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World Food System Center

Moving Towards a Sustainable Swiss Food System: An Estimation of the True Cost of Food in Switzerland and Implications for Stakeholders

Master Thesis in the Field of Food Science
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ABSTRACT

Whilst the benefits of food production and consumption are unarguably large, scientific consensus on the need for food system transformation is increasing. The global food system is one of the main contributors to climate change, biodiversity and ecosystem service loss, human health and animal welfare issues, as well as to insufficient livelihood conditions along the entire food supply chain. Creating a common, transparent standard for identifying food system impacts, their measurement and cost to society is key for the transformation towards a sustainable and resilient food system. By proposing a concrete methodology to calculate the true cost of food and applying it to Switzerland, this thesis aims to contribute to the discussion and highlight its importance.

The methodology defined assesses food system impacts on natural resources, livelihoods, human health, economy and animal welfare. 100 externalities were collected across all of these areas, of which 28 were prioritized based on their relevance and feasibility to be quantified. The true cost of (i) the national Swiss food system and (ii) eight conventionally produced Swiss products (apple, potato, carrot, wheat, milk, cheese, chicken and beef) is then approximated based on the prioritized externalities. This results in (i) national level external costs of 0.87 (0.61 - 1.12) CHF per CHF spent. Total national level costs amount to 70 (60 - 79) billion CHF, i.e. the sum of 37 billion CHF of national food expenditure and 33 (23-42) billion CHF of external costs. The latter are driven by human health, (14.8 billion CHF) and biodiversity (10.4 billion CHF) costs, with livelihood costs underestimated due to limited data availability. On a product level (ii), based only on environment, biodiversity and human health costs, cheese, chicken, and beef cause the highest external costs: 0.20 CHF (53% higher than retail price), 0.49 CHF (+38%) and 2.14 CHF (+125%) per 100 kcal, respectively.

The results illustrate the urgency of Swiss food system transformation. This is evident despite an underestimation of true costs by focusing on only 28 externalities, limited data availability and data accessibility. Swiss food system stakeholders are called to design a food system where sustainable choices are facilitated and incentivized along the entire supply chain. Based on both a transparent standard for measuring food system impacts and focusing on increasing consumer awareness, two things in particular should be strived for. First, reducing external costs of the current food system, e.g. by reducing food waste. Second – more crucially –, reducing external costs by shifting current production and consumption patterns. This includes redirecting agricultural support from products with high external costs, such as intensively farmed beef, to products with low external costs.

In 2021, the United Nations will host a Food Systems Summit targeting food system transformation. Switzerland could play a key role in this transformation by co-creating an improved methodology for measuring food system impacts with all relevant stakeholders. Food system transformation, based on measurable and transparent targets, both in terms of food system costs and benefits, represents an unmissable opportunity for achieving sustainable development, and now is the time to take it.

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I sincerely hope this thesis will contribute to (Swiss) food system transformation and look forward to continuing my work on this topic.

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GLOSSARY

1,4-DB	1,4-dichlorobenzene
ALYs	Animal life years suffered
ARE	Federal Office for Spatial Development
CH	Switzerland
CHF	Swiss franc
CO_2	Carbon dioxide
COVID-19	Coronavirus
Cu	Copper
DALY	Disability-adjusted Life Year
EFSA	European Food Safety Authority
EMF	Ellen MacArthur Foundation
-eq	equivalent
FAO	Food and Agriculture Organization
FOAG	Federal Office for Agriculture
FOEN	Federal Office for the Environment
FoodSIVI	Food System Impact Valuation Initiative
FOPH	Federal Office of Public Health
FSO	Federal Statistical Office
FSVO	Federal Food Safety and Veterinary Office
FTE	Full-time equivalent
GAFF	Global Alliance for the Future of Food
GBD	Global Burden of Disease
GBP	Pound sterling
GHG	Greenhouse gas
GLO	Global production
Gt	Gigaton
ha	Hectare
H&S	Health and safety
ID	Identifier
IFAD	International Fund for Agricultural Development
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
Kg	Kilogram
LCA	Life Cycle Assessment
m^2	Square meter

m^3	Cubic meter
MJ	Megajoule
MF	Monetization factor
MSA	Mean species abundance
N	Nitrogen
NH_3	Ammonia
NMVOC	Non-methane volatile organic compound
n/a	Not available
OECD	Organization for Economic Co-operation and Development
OHCR	Office of the United Nations High Commissioner for Human Rights
P	Phosphorus
PAF	Population attributable factor
PEP	Proof of Ecological Performance
$PM_{2.5}$	Particulate matter ≤ 2.5 micrometers diameter
PM_{10}	Particulate matter ≤ 10 micrometers diameter
SBLV	Swiss female farmers and women in agriculture association
SDGs	Sustainable Development Goals
SO_2	Sulfur dioxide
SOC	Soil organic carbon
TCA	True cost accounting
TEEB AgriFood	The Economics of Ecosystems and Biodiversity for Agriculture and Food
TMREL	Theoretical minimum risk exposure Level
UN	United Nations
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations International Children's Emergency Fund
US	United States
USD	United States Dollar
WBCSD	World Business Council for Sustainable Development
WEF	World Economic Forum
WFP	World Food Programme
WHO	World Health Organization
WWF	World Wildlife Fund
Yr	Year
ZHAW	Zurich School of Applied Sciences

1 INTRODUCTION

The following chapter highlights how creating transparency on food system impacts and their costs to society is key to achieving sustainable development. It examines the current state of the planet, the role of food systems in the context of global sustainable development and the costs caused by current consumption patterns. It then gives a brief input on the situation in Switzerland, making a case for Swiss food system transformation. True cost accounting – the practice of analyzing and accounting for all costs and benefits related to food production systems and the consumption of their products – will be introduced as a crucial methodology to understand current cost drivers and build the basis for an informed transformation towards a sustainable (Swiss) food system.

1.1. THE STATE OF THE PLANET

Planet Earth is facing unprecedented environmental, human health and socioeconomic challenges. According to the United Nations Environment Programme (UNEP) (2019), global greenhouse gas (GHG) emissions reached a record high of 55.3 Gt CO_2-eq in 2018. It elaborates that meeting the 2015 Paris Agreements and hence limiting global warming to 1.5 degrees Celsius above pre-industrial levels requires a 55% reduction of global GHG emissions by 2030. Regardless, under the environmental policies currently in place, the programme expects emissions to reach 60 Gt CO_2-eq by the end of the decade, prompting over 11'000 scientists to declare a climate emergency in January 2020 (Ripple, Wolf, Newsome, Barnard, & Moomaw, 2019). Biodiversity is declining rapidly and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (2019) warns that current global rates of species extinction are exceeding the average rate over the last 10 million years by factor of 10 to 100. In terms of human health challenges, non-communicable diseases (NCDs) – for which unhealthy diets are a key risk factor – caused 71% of global deaths in 2016 (FAO, IFAD, UNICEF, WFP, & WHO, 2020). Since 2014, after steadily declining over the previous years, the number of people suffering from undernourishment has been rising, reaching 9% of the population in 2019. This results in a total of 25% of the global population being classified as food insecure, having only irregular access to sufficient, nutritious food (FAO et al., 2020). The current coronavirus (COVID-19) pandemic is further challenging socioeconomic development. With millions of people slipping back into poverty, the World Bank (2020a) estimates that extreme poverty will affect 9% of the population in 2020, reversing the progress made over the last five years.

The international community's failure to progress towards sustainable development represents a huge economic risk. The World Economic Forum (WEF) recently identified climate action failure as the most threatening global risk in terms of impact and second-highest risk in terms of likelihood over the next decade (WEF, 2020a). It estimates that a total of 44 trillion USD of global value generation is either moderately or highly dependent on nature and its services. This equals to more than half of the global GDP being vulnerable in regards to climate change, biodiversity loss and ecosystem collapse (WEF, 2020b). The surpassing of system thresholds and dependencies between different industries are expected to lead to non-linear socioeconomic impacts, making even higher societal costs likely (McKinsey Global Institute, 2020). Already today, terrestrial surface productivity has declined by 23% compared to 1970 due to land degradation, resulting in an annual cost of 235

- 577 billion USD (IPBES, 2019). In terms of human health, public health costs related to non-communicable diseases are expected to reach a yearly cost of 1.3 trillion USD (FAO et al., 2020). In low- to middle-income nations, the cost of productivity losses due to malnutrition are estimated to 130 - 850 billion USD per year (Wellesley et al., 2020).

Over 30 years after first discussions about the term global sustainable development in the renowned Brundtland Report and five years after agreeing on 17 Sustainable Development Goals (SDGs) within the 2030 Agenda for Sustainable Development, global communities remain far from achieving it (UN, 2019). It is high time to rethink the way humans live on this planet and initiate a large-scale transformation of the systems responsible for the status quo.

1.2 THE ROLE OF FOOD

"Getting it right on food is not only a prerequisite for achieving the Paris Agreements and deliver on the UN Sustainable Development Goals – it might indeed be our greatest opportunity to improve the lives of people everywhere and help secure our common future on Planet Earth"

– Gunhild Stordalen, Founder and President of the EAT Foundation (EAT Forum, 2019)

The global agriculture and food industry are widely recognized to play a crucial role in reducing the environmental impacts of humankind (Gates, 2018; Poore & Nemecek, 2018; Willett et al., 2019). It is estimated that 26% of anthropogenic GHG emissions are currently emitted by agriculture and food production systems. Furthermore, no other industry consumes as much water, covers as much ice- and desert-free land, or contributes as significantly to biodiversity loss. Agriculture and food production systems are accountable for roughly 32% of global terrestrial acidification and roughly 78% of global eutrophication, both of which bear long-lasting impacts on natural ecosystems and contribute to the reduction of ecological resilience (Poore & Nemecek, 2018). Food production systems are the main drivers of natural land conversion, which is happening at a rate and causing a level of biodiversity loss that has led scientists to define the current period as the sixth mass extinction (Ceballos, Ehrlich, & Raven, 2020). Simultaneously, unhealthy diets are the leading risk factor for deaths worldwide (Afshin et al., 2019). In the context of the current pandemic, unhealthy diets have also been shown to increase the risk for severe COVID-19 outcomes (Burridge, Bradfield, Jaffee, Broadley, & Ray, 2020). Whilst consumption-related health costs are rising, production-related health costs are doing so too. The Ellen MacArthur Foundation (EMF) (2019) estimates that by 2050, five million deaths yearly could be caused by excessive use of pesticides in farming and antibiotics in livestock farming, as well as by poor fertilizer management. Widespread suboptimal production practices lead to air, soil and water pollution, and contribute to the development of antimicrobial resistance; all of which can be severely problematic. In terms of citizens affected by extreme poverty, the majority live in rural areas and work in agriculture (World Bank, 2015). Overall, it appears clear that food production systems play a key role in achieving sustainable development.

A significant part of environmental food system impacts are generated by animal-based products. According to Poore and Nemecek (2018), 83% of global farmland is used for meat, aquaculture, eggs and dairy production systems. Animal-based products contribute to 56-58% of the food system emissions, whilst only providing 37% of global protein intake and a mere 18% of global calorie intake. Poore and Nemecek found that average GHG emissions, eutrophication, acidification and land use impacts of plant-based products are typically surpassed by even the lowest impact animal-based products. Despite there being a large potential to reduce environmental impacts in existing animal production systems, reducing consumption of animal products will thus yield larger environmental benefits. The environmental impact of beef is particularly big. If cattle-related GHG emissions were treated like a country, the land of cattle would be accountable for roughly 10% of global greenhouse gas emissions (FAO, 2013). The argument to reduce the consumption of animal-based foods, particularly beef – where it lies significantly above the recommended intake, and thus also benefits human health – is therefore strong. It is important to note that the above does not suggest to completely eliminate meat consumption, but merely adapt it to the natural limits for its production.

Whilst the environmental impact of agriculture and food production systems is unarguably substantial, it is especially problematic when food products are lost or wasted along the food supply chain. Food waste accounts for 6% of global GHG emissions, making it the third-largest emitter of GHG emissions after China (21%) and the United States (13%), if treated as a country (Ritchie, 2020). It is estimated that one third of all food produced worldwide is lost or wasted along the food supply chain (FAO, 2017). According to the FAO, the economic value of this food amounts to 1 trillion USD every year, resulting in an additional 700 billion USD in environmental costs and 900 billion USD in social costs (FAO, 2014). Overall, global food loss and waste thus results in a loss of 2.6 trillion USD per year, a value roughly four times the size of the Swiss GDP (FSO, 2018).

By 2050 – using a 2013 baseline – the FAO expects that population growth combined with economic development will increase food demand by another 50% (FAO, 2017). Despite enabling consumers to purchase more diverse products, increasing economic development has historically correlated with an increased consumption of animal products and processed foods, as well as higher rates of food waste. This is not only a challenge due to the high environmental impact of animal products and unnecessary impact of food waste, but also because typical high-income diets are associated with higher rates of both adult and child obesity as well as increasing rates of diet-related NCDs (FAO, 2018a). Assuming that the current average share of meat consumption is not reduced, agricultural greenhouse gas emissions are expected to increase by a further 15-20% by 2050 (McKinsey & Company, 2020). According to the Ellen MacArthur Foundation, every dollar spent on food today requires an additional spending of two dollars in health, environmental and economic costs. The foundation estimates that this hidden cost of food amounts to 5.7 trillion USD per year, elaborating that half of this additional cost can be led back to current production practices (EMF, 2019). In an examination of the hidden cost of food in the United Kingdom, the Sustainable Food Trust estimates that every British pound spent on food is associated to roughly another pound of hidden costs (Fitzpatrick et al., 2019). In the previously mentioned report on the cost of food waste, the FAO (2014) estimates the social and environmental cost of global food loss and waste to 1.6 USD per dollar spent. These numbers – which all reports highlight as underestimations – lie in similar orders of magnitude and will increase if food production continues as is. Transforming the food system could hugely contribute to reducing humankind's environmental impact, whilst simultaneously improving human health and livelihoods worldwide.

Whereas Planet Earth clearly faces global challenges, solutions will require to be adapted to the local environments. This thesis focuses on the situation in Switzerland.

1.3 THE SITUATION IN SWITZERLAND

According to the Federal Office for the Environment (FOEN) (2011), Swiss diets are responsible for 30% of the national environmental footprint. The FOEN also states that biodiversity is unsatisfactory in Switzerland and that roughly a third of species are endangered (FOEN, 2018). In terms of the population's health, the situation in Switzerland is typical for a highly developed country. Hunger and undernourishment are almost non-existent, whereas unhealthy diets represent a major national issue (Federal Food Safety and Veterinary Office (FSVO), (2017a)). 42% of Swiss adults are classified as overweight, whereof roughly a third are classified obese (FSO, 2020a). Overweight and obesity are one of the key risk factors for NCDs such as cardiovascular diseases, diabetes type 2, and several forms of cancer, and thus present a substantial challenge to the Swiss health care system (FSVO, 2017a). Out of a population of over 8 million citizens, 2.2 million are currently affected by NCDs. NCDs account for 80% of current health care costs (around 80 billion CHF), which are expected to further increase substantially in line with the ageing population (FOPH, 2016). In the first national survey measuring the actual nutritional intake of the Swiss population, conducted in 2014-2015, it was concluded that insufficient amounts of plant-based foods, and excessive amounts of animal-based foods, animal fat, sugar and salt are consumed (FSVO, 2017b). Swiss citizens consume three times the recommended amount of red meat, and four times the recommended amount of animal-based fat, sweet, salty and alcoholic products. In turn, only 3.6 out of 5 recommended portions of fruits and vegetables per day are consumed. The recommended amount of whole grain and pulses are also not met (FSVO, 2017a).

The Swiss government spends roughly 4 billion CHF a year on financial support for agriculture, as visualized in Table 22 in the appendix (based on Avenir Suisse, 2020). 71% of the payments listed in Table 22 either potentially, partially or fully harm biodiversity in Switzerland (Gubler, Ismail, & Seidl, 2020). Gubler et al. also note that although an estimated 400 million CHF of payments are used to promote biodiversity across all sectors, a large majority of payments promote the opposite. As also derived from Table 22 in the appendix, an estimated 24% of payments support animal production systems. The system in place – with both harmful and conflicting subsidies – incentivizes the maintenance of an unsustainable Swiss food system. In addition to direct governmental support, Swiss agricultural products and food are subject to strong border protection. Whilst this is intended to primarily benefit producers, the Federal Office for Agriculture (FOAG) (2018) states that border protection is both costly and inefficient, despite enabling stable high domestic prices.

Tackling the way food is produced, consumed and regulated is not only key to reducing the national environmental footprint, but presents a huge opportunity to improve Swiss diets, as well as creating a more equitable, just and food secure society both inside and outside of Switzerland. It also offers a chance to reconsider and redirect governmental support of the system. The Food and Land Use Coalition (FOLU) (2019) estimates the benefits of food system transformation to exceed investment costs by factor of 15. Transformation should therefore be considered an economic imperative.

1.4 FOOD SYSTEM TRANSFORMATION

Healthy diets are at the core of food system transformation (FOLU, 2019). There is growing evidence and consensus on the environmental and health benefit of diets with a reduced share of animal-based foods and instead a stronger focus on plant-based foods. Early 2019, the EAT-Lancet Commission published the planetary health diet, a diet optimizing both human and planetary health. The commission found that in order to reach such a diet, global consumption of healthy foods such as fruits, vegetables, legumes and nuts is required to double, whereas the consumption of foods considered to be less healthy – such as added sugars, saturated fats and red meat – is required to be cut down to less than half of the current consumption. High-income countries in particular will have to stem most of the reduction of unhealthier foods, as their consumption thereof lies significantly above the healthy amount defined by the Commission, and even significantly above their own national guidelines. The report emphasizes the importance of using multiple strategies for achieving a sustainable and healthy food system. If the global community desires to stay below the defined boundaries, the world food system is required to 1) significantly improve food production practices, 2) halve food loss and waste and 3) achieve the dietary shift towards the planetary health diet (Willett et al., 2019). A food system that incentivizes sustainable production practices and the reduction of food loss and waste, disadvantages unsustainable production practices, and promotes the consumption of foods enabling human and planetary health, is urgently needed. As decisions along the entire food supply chain are driven by food prices, which in turn are influenced by policies, a deeper understanding of their role in the status quo is needed (Gittelsohn, Trude, & Kim, 2017).

1.4.1 THE ROLE OF FOOD PRICES

In highly developed countries such as Switzerland the share of income spent on food has decreased significantly in recent decades. Whilst this has been viewed as a big success and enabled the consumption of more diverse goods, consumers have started paying for cheap food through other channels. Food is paid for directly by consumers in-store, indirectly through taxes and through the payment of external costs (Fitzpatrick et al., 2019). The United Nations environment initiative The Economics of Ecosystems and Biodiversity for Agriculture and Food (TEEB AgriFood) (2018, p. 2) defines external costs or externalities as “third-party costs (or benefits) of bilateral economic transactions whose counterparties have not accounted for these costs (or benefits) when undertaking their transaction”. Throughout this thesis, all costs which are not directly reflected in current food procures will be referred to as externalities.

The major components influencing price determination of products at agricultural stage in Switzerland are agricultural inputs such as seed and plant material, feed, fertilizers and pesticides, as well as energy and maintenance costs (FSO, 2020b). Whilst the cost of all agricultural inputs are reflected in food prices, many additional factors influence prices: labor costs, overhead costs, as well as profit margins. This repeats at every step of the food supply chain until a product reaches consumers. However, as indicated above, food prices do not generally reflect the environmental, social and human health impacts of their products’ production and consumption.

There is growing consensus that current food pricing and agricultural policies are part of the problem (FOLU, 2019). The FAO states that food prices should be "right", elaborating that both the nutritional value of a food item as well as its production- and consumption-associated costs along the food supply chain should be represented in food prices (FAO, 2018a, p. 30). However, the FAO also stresses that an increase in food prices could negatively affect the ability of the poor to buy food and that options to increase their purchasing power need to be considered. Similarly, the Eat-Lancet Commission states that "food prices should fully reflect the true costs of food". (Willett et al., 2019, p. 479). The Commission also emphasizes that vulnerable populations need to be protected from a potential increase of food prices. The effects of changing food prices - or alternatives to directly changing food prices - therefore need to be considered.

Food prices and what they do or do not include, as well as the financial support of unsustainable production systems, play a key role in the current food system. For the transformation towards such a sustainable food system, creating a common understanding of all externalities of the food system, their measurement and reduction targets is crucial.

1.4.2 CREATING TRUE COST TRANSPARENCY

True cost accounting (TCA), the practice of defining, quantifying and monetizing (food system) impacts, has seen a rise in international interest over the past few years. Multiple organizations have recently published reports on the need to create true cost transparency in order to enable stakeholders such as producers, consumers, regulators and investors to make better, more sustainable decisions along the entire food supply chain (Food Tank, 2015; GAFF, 2019; TEEB AgriFood, 2018; WBCSD, 2018). However, most of these reports remain on a relatively high level and do not specify which concrete externalities need to be considered – in which unit and with which monetization factor – to calculate a holistic true cost of food. In May 2020, the Food System Impact Valuation Initiative (FoodSIVI) (2020), led by the Oxford University Environmental Change Institute, published the report *Valuing the impact of food: Towards practical and comparable monetary valuation of food system impacts*. It concludes that an intergovernmental standard on the footprint of food and therefrom derived measurable reduction targets are urgently needed, stating that the scientific knowledge to initiate this process is available. The development of such a standard requires a framework defining which impacts should be included, how they can be measured, as well as a better understanding of where data availability is currently insufficient. Creating transparency on how much these impacts cost society further allows the prioritization of reduction targets and gives governments an indication of the savings connected to these targets. Developing true cost transparency is key to food system transformation and is exactly what this thesis aspires to contribute towards.

This thesis aims to provide a comprehensive overview of food system externalities and propose a new methodology to calculate the true cost of food based on these externalities. The next chapter explains the methodology defined for assessing the true cost of food and how it is applied to calculate the true cost of the Swiss food system, national level true costs, and the true cost of eight selected Swiss food products, i.e. product level true costs. Chapter 3 illustrates national and product level results. All results are visualized in order to provide easily communicable results. The discussion chapter then reviews the methodology defined, the national level true cost results as well as the product level true cost results, highlighting where more data and research are required. It also gives concrete recommendations for action along the entire food supply chain in Switzerland. The thesis concludes with summary of the insights and a call for action.

2 METHODOLOGY

This chapter explains the methodology defined to calculate the true cost of food within this thesis. It details how externalities were identified and prioritized, which data sources were used, and how the methodology was applied to calculate the true cost of both the national Swiss food system and of eight different, conventionally produced Swiss food products. Aiming to serve as the basis for a universal true cost calculation, the following methodology can also be applied to other food systems and products with slight adaptions to the local context. Results of the quantification will be presented in the following chapter (Table 1).

Table 1: Methodology overview including relevant steps (explained in following subchapters)

Subchapter	Relevant steps
Externality identification	1. Impact area definition
	2. Externality collection
	3. Externality prioritization
	4. Data sources
Quantification	5. Monetization
	6. National level quantification
	7. Product level quantification

2.1 IMPACT AREA DEFINITION

In a first step, a clear definition of food system impact areas is needed. According to the FAO (2018b, p. 1), a sustainable food system is "a food system that delivers food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised". As such, it should be profitable, benefit society and positively or at least neutrally affect the natural environment. TEEB AgriFood, a UNEP initiative, is widely referred to as the standard for evaluating food system impacts (Aspenson, 2020). The initiative differentiates between four types of capitals to assess in terms of evaluating food system impacts: natural, human, social and produced capital (TEEB AgriFood, 2018). The capitals are explained in detail in the appendix in Table 17. This thesis builds on these capitals, replacing the terminology used by TEEBAgriFood with food system impact areas, which are assumed to be easier to understand and communicate outside of academia.

In order to clearly distinguish between the impact on non-living natural resources and the impact on non-human life on Earth, this thesis divides impacts on natural capital into the a) environment (abiotic) and b) biodiversity impact area. Impacts on human and social capital are accounted for in the human health and livelihood impact area, whilst impacts on produced capital are embedded in the economy impact area. This thesis further adds animal welfare as an impact area, as current food production systems often heavily affect animal welfare (Scherer, Tomasik, Rueda, & Pfister, 2018). As illustrated in Table 2, this results in a definition of six main food system impact areas.

Table 2: Main impact areas of the food system

Impact area	Definition
Environment (abiotic)	Impact on quality and quantity of non-living natural resources
Biodiversity	Impact on living non-human life and ecosystem services
Livelihoods	Impact on the quality of life of all human food system participants
Human Health	Impact on human health connected to food production or consumption
Economy	Impact on the local and global economy, including policies
Animal Welfare	Impact on the quality and duration of animal lives held for food

2.2 EXTERNALITY COLLECTION

In a second step, each of the defined impact areas were researched in order to understand which concrete measurable food system externalities cause the defined impact areas to be negatively affected. This thesis focuses on negative externalities of the food system, which are at the heart of the current unsustainable food system. Positive externalities, such as carbon sequestration, should also be considered in the creation of a sustainable food system but are beyond the scope of this thesis. The framework presented in Figure 1 can however also be used as a basis for understanding positive food system externalities.

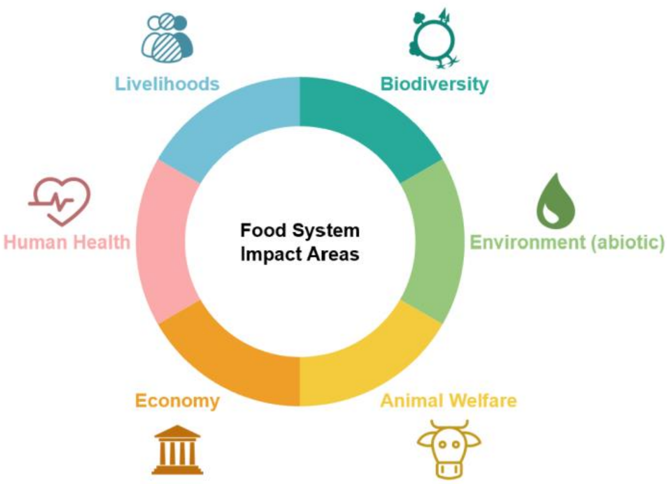

Figure 1: The food system impact framework

Overall, 100 negative externalities attributable to different steps of the food supply were collected. The majority of externalities are directly connected to the production or consumption of food, such as the emission of GHGs. A small number of indirect externalities, such as higher suicide rates among farmers, are included to demonstrate the need for a deeper understanding of complex food system externalities. Some food system externalities affect multiple of the defined impact areas. In that case, the externality was allocated to its main impact area, although the secondary and even tertiary impacts may also be significant. This was the case for several of the externalities impacting the environment and biodiversity. In addition, some externalities were challenging to identify in a measurable manner. Externalities that are considered important but lack clear scientific indicators are listed in the overview without units.

Externalities in the environment and biodiversity impact area were predominantly derived from the impact assessment methodology most commonly used in life cycle assessments (LCA), ReCiPe (Huijbregts et al., 2016). ReCiPe was also used as the basis for the monetization factors used in this thesis. Livelihood indicators were largely derived from the set of social externalities defined by the monetization standard used in this thesis. These indicators in turn are based on human rights, labor rights and corporate responsibility standards (True Price, 2020). Human health as well as economy externalities were partly derived from the WBCSD (2018) framework. Human health externalities are measured by disability-adjusted life years (DALYs), which are calculated by adding years of life lost and years of life lost due to disability (WHO, 2020). Animal welfare externalities are accounted for with an indicator proposed by Scherer et al. (2018).

All externalities collected including their sources are listed in Table 3, which divides impact areas into impact categories in order to illustrate different types of impacts within each impact area. For both livelihood and economy externalities, the framework is unlikely to be exhaustive. Additional expert input is needed to improve the framework in those areas. The framework also requires further development to better reflect animal welfare externalities. As the basis for true cost calculation, Table 3 requires frequent updates to reflect current scientific knowledge and incorporate new insights on interactions between different externalities.

Table 3: Overview of globally relevant food-system externalities including the respective source (: included to better reflect diversity of food system workers and highlight unpaid/insufficiently insured labor, **: included based on discussions with food system experts, further research required)*

Impact area	Impact category	Externality	Unit	Source
Environment (abiotic)	Contribution to climate change	Greenhouse gas emissions	kg CO_2-eq	Huijbregts et al. (2016)
Environment (abiotic)	Contribution to climate change	Carbon dioxide losses due to land conversion	kg CO_2	FAO (2014)
Environment (abiotic)	Pollution of the living environment	Particulate matter (PM) formation	kg $PM_{2.5}$-eq	Huijbregts et al. (2016)
Environment (abiotic)	Pollution of the living environment	Ammonia emissions	kg NH_3	Fitzpatrick et al. (2019)
Environment (abiotic)	Pollution of the living environment	Photochemical oxidant formation (POF)	kg NMVOC-eq	True Price (2020)
Environment (abiotic)	Pollution of the living environment	Acidification	kg SO_2-eq	Huijbregts et al. (2016)
Environment (abiotic)	Pollution of the living environment	Ozone layer depleting emissions	kg CFC11-eq	Huijbregts et al. (2016)
Environment (abiotic)	Degradation of land	Soil loss from wind erosion	kg soil lost	Fitzpatrick et al. (2019)
Environment (abiotic)	Degradation of land	Soil loss from water erosion	kg soil lost	Fitzpatrick et al. (2019)
Environment (abiotic)	Degradation of land	Soil organic carbon loss	kg SOC	Fitzpatrick et al. (2019)
Environment (abiotic)	Depletion of scarce abiotic resources	Fossil fuel depletion	kg oil-eq	Huijbregts et al. (2016)

Impact area	**Impact category**	**Externality**	**Unit**	**Source**
Environment (abiotic)	Depletion of scarce abiotic resources	(Other) non-renewable material depletion	kg Cu-eq	Huijbregts et al. (2016)
Environment (abiotic)	Depletion of scarce abiotic resources	Scarce water use (blue water)	m^3	Huijbregts et al. (2016)
Biodiversity	Pollution of the living environment	Terrestrial ecotoxicity (air pollution)	kg 1,4-DB-eq	Huijbregts et al. (2016)
Biodiversity	Pollution of the living environment	Freshwater ecotoxicity (air pollution)	kg 1,4-DB-eq	Huijbregts et al. (2016)
Biodiversity	Pollution of the living environment	Marine ecotoxicity (air pollution)	kg 1,4-DB-eq	Huijbregts et al. (2016)
Biodiversity	Pollution of the living environment	Terrestrial ecotoxicity (water pollution)	kg 1,4-DB-eq	Huijbregts et al. (2016)
Biodiversity	Pollution of the living environment	Freshwater ecotoxicity (water pollution)	kg 1,4-DB-eq	Huijbregts et al. (2016)
Biodiversity	Pollution of the living environment	Marine ecotoxicity (water pollution)	kg 1,4-DB-eq	Huijbregts et al. (2016)
Biodiversity	Pollution of the living environment	Freshwater eutrophication	kg P-eq to freshwater	Huijbregts et al. (2016)
Biodiversity	Pollution of the living environment	Marine eutrophication	kg N-eq to marine water	True Price (2020)
Biodiversity	Pollution of the living environment	Terrestrial ecotoxicity (soil pollution)	kg 1,4-DB-eq	Huijbregts et al. (2016)
Biodiversity	Pollution of the living environment	Freshwater ecotoxicity (soil pollution)	kg 1,4-DB-eq	Huijbregts et al. (2016)
Biodiversity	Pollution of the living environment	Marine ecotoxicity (soil pollution)	kg 1,4-DB-eq	Huijbregts et al. (2016)
Biodiversity	Degradation of biodiversity and ecosystems	Land occupation	MSA ha yr	True Price (2020)
Biodiversity	Degradation of biodiversity and ecosystems	Land transformation	ha	True Price (2020)
Livelihoods	Labor	Underage workers below minimum age (12-13)	child FTE	True Price (2020)
Livelihoods	Labor	Underage workers that are not attending school	children	True Price (2020)
Livelihoods	Labor	Labor force to be audited for child labor	FTE (full-time equivalent)	True Price (2020)
Livelihoods	Labor	Forced workers	FTE	True Price (2020)
Livelihoods	Labor	Forced workers in debt bondage	FTE	True Price (2020)
Livelihoods	Labor	Forced workers who are victims of abuse	FTE	True Price (2020)
Livelihoods	Labor	Labor force to be audited for forced labor	FTE	True Price (2020)

Impact area	Impact category	Externality	Unit	Source
Livelihoods	Labor	Unpaid labor (work-related)	FTE	*
Livelihoods	Labor	Unpaid labor (other, e.g. care)	FTE	*
Livelihoods	Discrimination	Female workers without maternity leave provision	FTE	True Price (2020)
Livelihoods	Discrimination	Value of denied maternity leave	$	True Price (2020)
Livelihoods	Discrimination	Male workers without paternity leave provision	FTE	*
Livelihoods	Discrimination	Value of denied paternity leave	$	*
Livelihoods	Discrimination	Wage gap from gender discrimination	$	True Price (2020)
Livelihoods	Discrimination	Wage gap from unequal opportunities (gender discr.)	$	True Price (2020)
Livelihoods	Discrimination	Labor force to be audited for gender discrimination	FTE	True Price (2020)
Livelihoods	Discrimination	Wage gap from racial discrimination	$	*
Livelihoods	Discrimination	Wage gap from unequal opportunities (racial discr.)	$	*
Livelihoods	Discrimination	Labor force to be audited for racial discrimination	FTE	*
Livelihoods	Discrimination	Wage gap from religious discrimination	$	*
Livelihoods	Discrimination	Wage gap from unequal opportunities (religious discr.)	$	*
Livelihoods	Discrimination	Labor force to be audited for religious discrimination	FTE	*
Livelihoods	Non-guarantee of a decent living standard	Wage gap of workers earning below minimum wage	$	True Price (2020)
Livelihoods	Non-guarantee of a decent living standard	Wage gap of workers earning above minimum but below decent living wage	$	True Price (2020)
Livelihoods	Non-guarantee of a decent living standard	Labor force to be audited for insufficient wages	FTE	True Price (2020)
Livelihoods	Non-guarantee of a decent living standard	Workers without legal social security	$	True Price (2020)
Livelihoods	Non-guarantee of a decent living standard	Workers with insufficient social security	$	*
Livelihoods	Non-guarantee of a decent living standard	Value of denied paid leave	$	True Price (2020)
Livelihoods	Non-guarantee of a decent living standard	Value of denied sick leave	$	*
Livelihoods	Non-guarantee of a decent living standard	Labor force to be audited for insufficient social security	FTE	True Price (2020)

Impact area	Impact category	Externality	Unit	Source
Livelihoods	Non-guarantee of a decent living standard	Workers performing illegal overtime	FTE	True Price (2020)
Livelihoods	Non-guarantee of a decent living standard	Workers performing underpaid overtime	FTE	True Price (2020)
Livelihoods	Non-guarantee of a decent living standard	Overtime wage gap	$	True Price (2020)
Livelihoods	Non-guarantee of a decent living standard	Labor force to be audited for illegal overtime	FTE	True Price (2020)
Livelihoods	Non-guarantee of a decent living standard	Income gap	$	True Price (2020)
Livelihoods	Non-guarantee of a decent living standard	Lack of access to education	$	True Price (2020)
Livelihoods	Occupational health and safety risks	Workers who experienced harassment	workers	True Price (2020)
Livelihoods	Occupational health and safety risks	Labor force to be audited for harassment	FTE	True Price (2020)
Livelihoods	Occupational health and safety risks	Non-fatal occupational incidents (insured)	incidents	True Price (2020)
Livelihoods	Occupational health and safety risks	Non-fatal occupational incidents (uninsured)	incidents	True Price (2020)
Livelihoods	Occupational health and safety risks	Fatal occupational incidents	incidents	True Price (2020)
Livelihoods	Occupational health and safety risks	Occupational incidents with breach of H&S standards	incidents	True Price (2020)
Livelihoods	Occupational health and safety risks	Work performed in violation of H&S standards	FTE	True Price (2020)
Livelihoods	Occupational health and safety risks	Labor force to be audited for H&S	FTE	True Price (2020)
Livelihoods	Occupational health and safety risks	Exposure to pesticides	DALYs	WBCSD (2018)
Livelihoods	Lack of union rights	Instances of denied freedom of association	violations	True Price (2020)
Livelihoods	Lack of union rights	Labor force to be audited for denied freedom of association	FTE	True Price (2020)
Livelihoods	Loss of livelihood	Income loss due to price volatility	$	**
Livelihoods	Loss of livelihood	Income loss due to conflict	$	**
Livelihoods	Loss of livelihood	Lack of access to financial services	$	**
Livelihoods	Mental health	Contribution to increased divorce rates in agriculture (indirect)	n/a	**
Livelihoods	Mental health	Contribution to increased suicide rates in agriculture (indirect)	n/a	**

Impact area	Impact category	Externality	Unit	Source
Livelihoods	Mental health	Impact of working away from home (seasonal workers) (indirect)	n/a	**
Human Health	Production-related human health impacts	Human toxicity (air pollution)	DALYs	Huijbregts et al. (2016)
Human Health	Production-related human health impacts	Human toxicity (water pollution)	DALYs	Huijbregts et al. (2016)
Human Health	Production-related human health impacts	Human toxicity (soil pollution)	DALYs	Huijbregts et al. (2016)
Human Health	Consumption-related human health impacts	Health impact of undernutrition	DALYs	Fitzpatrick et al. (2019)
Human Health	Consumption-related human health impacts	Health impact of malnutrition	DALYs	WBCSD (2018)
Human Health	Consumption-related human health impacts	Health impact of overweight and obesity	DALYs	WBCSD (2018)
Human Health	Consumption-related human health impacts	Health impact of hypertension	DALYs	WBCSD (2018)
Human Health	Consumption-related human health impacts	Health impact of non-communicable diseases	DALYs	WBCSD (2018)
Human Health	Consumption-related human health impacts	Health impact of dementia	DALYs	Fitzpatrick et al. (2019)
Human Health	Consumption-related human health impacts	Health impact of food poisoning	DALYs	WBCSD (2018)
Human Health	Consumption-related human health impacts	Health impact of pesticide exposure	DALYs	WBCSD (2018)
Human Health	Public health threats from livestock production	Health impact of antibiotic use	DALYs	Fitzpatrick et al. (2019)
Human Health	Public health threats from livestock production	Contribution to the exposure to zoonotic diseases (indirect)	DALYs	**
Economy	Additional spending through taxes	Taxes for food system-targeted subsidies	$	Fitzpatrick et al. (2019)
Economy	Additional spending through taxes	Taxes for regulation and research	$	Fitzpatrick et al. (2019)
Economy	Additional spending through taxes	Taxes for welfare and social services (received from food workers) (indirect)	$	**
Economy	System stability	Reduction of small family farms (indirect)	n/a	**
Economy	System stability	Decline of rural communities (indirect)	n/a	**
Economy	System stability	Creation of local jobs	FTEs	**
Animal welfare	Animal welfare	Animal years suffered	ALYs	Scherer et al. (2018)

For a full true cost of food picture, the cost of all of these externalities need to be considered. In reality, many of them are currently not quantifiable due to limited data availability or accessibility. For the true cost quantification of this thesis, the true cost is therefore approximated with a selection of externalities most relevant to the Swiss food system.

2.3 EXTERNALITY PRIORITIZATION

In a final externality selection step, 28 externalities were prioritized for the true cost quantification undertaken in this thesis (Table 4). Whilst the overall goal was to select the most important and impactful externalities in the Swiss context, externalities of some impact areas were selected based on the feasibility of their quantification. For environment, the most important indicators in the Swiss context were chosen. For biodiversity, all indicators were chosen. For livelihoods, only three of over 50 externalities were chosen due to a significant lack of data. The prioritized externalities represent issues relevant in Swiss agriculture. For human health, almost all indicators are represented in the selection below. For economy externalities, the framework assesses the amount of taxes used for food system-targeted subsidies, market support as well as taxes for regulation and research. These costs do not fall into the classic definition of externalities but are included because they are not directly reflected in what consumers pay for food today. Other economic externalities should be considered in future holistic true cost accounting frameworks. Last but not least, in the case of animal welfare externalities, the single indicator identified was included.

Table 4: Overview of prioritized food system externalities

ID	Impact Area	Impact Category	Externality	Unit
Env1	Environment (abiotic)	Contribution to climate change	Greenhouse gas emissions	kg CO_2-eq
Env2	Environment (abiotic)	Pollution of the living environment	Acidification	kg SO_2-eq
Env3	Environment (abiotic)	Degradation of land	Soil loss from water erosion	kg soil lost
Env4	Environment (abiotic)	Degradation of land	Soil organic carbon loss	kg SOC
Env5	Environment (abiotic)	Depletion of scarce abiotic resources	Fossil fuel depletion	kg oil-eq
Env6	Environment (abiotic)	Depletion of scarce abiotic resources	(Other) non-renewable material depletion	kg Cu-eq
Env7	Environment (abiotic)	Depletion of scarce abiotic resources	Scarce water use (blue water)	m^3
Bio8	Biodiversity	Pollution of the living environment	Terrestrial ecotoxicity	kg 1,4-DB-eq
Bio9	Biodiversity	Pollution of the living environment	Freshwater ecotoxicity	kg 1,4-DB-eq
Bio10	Biodiversity	Pollution of the living environment	Marine ecotoxicity	kg 1,4-DB-eq
Bio11	Biodiversity	Pollution of the living environment	Freshwater eutrophication	kg P-eq to freshwater

ID	Impact Area	Impact Category	Externality	Unit
Bio12	Biodiversity	Pollution of the living environment	Marine eutrophication	kg N-eq to marine water
Bio13	Biodiversity	Degradation of biodiversity and ecosystems	Land occupation	MSA ha yr
Bio14	Biodiversity	Degradation of biodiversity and ecosystems	Land transformation	ha
Liv15	Livelihoods	Non-guarantee of a decent living standard	Workers with insufficient social security	$
Liv16	Livelihoods	Non-guarantee of a decent living standard	Workers performing free labor	$
Liv17	Livelihoods	Occupational health and safety	Exposure to pesticides	DALYs
Hum18	Human Health	Production-related human health impacts	Human toxicity	DALYs
Hum19	Human Health	Consumption-related human health impact	Health impact of malnutrition	DALYs
Hum20	Human Health	Consumption-related human health impact	Health impact of overweight and obesity	DALYs
Hum21	Human Health	Consumption-related human health impact	Health impact of hypertension	DALYs
Hum22	Human Health	Consumption-related human health impact	Health impact of non-communicable diseases	DALYs
Hum23	Human Health	Consumption-related human health impact	Health impact of food poisoning	DALYs
Hum24	Human Health	Consumption-related human health impact	Health impact of pesticide exposure (consumption)	DALYs
Hum25	Human Health	Consumption-related human health impact	Health impact of antibiotic use	DALYs
Eco26	Economy	Additional spending through taxes	Taxes for food system-targeted subsidies	$
Eco27	Economy	Additional spending through taxes	Taxes for regulation and research	$
Ani28	Animal Welfare	Animal Welfare	Animal years suffered	ALYs

Based on these 28 externalities, the goal is to approximate a true cost picture as complete as possible with currently available data.

2.4 DATA SOURCES

Data was sourced for both the Swiss food system as well as for eight selected products. Data availability was found to be limited on both the system and product level (Table 5). This is discussed in more detail in the discussion part of this thesis.

Table 5: Data availability for system and product level quantification (red: no or very limited data, yellow: limited data availability, green: data available)

Impact area	System level quantification	Product level quantification
Environment (abiotic)	System level emissions and natural capital degradation	Product-specific life-cycle assessment (LCA)
Biodiversity	System level state of biodiversity and ecosystems	Product-specific life-cycle assessment (LCA)
Livelihoods	System level statistics on quality of life of all human food system participants	Product-specific social life-cycle assessment (S-LCA)
Human Health	Public health costs for environmental and personal human health externalities, share attributable to diet	Environmental human health externalities (production-related): LCA
		Personal human health externalities (consumption-related): DALYs attributable to diet/food group intake
Economy	Taxes and subsidies for food system sectors, economic data	Product-specific taxes and subsidies
Animal Welfare	System level statistics on animal welfare	Product-specific animal welfare impact

Despite some of the externalities being quantifiable on both a system and product level, direct comparability due to different data sources and monetization factors is limited. System level studies often provide impacts in monetary terms, whilst product level externalities require monetization factors specific to their respective units.

2.5 MONETIZATION

The missing link between the defined externalities and the cost they represent to society are unit-specific monetization factors (MF). In order to be as consistent as possible, this thesis uses only one set of monetization factors to translate measurable externalities into monetary costs, global monetization factors published by the Dutch True Price Foundation. The standard was published in May 2020 and was specifically developed for the comparison of different human activity-related externalities. It is thus highly suitable for this thesis. The monetization factors are derived from four different types of costs: restoration, compensation, prevention of re-occurrence and retribution costs, which are combined to define a remediation cost for every externality. The exact definition of each type of cost is defined in Table 18 in the appendix. The foundation cites Article 22 of the UN Guiding Principles on Business and Human Rights as the basis for this approach, which states that "Where business enterprises identify that they have caused or contributed to adverse impacts, they should provide for or cooperate in their remediation through legitimate processes" (True Price, 2020, p. 12). All monetization factors listed in Table 6 were converted from Euro to Swiss francs with the average conversion rate between January and June 2020, 1.06 (European Central Bank, 2020).

Monetization factors are especially useful for the product level estimations, where the units can simply be monetized with the factors. On a system level, externalities are often not monetized based on system level externalities or emissions but quantified in terms of system level expenditure. In this thesis, only the GHG emissions, soil organic carbon loss and DALY monetization factor is used on a system level. The cost of all other externalities is derived from other, Swiss-specific system level costs. On a product level, the True Price monetization factors are used for all quantifiable externalities. The foundation provides no monetization factors for the consumption-related human health, animal welfare and economy impact areas. For the DALYs caused by the consumption of food, it is assumed that the DALY monetization factor for production-related DALYs can be used. Animal welfare and economy costs can only be assessed on a system level using Swiss-specific sources. In terms of livelihood externalities, True Price does not provide monetization factors. Livelihood costs on a system level are approximated as explained in chapter 2.4 of the appendix.

Table 6: Unit-specific monetization factors

ID	Impact area	Externality	Unit	CHF/unit
Env1	Environment (abiotic)	Greenhouse gas emissions	kg CO_2-eq	0.16
Env2	Environment (abiotic)	Acidification	kg SO_2-eq	3.56
Env3	Environment (abiotic)	Soil loss from water erosion	kg soil lost	0.03
Env4	Environment (abiotic)	Soil organic carbon loss	kg SOC	0.03
Env5	Environment (abiotic)	Fossil fuel depletion	kg oil-eq	0.46
Env6	Environment (abiotic)	(Other) non-renewable material depletion	kg Cu-eq	0.24
Env7	Environment (abiotic)	Scarce water use (blue water)	m^3	1.35
Bio8	Biodiversity	Terrestrial ecotoxicity	kg 1,4-DB-eq	7.71
Bio9	Biodiversity	Freshwater ecotoxicity	kg 1,4-DB-eq	0.03
Bio10	Biodiversity	Marine ecotoxicity	kg 1,4-DB-eq	0.01
Bio11	Biodiversity	Freshwater eutrophication	kg P-eq to freshwater	322.24
Bio12	Biodiversity	Marine eutrophication	kg N-eq to marine water	67.20
Bio13	Biodiversity	Land occupation (land type “other forest”)	MSA ha yr	1’060
Bio14	Biodiversity	Land transformation (land type “other forest”)	ha	2’173
Liv15	Livelihoods	Workers with insufficient social security	$	-
Liv16	Livelihoods	Workers performing free labor	$	-
Liv17	Livelihoods	Exposure to pesticides	DALYs	123’808
Hum18	Human Health	Human toxicity	DALYs	123’808

ID	Impact area	Externality	Unit	CHF/unit
Hum19	Human Health	Health impact of malnutrition	DALYs	123'808
Hum20	Human Health	Health impact of overweight and obesity	DALYs	123'808
Hum21	Human Health	Health impact of hypertension	DALYs	123'808
Hum22	Human Health	Health impact of non-communicable diseases	DALYs	123'808
Hum23	Human Health	Health impact of food poisoning	DALYs	123'808
Hum24	Human Health	Health impact of pesticide exposer (consumption)	DALYs	123'808
Hum25	Human Health	Health impact of antibiotic use	DALYs	123'808
Eco26	Economy	Taxes for food system-targeted subsidies	$	-
Eco27	Economy	Taxes for regulation and research	$	-
Ani28	Animal Welfare	Animal years suffered	ALYs	n/a

All monetization factors are globally applicable monetization factors, with the exception of the cost of one DALY. Whilst True Price has defined country-specific monetization factors, these are not publicly available. The foundation has however provided the information that the DALY cost in Switzerland equals more than double the global value. This thesis therefore uses twice the global value for the cost per DALY in Switzerland (P. Galgani, personal communication, August 10, 2020).

2.6 NATIONAL LEVEL QUANTIFICATION

Current true cost estimates generally focus on food systems and not individual products. System level quantifications are especially useful for understanding which impact areas drive external costs and for quantifying externalities that are most easily quantified at a system level. This thesis thus first undertakes a system level quantification of the Swiss food system true cost based on the previously prioritized 28 externalities. As many of these externalities are not only caused by the food system, it is necessary to define how much of the system level external costs are connected to the food system. As visualized in the equation below, the external cost connected to each individual externality (i) is summed up to represent the external cost of each food impact area. The sum of external costs is then added to the current national expenditure on food and non-alcoholic drinks.

$$True\ cost\ (system) = National\ food\ expenditure + \sum_{i=1}^{n} (National\ external\ cost * share\ attributable\ to\ the\ food\ system)_i$$

In a first step, total consumer expenditure on food and non-alcoholic drinks in Switzerland in 2018 is estimated. This was done based on FSO (2019a) data on private and collective household (e.g. schools, hospitals, prisons) expenditure at the retail and wholesale level, as well as in hospitality. In a second step, all externalities prioritized are quantified for 2018. Table 7 illustrates which data sources were used for the externalities possible to quantify in this thesis and what collected data covers. Many externalities cover only a part of total external costs and are thus underestimations.

Table 7: Main data sources and exhaustiveness of data used at system level

ID	Externality	Calculation	Covered
Env1	Greenhouse gas emissions	Application of 5th IPCC conversion rates (2014) to FOEN emission data (2020) (CO_2, CH_4, N_2O), True Price MF	Agriculture, food and beverage industry
Env4	Soil organic carbon loss	Application of average loss rate due to common Swiss agricultural practices (Keel et al., 2019) to relevant area, True Price MF	Losses on cropland and permanent grassland
Bio8-14	Biodiversity and ecosystem service loss due to agriculture	Application of average GDP loss per year (Braat et al., 2008) to Swiss GDP, 35.4% caused by food (derived from Wilting et al., 2017)	Selected drivers of biodiversity and ecosystem service loss
Liv16	Workers performing free labor	Own calculation based on multiple data sources	Free labor of family members living on farm
Hum18	Human toxicity (air pollution)	Health costs due to agriculture-caused air pollution in the canton of Zurich (Econcept, 2018)	Direct, indirect and intangible costs of PM_{10}
Hum20	Health impact of overweight and obesity	Cost of 11 co-morbidities of overweight and obesity (Schneider & Venetz, 2014), 30% caused by food (Fitzpatrick et al., 2019)	Direct and indirect cost of comorbidities
Hum21	Health impact of hypertension	FSO (2020a) prevalence data multiplied with direct costs (Schaefer & Scheunert, 2013), 58% caused by food (Fitzpatrick et al., 2019)	Direct costs
Hum22-1	Health impact of cardiovascular disease	Cost of NCDs (Wieser et al., 2014), 33% caused by diet (Scarborough et al., 2011)	Direct and indirect cost of cardiovascular disease
Hum22-2	Health impact of diabetes	Cost of NCDs (Wieser et al., 2014), 33% caused by diet (Scarborough et al., 2011)	Direct and indirect cost of diabetes
Hum22-3	Health impact of cancer	Cost of NCDs (Wieser et al., 2014), 33% caused by diet (Scarborough et al., 2011)	Direct and indirect cost of cancer
Hum23	Health impact of food poisoning	Cost of acute gastroenteritis and human campylobacteriosis (Schmutz et al., 2017)	Direct costs
Hum24	Health impact of pesticide exposure	Cost of pesticide exposure in Switzerland (Zandonella, Sutter, Liechti, & von Stokar, 2014)	Direct and indirect costs
Hum25	Health impact of antibiotic use	DALYs lost due to antimicrobial resistance (Gasser, Zingg, Cassini, & Kronenberg, 2019), True Price MF, 22% caused by food (Fitzpatrick et al., 2019)	Cost of DALYs lost

ID	Externality	Calculation	Covered
Eco26	Taxes for food system-targeted subsidies	Taxes used on support of structure, sales, animal welfare and environment (Avenir Suisse, 2020)	Government expenditure at agricultural level
Eco27	Taxes for regulation and research	Taxes used on research, regulation and administration (Avenir Suisse, 2020)	Government expenditure at agricultural level
Ani28	Animal years suffered	Cost of animal suffering based on subsidies paid to improve animal welfare (Schlaepfer, 2020)	Animal suffering due to lack of outdoor space and animal-friendly housing

Detailed information on the methodology used for the quantification of each individual externality assessed can be found in the appendix in chapter 2. A number of externalities were not possible to quantify on a system level. This is elaborated in the results.

The Swiss national household expenditure also includes expenditure on imported food, which causes external costs outside of Switzerland. External costs of imported food were approximated by applying the production-related share of external costs caused by locally produced food to the difference between the Swiss food import and export value. Table 24 in the appendix elaborates on which exact externalities were included for this approximation.

To illustrate the general methodology used, one externality is explained in detail in the following.

2.6.1 EXAMPLE CALCULATION: ENV1

The cost of greenhouse gas (GHG) emissions in Switzerland was estimated using government statistics from the Federal Office of the Environment (FOEN) (2020). The FOEN provides yearly overviews of carbon dioxide, methane and nitrous oxide emissions of different industries according to the UNFCCC (United Nations Framework Convention on Climate Change) industry categorization guidelines. It also converts the GHG into kg CO_2 equivalents emitted per year based on the 4th IPCC report conversion rates of methane (25) and nitrous oxide (298) (Greenhouse Gas Protocol, 2014). In 2018, agriculture and the agriculture-related subsection of the energy industry emitted 6.59 million tons of CO_2 equivalents. Furthermore, the “food, beverages and tobacco” industry emitted 0.85 million tons of CO_2 equivalents. 91% of these are attributed to the food industry (A. Schilt, personal communication, May 27, 2020). Within this thesis, the individual carbon dioxide, methane and nitrous oxide emissions are converted into CO_2 equivalents using the more current 5th IPCC report conversion factors for methane (28) and nitrous oxide (265), as recommended by the Greenhouse Gas Protocol. As a result, 2018 GHG emissions in Switzerland lie at 7.61 million tons of CO_2 equivalents, with the majority of the CO_2 equivalents coming from methane emissions. Using the 5th IPCC report conversion factors is especially important due to the high relevance of agriculture regarding methane and nitrous oxide emissions. Cattle-related methane emissions account for 45% of Swiss agricultural GHG emissions, which in turn account for 14% of national GHG emissions. Livestock-related emissions account for 48% of agricultural emissions (FOEN, 2020). To put this value into perspective: agricultural GDP represents 0.65% of national GDP (FSO, 2020c).

The resulting amount of GHG emissions is multiplied by the True Price monetization factor 161 CHF/ton. Estimates for the cost of GHG emissions – the cost society incurs for every additional ton of CO_2 equivalents emitted – vary widely, with a Stanford University estimate lying at 220 USD (211 CHF) (Moore & Diaz, 2015). The True Price monetization factor used throughout this thesis is based on an assessment of 62 marginal abatement cost estimates (True Price, 2020). The resulting external food system costs related to greenhouse gas emissions in Switzerland thus lie at 1.23 billion CHF. A range of possible costs lies between 0.45 (61 CHF/ton, (Avenir Suisse, 2020)) and 1.61 billion CHF (211 CHF/ton), depending on monetization factor used. These values only include GHG emissions of agricultural production and the food industry. Transport and retail are not included and would further increase the environment-related cost of the food system. However, agriculture is the main emitter of GHG emissions along the food supply chain, with an estimated agricultural share of 61% of food chain emissions (Poore & Nemecek, 2018). The majority of GHG emission costs is therefore likely to be included in this estimation.

2.7 PRODUCT LEVEL QUANTIFICATION

Whilst system level true cost estimates inform on the magnitude of true costs and what they are driven by, they do not provide insights into the specific products contributing to these external costs. This thesis therefore applies the same framework used for the national level true cost calculation to eight specific food products. Despite many of the externalities not being quantifiable on a product level, this second step is highly relevant. It provides initial insights in response to the question of which products' production and consumption should be promoted and which in turn should be reduced. True cost transparency on a product level is key to enabling decision makers along the entire supply chain to support food system transformation.

The true costs of eight different popular Swiss products in the average Swiss consumer basket are approximated in this thesis: apple, carrot, potato, wheat, milk, cheese, chicken and beef (FOAG, 2019a). Again, the external costs of each individual externality (i) are summed up to represent the external cost of each impact area per product. Product level external costs are then added to the average retail price of each respective product.

$$True\ cost\ (product) = \ Current\ retail\ price + \sum_{i\,=\,1}^{n} (Product\ level\ external\ costs)_i$$

Two main data sources were used for the identification of product level externalities (Table 8). Data by Beretta (2018) was used for externalities in the impact areas environment, biodiversity and production-related human health. The data provided is listed in chapter 3.7 in the appendix. This data is specific to the Swiss context wherever possible and thus suitable to model the true cost of Swiss food products. All externalities used from Beretta are LCA midpoint indicators quantified with the life cycle impact assessment method ReCiPe 2008 (Goedkoop et al., 2009). With the exception of GHG emissions, product level data from Beretta (2018) only reflects externalities at agricultural level. GHG emissions, however, also consider food supply chain impacts including transport, storage, processing, preparation, cooking and disposal of by-products. This is an acceptable approximation, since agriculture accounts for the majority of food system externalities in most impact areas, as elaborated in the introduction (Poore & Nemecek, 2018). Furthermore, GHG emissions cover all stages of the food supply chain. For consumption-related human health externalities, data from Schwingshackl et al. (2019) was used. Schwingshackl et al. identify the DALYs caused by non-communicable diseases connected to the under- or overconsumption of selected food groups. Products were allocated to their respective food group in order to represent the consumption-related human health impact of their respective food group. This was possible for the products apple, carrot, milk and beef, which belong to the food groups fruit, vegetables, dairy, and red meat, respectively. Schwingshackl et al. provide no information on the food groups of the other products. All externalities were monetized with the True Price (2020) monetization factors. The monetization factors used for Env5 and Bio13 had to be converted to a different unit to be applicable to the data used. This is explained in the appendix in chapter 3.3.

Table 8: Main data sources and exhaustiveness of data used at product level

ID	Externality	Data source	Monetization factor	Covered
Env1	Greenhouse gas emissions	Beretta (2018)	True Price (2020)	Agricultural impact to final consumption
Env2	Acidification	Beretta (2018)	True Price (2020)	Agricultural impact
Env5	Fossil fuel depletion	Beretta (2018)	True Price (2020), unit conversion	Agricultural impact
Env6	(Other) non-renewable material depletion	Beretta (2018)	True Price (2020)	Agricultural impact
Bio8	Terrestrial ecotoxicity	Beretta (2018)	True Price (2020)	Agricultural impact
Bio9	Freshwater ecotoxicity	Beretta (2018)	True Price (2020)	Agricultural impact
Bio10	Marine ecotoxicity	Beretta (2018)	True Price (2020)	Agricultural impact
Bio11	Freshwater eutrophication	Beretta (2018)	True Price (2020)	Agricultural impact
Bio12	Marine eutrophication	Beretta (2018)	True Price (2020)	Agricultural impact
Bio13	Land occupation	Beretta (2018)	True Price (2020), unit conversion	Agricultural impact
Bio14	Land transformation	Beretta (2018)	True Price (2020)	Agricultural impact
Hum18	Human toxicity	Beretta (2018)	True Price (2020)	Agricultural impact
Hum22	Health impact of non-communicable diseases	Schwingshackl et al. (2019)	True Price (2020)	DALY impact of the respective food group (apple, carrot, milk, beef)

A number of externalities were not possible to quantify on a product level, which will be explained in the results. In order to calculate the true cost of each of the products, the steps in Table 9 were taken for each of the assessed products.

Table 9: Methodology used for product level quantification including reference table

Subchapter	Relevant steps	Details
Environment, biodiversity and production-related human health impact	1. Selection of reference products in Beretta (2018)	Table 10
	2. Impact identification	Table 25 (appendix)
Consumption-related human health impact	3. Allocation of food items to their food group from Schwingshackl et al. (2019)	Table 27 (appendix)
	4. Calculation of food group impact per kg of food	Table 29 (appendix)
Monetization	5. Application of True Price (2020) monetization factors (incl. unit conversion where necessary)	Table 30 (appendix)
= **External cost** of each of the assessed food products		
Definition of average retail price	6. Selection of reference product in FOAG (2019a) average retail price data	Table 31 (appendix)
Addition of external costs	7. Addition of external costs to average retail price	
= **True cost** of each of the assessed food products (CHF/kg)		
Conversion to kcal	8. Selection of reference product in Swiss food composition database (FSVO, 2019), conversion to kcal	Table 34 (appendix)
= **True cost** of each of the assessed food products (CHF/100 kcal)		

Each of the additional steps necessary for the product level quantification is elaborated in detail in the appendix, as referenced in Table 9. The allocation of reference products – including the database they were sourced from – for environment, biodiversity and production-related human health externalities as well as a high-level example are provided below. Apart from carrot, cheese and chicken, the LCA data of all reference products is related to Swiss production practices (C. Beretta, personal communication, August 6, 2020). Data referring to Switzerland is based on the minimal Swiss production standard, the Proof of Ecological Performance (PEP), which is also referred to as integrated production. The majority of Swiss food is produced according to PEP (FOAG, 2019b). Almost all data used from Beretta (2018) is based on the Swiss database Ecoinvent, a leading LCA database worldwide. Data for milk and beef is based on data from the Zurich School of Applied Sciences ZHAW, since no Swiss data was available in Ecoinvent. Data for carrots and poultry is based on the World Food LCA Database and refers to the average global production. Table 10 illustrates all selected reference products.

Table 10: Reference products for environment, biodiversity and production-related externalities (CH: Swiss PEP production, GLO: global production (main producing or exporting countries) (Beretta, 2018)

Product	Product group	Product used	Database	Comment
Apple	Table apples	Apple from Italy	Ecoinvent	Based on Swiss data
Potato	Potatoes	Potato, Swiss integrated production | potato production, Swiss integrated production, intensive	Ecoinvent	
Carrot	Other storable vegetables	Carrot, at farm /GLO	World Food Database 3.0	
Wheat	Wheat and pastries	Wheat grain intensive from CH	Ecoinvent	
Milk	Milk, other dairy	Milk IP, at farm /CH	ZHAW database	
Cheese	Cheese, whey	Cheese, from cow milk, fresh, unripened (GLO) | cheese production, soft, from cow milk (Soft Cheese Mozzarella Style)	Ecoinvent	Based on United States (US) data
Chicken	Poultry	Chicken, fresh meat and offal, at slaughterhouse /US	World Food Database 3.0	Choice between GLO, Brazil and US -> US with smallest impact
Beef	Beef, horse, veal	Beef IP, meat + inwards, intensive cattle fattening, at slaughterhouse/CH	ZHAW database	

The quantification of product level external costs is again illustrated by the example of greenhouse gas emissions, as following below.

2.7.1 EXAMPLE CALCULATION: ENV1

The emission of GHGs is the only externality that Beretta (2018) also provides on a gastronomy level. The retail level impact is based on standardized transport assumptions, which are elaborated in the appendix in chapter 3.1. In order to represent the GHG emission impact of each respective product as accurately as possible, this thesis uses whichever of the agricultural and retail impact values is higher. Retail level impact is higher for all products except mozzarella. This is because the food group cheese also contains whey, which has a lower environmental impact and thus decreases the average food group impact (C. Beretta, personal communication, August 6, 2020).

Retail level externalities of the products are monetized with the True Price monetization factor, 0.16 CHF/kg CO_2-eq. This results in an external CO_2-eq cost for each product, which is added to the products' average 2018 retail price in order to define its true cost (FOAG, 2019a). In a last step, the true cost per kg of product is converted to represent the true cost per 100 kcal of each product. The true cost of the products lies between 2% and 19% higher than current retail prices, only considering greenhouse gas emissions (Table 11).

Table 11: True cost calculation based on greenhouse gas emissions (dark grey font: not used for calculation)

ID	Apple	Potato	Carrot	Wheat	Milk	Cheese	Chicken	Beef
Ag level impact (kg CO_2-eq)	0.091	0.086	0.090	0.452	1.232	7.382	3.537	15.123
Retail level impact (kg CO_2-eq)	0.550	0.650	0.620	1.280	1.680	3.320	7.480	22.120
CHF/kg CO_2-eq	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
External cost	0.09	0.10	0.10	0.21	0.27	1.19	1.21	3.56
Average retail price/kg	3.73	1.77	2.34	1.85	1.46	9.73	13.86	21.37
True cost/kg	**3.82**	**1.87**	**2.44**	**2.06**	**1.73**	**10.92**	**15.06**	**24.93**
Kcal/kg	550	760	380	3'440	680	2'560	1'070	1'340
Retail price/100 kcal	0.68	0.23	0.62	0.05	0.21	0.38	1.30	1.59
External cost/100 kcal	0.02	0.01	0.03	0.01	0.04	0.05	0.11	0.27
True cost/100 kcal	**0.69**	**0.25**	**0.64**	**0.06**	**0.25**	**0.43**	**1.41**	**1.86**
True cost/retail price	**102%**	**106%**	**104%**	**111%**	**119%**	**112%**	**109%**	**117%**

Greenhouse gas emissions are of course only one of multiple externalities assessed in this thesis, and the true cost presented in the results contains the external costs related to all quantifiable externalities. The next chapter presents the true cost of both the Swiss food system as a whole and of eight Swiss food products.

3 RESULTS

The following results are based on the methodology presented in chapter 2. The true cost of food is calculated for both the national Swiss food system in 2018 as well as for eight conventionally produced Swiss products.

3.1 NATIONAL LEVEL TRUE COSTS

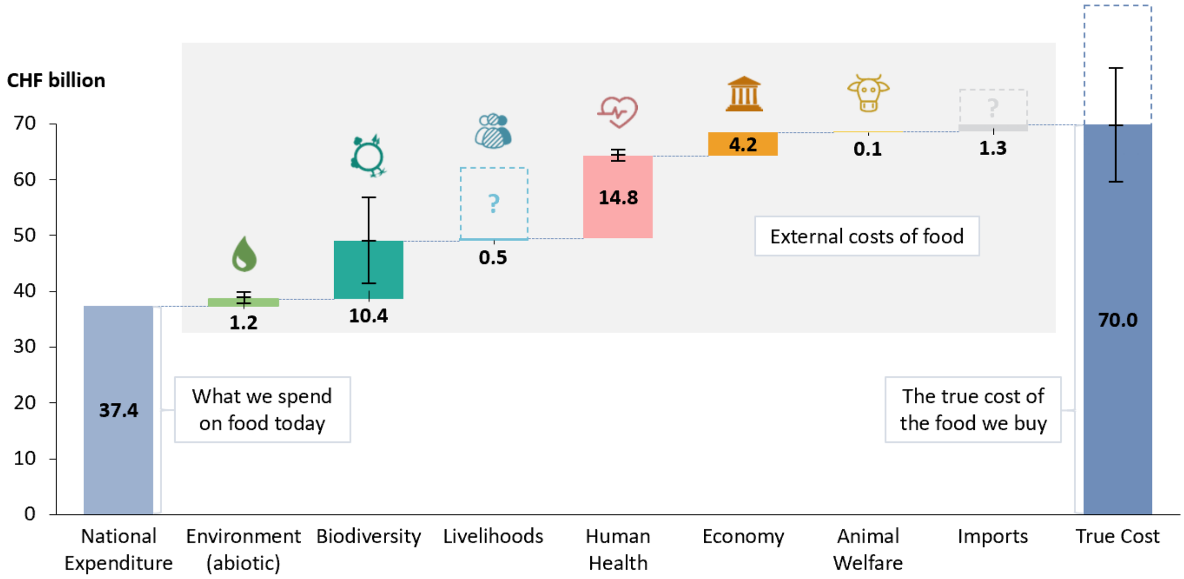

Figure 2: Direct expenditure vs. true cost of the Swiss food system in 2018 (black bars indicate range of estimation, question marks indicate limited data availability)

The total cost of the national Swiss food system, based on all quantifiable external costs, amounts to 70.0 (60.2 - 79.4) billion CHF. This cost is almost double the national expenditure on food and non-alcoholic beverages, 37.4 billion CHF. The true cost per CHF spent on food and non-alcoholic drinks in Switzerland is therefore estimated to lie at 1.87 CHF. External costs of this first estimation are mainly driven by biodiversity and human health costs (Figure 2). However, as previously discussed in chapter 2, only a small part of livelihood costs was quantifiable. External livelihood costs of the food system are expected to be significantly higher. External costs of food imports are also likely to be higher, as detailed in the appendix in chapter 2.8. Environment and animal welfare costs only make up a small part of external costs. The relatively low environment cost is elaborated in the discussion.

Uncertainty lies both within the data that is available in terms of data quality as well as within the data that is not available. The quality of the data used for this thesis is reflected in the column *data quality* of Table 12. The uncertainty due to missing data is reflected in the column *cost covered*. Both of these columns are based on the research undertaken within this thesis.

Table 12: National level cost for all quantifiable externalities (:cost approximation based on own calculation)*

ID	Externality	Cost (million CHF)	Quality of data used	Cost covered
Env1	Greenhouse gas emissions	1'227 (464 - 1'608)	High	Medium
Env4	Soil organic carbon loss	3.8	High	High
Bio8-14	Biodiversity and ecosystem service loss due to agriculture	10'374 (2'441 - 18'307)	Medium	High
Liv16	Workers performing free labor	485	Medium*	Medium
Hum18	Human toxicity (air pollution)	1'096	High	Medium
Hum20	Health impact of overweight and obesity	1'797	High	High
Hum21	Health impact of hypertension	328	High	Medium
Hum22-1	Health impact of cardiovascular disease	6'716 (6'393 - 7'039)	High	High
Hum22-2	Health impact of diabetes	802 (636 - 968)	High	High
Hum22-3	Health impact of cancer	3'737 (3'330 - 4'144)	High	High
Hum23	Health impact of food poisoning	37 (29 - 45)	High	High
Hum24	Health impact of pesticide exposure	50 (25 - 75)	High	High
Hum25	Health impact of antibiotic use	207	High	Medium
Eco26	Taxes for food system-targeted subsidies	3'988	High	High
Eco27	Taxes for regulation and research	257	High	High
Ani28	Animal years suffered	110	High	Medium
Import	External cost of food imports	1'329	Low*	Low
Total	**External cost of Swiss food system**	**32'543 (22'752 - 41'945)**		

External costs were estimated as a range wherever possible, resulting in a true cost range of 1.61 - 2.12 CHF per CHF spent. The range itself is expected reflect a minimum true cost range, as many of the individual external cost estimations are conservative, incomplete or both. Furthermore, a number of the 28 externalities prioritized in chapter 2 were not possible to quantify due to a lack of data or the data available for Switzerland was not transparent. Table 13 below informs for which externalities this was the case and why they were not included.

Table 13: Externalities not quantified on a Swiss food system level

ID	Externality	Data availability	Reason/Comment
Env2	Acidification	No data	-
Env3	Soil loss from water erosion	Ledermann (2012): 53 million CHF	Estimation part of a PhD, relevant part of cost of soil erosion not published, unclear calculation methodology
Env5	Fossil fuel depletion	No data	-
Env6	(Other) non-renewable material depletion	No data	-
Env7	Scarce water use	No data	Water scarcity is currently not an issue in the Swiss context

ID	Externality	Data availability	Reason/Comment
Liv15	Workers with insufficient social security	Insufficient data	Elaborated in appendix chapter 2.4
Liv17	Exposure to pesticides (production)	No data	Negligible in the Swiss context
Hum19	Health impact of malnutrition	Ballmer (2014): 22.8 million CHF	Unclear source and calculation methodology

The Swiss food system generates significant costs for Swiss society. It is therefore essential to understand which products cause these external costs.

3.2 PRODUCT LEVEL TRUE COSTS

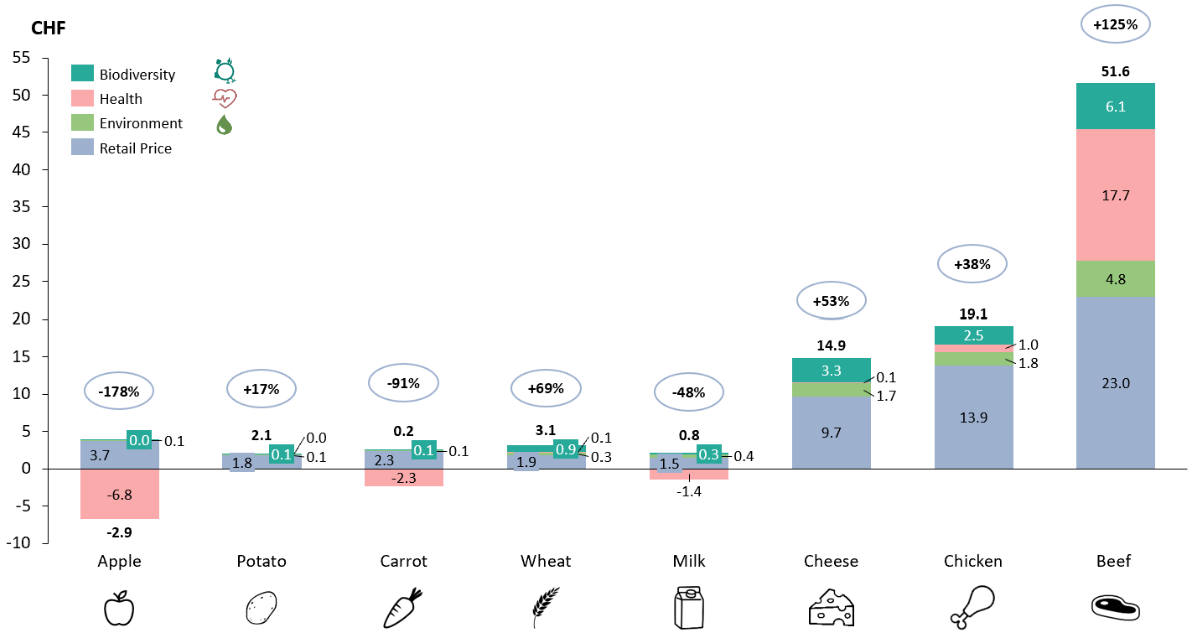

Figure 3: True cost per kg of selected food products (difference to retail price in bubbles)

Product level costs were estimated for eight conventionally produced Swiss products: apple, potato, carrot, wheat, milk, cheese, chicken and beef. Detailed costs for each externality per kg of food are listed in Table 30 in the appendix. The external costs calculated are added to the average 2018 retail price of each respective product, as defined in Table 31 in the appendix. Livelihood, economy and animal welfare costs could not be quantified on a product level. Animal welfare costs are naturally only connected to animal-based products. As visualized in Figure 3, animal-based products generate the highest external costs, with beef causing the highest costs. In order to better account for the nutritional value of each product, the external cost was also calculated per 100 kcal of product (Figure 4).

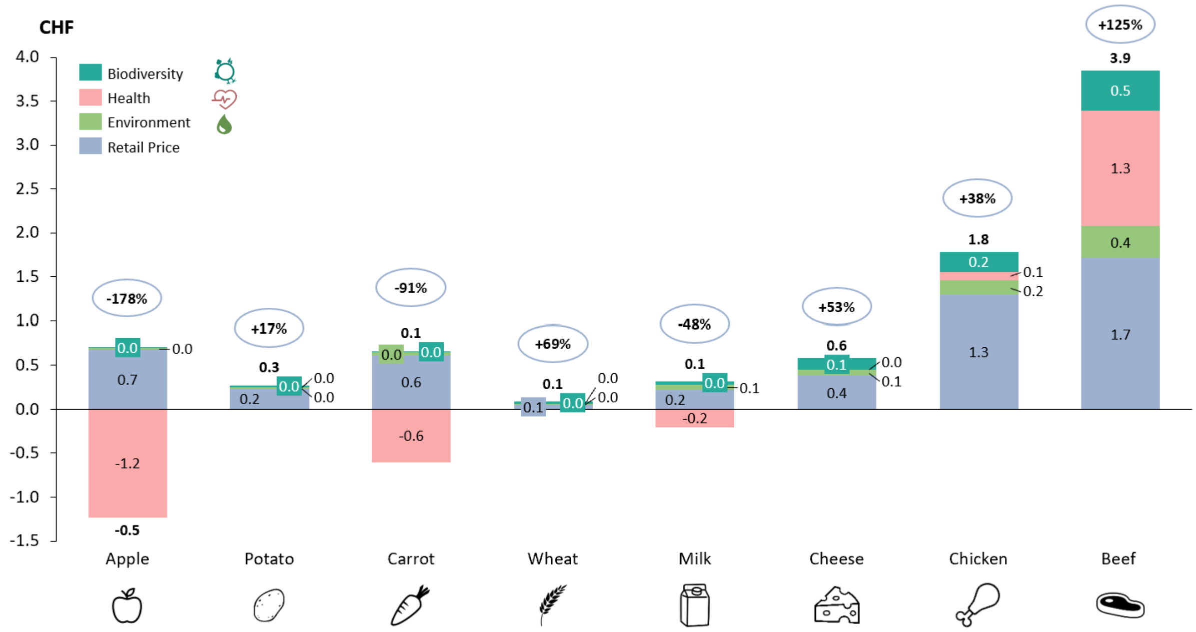

Figure 4: True cost per 100 kcal of selected food products (difference to retail price in bubbles)

Although animal-based products perform slightly better in terms of costs per 100 kcal of product compared to costs per kg of product, they still generate the highest amount of external costs. External costs are particularly driven by Env1 (GHG emissions), Bio12 (marine eutrophication) and Hum18 (human toxicity) (Table 14). In terms of Hum22 (consumption-related health costs due to non-communicable diseases), external costs of beef consumption are also high. Consumption-related human health costs were only quantifiable for apple, carrot, milk and beef, as explained in chapter 2. Where the average intake lies below recommended intake, a 100 kcal product consumption is associated with a health benefit. This is reflected by the negative Hum22 costs for apple, carrot and milk.

Table 14: Cost (in CHF) per 100 kcal of product (weight per 100 kcal in brackets, light green: <0, light red: > 0.03:, red > 0.05)

ID	Apple (182 g)	Potato (132 g)	Carrot (263 g)	Wheat (29 g)	Milk (147 g)	Cheese (39 g)	Chicken (93 g)	Beef (75 g)
Env1	0.02	0.01	0.00	0.01	0.04	0.05	0.11	0.27
Env2	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.05
Env5	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.04
Bio8	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02
Bio9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bio10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bio11	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.03
Bio12	0.00	0.02	0.00	0.02	0.03	0.09	0.13	0.32
Bio13	0.00	0.00	0.01	0.00	0.01	0.01	0.04	0.08
Bio14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hum18	0.01	0.00	0.00	0.00	0.05	0.07	0.10	0.27
Hum22	-1.24	n/a	-0.62	n/a	-0.25	n/a	n/a	1.05
Total	**-1.21**	**0.04**	**-0.56**	**0.04**	**-0.11**	**0.27**	**0.49**	**2.14**

The quality of the data used for environment and biodiversity, and production-related human health externalities, being based on a recent and comprehensive Swiss study, is high. For consumption-related human health externalities, a European study served as an approximation for the Swiss context. Ideally, Hum22 would also be based on a study specific to the Swiss context. Again, a number of externalities were not quantifiable on a product level (Table 15).

Table 15: Externalities not quantified on a product level

ID	Externality	Data availability	Comment
Env3	Soil loss from water erosion	No data	-
Env4	Soil organic carbon loss	No data	-
Env6	(Other) non-renewable material depletion	Available in MJ	Conversion MJ to kg Cu-eq unclear
Env7	Scarce water use	Available	Water scarcity is currently not an issue in the Swiss context
Liv15	Workers with insufficient social security	No data	-
Liv16	Workers performing free labor	No data	-
Liv17	Exposure to pesticides (production)	No data	Negligible in the Swiss context
Hum19	Health impact of malnutrition	No data	-
Hum20	Health impact of overweight and obesity	No data	Foods high in sugar, fat
Hum21	Health impact of hypertension	No data	Foods high in salt, fat
Hum23	Health impact of food poisoning	No data	-
Hum24	Health impact of pesticide exposure	No data	-
Hum25	Health impact of antibiotic use	No data	Animal-based products only
Eco26	Taxes for food system-targeted subsidies	No data	-
Eco27	Taxes for regulation and research	No data	-
Ani28	Animal years suffered	No data	Animal-based products only

Despite a lack of data and large uncertainties, the results presented in this chapter allow the derivation of high-level conclusions. Concrete implications are discussed in the following chapter.

4 DISCUSSION

The following chapter first discusses the methodology defined for the true cost calculation within this thesis. It then examines the results derived from the methodology's application to the national Swiss food system and eight selected Swiss products. In a last step, it elaborates on the implications of the results for the Swiss food system, highlighting the need for a true cost standard for facilitating and accelerating the transformation towards a sustainable Swiss food system.

4.1 METHODOLOGY

The methodology defined within this master's thesis offers a first publicly available and holistic overview of measurable food system externalities on the environment, biodiversity, livelihoods, human health, animal welfare and the economy for Switzerland. It provides the basis for a discussion about what an improved methodology requires, and whether or not better indicators are needed to measure food system externalities. As stated in chapter 2, the defined methodology does not include positive externalities, is very likely not exhaustive in terms of externalities considered and uses global monetization factors instead of local monetization factors. Despite also being an important part of a full true cost picture, the assessment of positive externalities is beyond the scope of this thesis. As positive externalities do not necessarily offset negative externalities and because reducing negative externalities in food systems is crucial for sustainable development, the focus on negative externalities is deemed a valid first step (Fitzpatrick et al., 2019). In terms of externalities collected, further expert input is needed to include all relevant food system externalities in the methodology, including a clear definition of how – and to what extent – to account for indirect food system externalities. Last but not least, as external costs depend on the environment they occur in, true costs should be defined using location-specific monetization factors. This thesis' use of global monetization factors (based on True Price, 2020) allows only an approximation of the true cost picture in Switzerland. Monetizing food system externalities also comes with drawbacks, with critics highlighting the complexity and danger of subjectivity related to monetizing food system externalities (Rundgren, 2017). This should be considered in the definition and use of monetization factors.

When applying the methodology to the national Swiss food system and the selected food products, the biggest challenges were found to be the identification of appropriate data sources on a national level, and the limited access to data sources on a product level. Particularly striking was the lack of publicly available data on livelihood externalities. This was the case for both national level costs as well as product level costs. Furthermore, the lack of a common platform for issues at the food system level between the FSO, FOAG, FOEN, FOPH and FSVO resulted in the use of multiple data sources. This leads to limited direct comparability between national and product level results. Ideally, a system level LCA would be used in order to directly compare system and product level true cost. In a next step, the methodology should be applied to more products and different production systems, allowing the derivation of more concrete recommendations. A focus should be laid on legumes and nuts, as these are both high in protein and healthy, and are thus expected to gain importance in the global diet (Willett et al., 2019).

4.2 NATIONAL LEVEL RESULTS

National level results are likely to represent an underestimation of national level true costs. This is reinforced by the fact that the results lie in a similar magnitude to the external cost estimations mentioned in the introduction. Fitzpatrick et al. (2019), FAO (2014) and EMF (2019) estimate system level external costs to 1.0, 1.6 and 2.0 USD per USD spent, respectively, emphasizing the values as underestimations. In this thesis, almost no data was included on food supply chain steps following agriculture due to a lack of data. In addition, many of the externalities collected could not be quantified, especially in terms of livelihood externalities. The results are only based on the 28 externalities prioritized for quantification within this thesis, and even some of these were not or only partially quantifiable. However, in terms of environment, biodiversity and human health costs, the results are expected to roughly represent the possible dimension of true costs.

Quantifiable national level external costs of the Swiss food system are mainly driven by human health, biodiversity and economy costs. It is expected that livelihood costs would also drive external food system costs, if possible to quantify. Since system level costs are mostly not derived from monetizing system level externalities, direct comparisons between the different impact areas should always be made with caution. Nevertheless, the results indicate that Swiss food system transformation should especially focus on reducing external costs in terms of human health and biodiversity. Economy costs in the form of agricultural direct payments and market support should be redirected to accelerate the transformation towards a sustainable food system, instead of supporting current high external cost production systems. Agricultural subsidies in particular should increasingly support production according to agroecological practices, and governmental support should be reassessed to avoid conflicting financial incentives. Despite the international focus on climate change, the external cost related to the emission of GHGs is relatively small compared to the other costs. Even when using the highest monetization factor, 211 CHF/ton of kg CO_2-eq, the external costs of GHG emissions are surpassed by the lowest biodiversity impact costs. This does not suggest that climate change should be ignored – surpassing the 1.5 degree target should by all means be avoided, and the cost of GHG emissions is expected to increase non-linearly every year –, but that the current focus on climate change should be expanded to also include the other important food system impact areas. It also highlights the need for an improved methodology to reflect the cumulative external costs of not transforming the food system.

In a Federal Office for Spatial Development (ARE) evaluation of costs and benefits of the Swiss mobility sector in 2017, external costs of mobility were estimated to 13.4 billion CHF, largely driven by private motorized transport. External benefits were estimated to 1.4 billion CHF (ARE, 2020). In the same year, Swiss households spent roughly 30.5 billion CHF on transport (FSO, 2019a). This results in an external cost of 0.44 CHF per franc spent on transport. Whilst the direct comparability of these numbers needs to be further assessed, the numbers indicate that the food and agriculture sector causes higher external costs than mobility.

4.3 PRODUCT LEVEL RESULTS

Product level results are based on environment, biodiversity and production-related human health externalities at the agricultural level, with the exception of GHG emissions. As explained in chapter 2, GHG emissions were also provided at retail level. No quantifications were possible in the livelihood, economy and animal welfare impact area. The results for environment, biodiversity and production-related health costs rely on just one data set. However, the data used is both up to date as well as specific to the Swiss context (Beretta, 2018). In terms of consumption-related health costs, the results are also based on one data set only, focusing only on non-communicable diseases (Schwingshackl et al., 2019). This approximation is considered acceptable, as non-communicable diseases account for 80% of current public health costs (FOPH, 2016). Consumption-related health costs represent the average health cost or benefit connected to the under- or overconsumption of each respective food group. Every individual's actual cost or benefit therefore strongly depends on the individual's current consumption level.

The results indicate that external costs of the Swiss food system are to a large extent driven by the high consumption of red meat. External costs of beef are highest both in absolute and relative terms, despite not accounting for animal welfare and economy costs of beef. The results in this thesis only represent intensively farmed beef. Further research is needed on different types of production systems. However, even meat that is produced most sustainably causes significantly higher harm to the environment and biodiversity than most plant-based products (Poore & Nemecek, 2018). The results do also not account for the animal part consumed. Whilst every kg of beef or chicken is connected to the same amount of externalities, more animals are needed if consumers buy only the prime meat cuts. A beef filet could appear to have lower relative external costs due do its higher retail price, despite leading to the consumption of more animals. This should be addressed when further developing the methodology. Whilst the overall meat intake exceeds the recommended amount by roughly factor 3 in Switzerland, the intake of red meat exceeds the recommended amount by the planetary health diet by factor 7.5 (Hirstein & Forster, 2020). The argument to reduce meat consumption is therefore strong. Reducing national consumption of beef represents a win-win-win situation in terms of reducing environment, biodiversity and human health costs.

By indicating the magnitude of actual costs caused by the current food system, national and product level results allow the derivation of recommendations for Swiss food system transformation, including an indication of how much governments should invest in such a transformation.

4.4 IMPLICATIONS

As mentioned in the introduction, the Eat-Lancet Commission highlights the need to significantly improve food production practices, halve food loss and waste and achieve the dietary shift towards the planetary health diet in order to transform the food system (Willett et al., 2019). All strategies effectively aim at reducing external costs of the current food system. In line with the commission, this thesis recommends stakeholders of the Swiss food system to focus on the four points listed in Table 16. The first and second focus point, being the establishment of a standard for evaluating the true cost of food and increased consumer awareness, are viewed as the crucial basis for an effective food system transformation. A common language for measuring impacts, their costs and setting reduction goals, supported by the public, is key for reducing external costs of the food system. Whilst the first three focus points should be actionable without significant political intervention, the fourth, perhaps most significant focus point, highly depends on the will of the Swiss political system to enable food system transformation.

Table 16: Recommendations for Swiss food system transformation

Main focus points	**Implementation**
1. Define a standard for measuring the true cost of food	• Co-create standard with relevant stakeholders • Set concrete reduction targets for national level and product level true costs
2. Increase consumer awareness on food system impacts	• Communicate the true cost of food through true cost label and campaigns • Expand compulsory food education in kindergarten, primary, secondary and high school, as well as in medical education due to high health impact
3. Reduce external costs without shifting current production and consumption patterns	• Reduce food waste along entire supply chain • Leverage technology and innovation to improve current production systems (e.g. optimized feed for reduction of methane emissions in livestock)
4. Reduce external costs by shifting current production and consumption patterns	
a) Promote production and consumption of products with low external costs	• Increase governmental support to agroecological production systems • Incentivize low external cost production systems (e.g. roughage-based cattle production) • Adapt public food procurement guidelines to adhere to planetary health diet (canteens, schools, prisons etc.)
b) Discourage production and consumption of products with high external costs	• (Gradually) cease governmental support for products with high external costs (e.g. sales support for animal-based products, direct payments for intensive livestock production) • Tax high external cost products (e.g. intensively farmed livestock, in particular cattle) • Reevaluate medial and in-store promotion of products with high external costs (sugary, ultra-processed and animal-based products)

A key step towards a thorough food system transformation is the establishment of an improved methodology and the definition of a (inter-)national standard on true cost accounting, including positive food system externalities. Such a standard is especially important for tracking progress and supporting decisions between individual production systems and products. Further educating consumers is also key to food system transformation. In 2014, Swiss consumers perceived the avoidance of excessive food packaging to have significantly higher environmental benefits than avoiding food imported by air, with the consumption of less meat having the lowest perceived environmental benefit (Siegrist, Visschers, & Hartmann, 2015). This presents a severe mismatch to scientific consensus and highlights the need for an increased focus on consumer awareness.

In terms of reducing external costs without shifting current production and consumption patterns, two things appear especially important. First, the reduction of food waste. Even without changing any other components of the food system, reducing food waste would have a substantial impact. 2.5 million tons of food are currently lost or wasted along the Swiss food supply chain every year. The economic value of this food loss and waste is estimated to lie around 8.8 billion CHF (FOEN, 2019). The external costs of this lost or wasted food represent costs that are truly unnecessary and to a large part avoidable. This thesis estimated external costs of food loss and waste to lie at 3.3 billion CHF every year, 10% of external Swiss food system costs (appendix chapter 2.9). This value lies in stark contrast to the amount spent on increasing consumer awareness about food waste, 0.33 million CHF per year (A. Hauser, personal communication, September 8, 2020). It is evident that reducing food waste presents a huge opportunity for Switzerland. In terms of reducing external costs of the current food system, technology and innovation should also be leveraged. The addition of seaweed supplements to feed for instance promises a reduction of cattle-related methane emissions by up to 80% (Ellis, 2020).

Despite opportunities in reducing external costs of the current system, reducing external costs by shifting current production and consumption patterns is imperative. Achieving a dietary shift away from animal-focused diets is particularly important. A healthier and environmentally friendlier diet with a stronger focus on plant-based foods is further projected to increase Swiss self-sufficiency and food security through a reduced need for imports (von Ow, Waldvogel, & Nemecek, 2020). This thesis estimates animal-based products to account for at least 9.7 billion CHF of external costs, 30% of external Swiss food system costs (appendix chapter 2.9). It is important to highlight that meat consumption is not required to be reduced to zero. As a grassland country, cattle production in Switzerland is rational – the magnitude of current meat consumption however does not appear sensible. Cattle production volumes should be adapted to best utilize the available resources, supported by direct payments for roughage-based meat production only. Reduced Swiss production volumes should in no case be compensated by an increased import of meat products, but should be supplemented by a shift towards more plant-based and alternative protein. The consultancy Kearney predicts that by 2040, more than half of globally consumed meat products will be sourced from cultured meat and meat replacements instead of animals (Kearny, 2019). In Switzerland, the start-up Planted is contributing to a growing alternative protein market. Its product planted.chicken, a chicken imitation, emits roughly a fifth of GHG emissions of animal-based chicken (C. Perotti, personal communication, August 19, 2020).

There is an urgent need to adjust governmental support to increase the attractiveness of the production of food with lower external costs. In addition to reforming governmental support of the food system, the taxation of products with high external costs should also be considered. Such taxes could be used to fund research in food system transformation, support the healthcare system, or be partially redistributed to the population. A similar tax is currently proposed for all flights leaving Switzerland and is expected to financially benefit 60% of the population (Sotomo, 2020).

4.4.1 SEIZING THE MOMENT

In June 2020, the WEF launched *The Great Reset*, an initiative aiming to redefine the social and economic foundations of human life on Earth. Four building blocks are singled out as crucial to such a reset. First, the need to change the human mindset, creating room for the transformation away from inequality and centered around human kindness. Second, the need for improved metrics. Moving away from economic growth-focused metrics such as GDP towards metrics that include social equity, planetary and human health – current externalities of human activity – are promoted as key to *The Great Reset*. Third, the need to incentivize change towards sustainable development by making businesses accountable for the new metrics defined. Last but not least, the need to collaborate and build connections (Sutcliffe, 2020).

The same building blocks should be used to guide food system transformation. With its far-reaching implications for sustainable development, the food system is the ideal candidate to focus on for *The Great Reset*. Understanding all relevant positive and negative externalities of food-related human activity and how they can be supported or reduced, whilst simultaneously optimizing human health and contributing to a more just society is a unique chance for humanity. It should be used as an opportunity to genuinely reconsider what should be valued, how it should be valued and who should be held accountable for it. Switzerland could lead transition by introducing a standard for measuring food system impacts and translating its insights into concrete policies. With a functioning governmental support system already in place and gradually increasing consumer awareness on food system impacts, Switzerland is ideally equipped to initiate food system transformation.

5 CONCLUSION

"Until you dig a hole, you plant a tree, you water it and make it survive, you haven't done a thing. You are just talking."

– Wangari Maathai, 2004 Nobel Peace Prize laureate (The Conservation Volunteers, 2020)

Global food systems should be designed to make sustainable production and consumption choices the default choice. They should not lead to the creation of unnecessary external costs, for which no one is held accountable. From what farmers decide to produce, to what retailers choose to promote, to what is offered to consumers in food environments, the whole food system should be aligned to minimize its negative consequences. The science is clear; the current food system requires transformation. In order to move from simply talking to truly transforming the system, all stakeholders of the food system are required to act. In the Swiss context, the government should launch an initiative to create a standard for measuring food system impacts and start implementing its insights. Not only would this hugely contribute to achieving the SDGs, which Switzerland has also committed to, but it would also liberate future generations from suffering significant costs. As a first concrete and actionable step, the standard could be presented at the 2021 UN Food Systems Summit, making a tangible contribution to global food system transformation.

COVID-19 has reinforced the importance of a sustainable and resilient food system. It has also revealed how quickly and determined governments can take action against threats to society. The current food system causes significantly more deaths than the pandemic is expected to cause; food system transformation must therefore be treated just as urgently. Transformation will take place sooner or later; either through even larger external pressures in the context of an (inter-)national food, environment and health crisis or through initiating better stewardship of the system today. It is up to us to decide which role we want to take in this transformation.

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APPENDIX

SUPPLEMENTARY INFORMATION

1 METHODOLOGY

1.1 IMPACT AREA DEFINITION

Table 17: Types of capital generally considered in TCA approaches (TEEB AgriFood, 2018, p. 48)

Capital	Description
Natural capital	"Refers to "the limited stocks of physical and biological resources found on earth, and of the limited capacity of ecosystems to provide ecosystem services." (TEEB 2010, p.33) For measurement purposes, following the SEEA, it incorporates the "naturally occurring living and non-living components of the Earth, that in combination constitute the biophysical environment" (UN et al. 2014, p.134). It thus includes all mineral and energy resources, timber, fish and other biological resources, land and soil resources and all ecosystem types (forests, wetlands, agricultural areas, coastal and marine)."
Human capital	"Represents "the knowledge, skills, competencies and attributes embodied in individuals that facilitate the creation of personal, social and economic well-being" (Healy and Côte 2001, p.18). Human capital will increase through growth in the number of people, improvements in their health, and improvements in their skills, experience and education. Income-based measurements of human capital usually need to be supplemented with quality indicators such as 'decent' working conditions (ILO 2008)."
Social capital	"Networks, including institutions, together with shared norms, values and understandings that facilitate cooperation within or among groups" (OECD 2007, p.103). Social capital may be reflected in both formal and informal arrangements and can be considered as the "glue" that binds individuals in communities. More broadly, it can be seen as the form of capital that 'enables' the production and allocation of other forms of capital (UNU-IHDP and UNEP 2014)."
Produced capital	"Refers to all man-made assets, such as buildings, factories, machinery, physical infrastructure (roads, water systems) as well as all financial assets. Human knowledge – sometimes called "intellectual capital" - is usually found embedded within produced capital (technology, software, patents, brands, etc.)."

1.2 MONETIZATION

Table 18: Cost types considered in monetization factors (True Price, 2020, pp. 12, 13)

Cost	Definition
Restoration costs	"Restoration costs are the cost of bringing people's health, wealth, circumstances, capabilities, or environmental stocks and environmental qualities to the state they would have been in the absence of the social and environmental damage associated with an impact (e.g. cost of ecosystem restoration). Restoration cost is applied for impacts where restoration is feasible, or feasible and more economically efficient than compensation when the damage to people or communities is not severe."

Compensation costs	"Compensation costs are the cost of compensating affected people for economic and/or non-economic damage caused by the social and environmental impacts of producing or consuming a product. In the valuation literature, this is also called " damage cost" (e.g. compensating for denied income, or the value of lost human health). Non-economic damage can be assessed using the best available stated and revealed preference valuation techniques. Compensation costs are part of the remediation costs for impacts where restoration is not considered feasible."
Prevention of re-occurrence costs	"Prevention of re-occurrence cost represents the cost that would be incurred in the future to avoid, avert or prevent the identified social and environmental impacts of a product from occurring again (e.g. the cost of introducing human rights audits in a supply chain). Prevention cost of re-occurrence is part of the remediation costs in addition to restoration or compensation when the damage is considered more severe and irreversible. Whereas the other types of costs refer to realized damage, this cost relates to the prevention of future damage. It finds its basis in, among others, the UN Guiding Principles mentioned above (OHCR, 2011) that acknowledge a responsibility to prevent reoccurrence of human rights breaches."
Retribution costs	"Retribution costs are the cost associated with fines, sanctions or penalties imposed by governments for certain violations of legal or widely accepted obligations. They represent the damage to society caused by the breaking law. For impacts that correspond to the breach of a legal or a widely accepted obligation, retribution costs are part of remediation costs, over and above restoration, compensation and/or prevention of re-occurrence costs."

2 NATIONAL LEVEL QUANTIFICATION

The following chapter explains the methodology used to estimate national food expenditure and the external costs of the Swiss food system in the six defined food system impact areas: environment (abiotic), biodiversity, livelihoods, human health, economy and animal welfare. All foreign currencies used were converted to Swiss francs (CHF) with the average currency conversion rate in each respective sources' publication year. As inflation rates for Swiss francs are negligible and the data used was in rarely older than five years, Swiss francs are not adjusted for inflation.

2.1 FOOD EXPENDITURE

National food expenditure is based on FSO (2019a) data, which informs on the sum of consumption-related expenditure of both private and collective (e.g. schools, hospitals, prisons) households in Switzerland. The data offers a detailed breakdown of expenditure for 2017, but not for 2018. It is thus assumed that the share of food expenditure relative to overall expenditure remains the same. In 2018, private and collective Swiss households spent 32.4 billion CHF on food and non-alcoholic drinks in retail and wholesale. In addition, private households spent another 24.5 billion CHF in restaurants and hotels, including cafes, bars, self-service, take-aways, and canteens. The second number cannot be added directly to direct food expenditure of private and collective households, as it includes the price consumers pay for hotel stays and the margin gastronomy businesses take on food. In order to arrive to the same supply chain stage as for direct food expenditure – the retail and wholesale stage –, the price gastronomy businesses pay for food needs to be estimated. First, a detailed breakdown of household expenditure in 2017 by the FSO (2019b) was used to derive how much of national hotel and restaurant expenditure was spent on food and non-alcoholic drinks (69%). It is then assumed that the price gastronomy business pay for food and non-alcoholic drinks equals 30% of the price they charge consumers (Fitzpatrick et al., 2019). This results in 20.6% (30% of 69%) of private household expenditure on hotels and restaurants, 5.0 billion CHF, approximated as the direct spending. Overall, at the retail and wholesale level, consumers therefore spent an estimated 37.4 billion CHF on food and non-alcoholic beverages in Switzerland in 2018.

2.2 ENVIRONMENT

Impacts on the environment are generated along the entire supply chain. The main focus within this thesis is on externalities generated by agriculture, as most publicly available numbers focus on agriculture. This leads to an underestimation of environment impacts overall. However, Poore and Nemecek (2018) estimate that the main environmental externalities of food production systems stem from the production stage: the researchers attribute 61% of global greenhouse gas emissions (excluding deforestation), 79% of terrestrial acidification and 95% of freshwater and marine eutrophication generated by the global food system to the farm stage of the supply chain. The majority of externalities should therefore be covered when looking at agriculture.

ENV1: GHG EMISSIONS (CO2, CH4, N20)

The cost of greenhouse gas emissions in Switzerland is explained in chapter 2.

ENV4: SOIL DEGRADATION (INCL. SOIL CARBON LOSS)

Suboptimal farming practices can lead to the loss of soil organic carbon (SOC) in mineral topsoil, causing a chemical, physical, biological and ecological decline of soil. A 2019 study examining the effect of different agricultural practices on long-term mineral topsoil loss in cropland and permanent grassland in Switzerland found that on average, carbon losses of 0.4 tons C/ha/y were incurred with common Swiss agricultural practices (Keel et al., 2019). This value is applied to the agricultural area utilized as cropland and permanent grassland in Switzerland in 2018, 299'657 ha (FOAG, 2019c). The resulting loss of SOC is monetized with the True Price (2020) monetization factor of 0.03 CHF/kg SOC lost. This results in yearly cost of soil organic carbon loss of 3.8 million CHF.

2.3 BIODIVERSITY

It is currently not possible to differentiate between the individual biodiversity and ecosystem service externalities on a system level. However, studies on the total external costs exist.

BIO8-14: BIODIVERSITY

In 2008, a landmark report estimated the social and economic cost of biodiversity and ecosystem service loss to between 1 and 7.5% of global GPD every year. The estimation was considered an underestimation, as not all ecosystem services could be included in the study, the rates of land-use change and biodiversity loss used for the calculation were conservative, and it did not account for non-linearities and threshold effects (Braat et al., 2008). For this thesis, the average annual cost of biodiversity and ecosystem service loss is estimated at 4.3% of Swiss GDP, the average of the range defined by Braat et al.. This value is in line with the communication of the FOEN, which estimates the annual costs resulting from biodiversity and ecosystem services losses to roughly 4% of GDP (FOEN, 2017). This thesis then assumes that 35.4% (own calculation based on Wilting et al. (2017), elaborated in Table 19) of biodiversity and ecosystem service loss costs are attributable to the food system, which results in a cost of 10.3 billion CHF per year.

Wilting et al. (2017) assessed how the consumption of different goods contributes to biodiversity losses in 45 different countries. Switzerland was not included in the assessment. Differentiating between the consumption categories housing, transport, food, goods, services and others, the study identified food consumption as the main driver of biodiversity losses, contributing to a global average of 40% of losses. This thesis uses an average value of 35.4%, which was derived by excluding non-European countries from the countries evaluated in the study based on information in the supplementary materials. It is assumed that this European value is applicable to Switzerland. Countries excluded are Australia, Brazil, Canada, China, Indonesia, India, Japan, South Korea, Mexico, Taiwan, United States, Rest of Oceania, Rest Asia and Rest of America. According to the author, the values defined by the study are likely to underestimate the role of food consumption, as it only assesses impacts on terrestrial biodiversity.

Table 19: Share of biodiversity loss due to food consumption in European countries

Country	% caused by food system	Country	% caused by food system
Austria	26%	*Italy*	33%
Belgium	36%	*Lithuania*	42%
Bulgaria	42%	*Luxembourg*	27%
Cyprus	45%	*Latvia*	41%
Czech Republic	31%	*Malta*	41%
Germany	31%	*Netherlands*	35%
Denmark	35%	*Poland*	40%
Spain	37%	*Portugal*	38%
Estonia	31%	*Romania*	48%
Finland	18%	*Russia*	42%
France	35%	*Slovak Republic*	35%
United Kingdom	31%	*Slovenia*	27%
Greece	42%	*Sweden*	21%
Hungary	36%	*Turkey*	48%
Ireland	28%	*ROE (rest of Europe)*	40%
(table is continued on the right)		**Average**	**35.4%**

2.4 LIVELIHOODS

Data availability and accessibility was found to be extremely limited for livelihood costs. The two livelihood externalities quantified in this thesis are thus both based on own calculations with publicly available data.

LIV15: INSUFFICIENT SOCIAL SECURITY

According to the Federal Office for Agriculture (FOAG) (2012), 12% of female farmers in Switzerland lack independent social security. With roughly 58'000 female farmers in Switzerland, an estimated 7'000 women in Swiss agriculture are thus underinsured (SBLV, 2020). Through the work of their husbands, these female farmers are only covered in the first pillar of the Swiss pension system. The women do not contribute to the second pillar of the Swiss pension system, are not covered in case of unemployment – which is especially relevant in case of divorce, which is more common amongst farmers than amongst the rest of the population – and do not receive any paid maternity leave (Ryser, 2020). In 2013, only 37% of female farmers had their own second pillar (Contzen & Klossner, 2015). Whilst this in an important livelihood externality of the Swiss food system, data availability on the topic does not allow a data-based estimation of the magnitude of costs generated.

LIV16: FREE LABOR

Farmers worldwide rely on free farm-related labor provided by their family members. This is also the case in Switzerland. Whilst free labor is most commonly provided by women – over 90% of Swiss farms are owned by men –, other family members such as siblings, parents, sons and daughters also provide free labor. In a 2013 assessment of 50'368 farms with family members above the age of 15 living on the farm, 57.1% of the 74'018 family members working on the farm were not compensated. Almost half of the family members providing free labor were women. Dividing the number of non-compensated family workers (57.1% of 74'018, 42'281) by the numbers of farms in the assessment (50'368), an average of 0.84 family members provide free labor per farm (Contzen & Klossner, 2015). Applying this to the total number of farms in Switzerland in 2018, 50'852, a total of 42'687 family members provided free labor in 2018 (FOAG, 2019d).

The average number of hours of free labor provided is estimated based on a 2016 Federal Council report on women in agriculture, which examined the weekly time investment of women on farms for different activities in 2011. The report estimates this investment to 20.4 hours per week (Table 20). It is further assumed that the average free labor provided by all other family members is half as high as the free labor provided by women, resulting in an average of 15.3 hours of free labor for farm-related activities. Using the minimum agricultural salary for temporary workers without experience, 14.25 CHF/hour, this results in a social cost of 485 million CHF (Agrimpuls, 2017). Unpaid household and care work is not included in this estimation.

Table 20: Weekly time consumption of farm-related activities for women

Activity	**Hours/week**
Operations	15.3
Agriculture-related activities	1.9
Administration	3.2
Total	20.4

2.5 HUMAN HEALTH

Human health costs can be caused by the both the production of food and the consumption of food. According to Wieser et al. (2014), they are generally assessed through three different cost types:

1. Direct costs: Medicinal treatment costs (inpatient and outpatient)
2. Indirect costs: Productivity losses (work absenteeism, morbidity, premature mortality)
3. Intangible costs: Immaterial costs (physical or mental suffering)

For each of the following externalities, the type of cost included is mentioned in both Table 7 in the methodology as well as in the explanation of the calculation.

HUM18: AIR POLLUTION

A study commissioned by the Canton of Zurich estimated its 2015 cost of air pollution to 1010 million CHF. 200 million CHF of these costs were caused by agriculture. The study assesses human health costs related to the emission of PM_{10} (particulate matter ≤ 10 micrometers diameter), as well as costs related to building, forest, biodiversity and yield loss caused by the emission of PM_{10}, NO_x (nitrogen oxides), O_3 (ozone) and NH_3 (ammonia). All of the latter costs are not included in Hum18. Human health costs make up the majority of identified costs, accounting for 950 million CHF of total costs. The study assesses all three cost types commonly used for the estimation of human health costs: direct costs, indirect costs and intangible costs (Econcept, 2018).

Assuming that agriculture is accountable for the same share of human health costs as for overall costs, 20%, this results in an agriculture-related cost of 188 million CHF. To approximate the national costs of air pollution due to agriculture, a cost per citizen in 2015 (1.5 million citizens in the Canton of Zurich) was derived from the cost of air pollution in Zurich. This value was multiplied with the number of Swiss citizens in 2018 (8.5 million) (FSO, 2020d). The national cost of air pollution in 2018 is thus estimated to 1.1 billion CHF.

This estimation only accounts for the cost of air pollution attributable to agriculture; air pollution attributable to the rest of the food supply chain is not included. The estimated value further only includes human health costs due to the emission of PM_{10}, whose effects on human health are well-researched and is therefore often used as the main air pollutant to approximate costs. However, PM_{10} is only one of many air pollutants impacting human health. The study also estimates human health costs connected to the emission of NO_2, which it estimates to be 0.4 billion CHF in a scenario assuming health effects from 20 $\mu g/m^3$ and roughly 2 billion CHF in scenario assuming health effects from 5 $\mu g/m^3$. Again, roughly 20% of these costs would be attributed to agriculture. These values are not included due to an overlap with PM_{10}-related costs, which is estimated at roughly a third of NO_2 costs, and lower epidemiological consensus on the health effects of NO_2. Nevertheless, it is expected that NO_2 will gain importance in the definition of human health costs (Econcept, 2018).

HUM20: OVERWEIGHT AND OBESITY

In a report prepared for the Federal Office of Public Health (FOPH), the national cost of obesity was estimated to 8 billion CHF in 2011 (Schneider & Venetz, 2014). The report assessed direct costs for overweight and obesity, with overweight defined as 25 - 29.0 kg/m^2 and obesity as > 30 kg/m^2, as well as indirect costs for the comorbidities of overweight and obesity. Eleven comorbidities were assessed for the indirect cost estimation: hypertension, type II (non-insulin dependent) diabetes mellitus, stroke, coronary heart disease, breast cancer, colorectal cancer, gallstones, osteoarthritis, depression, and road traffic accidents due to sleep apnea and asthma. In order to avoid double counting of hypertension, type II diabetes, stroke, cardiovascular disease, breast cancer and colorectal cancer, all of which are covered in HUM21 or HUM22, the numbers for these diseases were excluded from the 8 billion CHF cost defined by the report. This reduces the number to 4.7 billion CHF. The value identified for 2011 was extrapolated to 2018 relative to the increase in Swiss public health expenditure: national expenditure increased from 64.2 billion CHF in 2011 to 81.9 billion CHF in 2018, an increase of 27.5% (FSO, 2020e). Direct and indirect costs of overweight and obesity are assumed to have increased at the same rate as overall public health expenditure. Applied to the 4.7 billion CHF, this results in overweight and obesity costs of roughly 6 billion CHF. According to Fitzpatrick et al. (2019), 30% of overweight and obesity can be tracked to dietary factors. Total costs of overweight and obesity attributable to diet thus amount to 1.8 billion CHF in 2018. Intangible costs are not included in this estimation.

HUM21: HYPERTENSION

According to the FSO (2020a), 18% of citizens above the age of 15 were affected by hypertension in 2017. Applying this percentage to the Swiss population above the age of 15 in 2018 results in roughly 1.3 million cases of hypertension (derived from FSO (2020f)). Average medicinal therapy treatment costs are estimated to lie around 1.198 CHF/day (Schaefer & Scheunert, 2013). Assuming that 58% of hypertension is diet-related, this results in a cost of 328 million CHF in 2018 (Fitzpatrick et al., 2019). This value only covers the direct medicinal treatment costs of hypertension. Indirect and intangible costs related to hypertension are not included in this estimation.

HUM22: CARDIOVASCULAR DISEASE, DIABETES, CANCER

The cost of cardiovascular diseases, diabetes and cancer is based on a study commissioned by the FOPH (Wieser et al., 2014). The study estimated the direct and indirect costs of major non-communicable diseases in Switzerland in 2011 with both a bottom-up (direct costs only) and top-down approach (direct and indirect costs). The bottom-up approach uses Swiss public health expenditure in order allocate costs to each of the different NCDs, whilst the top-down approach estimates the cost of each disease based on Swiss and international literature. This thesis uses the bottom-up data for direct costs, as it is deemed more robust by the study author. Indirect costs are added to the direct costs based on the data from the top-down approach. This thesis reflects the identified possible range of indirect costs by using minimum, mean, and maximum estimates for the indirect costs of each disease.

Table 21: Direct and indirect costs of major non-communicable diseases in Switzerland

Disease	Direct cost (billion CHF)	Indirect cost (billion CHF)
Cardiovascular disease	10.3	4.9 - 6.4 (mean: 5.7)
Diabetes	1.0	0.5 -1 3 (mean: 0.9)
Cancer	4.0	3.9 - 5.8 (mean: 4.9)

The values in Table 21 were extrapolated to 2018 in line with the increase in Swiss public health expenditure in said time period, 27.5% (FSO, 2020e). It is assumed that direct and indirect costs for cardiovascular diseases, cancer and diabetes rose at the same rate as overall public health expenditure.

In order to estimate how much of each respective NCD cost burden is caused by diets, this thesis refers to Scarborough et al. (2011). Scarborough et al. quantified the cost of NCDs due to poor diet, physical inactivity, use of tobacco and alcohol as well as obesity in the United Kingdom. The study estimated the direct costs of NCDs to 5.8 billion GBP. It used a population attributable fraction (PAF) of 33% to approximate the share of the total costs of each NCD attributable to dietary factors. PAFs are used to identify how much a risk factor contributes to the development of a disease, providing information on how much the prevalence of a disease would decrease by if the risk factor was eliminated (e.g. poor diet vs. healthy diet) (WHO, 2020). The defined percentage was applied to the sum of direct medicinal costs and the range of indirect costs found in the study of Wieser et al., based on the assumption that indirect cost directly correlate to direct costs and thus are to the same part derived from dietary factors.

Overall, the cost of NCDs caused by diet is estimated to 5.8 (5.5 - 6.1) billion CHF for cardiovascular diseases, 0.7 (0.5 - 0. 8) billion CHF for diabetes and 3.2 (2.9 - 3.4) billion CHF for cancer.

This study also provides PAFs for non-communicable diseases attributable to overweight and obesity. These could be used to derive the cost of non-communicable diseases attributable to overweight and obesity from their respective total public health costs. In a second step, the contribution of dietary factors to these overweight and obesity-connected NCD costs could be derived. The cost of non-communicable diseases attributable to overweight and obesity is currently not added in order to ensure there is no double counting of costs. However, in a refined version of this methodology, these costs should also be included.

HUM23: FOOD POISONING

Schmutz et al. (2017) estimate the total healthcare costs related to acute gastroenteritis and human campylobacteriosis in Switzerland to 29 - 45 million CHF per year. The study includes direct medicinal costs only.

HUM24: PESTICIDES

A 2014 study estimates the health costs of pesticides connected to the consumption of pesticides in Switzerland to 25 - 75 million CHF in 2011, depending on the monetization factors used (Zandonella et al., 2014). Due to an increased public focus on pesticides, it is assumed that yearly costs stay the same. The study provides no cost estimation for costs related to pesticide exposure in food production, stating that high Swiss production standards successfully minimize these costs. The share of water purification costs attributable to the use of pesticides in agriculture could also be viewed as an externality, but would be attributed to the environment or economy impact area.

HUM25: ANTIMICROBIAL RESISTANCE

In 2015, an estimated 7'156 cases of antibiotic resistance were recorded in Switzerland, resulting in a loss of 7'400 DALYs and 276 deaths (Gasser et al., 2019). Assuming that the number of cases increases in line with population growth, an estimated 7'343 cases occurred in 2018, which in turn caused the suffering of 7'593 DALYs. Using the True Price monetization factor provided for DALYs, 116'800 EUR (123'808 CHF), this results in an antimicrobial resistance-related cost of roughly 940 million CHF per year. The value of human lives lost is not included in the cost estimate due to a potential overlap of DALY and human life cost estimates.

Based on the assumption that 22% of antimicrobial resistance is attributable to the food system, this results in a cost of 206 million CHF in 2018 (Fitzpatrick et al., 2019).

2.6 ECONOMY

ECO26: FOOD SYSTEM-TARGETED SUBSIDIES

According to Avenir Suisse (2020), the Swiss government spends almost 4 billion CHF on supporting agriculture every year. All expenditures collected by Avenir Suisse that are identified as direct monetary expenditure, paid for by taxpayers and support market structure, sales, animal welfare and the environment are listed in Table 22. It also provides the basis for the share of subsidies identified to negatively impact biodiversity according to Gubler et al. (2020) and support animal production systems (own assessment).

Table 22: Agricultural support for market structure, sales, animal welfare and the environment (German only)

Cost category	**Cost (CHF)**	**Negative biodiversity impact**	**Support of animal production systems**
Basisbeitrag (Direktzahlung)	811’549’623	X (partial)	
Weitere Nettoausgaben Kantone	286’696’000	X (partial)	
Verkaeste Milch	263’186’099	X (partial)	X
Tierwohl RAUS (Direktzahlung)	191’616’256	X (potential)	X
Produktionserschwernisbetrag (Direktzahlung)	159’431’784	X (potential)	
Qualitaetsbeitrag I (Direktzahlung)	155’822’097		
Qualitaetsbeitrag II (Direktzahlung)	152’094’701		
Landschaftsqualitaetsbeitrag (Direktzahlung)	145’917’053		
Offenhaltungsbeitrag (Direktzahlung)	139’992’958	X (partial)	
Hangbeitrag (Direktzahlung)	126’601’720	X (potential)	
Soemmerungsbeitrag (Direktzahlung)	123’980’368	X (potential)	
Uebergangsbeitrag (Direktzahlung)	113’846’761	X (partial)	
Offene Ackerflaechen und Dauerkulturen (Direktzahlung)	113’123’296	X (potential)	
Graslandbasierte Milch- und Fleischproduktion (Direktzahlung)	110’790’923	X (partial)	X
Alpungsbeitrag (Direktzahlung)	108’498’077	X (potential)	X
Vernetzungsbeitrag (Direktzahlung)	102’721’254		
Exportsubvention „Schoggigesetz“	94’600’000	X (potential)	
Tierwohl BTS (Direktzahlung)	83’916’838	X (potential)	X
Bodenverbesserungen	59’400’026		
Zusaetzliche Ausgaben Tiergesundheit	55’527’319		X
Biologische Landwirtschaft (Direktzahlung)	55’209’236		
Familienzulagen Landwirtschaft (Anteil Bund)	54’700’000		
Zusaetzliche Ausgaben Viehwirtschaft	43’740’597		X
Tierzucht und genetische Ressourcen	38’494’663	X (potential)	X
Extensive Produktion (Direktzahlung)	35’221’872		
Zuckerrueben (Flaechenbeitraege)	33’285’510		
Fonds fuer nicht versicherbare Elementarschaeden	30’000’000		
Fuetterung ohne Silage	29’804’020		X
Familienzulagen Landwirtschaft (Anteil Kantone)	26’680’000		
Landwirtschaftliche Gebaeude	22’799’974		

Cost category	**Cost (CHF)**	**Negative biodiversity impact**	**Support of animal production systems**
Kaese Inland und Ausland (Absatzfoerderung)	21'500'000		X
Oelsaaten (Flaechenbeitraege)	21'353'981		
Folgekosten tiefer Eigenmietwert I	20'340'800		
Schonende Bodenbearbeitung (Direktzahlung)	16'715'968		
Ressourcenprogramme (Direktzahlung)	16'084'122		
Emissionsmindernde Ausbringverfahren (Direktzahlung)	13'079'300		
Hangbeitrag fuer Rebflaechen (Direktzahlung)	11'456'195	X (partial)	
Steillagenbeitrag (Direktzahlung)	11'314'875	X (potential)	
Landwirtschaftliches Beratungswesen	10'813'180	X (potential)	
Milch und Butter (Absatzfoerderung)	8'500'000	X (partial)	X
Koernerleguminosen (Flaechenbeitraege)	5'742'804		
Fleisch (Absatzfoerderung)	5'325'000	X	X
Gewaesserschutzbeitrag (Direktzahlung)	5'045'121		
Uebergreifende Massnahmen (Absatzfoerderung)	4'708'000		
Kaese (Exportinitiative)	3'530'000		X
Wein (Absatzfoerderung)	3'200'000		
Ueberregionale Projekte (Absatzfoerderung)	3'112'000		
Administration Milchproduktion- und Verwertung	2'723'689	X	X
Gemeinwirtschaftliche Leistungen (Absatzfoerderung)	2'653'360		
Einlagerungsbeitraege Kalbfleisch	2'586'785	X	X
Gemeinsame Massnahmen (Absatzfoerderung)	2'440'000		
Zwei-Phasenfuetterung Schweine	2'425'211		X
Obst (Absatzfoerderung)	2'260'000		
Schweizer Produkte fuer die Schweizer Armee	1'900'000		
Reduktion von Pflanzenschutzmittel	1'779'303		
Marktstuetzung Eier	1'761'983	X	X
Obstverwertung	1'753'763		
Saatgut (Flaechenbeitraege)	1'575'135		
Praezise Applikationstechnik (Direktzahlung)	1'395'646		
Beitraege Pflanzenschutz	1'245'561		
Eier (Absatzfoerderung)	1'200'000	X	X

Cost category	Cost (CHF)	Negative biodiversity impact	Support of animal production systems
Foerderung des Weinbaus	1'022'144		
Ausfall Investitionskredite (Bund)	938'518		
Verwertung Schafwolle	909'446		
Gemuese (Absatzfoerderung)	824'750		
Lebende Tiere (Absatzfoerderung)	785'000		X
Fleisch (Exportinitiative)	700'000		X
Bio-Produkte (Exportinitiative)	636'000		
Kartoffeln (Absatzfoerderung)	570'000		
Oelsaaten (Absatzfoerderung)	488'000		
Zierpflanzen (Absatzfoerderung)	420'000		
Getreide (Absatzfoerderung)	329'972		
Agrotourismus (Absatzfoerderung)	320'000		
Sonderprojekte (Absatzfoerderung)	311'500		
Pilze (Absatzfoerderung)	280'000		
Zierpflanzen (Exportinitiative)	150'000		
Rindergenetik (Exportinitiative)	125'000		X
Umschulungsbeihilfen	41'164		
Viehmaerkte im Berggebiet	25'000		X
Betriebshilfe	-1'036		
Total	3'987'646'265	2'822'007'073 (71%)	976'762'460 (24%)

ECO27: REGULATION AND RESEARCH

Avenir Suisse (2020) also provides an overview of payments made to support administration, research and development in agriculture, which amounts to 257 million CHF per year. All expenditures collected by Avenir Suisse that are identified as direct monetary expenditure, paid for by taxpayers and support research, development and administration are listed in Table 23.

Table 23: Agricultural support for research, development and administration (German only)

Cost category	Cost (CHF)
Forschung und Entwicklung Landwirtschaft	82'167'195
Vollzug und Kontrolle (Agroscope)	62'492'416
Aufgaben Bundesamt fuer Landwirtschaft	53'270'818
Weitere Ausgaben (Agroscope)	42'739'766
Gestuet (Agroscope)	8'257'041
Food and Agriculture Organization of the United Nations (FAO)	7'671'431
Vollzug Schlachtvieh und Fleisch	6'588'800
Korrektur aufgrund Kuerzungen, Vor- und Nachzahlungen usw. (Direktzahlung)	-6'385'608
Total	256'801'859

2.7 ANIMAL WELFARE

Schlaepfer (2020) estimates the yearly national external costs of animal suffering to 110 million CHF. The estimation is based on an assessment of two voluntary animal welfare-targeted initiatives supported with agricultural direct payments, additional outdoor space (Tierwohl RAUS, as listed in Table 22) and animal-friendly housing (Tierwohl BTS, also in Table 22), which are in place today. Schlaepfer approximates animal suffering as the absence of the animal life improving conditions supported by these direct payments. The number of livestock units (LSU) not raised with additional outdoor space and animal-friendly housing, but raised merely in alignment with the standard legal requirements, is multiplied with the payment received for the introduction of these additional animal welfare measures per LSU. The amount the government is willing to pay for these animal welfare-targeted initiatives today thus represents the average avoidance cost of animal suffering. Based on the "average avoidance costs" used in the study, this results in external costs of 58 million CHF for outdoor space and 52 million CHF for housing conditions. Taking the "highest avoidance costs", which are based on the highest observed payments per LSU, animal suffering connected to a lack of outdoor space and poor housing conditions increases to 83 and 178 million CHF, respectively. Other animal welfare costs, such as those connected to livestock transport or slaughtering, are not included. Animal welfare costs are thus expected to exceed the value estimated in this thesis.

2.8 FOOD IMPORTS

Table 24 illustrates which external costs of locally produced food were considered to approximate external costs of imported food. Locally produced food is defined as the sum of national food expenditure (37.4 billion CHF) minus the value of imported food (12.8 billion CHF) plus the value of exported food (9.4 billion CHF), resulting in a value of 34.0 billion CHF (FOAG, 2019e).

Table 24: Impact areas included in the external cost estimation of locally produced food

Impact area	Inclusion/Exclusion	External cost per CHF spent (CHF/CHF)
Environment (abiotic)	Included	0.036 (1'231/34'029)
Biodiversity	Included	0.305 (10'374/34'029)
Livelihoods	Included	0.014 (485/34'029)
Human Health	Only production-related human health externalities	0.032 (1'096/34'029)
Economy	Excluded	-
Animal Welfare	Included	0.003 (110/34'029)
Total		**0.391**

Applying the share of external costs attributable to Swiss food production (39%) to the 3.4 billion CHF difference between food imports and exports, this results in external costs of 1.4 billion CHF. This is expected to be an underestimation due to three main reasons:

1. The import and export value of food is likely lower than its value at retail/wholesale stage – this estimation of external costs of imported food therefore undervalues external costs
2. Environment and biodiversity-related costs increase significantly for food produced in areas suffering from water scarcity and deforestation
3. Livelihood costs are likely to be significantly higher in other countries

It could be argued that Swiss citizens and society will not have to pay for the external cost of food produced outside of Switzerland and that it should therefore not be included. This thesis includes the cost based on the understanding that a sustainable food system in the context of achieving the UN sustainable development goals needs to consider all of its externalities, both within its national borders and outside of them.

2.9 IMPLICATIONS

The share of external costs caused by food loss and waste is approximated by applying the FOEN (2019) estimate that a quarter of the national environmental impact is caused by the Swiss diet to Env1, Env4, Bio8-14, Hum18 and Ani28. In terms of external costs caused by animal-based products, the individual sources are listed in Table 25 below. It is assumed that the share of Hum20 costs caused by animal-based products is applicable to all consumption-related health externalities. (derived from Hirstein and Forster (2020), by dividing the sum of DALYs associated to diets high in processed meat and red meat, diets low in milk and 20% of DALYs associated to diets high in salt by overall NCD-related DALYs). External costs of Hum23, Hum25 and Ani28 are assumed to be fully caused by the production and consumption of animal-based products.

Table 25: Share of national level costs attributable to food waste and animal-based products (million CHF). Estimated share of total costs caused by food waste or animal-based products in brackets

ID	Externality	Cost	Food waste	Animal-based products
Env1	Greenhouse gas emissions	1’227	307 (25%)	589 (48%) (FOEN, 2020)
Env4	Soil organic carbon loss	3.8	1 (25%)	-
Bio8-14	Biodiversity and ecosystem service loss due to agriculture	10’374	2’594 (25%)	6’225 (60%) (Chow, 2017)
Liv16	Workers performing free labor	485	121 (25%)	
Hum18	Human toxicity (air pollution)	1’096	274 (25%)	526 (48%) (FOEN, 2020)
Hum20	Health impact of overweight and obesity	1’797	-	143 (8%)
Hum21	Health impact of hypertension	328	-	26 (8%)
Hum22-1	Health impact of cardiovascular disease	6’716	-	533 (8%)
Hum22-2	Health impact of diabetes	802	-	64 (8%)
Hum22-3	Health impact of cancer	3’737	-	296 (8%)
Hum23	Health impact of food poisoning	37	-	37 (100%)
Hum24	Health impact of pesticide exposure	50	-	-
Hum25	Health impact of antibiotic use	207	-	207 (100%)
Eco26	Taxes for food system-targeted subsidies	3’988	-	977 (24%) (Table 22)
Eco27	Taxes for regulation and research	257	-	7 (3%) (Table 23)
Ani28	Animal years suffered	110	28 (25%)	110 (100%)
Import	External cost of food imports	1’329	-	-
Total	**External cost of Swiss food system**	**32’543**	**3’324 (10%)**	**9’738 (30%)**

3 PRODUCT LEVEL QUANTIFICATION

3.1 ENVIRONMENT, BIODIVERSITY AND PRODUCTION-RELATED HUMAN HEALTH EXTERNALITIES

Table 26: Impact per product for all quantified externalities

	Env1	**Env2**	**Env5**	**Env6**	**Bio8**	**Bio9**
	IPCC GWP 100a	Terrestrial acidification	Non-renewable, fossil	Non-renewable, sum of nuclear and biomass	Terrestrial ecotoxicity	Freshwater ecotoxicity
	kg CO_2-eq	kg SO_2-eq	MJ	MJ	kg 1,4-DB-eq	kg 1,4-DB-eq
Apple	0.091	0.001	1.112	0.084	0.000	0.003
Potato	0.086	0.002	0.649	0.127	0.000	0.001
Carrot	0.090	0.002	0.855	0.089	0.002	0.001
Wheat	0.452	0.005	3.307	0.676	0.005	0.005
Milk	1.232	0.023	3.171	1.784	0.001	0.001
Cheese	7.382	0.047	34.974	9.604	0.039	0.054
Chicken	3.537	0.059	32.911	4.480	0.020	0.028
Beef	15.123	0.196	49.476	9.954	0.038	0.018
	Bio10	**Bio11**	**Bio12**	**Bio13**	**Bio14**	**Hum18**
	Marine ecotoxicity	Freshwater eutrophication	Marine eutrophication	Agricultural land occupation	Natural land transformation	Human health
	kg 1,4-DB-eq	kg P-eq	kg N-eq	m^2a	m^2	10^{-7} DALY
Apple	0.003	0.000	0.000	0.323	0.000	2.361
Potato	0.001	0.000	0.002	0.328	0.000	2.431
Carrot	0.001	0.000	0.000	0.233	0.000	2.572
Wheat	0.003	0.000	0.010	1.229	0.000	11.088
Milk	0.001	0.000	0.003	1.075	0.001	25.686
Cheese	0.044	0.001	0.033	5.717	0.013	147.705
Chicken	0.023	0.001	0.021	6.760	0.001	82.881
Beef	0.010	0.001	0.065	17.765	0.001	293.415

Table 25 only includes impacts at the production stage. GHG emissions of each food group at the final consumption level are also available in Beretta (2018) (Table 26). These are preferred to GHG emissions at production stage if they are higher at retail level, as explained in chapter 2. More information on the other externalities are not available in detail at the consumption stage.

Table 27: Greenhouse gas emissions at consumption level (ENV1)

Product	**Food group**	**kg CO_2-eq**
Apple	Table apples	0.550
Potato	Potatoes	0.650

Product	Food group	kg CO_2-eq
Carrot	Other storable vegetables	0.620
Wheat	Bread and pastries	1.280
Milk	Milk, other dairy	1.680
Cheese	Cheese, whey	3.320
Chicken	Poultry	7.480
Beef	Beef, horse, veal	22.120

According to Beretta (2018), these numbers are based on an estimation by the Swiss gastronomy and hotel group SV. The group assumes a 90 km transport in a chilled 18 t truck for half of the products, and a 45 km transport in a 3.5-8 t truck, half of which is chilled, for the rest of the products. Beretta applies an average of these assumptions to all of the products in his study.

3.2 CONSUMPTION-RELATED HUMAN HEALTH EXTERNALITIES

Consumption-related health externalities are not available on a product level. Instead, international research focuses on the health effects of diets or food groups (Afshin et al., 2019). This thesis assumes that the health impact connected to the under- or overconsumption of certain food groups is applicable to the individual products within these food groups. Of course, for a healthy and balanced diet, different products should be consumed within a food group. As shown in Table 27, only four of the different food products could be allocated a food group. This is further explained in chapter 2.

Table 28: Allocation of food items to their respective food group

Product	Food group
Apple	Fruit
Potato	n/a
Carrot	Vegetables
Wheat	n/a
Milk	Dairy
Cheese	Dairy
Chicken	n/a
Beef	Red meat

The health impact caused by the under- or overconsumption of food groups is generally expressed in DALYs. This thesis uses a study by Schwingshackl et al. (2019) to define the number of DALYs connected to the over- or underconsumption of each food group included in this thesis. The study identifies the number of DALYs caused by coronary heart disease, stroke, type 2 diabetes, and colorectal cancer in 16 different European countries in 2016 (Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Hungary, Ireland, Italy, Latvia, Netherlands, Romania, Spain, Sweden, United Kingdom) and attributes these to the over- or underconsumption of 12 different food groups. The study calculates four different scenarios, differentiating between disease-specific TMRELs (theoretical minimum risk exposure level) and a single TMREL across all assessed diseases, which has the most practical relevance for the development of dietary recommendations, as well as between looking at all food-disease associations versus only the significant food-disease associations. For this thesis, scenario D (single TMREL, only significant food-disease associations) is used. DALYs calculated in scenario D are listed in Table 28 below.

Table 29: DALYs connected to under- or overconsumption of food groups

Product group	Dietary health impact due to	Total 2016 DALYs across 16 European countries
Fruit	Underconsumption	908’337 (890’765 - 926’085)
Vegetables	Underconsumption	602’009 (587’606 - 616’785)
Dairy	Underconsumption	392’300 (384’393 - 400’305)
Red meat	Overconsumption	529’416 (513’453 - 545’873)

The resulting number of DALYs associated to every food group was divided by the total number of citizens in the respective countries in 2016, roughly 420 million, in order to reach an average yearly dietary impact from the consumption of the food group (World Bank, 2020b). The average yearly dietary DALY-impact per person is multiplied with the True Price monetization factor of 123’808 CHF/DALY, resulting in a yearly cost connected to each food group for every person. By comparing the actual food group intake used in the study, which is based on European food and safety authority (EFSA) data, with the recommended intake according to the global burden of disease (GBD) study, both provided by Schwingshackl et al., a cost or savings potential for the consumption of each additional kg of the product can be identified (Table 29).

Table 30: Definition of cost/savings per additionally consumed kg of food group

			Current intake (EFSA)	Recommended Intake (GBD)	Cost/savings per additionally consumed kg
Product group	**DALYs/ year**	**Cost/ person/year**	**kg/year**	**kg/year**	**CHF/kg**
Fruit	908’337	134	51.83	91.25	- 6.81
Vegetables	602’009	89	55.48	131.40	- 2.34
Dairy	392’300	58	91.62	158.78	- 1.73
Red meat	529’416	71	19.35	8.21	+ 14.05

It is assumed that current dietary intakes and health externalities of the European citizens in the sample are similar to the dietary intake and health externalities of the Swiss population. It was not possible to quantify other human health externalities within this thesis. However, NCDs are among the leading causes of rising public health costs in Switzerland and are thus assumed to represent a sensible approximation human health costs (FOPH, 2016). The cost of NCDs on a product level cannot be directly compared to the cost of non-communicable disease on a Swiss system level, as the costs on national level are not derived from the monetization of DALYs.

Environment, biodiversity and human health costs attributed to a food product are added up to their respective categories and added to their retail price.

3.3 MONETIZATION

All externalities are monetized with the True Price monetization factors listed in Table 6. For Env5, the monetization factor was converted from kg oil-eq to MJ by dividing by 41.868 (Stallinga, 2020). For Bio13, the monetization factor for m2a was converted to MSA ha yr (mean species abundance per hectare per year) by dividing by 10'000 (m^2 to ha) and multiplying with 0.6, the MSA coefficient associated to the introduction of low-intensity production systems (Natural Capital Impact Group, 2020). This results in the product level external costs listed in Table 30.

Table 31: External costs for each externality, per kg of food product

ID	Apple	Potato	Carrot	Wheat	Milk	Cheese	Chicken	Beef
Env1	0.09	0.10	0.10	0.21	0.27	1.19	1.21	3.56
Env2	0.00	0.01	0.01	0.02	0.08	0.17	0.21	0.70
Env5	0.01	0.01	0.01	0.04	0.04	0.39	0.36	0.55
Env6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bio8	0.00	0.00	0.02	0.04	0.01	0.30	0.16	0.30
Bio9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bio10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bio11	0.02	0.01	0.01	0.05	0.02	0.42	0.45	0.37
Bio12	0.00	0.11	0.03	0.70	0.20	2.23	1.42	4.34
Bio13	0.02	0.02	0.01	0.08	0.07	0.36	0.43	1.13
Bio14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hum18	0.03	0.03	0.03	0.14	0.32	1.83	1.03	3.63
Hum22	-6.81	n/a	-2.34	n/a	-1.73	n/a	n/a	14.05

3.4 DEFINITION OF AVERAGE RETAIL PRICES

The average retail price listed in Table 31 represents the average price paid for the products at retail level in 2018, excluding organic products (FOAG, 2019a). Average prices for chicken and beef are based on the FOAG data but adapted to account for the average price per entire animal. The Average price for wheat is based on flour. Future calculations should be based on wheat prices.

Table 32: Selection of reference product for average retail price definition (German only)

Product	Reference product	2018 Price (CHF)	Conversion	Price used
Apple	Aepfel, Golden Delicious, Klasse I (Obst)	3.73/kg	1	3.73/kg
Potato	Festkochende Speisekartoffeln (Kartoffeln)	1.77/kg	1	1.77/kg
Carrot	Karotten (Gemuese)	2.34/kg	1	2.34/kg
Wheat	Weissmehl (Mehl und Brot)	1.85/kg	1	1.85/kg
Milk	Vollmilch, pasteurisiert, verpackt (Milch und Milchprodukte)	1.50/l	1	1.50/kg
Cheese	Mozzarella (Milch und Milchprodukte)	1.46/150 g	6.67	9.73/kg
Chicken	Inland, frisch Brust	8.59/kg (A) 30.52/kg (B)	Table 32	13.86/kg

Product	Reference product	2018 Price (CHF)	Conversion	Price used
	Schenkel	12.02/kg (C)		
Beef	Entrecôte, geschnitten	73.44/kg (A)	Table 33	21.37/kg
	Plaetzli, Eckstueck	50.33/kg (B)		
	Braten, Schulter	32.59/kg (C)		
	Hackfleisch (Rindfleisch)	18.91/kg (D)		

The average price of chicken is derived according to Table 32, with the average 2018 prices provided by the FOAG serving as the basis for the average price definition. The average carcass weight, defined as the full weight minus head, feat and offal, of a chicken is assumed to be 2 kg. Average yields are based on numbers for the broiler hybrid Ross 308 (Simon & Stegemann, 2007). Ross 208 is the most commonly produced and consumed broiler in Switzerland (Brodmann & Roth, 2017). It is assumed that bones, fat, tendons and other losses can be sold at an average price of 2.50 CHF per kilogram (Bianchi, 2020). Due to the fact that environment, biodiversity and production-related health externalities are caused by the whole animal, the full carcass weight is accounted for in the definition of the average price of chicken.

Table 33: Definition of average chicken price

Chicken part	Yield (%)	Yield (kg)	Price category	CHF/kg	Value (CHF)
Breast	26.9%	0.54	B	30.52	7.63
Leg	32.8%	0.65	C	12.02	1.68
Rest	11.3%	0.22	A	8.59	5.24
Bones, fat, tendons, losses	29.0%	0.58	n/a	2.50	1.44
Total value (26 CHF)/carcass weight (2.0 kg) = Average chicken price (CHF/kg)					**13.86**

The average price per kilogram of beef is derived according to Table 33, with the average 2018 FOAG prices again serving as the basis for the average price definition. The average cow weight amounts to 530 kg, of which 185.5 kg are sellable in the form of the various meat pieces listed below (AGRIDEA, 2017). It is assumed that bones, fat, tendons and other losses can be sold at an average of 5 CHF per kilogram, double the price for chicken bones, fat, tendons and other loses.

Table 34: Definition of average beef price

Beef part	Yield (%)	Yield (kg)	Price category	CHF/kg	Value (CHF)
Filet	1.5%	2.78	A	73.44	204.35
Roastbeef	3.6%	6.68	A	73.44	490.43
Huft	1.9%	3.52	B	50.33	177.39
Plaetzli vom Eckstueck und Nuss	6.8%	12.61	B	50.33	634.86
Geschnetzeltes	4.6%	8.53	B	50.33	429.47
Stotzenbraten	5.0%	9.28	C	32.59	302.27
Schulterbraten	4.8%	8.90	C	32.59	290.18
Hohruecken	1.8%	3.34	C	32.59	108.82

Beef part	Yield (%)	Yield (kg)	Price category	CHF/kg	Value (CHF)
Siedfleisch durchzogen	8.1%	15.03	D	18.91	284.13
Siedfleisch mager	4.6%	8.53	D	18.91	161.36
Ragout	8.2%	15.21	D	18.91	287.64
Hackfleisch	8.7%	16.14	D	18.91	305.18
Wurstfleisch	8.2%	15.21	D	18.91	287.64
Bones, fat, tendons, losses	32.2%	59.73	n/a	5.00	298.66
Total value (3963 CHF)/carcass weight (185.5 kg) = Average beef price (CHF/kg)					**21.37**

3.5 ADDITION OF EXTERNAL COSTS

After having defined the average 2018 prices of each product, external costs are added in order to define the true cost per kg of each product. The result of this step is presented in the results chapter.

3.6 CONVERSION TO KCAL

These results are converted from impacts per kg to impacts per 100 kcal to provide more valuable information. Data from the Swiss food composition database (SFCDB) (FSVO, 2019) is used for this conversion, again based on a selection of reference products seen in Table 34.

Table 35: Selection of reference product for kg to kcal conversion

Product	Reference product (exact SFCDB wording)	Kcal per kg
Apple	Apple, fresh	550
Potato	Potato, peeled, raw	760
Carrot	Carrot, raw	380
Wheat	Flour, white and semi-white (average)	3’440
Milk	Whole milk, pasteurized	680
Cheese	Mozzarella	2’560
Chicken	Chicken, breast, without skin, raw (Switzerland)	1‘070
Beef	Beef (average excluding offal, chop), raw	1‘340

3.7 PRODUCT LEVEL DATA SOURCE

Table provided by Claudio Beretta (April 14, 2020) (selected reference products only, part 1/2)

Impact category:	LCA database	IPCC GWP 100a	IPCC GWP 100a (final consumption level)	Human Health	Resources	CED Non renewable	CED Total	Non renewable, fossil	Non-renewable, nuclear
Unit		**kg CO2 eq**	**kg CO2 eq**	**10^-7 DALY**	**10^-3 $**	**MJ**	**MJ**	**MJ**	**MJ**
Table apples			0.550						
Apple from Italy PhD	EI	0.091		2.4E+00	5.2E+00	1.2E+00	4.3E+00	1.1E+00	8.3E-02
Potatoes			0.650						
Potato, Swiss integrated production {CH}| potato production, Swiss integrated production, intensive | Alloc Rec, U	EI	0.086		2.4E+00	3.2E+00	7.8E-01	5.0E+00	6.5E-01	1.3E-01
Other storable vegetables			0.620	3.7E+00	6.2E+00	1.6E+00	4.1E+00	1.5E+00	1.2E-01
Carrot, at farm (WFLDB 3.0)/GLO U PhD	WF	0.090		2.6E+00	3.9E+00	9.4E-01	3.2E+00	8.5E-01	8.9E-02
Bread and pastries			1.280	1.2E+01	1.4E+01	4.0E+00	2.9E+01	3.3E+00	7.3E-01
Wheat grain IP intensive from CH PhD	EI	0.452		1.1E+01	1.4E+01	4.0E+00	2.9E+01	3.3E+00	6.8E-01
Milk, other dairy			1.680	2.6E+01	1.5E+01	4.9E+00	2.8E+01	3.1E+00	1.7E+00
milk IP, at farm/CH U CB	ZH	1.232		2.6E+01	1.5E+01	5.0E+00	2.8E+01	3.2E+00	1.7E+00
Cheese, whey			3.320	2.6E+01	1.5E+01	4.9E+00	2.8E+01	3.1E+00	1.7E+00
Cheese, from cow milk, fresh, unripened {GLO}| cheese production, soft, from cow milk | Alloc Rec, U (Soft Cheese Mozzarella Style)	EI	7.382		1.5E+02	1.4E+02	4.5E+01	1.2E+02	3.5E+01	2.7E+00
Poultry			7.480	8.9E+01	7.2E+01	3.8E+01	5.5E+01	1.8E+01	2.2E+00
Chicken, fresh meat and offal, at slaughterhouse (WFLDB 3.0)/US U PhD	WF	3.537		8.3E+01	1.3E+02	3.7E+01	9.5E+01	3.3E+01	4.5E+00
Beef, horse, veal			22.120						
beef IP, meat + inwards, intensive cattle fattening, at slaughterhouse/CH U PhD CB	ZH	15.123		2.9E+02	2.3E+02	5.9E+01	3.4E+02	4.9E+01	9.9E+00

Table provided by Claudio Beretta (April 14, 2020) (selected reference products only, part 2/2)

Impact category:	LCA database	Non-renewable, biomass	Agricultural land occupation Recipe	Natural land transformation Recipe	Terrestrial ecotoxicity Recipe	Freshwater ecotoxicity Recipe	Marine ecotoxicity Recipe	Freshwater eutrophication Recipe	Marine eutrophication Recipe	Terrestrial acidification Recipe
Unit		**MJ**	**m2a**	**m2**	**kg 1,4-DB eq**	**kg 1,4-DB eq**	**kg 1,4-DB eq**	**kg P eq**	**kg N eq**	**kg SO2 eq**
Table apples										
Apple from Italy PhD	EI	2.0E-04	3.2E-01	1.8E-05	2.3E-04	3.4E-03	2.6E-03	5.0E-05	4.9E-05	7.1E-04
Potatoes										
Potato, Swiss integrated production {CH}| potato production, Swiss integrated production, intensive | Alloc Rec, U	EI	1.3E-04	3.3E-01	1.2E-05	4.1E-04	7.9E-04	1.1E-03	3.5E-05	1.7E-03	1.7E-03
Other storable vegetables		2.2E-04	1.9E-01	2.5E-05	1.1E-01	2.0E-02	3.1E-03	5.6E-05	1.3E-03	1.2E-03
Carrot, at farm (WFLDB 3.0)/GLO U PhD	WF	1.8E-05	2.3E-01	1.8E-05	2.3E-03	9.4E-04	5.0E-04	2.8E-05	4.3E-04	2.0E-03
Bread and pastries		4.1E-04	1.5E+00	6.1E-05	3.4E-03	4.0E-03	2.8E-03	1.6E-04	1.3E-02	9.1E-03
Wheat grain IP intensive from CH PhD	EI	4.2E-04	1.2E+00	5.9E-05	5.1E-03	4.6E-03	2.9E-03	1.5E-04	1.0E-02	5.2E-03
Milk, other dairy		7.0E-02	1.1E+00	5.5E-04	1.1E-03	6.2E-04	5.1E-04	7.3E-05	2.9E-03	2.3E-02
milk IP, at farm/CH U CB	ZH	7.9E-02	1.1E+00	6.1E-04	1.1E-03	6.4E-04	5.2E-04	7.2E-05	2.9E-03	2.3E-02
Cheese, whey		7.0E-02	1.1E+00	5.5E-04	1.1E-03	6.2E-04	5.1E-04	7.3E-05	2.9E-03	2.3E-02
Cheese, from cow milk, fresh, unripened {GLO}| cheese production, soft, from cow milk | Alloc Rec, U (Soft Cheese Mozzarella Style)	EI	6.9E+00	5.7E+00	1.3E-02	3.9E-02	5.4E-02	4.4E-02	1.3E-03	3.3E-02	4.7E-02
Poultry		1.8E+01	2.2E+00	6.2E-02	2.3E-02	1.8E-02	1.1E-02	6.3E-04	1.0E-02	5.3E-02
Chicken, fresh meat and offal, at slaughterhouse (WFLDB 3.0)/US U PhD	WF	7.1E-04	6.8E+00	8.8E-04	2.0E-02	2.8E-02	2.3E-02	1.4E-03	2.1E-02	5.9E-02
Beef, horse, veal										
beef IP, meat + inwards, intensive cattle fattening, at slaughterhouse/CH U PhD CB	ZH	7.8E-02	1.8E+01	9.5E-04	3.8E-02	1.8E-02	1.0E-02	1.1E-03	6.5E-02	2.0E-01