacity as a potent carbon sink, they are replaced with cattle ranches, which, as seen from the previous section on livestock and climate change, is one of the most damaging practices possible for the climate, given cows' high methane output. About fifty years ago, rainforests comprised a total of fifteen percent of the planet's land surface. Nowadays this has been reduced to less than two percent (Oppenlander, 2012). Apart from climate-related issues of deforestation, there are also other concerns regarding the Amazon such as the disappearance of Amazonian tribes and loss of biodiversity.

In the U.S., around 700 million acres of rangeland have degraded by the overgrazing of livestock. Of the seven billion tons (one third) of the topsoil lost, six billion is directly attributable to grazing livestock and unsustainable methods of livestock feed production (Fleischner, 1994). Globally, about twenty percent of rangelands and pastures have been degraded by livestock. Desertification is another form of land degradation or depletion, and also occurs as a result of raising livestock. In this case topsoil is lost to the point of being unable to sustain plant life or to retain water. This is worrisome, considering that it takes approximately 500 years to replace one inch of lost top soil and that in the U.S., ninety percent of cropland loses soil at a rate that is thirteen times above the sustainable rate (Pimentel & Kounang, 1998). A short-term solution to this problem is the injection of (artificial) fertilizers into the ground and to irrigate lands using fresh water sources like rivers or underwater basins or aquafiers. In supporting animal agriculture in this way two significant problems are created: excessive fresh water usage and creating excessive toxic waste that seeps into the ground and oceans. On fresh water usage: in the U.S. over half of all fresh water resources are being given directly or indirectly to livestock (Turner et al., 2004). While it takes ten to twenty gallons of water in order to produce one pound of vegetables, pulses, grains, or fruit, it takes over five thousand gallons to produce one pound of meat (Pimentel & Pimentel, 2003b). Regarding toxic run-off: waterways deposit large amounts of animal feces, fertilizers, and other toxic waste in oceans. Eventually this creates "dead zones", where algae populations surge in size leaving too little oxygen in the water for plants and sea life to survive. The U.N. reports 150 dead zones in the oceans, caused by an excess of nitrogen from sewage and fertilizers. Livestock is often considered the primary inland source of such contamination (Sherman, Aquarone, & Adams, 2009).

So far, I have discussed the inefficient land use that comes with animal agriculture, along with the deforestation that ensues from these inefficiencies to create more available land for livestock. Fresh water resources are used in an unsustainable fashion. These are, so far, primarily land-based issues. The toxic run-off from animal agriculture leads to issues in our oceans as well and bridges this exploration into a primarily water-based one: the overexploitation of the Earth's oceans. Of the 181 fishing stocks in the Pacific Ocean, 77% was determined to be either moderately to fully exploited, or overexploited or depleted (FAO, 2005). Globally, 85% of fisheries have been pushed by exploitation to, or beyond, their biological limits (Oppenlander, 2013). Of the seventeen primary fishing stocks, all are either overexploited or on the verge of collapse (FAO, 2008). Scientists predict that by continuing fishing practices at current levels, all of the world's fisheries could collapse entirely by 2050 (Worm et al., 2006).

The production of plant foods is already considerable enough to feed the entire growing human population. However, in order to produce a category of products that comprises only about a quarter of total calories, even in an animal product-centered diet such as the Western diet, requires cutting down large forest areas, drains the oceans of marine life, and renders vast swaths of land practically unusable for future food production. Vast amounts of the plants grown annually are given to animals instead of being given directly to people. This results in an abysmal return on investment in terms of nutrients, energy expenditure, and resource use. Transitioning towards a plant-based diet will likely drastically reduce the impact of one of the primary causes of climate change and environmental degradation.

Food Choice and Other Concerns

Apart from health and environmental concerns, there are various other impacts of our choice of food. This section will discuss more briefly the issues of antibiotic resistance, animal wellbeing, and hunger and malnutrition in poor areas of the world. Each of these topics and how they relate to our dietary choices deserves more than the following terse overview. In this thesis, however, they are mentioned to further exemplify the diversity and complexity of various impacts that a food choice can have. I will close this section by discussing taste and culture in the context of feasibility and long-term adherence to a plant-based diet. No matter what the diet is, if no one can adhere to it for any appreciable amount of time, the practical relevance would decrease sharply.

Antibiotic Resistance

Within the U.S. it is estimated that 87% of all antibiotics are used for animals and primarily as a preventative tool instead of as a response to a medical situation (Union of Concerned Scientists, 2001). Any use of antibiotics brings the risk of the targeted bacteria becoming (more) resistant to a treatment. The indiscriminate use of antibiotics (i.e. using them when they are not (yet) explicitly necessary or useful) therefore, can lead to an exacerbation of this problem by giving the targeted pathogen more chances at mutating into a resistant form. Speaking long-term, the greatest threat of antibiotic resistance is that drug efficacy slowly erodes over time. This means that in the future, any bacterium that may cause (life-threatening) infections cannot be successfully treated, thereby greatly increasing the chances of post-surgical complications for example. Many scientists discussing antibiotic resistance find it surprising this issue does not garner more public attention, in spite of its scope and potentially devastating impact on global health in upcoming decades (Zhang, Eggleston, Rotimi, & Zeckhauser, 2006). Considering how many antibiotics are prescribed to livestock (either as a preventative measure or as a treatment), transitioning to a plant-based diet will likely be helpful regarding the issue of antibiotic resistance (Gilchrist et al., 2007).

Animal Wellbeing

Annually and globally, we raise and kill over seventy billion animals for food, a number that is more than nine times the amount of people alive today (Oppenlander, 2012). The great majority of animals and species roam free and are relatively unencumbered by human activity compared to those animals living on (factory) farms. To explain what goes on on (factory) farms and how animals are being held captive until their lives are inevitably cut short would warrant more than this short paragraph. However, one comparison may add some small level of perspective. The Second World War is generally considered to be the deadliest military conflict in history in terms of absolute casualties, with the death toll reaching as high as fifty million (Keegan, 1989). Notwithstanding the human tragedy and looking purely at numbers, that is the amount of land animals killed every six to eight hours given current practices. This does not take into account marine life yet, which is projected to be an order of magnitude bigger in terms of animal deaths (Oppenlander, 2012). In short, the harm, abuse, and death inflicted upon animals would be greatly diminished by transitioning away from animal agriculture.

Food Scarcity

Worldwide, over one billion people are undernourished (FAO, 2009). Malnutrition is the largest single underlying cause of death and has been associated with more than a third of all childhood deaths (WHO, 2010). Considering we already produce enough food to feed twice the current human population (Oppenlander, 2013), one can justifiably wonder how it is possible to still have one seventh of the world population living in hunger. Most people living in food scarcity live in the developing world, yet most of these countries also have enough food production to sustain themselves. Inefficient resource use, however, along with grains and livestock being bought by developed countries leave little to eat for people actually living in these countries (Oppenlander, 2012). A transition to a plant-based diet (even if only in developed countries) could help significantly in feeding a starving and malnourished population in developing countries.

Culture and Taste

Dietary patterns are often a significant part of culture. A switch to a plant-based diet would likely substantially deviate from the cultural norms in most developed countries. Consuming meat and other animal products is the norm. However, given the harmful effects of such practices, a change in cultural norms may be required. Thankfully the past offers us plenty of examples of behaviors and attitudes that were once normal, but were left behind in favor of something else. Bloodletting and slavery, for example, are a thing of the past largely due to the realization how harmful and/or unjust the practice was.

There is still the question of taste, though. Many, if not all, of the potential benefits of a plant-based diet will be unlikely to manifest if not enough people manage to adhere to such a dietary pattern. Even the most unhealthy and environmentally damaging diet in the world would not be adhered to if it does not taste well enough. In order to gauge the potential long-term adherence to a plant-based diet, (interventional) studies done on (plant-based) nutrition and health often include questionnaires that ask for people's experiences and expectations regarding these variables. One recent study in *Nature* found no difference in food satisfaction between the experimental (plant-based) group and the control group (standard Western diet) (Wright et al., 2017). In addition to both groups enjoying each diet equally, the plant-based group also gained significantly more self-esteem, general self-efficacy, improved cardiovascular health, and sustained weight loss. In other words: the plant-based groups attained significant health benefits (both physically and cognitively) for the same level of enjoyment and satisfaction.

In summary, a plant-based diet will likely yield significant benefits regarding health, greenhouse gas emissions, soil fertility, fresh water resources, animal wellbeing, and world hunger. A transition to a plant-based diet will not solve any particular issue, but it will be a significant step towards solving many issues. Furthermore, none of the issues discussed in this appendix can be solved without thoroughly and critically rethinking the role of animal products in our diet. The potential benefits for health and sustainability make it worthwhile to consider a transition away from current food production practices and towards a (more) plant-based system. Therefore, this thesis does not constitute a purely hypothetical "what-if" scenario, but is an attempt at exploring a worthwhile, real-world transition regarding food production and consumption.

REFERENCES

Appendix A

Allen, N. E., Appleby, P. N., Davey, G. K., & Key, T. J. (2000). Hormones and diet: low insulin-like growth factor I but normal bioavailable androgens in vegan men. *British Journal of Cancer* 83(1), pp. 95-97.

Allen, N. E., Appleby, P. N., Davey, G. K., Kaaks, R., Rinaldi, S., & Key, T. J. (2002). The associations of diet with serum insulin-like growth factor I and its main binding proteins in 292 woman meat-eaters, vegetarians, and vegans. *Cancer Epidemiology, Biomarkers, & Prevention* 11(11), pp. 1441-1448.

Boyle, J. P., Thompson, T. J., Gregg, E. W., Barker, L. E., & Williamson, D. F. (2010). Projection of the year 2050 burden of diabetes in the US adult population: dynamic modeling of incidence, mortality, and prediabetes prevalence. *Population Health Metrics* 8:29. doi: 10.1186/1478-7954-8-29

Campbell, T. C. & Campbell, T. M. II (2006). *The China Study: the most comprehensive study of nutrition ever conducted and the startling implications for diet, weight loss, and long-term health*. Dallas, TX: BenBella Books, Inc. ISBN: 1-932100-38-5.

Centers for Disease Control and Prevention (n.d.). *Leading causes of death, 1900-1998*. Retrieved from https://www.cdc.gov/nchs/data/dvs/lead1900_98.pdf. Accessed 9 March 2017.

Centers for Disease Control and Prevention (2013). *Number (in millions) of civilian, noninstitutionalized persons with diagnosed diabetes, United States, 1980-2011*. Retrieved from https://www.cdc.gov/diabetes/statistics/prev/national/figpersons.htm. Accessed 4 April 2017.

Centers for Disease Control and Prevention (2014). *National diabetes statistics report: estimates of diabetes and its burden in the United States*. Atlanta, GA: U.S. Department of Health and Human Services.

Centers for Disease Control and Prevention (2014). *2014 Statistics Report*. Retrieved from http://www.cdc.gov/diabetes/data/statistics/2014StatisticsReport.html. Accessed on 4 April 2017.

Centraal Bureau voor de Statistiek (2016). *Overleden; belangrijke doodsoorzaken (korte lijst), leeftijd, geslacht*. Retrieved from http://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLNL&PA=7052_95&D1=0,8, 18,20,24,42,44,47,49,51-52,79-84,88&D2=a&D3=0&D4=47,l&HD=130911-0957&HDR=G1,G2, G3&STB=T. Accessed on 11 March 2017.

Crimmins, E. M. & Beltrán-Sanchez, H. (2011). Mortality and morbidity trends: is there compression of morbidity? *Journal of Gerontology: Social Sciences* 66B(1), pp. 75-86. doi: 10.1093/geronb/gbq088

Enos, W. F., Holmes, R. H., & Beyer, J. (1953). Coronary disease among United States soldiers killed in action in Korea; preliminary report. *Journal of the American Medical Association* 152(12), pp. 1090-1093.

Esselstyn, C. B. (2010). Is the present therapy for coronary artery disease the radical mastectomy of the twenty-first century? *American Journal of Cardiology* 106(6), pp. 902-904.

Finkelstein, E. A., Khavjou, O. A., Thompson, H., Trogdon, J. G., Pan, L., Sherry, B., & Dietz, W. (2012). Obesity and severe obesity forecasts through 2030. *American Journal of Preventative Medicine* 42(6), pp. 563-570. doi: 10.1016/j.amepre.2011.10.026

Fleischner, T. L. (1994). Ecological costs of livestock grazing in Western North America. *Conservation Biology* 8(3), pp. 629-644.

Food and Agriculture Organization (2005). *Review of the state of world marine fishery resources*. FAO Fisheries Technical Paper No. 457. Rome, Italy: Food and Agriculture Organization of the United Nations.

Food and Agriculture Organization (2006). *Livestock's long shadow: environmental issues and options*. Eds.: Steinfeld, H., Food and Agriculture Organization of the United Nations., & Livestock, Environment and Development (Firm). Rome: Food and Agriculture Organization of the United Nations.

Food and Agriculture Organization (2008). *The state of world fisheries and aquaculture*. Rome, Italy: Food and Agriculture Organization of the United Nations. ISSN: 1020-5489.

Food and Agriculture Organization (2009). *The state of food insecurity in the world. Economic crises – impacts and lessons learned*. Rome, Italy: Food and Agriculture Organization of the United Nations.

Forster, P., Ramaswamy, V., Artaxo, P., Berntsen, T., Betts, R., Fahey, D. W., … & Van Dorland, R. (2007). *Changes in Atmospheric Constituents and in Radiative Forcing*. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Eds.: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M., & Miller, H. L. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Fraser, G. E. (2009). Vegetarian diets: what do we know of their effects on common chronic diseases? *American Journal of Clinical Nutrition* 89(5), pp. 1607S-1612S. doi: 10.3945/acjn.2009.26736K

Gilchrist, M. J., Greko, C., Wallinga, D. B., Beran, G. W., Riley, D. G., & Thorne, P. S. (2007). The potential role of concentrated animal feeding operations in infectious disease epidemics and antibiotic resistance. *Environmental Health Perspectives* 115(2), pp. 313-316. doi: 10.1289/chp.8837

Ginter, E. & Simko, V. (2012). Type 2 diabetes mellitus, pandemic in 21st century. *Advances in Experimental Medicine and Biology* 771, pp. 42-50.

Goff, L. M., Bell, J. D., So, P. W., Dornhorst, A., & Frost, G. S. (2005). Veganism and its relationship with insulin resistance and intramyocellular lipid. *European Journal of Clinical Nutrition* 59(2), pp. 291-298.

Gojda, J., Patková, J., Jaček, M., Potočková, J., Trnka, J., Kraml, P., & Anděl, M. (2013). Higher insulin sensitivity in vegans is not associated with higher mitochondrial density. *European Journal of Clinical Nutrition* 67(12), pp. 1310-1315. doi: 10.1038/ejcn.2013.202

Goodland, R. & Anhang, J. (2009). Livestock and Climate Change: What if the key actors in climate change were pigs, chickens and cows? *Worldwatch*, November/December. Worldwatch Institute, pp. 10–19.

Greger, M. & Stone, G. (2015). *How not to die: discover the foods scientifically proven to prevent and reverse disease*. New York, NY: Flatiron Books. ISBN: 978-1-250-06611-4 (hardcover) / 978-1-250-06612-1 (e-book).

Guevara-Aguirre, J., Balasubramanian, P., Guevara-Aguirre, M., et al. (2011). Growth hormone receptor deficiency is associated with a major reduction in pro-aging signaling, cancer, and diabetes in humans. *Science Translational Medicine* 3(70), pp. 70ra13. doi: 10.1126/scitranslmed.3001845

Kadoch, M. A. (2012). The power of nutrition as medicine. *Preventative Medicine* 55(1), pp. 80. doi: 10.1016/j.ypmed.2012.04.013

Keegan, J. (1989). *The Second World War*. United Kingdom, London: Penguin Books. ISBN: 014011341X / 978-0-140-11341-9.

Lenders, C., Gorman, K., Milch, H., Decker, A., Harvey, N., Stanfield, L., … Levine, S (2013). A novel nutrition medicine education model: the Boston University experience. *Advances in Nutrition* 4(1), pp. 1-7. doi: 10.3945/an.112.002766

Margulis, S. (2004). *Causes of deforestation of the Brazilian Amazon*. World Bank Working Paper (no. 22). Washington, DC: World Bank.

McMahan, C. A., Gidding, S. S., Malcom, G. T., Tracy, R. E., Strong, J. P., & McGill, H. C., Jr. (2006). Pathobiological determinants of atherosclerosis in youth risk scores are associated with early and advanced atherosclerosis. *Pediatrics* 118(4), pp. 1447-1455.

Moran, E. F. (1993). Deforestation and land use in the Brazilian Amazon. *Human Ecology* 21(1), pp. 1-21. doi: 10.1007/BF00890069

Murphy, S. L., Kochanek, K. D., Xu, J., & Arias, E. (2014). *Mortality in the United States*. NCHS Data Brief (229), pp. 178.

Murray, C. J., Atkinson, C., Bhalla, K., Birbeck, G., Burstein, R., Chou, D., … Wulf, S. (2013). The state of US health, 1990-2010: burden of diseases, injuries, and risk factors. *Journal of the American Medical Association* 310(6), pp. 591-608. doi: 10.1001/jama.2013.13805

National Center for Health Statistics (2016). Health, United States, 2015: with special feature on racial and ethnic health disparities. *U.S. Department of Health and Human Services* 2016(1232). Retrieved from https://www.cdc.gov/nchs/data/hus/hus15.pdf#019. Accessed on 11 March 2017.

Napoli, C., D'Armiento, F. P., Mancini, F. P., Postiglione, A., Witztum, J. L., Palumbo, G., & Palinski, W. (1997). Fatty streak formation occurs in human fetal aortas and is greatly enhanced by maternal hypercholesterolemia. Intimal accumulation of low density lipoprotein and its oxidation precede monocyte recruitment into early atherosclerotic lesions. *Journal of Clinical Investigations* 100(11), pp. 2680-2890.

Ngo, T. H., Barnard, R. J., Tymchuk, C. N., Cohen, P., Aronson, W. J. (2002). Effect of diet and exercise on serum insulin, IGF-I, and IGFBP-1 levels and growth of LNCaP cells in vitro (United States). *Cancer Causes & Control* 13(10), pp. 929-935.

Oppenlander, R. (2012). *Comfortably unaware: what we choose to eat is killing us and our planet*. New York, NY: Beaufort Books. ISBN: 978-0-8253-0686-0 (paper) / 978-0-8253-0622-8 (e-book).

Oppenlander, R. (2013). *Food choice and sustainability: why buying local, eating less meat, and taking baby steps won't work*. Minneapolis, MN: Langdon Street Press. ISBN-13: 978-1-62652-435-4.

Ornish, D., Scherwitz, L. W., Billings, J. H., Brown, S. E., Gould, K. L., Merritt, T. A., … Brand, R. J. (1998). Intensive lifestyle changes for reversal of coronary heart disease. *Journal of the American Medical Association* 280(23), pp. 2001-2007.

Pimentel, D. & Kounang, N. (1998). Ecology of soil erosion in ecosystems. *Ecosystems* (1), pp. 416-426. doi: 10.1007/s100219900035

Pimentel, D., Doughtry, R., Carothers, C., Lamberson, S., Bora, N., & Lee, K. (2002). *Energy use in developing and developed crop production*. In: Food security and environmental quality in the developing world. Eds: Lal, R., Hansen, D., Uphoff, N., & Slack, S. Boca Raton, FL: CRC Press.

Pimentel, D. & Pimentel, M. (2003a). Sustainability of meat-based and plant-based diets and the environment. *The American Journal of Clinical Nutrition* 78(3), pp. 660S-663S.

Pimentel, D. & Pimentel, M. (2003b). World population, food, natural resources, and survival. *The Journal of New Paradigm Research* 59(3-4), pp. 145-167. doi: 10.1080/02604020310124

Pimentel, D. (2007). *Livestock production and energy use*. In: Food, Energy, and Society, pp. 67-75. Eds: Pimentel, M. & Pimentel, D. Boca Raton, FL: CRC Press. ISBN: 978-1-4200-4667-0 (print) / 978-1-4200-4668-7 (e-book). doi: 10.1201/9781420046687.ch8

Popkin, B. M. (2006). Global nutrition dynamics: the world is shifting rapidly toward a diet linked with noncommunicable diseases. *American Journal of Clinical Nutrition* 84(2), pp. 289-298.

Reed, J. C. (1999). Dysregulation of apoptosis in cancer. *Journal of Clinical Oncology* 17(9), pp. 2941-2953.

Robbins, J. (2001). *The food revolution: how your diet can help save your life and our world*. San Francisco, CA: Conari Press. ISBN: 9780-1-57324-487-9.

Rijksinstituut voor Volksgezondheid en Milieu (n.d.). *Diabetes mellitus: cijfers en context*. Retrieved from https://www.volksgezondheidenzorg.info/onderwerp/diabetes-mellitus/cijfers-context/huidige-situatie#!node-prevalentie-diabetes-naar-leeftijd-en-geslacht. Accessed on 4 April 2017.

Roden, M., Price, T. B., Perseghin, G., Petersen, K. F., Rothman, D. L., Cline, G. W., & Shulman, G. I. (1996). Mechanism of free fatty acid-induced insulin resistance in humans. *Journal of Clinical Investigation* 97(12), pp. 2859-2865. doi: 10.1172/JCI118742

Roden, M., Krssak, M., Stingl H., Gruber, S., Hofer, A., Fürnsinn, C., … & Waldhäusl, W. (1999). Rapid impairment of skeletal muscle glucose transport/phosphorylation by free fatty acids in humans. *Diabetes* 48(2), pp. 358-364.

Rowlands, M. A., Gunnell, D., Harris, R., Vatten, L. J., Holly, J. M., Martin, R. M. (2009). Circulating insulin-like growth factor peptides and prostate cancer risk: a systemic review and meta-analysis. *International Journal of Cancer* 124(10), pp. 2416-2429. doi: 10.1002/ijc.24202

Santomauro, A. T., Boden, G., Silva, M. E., Rocha, D. M., Santos, R. F., Ursich, M. J., … Wajchenberg, B. L. (1999). Overnight lowering of free fatty acids with Acipimox improves insulin resistance and glucose tolerance in obese diabetic and nondiabetic subjects. *Diabetes* 48(9), pp. 1836-1841.

Sherman, K., Aquarone, M. C., & Adams, S. (2009). *Sustaining the world's large marine ecosystems*. Gland, Switzerland: IUCN.

Singh, P. N., Arthur, K. N., Orlich, M. J., James, W., Purty, A., Job, J. S., … Sabaté, J. (2014). Global epidemiology of obesity, vegetarian dietary patterns, and noncommunicable disease in Asian Indians. *American Journal of Clinical Nutrition* 100(1), pp. 359-364. doi: 10.3945/ajcn.113.071571

Spalding, K. L., Arner, E., Westermark, P. O., Bernard, S., Buchholz, B. A., Bergmann, O., … Arner, P. (2008). Dynamics of fat cell turnover in humans. *Nature* 453(7196), pp. 783-787. doi: 10.1038/nature06902

Tabák, A. G., Herder, C., Rathmann, W., Brunner, E. J., & Kivimäki, M. (2012). Prediabetes: a high-risk state for diabetes development. *Lancet* 379(9833), pp. 2279-2290. doi: 10.1016/S0140-6736(12)60283-9

Tonstad, S., Butler, T., Yan, R., & Fraser, G. E. (2009). Type of vegetarian diet, body weight, and prevalence of type 2 diabetes. *Diabetes Care* 32(5), pp. 791-796. doi: 10.2337/dc08-1886

Tonstad, S., Stewart, K., Oda, K., Batech, M., Herring, R. P., & Fraser, G. E. (2013). Vegetarian diets and incidence of diabetes in the Adventist Health Study-2. *Nutrition, Metabolism, & Cardiovascular Diseases* 23(4), pp. 292-299. doi: 10.1016/j.numecd.2011.07.004

Trumbo, P. R. & Shimakawa, T. (2011). Tolerable upper intake levels for trans fat, saturated fat, and cholesterol. *Nutrition Reviews* 69(5), pp. 270-278. doi: 10.1111/j.1753-4887.2011.00389.x

Turner, K., Georgiou, S., Clark, R., Brouwer, R., & Burke, J. (2004). *Economic valuation of water resources in agriculture: from the sectoral to a functional perspective of natural resource management*. FAO Water Reports. Rome, Italy: Food and Agriculture Organization of the United Nations.

Union of Concerned Scientists (2001). *Hogging It! Estimates of antimicrobial abuse in livestock*. Eds.: Mellon, M., Benbrook, C., & Benbrook, K. L. Cambridge, MA: UCS Publications.

Voller, R. D. & Strong, W. B. (1981). Pediatric aspects of atherosclerosis. *American Heart Journal* 101(6), pp. 815-836.

Weingart, S. N., Wilson, R. M., Gibberd, R. W., & Harrison, B. (2000). Epidemiology of medical error. *British Medical Journal (BMJ)* 320(7237), pp. 774-777.

World Health Organization (2010). *Communicable diseases and severe food shortage*. Geneva, Switzerland: World Health Organization.

Worm, B., Barbier, E. B., Beaumont, N., Duffy, E., Folke, C., Halpern, B. S., … Watson, R. (2006). Impacts of biodiversity loss on ocean ecosystem services. *Science* 314(5800), pp. 787-790. doi: 10.1126/science.1132294

Wright, N., Wilson, L., Smith, M., Duncan, B., & McHugh, P. (2017). The BROAD study: a randomised controlled trial using a whole food plant-based diet in the community for obesity, ischaemic heart disease or diabetes. *Nutrition & Diabetes* (7), e256. doi: 10.1038/nutd.2017.3

Zhai, F., Wang, H., Du, S., He, Y., Wang, Z., Ge, K., Popkin, B. M. (2009). Prospective study on nutrition transition in China. *Nutrition Review* 67(1), pp. 56-61. doi: 10.1111/j.1753-4887.2009.00160.x

Zhang, R., Eggleston, K., Rotimi, V., & Zeckhauser, R. J. (2006). Antibiotic resistance as a global threat: evidence from China, Kuwait and the United States. *Globalization and Health* 2(6). doi: 10.1186/1744-8603-2-6