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Can directed policy increase plant-based consumption in place of meat, to reduce GHG releases?

– the case of minced products in Sweden.

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Abstract

A dietary transition from meat to predominantly plant-based diets is a desirable target with regards to climate change mitigation efforts. Therefore, this study aims at analysing the question if taxes and subsidies across differentiated minced products could increase people's plant-based consumption in place of meat, to reduce greenhouse gas (GHG) emissions. A Swedish supermarket provided the instore dataset on minced products of plant-based and meat origins. We tested two policy scenarios, a taxation of external effects and the same taxation with a 10% subsidy on plant-based goods. To do so, we employed a Quadratic Almost Ideal Demand System. Results indicate that GHG in both scenarios could be reduced by decreased beef purchases. However, less meat in favour of plant-based consumption for emission mitigation cannot be reached. The obtained findings indicate that consumers highly prioritize beef and rather reduce their demand for substitutes to sustain meat purchases in case of taxation or use additional budget margins on further beef purchases once a subsidy is placed. We concluded that consumers need to perceive plant-based products as valid foods first before price-based measures could be effective and induce a dietary shift. Therefore, knowledge-based instruments to reach a shift in preferences could be used as the first measures.

Keywords: Consumption-based policy, GHG mitigation, dietary transition, plant-based substitutes, minced products, Sweden.

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Abbreviations

ADC	Average damage cost
AIDS	Almost Ideal Demand System
GHG	Greenhouse gases
LCA	Life cycle assessment
LM	Lagrange Multiplier
MBp	Marginal private benefits
MCp	Marginal private costs
MCs	Marginal social costs
PIGLOG	Price-Independent generalized logarithmic
QAIDS	Quadratic Almost Ideal Demand System

1. Introduction

Among the world community, there is general agreement on the fact that greenhouse gases (GHG) as the main determinant of climate change and environmental degradation need to be reduced. To this end, 196 countries signed the Paris Agreement in 2015 with the commitment to limit the global temperature increase to 2°C (UNFCCC, 2021). Within this context, agriculture has been identified to play a key role in the emitting process. According to IPCC (2019), the sector accounts for 21-37% of global carbon emissions. Among those, especially livestock and livestock-related activities weigh particularly heavy. Special importance to reduce the release of GHG is therefore being sought in the field of livestock farming and its intensive consumption in typical western diets.

In this regard, changing demand patterns relying on reduced meat intakes and predominantly plant-based diets are focalized. Various studies confirm the beneficial effect of such a dietary transition on GHG releases, based on the comparatively low environmental impact that plant-based goods entail (e.g. IPCC, 2019; Springmann et al., 2018). In recent years, the role of plant-based substitutes as a potential help to promote the reduction and replacement of meaty diets is increasingly gaining attention in this debate (e.g. Ritchie, 2018; Apostolidis & McLeay, 2016). Their similarity in terms of taste, appearance and nutritional content make them suitable alternatives to meats, while also posing the more sustainable food option (Schösler et al., 2012; Nijdam et al., 2012). As stated by Euromonitor Research (2017) and Geijer & Gammoudy (2020), this debate is not only fuelled by increased environmental awareness, but also by unprecedented growth in the market of replacement goods – constantly offering consumers new products to integrate into their meals.

Even though progress in industrialized countries is noticeable, consumption of meat is still high and therewith connected problems remain. A case in point is Sweden. According to Ridder (2021), 9% of the population indicated eating vegetarian or vegan in 2018 while Richter (2019) confirms the Swedish market for plant-based substitutes to be among the fastest-growing ones worldwide. Additionally, Swedish meat consumption has fallen within the past four years, however, is still high with 78.6 kg per capita consumed (Swedish Board of Agriculture, 2021). Moberg et al. (2020) have shown that the average Swedish diet cannot be considered ecologically sustainable when benchmarked to the planetary boundaries as defined by Willett et al. (2019). This is in big parts due to the substantial carbon impact of meat products. Hence, the resulting high release of emissions and the corresponding environmental effects need to be addressed.

To limit food-related GHG releases and offset the resulting societal burden due to environmental damages, consumption-sided policies to accelerate the desired transition are needed (Röös et al., 2021). Existing public measures however are mainly production-oriented and reduced to territorial targets (Bonde et al., 2020). Although they bear the potential to reduce food-related GHG by 20-25% (Swedish Environmental Protection Agency, 2019), those measures have their limitations. Emission leakages from imports weigh particularly heavy as two-third of food-related emissions stem from outside the country (Moberg et al., 2020). National reductions might even be offset if imports increase towards less sustainable products – at the expense of Swedish producers not able to compete anymore (Jansson & Säll, 2018). A sole application of production-oriented approaches is therefore not sufficient. Rather, a holistic policy framework is needed that additionally includes demand-targeted policies offering ways to overcome problems production policies entail (Willett et al., 2019). Among those, Swedish governmental agencies and non-governmental organisations deem price-based instruments as most effective as dietary patterns are firmly entrenched and voluntary measures not sufficient (Lööv et al. 2013; Röös et al., 2021). To that effect, they provide a popular approach to drive consumers' decisions, with the possibility to foster sustainable goods by lower pricing while disincentivizing unsustainable ones with higher charges (ibid.).

Given the outlined background, the study contributes to deeper understand the mitigation potential of economic consumption-targeted policies while including plant-based substitutes. The special emphasis put on meat substitutes addresses not only its increasingly important role in shaping Swedish demand patterns but is also fundamental to fully understand the effect of possible policy interventions. Therefore, it is the aim of this work to analyse the question if taxes and subsidies across differentiated minced products could increase people's plant-based consumption in place of meat, to reduce diet-related GHG emissions. For this purpose, two policy scenarios – both aiming at increasing the relative attractiveness of replacement products – are tested:

- *Scenario 1* refers to a taxation of the products' external effects with plant-based as the least emitting ones being relatively lower-taxed.
- *Scenario 2*, a mixed approach, considers the same taxation with an additional 10% subsidy on plant-based goods, further increasing the price gap to meats.

To answer the proposed research question, we used an instore supermarket dataset specified on various minced meats of animal and plant origins. To our prior knowledge, this is the first study addressing demand-based policies while including real market data on plant-based substitutes. Accordingly, we first estimate consumers' price sensitivity within the considered product range by setting up a Quadratic Almost Ideal Demand System (QAIDS). This provides the empirical framework to estimate expenditure functions and associated income and price elasticities. Following this, we took obtained elasticities to construct a system of linear demand curves. This allowed determining variations in demand as a response to price alterations and resulting changes in GHG emissions.

The following Chapter 2 gives an overview of the theoretical background and the conceptual framework this work is based on. Chapter 3 outlines previous studies. Chapter 4 provides a description of the empirical data with an indication of its limitations while Chapter 5 explains the used methods. In Chapter 6 we present results with their analysis. We finalize the work in Chapter 7 with the discussion and concluding remarks, followed by References and the Appendix.

2. Theoretical Perspective and Policy Conceptualization

In the following chapter we present the theoretical foundations underlying the research aim of this work: the concept of negative environmental externalities. Subsequently, we discuss the choice of policy instruments.

2.1. Negative Environmental Externalities

In economic theory, the problem of high GHG releases connected to meat consumption and the resulting adverse ecological effects are known as a form of negative environmental externalities – a classical example of market failure (Pais et al., 2020). Those failures arise when market mechanisms and their corresponding price level for inputs and outputs do not determine existing supply and demand patterns correctly. Consequently, inconsistencies regarding the social optimum arise and thus give justification for governmental intervention to correct for losses in overall societal welfare (Hill, 2012, pp. 186). According to the definition of Hill (2012), negative environmental externalities in this context can be defined as negative costs promoted by meat consumption which are not incurred by those eating but by overall society. The use of resources determined by dietary choices is thus suboptimal from a societal point of view. This can be based on a lack in the pricing of the external costs stemming from meat consumption.

Figure 1 illustrates such a situation. We adapt the explanation of Tietenberg & Lewis (2018, pp. 25) to our specific case. Accordingly, for overall society, the optimal amount of meat consumed is marked where marginal social costs (MC_S) cross marginal private benefits (MB_P), denoted by Q*. This refers to a situation in which the existing negative effects of meat consumption are considered and directly borne by the consumer in the form of higher prices, P*. However, as market prices for meats, P_M, do not entail the additional costs stemming from GHG emissions, consumers who make their purchasing decisions have no incentive to buy at quantity Q*. Rather, they maximize their utilities at the interface of marginal private costs (MC_P) and marginal private benefits (MB_P), at the corresponding quantity Q_M. Accordingly, the preferred demand for society is less than it is perceived from a private standpoint ($Q^* < Q_M$), with market prices too low to be socially optimal ($P_M < P^*$).

As society must bear the negative externalities stemming from individuals' consumption decisions, governments are incentivized to take respective steps to minimize arising costs and come closer to the social optimum. Concerning meat consumption, authorities thus have the possibility to reduce food-related GHG emissions by steering dietary choices. Therefore, a substitution from high-emitting meat to low-emission food such as plant-based products is a desirable target. This does not only allow to reduce the negative external effects but also the burden on society. However, adequate measures to promote such a shift are necessary. An intervention scheme consisting of taxes and subsidies seems most appropriate, with a special focus on Pigovian taxes as a mean to price negative external effects (Pigou, 1947). In the following, we give a thorough discussion on the choice of policy instrument.

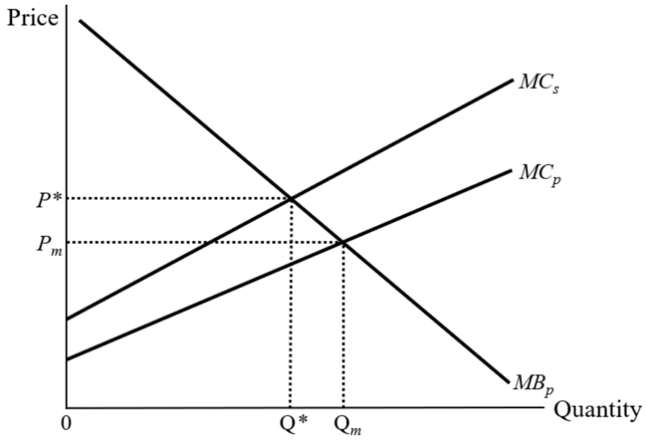

Figure 1. Illustration of negative environmental externalities. Source: Modified, Tietenberg & Lewis (2018, pp. 25).

2.2. Policy Conceptualization

For policymakers to steer consumption choices, three main instrument categories within the toolbox of consumption-sided measures are subject of the current scientific discussion: regulatory measures, information provision as well as market-based instruments (Röös et al., 2021). It has to be mentioned beforehand that the respective measures are not without its criticism. Disclosure to the public and perceived interference in people's decisions pose a potential political threat while consumers' unpredictable response reactions leave space for concern about the effectiveness of the policy tool (Schanes et al., 2019). However, relevant progress in researching consumer behaviour as well as thereon adapted policy drafting and implementation has been noted in recent years, making consumption-oriented measures a promising policy tool (Reisch & Zhao, 2017).

First ones, requirements and regulations, find high usage within the production side of the sector with a predominantly perceived positive effect. For what concerns consumption, however, few of those measures are currently taken to direct dietary choices for environmental reasons. Among those are mainly guidelines, suggestions and public procurement requisitions. According to the authors, further promising regulating tools for the Swedish state exist, yet acceptance in society and their lacking simplicity to implement pose challenges that must be faced. On these grounds, governments rely on their insertion mainly in case of acute life threats or health concerns as stated by Reisch et al. (2013).

Second, informational measures as a tool to alter people's attitudes and behaviour, currently find implementation in the country also with regards to the environment. According to Röös et al. (2021), various research emphasizes their key role in raising awareness and building knowledge, yet also point to their low impact force. Furthermore, their effectiveness specifically for GHG emissions might be questioned particularly if individual constraints are required (Swedish Environmental Protection Agency, 2017). In recent years, however, a new tool, nudging, has been added to this category. Its approach, to change people's decisions by presenting choices and information differently, found increased political application and is deemed successful – even though effects are also in small frame (Reisch et al., 2013).

Third, price-based measures, mainly rely on the effect that relative price changes between different commodities have on consumption decisions. Among those, especially taxes and subsidies find political interest with regards to the regulation of public food demand on a large scale. By imposing those measure, regulators aim at steering demand patterns away from unsustainable goods towards more sustainable ones (Röös et al., 2021). As emphasized by the authors, various research exists that confirms their potential positive effect in the food sector. However, those instruments come not without their caveats. On the one hand, there exists a variety of aspects that determine eating patterns besides the price. On the other hand, they are difficult to implement as their social acceptance might be low. However, despite other influences, prices are confirmed to be a major driver of demand structures (Reisch et al., 2013) and governments have leeway in the implementation of the measures to increase their approval.

Among those, one way to directly address negative environmental externalities is through Pigovian taxes (Pigou, 1947). Accordingly, products are associated with their marginal damage costs by increasing their price respectively. This would imply taxation directly during the production process by attaching every food unit to its social cost of causing a 1 kg GHG release. However, limited information, difficulties in monitoring the exact amount of GHG releases as well as the mentioned risks of emission leakages and reduced competitiveness of national farmers highly complicate such realization, as discussed in Jansson & Säll (2018).

The taxation of consumer prices, therefore, provides a more favourable approach suited to overcome those problems. Hence, financial disincentives for consumers to buy unsustainable goods are created while products with low associated damage costs become relatively more attractive (Röös et al., 2021).

Based on this logic, we apply Pigovian taxes in *Scenario 1* of this work. As plant-based goods have a lower carbon footprint compared to most meat products, we impose proportionally lower charges. By doing so, we aim at encouraging the decrease in minced meat purchases given their higher pricing while generating financial stimulus for consumers to buy more lower-emitting plant-based products. Accordingly, we augment their relative financial attractiveness compared to meats, holding potential in promoting dietary changes and GHG reductions. With the mixed approach in *Scenario 2*, we intend to further stipulate the demand for plant-based goods by placing an additional subsidy of 10% while keeping meats taxed. Consequently, such a mixed approach not only widens the monetary gap further but actively promotes plant-based food alternatives.

3. Literature Review

Consumption-side targeted taxes and subsidies in various contexts are currently debated or already applied in several countries, especially related to health improvements. Multiple studies attribute great potential to the proposed policies, though the assessed effects vary widely and context-dependent consideration is indispensable (Martos et al., 2015; Smed et al., 2007; Nordström & Thunström, 2011). The increased research and substantial favourable resonance of many consumption-sided measures promoted their consideration also within the food sector. So far, however, only a limited number of studies has been conducted. Among those, predominantly the effect of GHG-weighted taxes on demand patterns has been investigated.

On a global scale, Springmann et al. (2017) investigated the effect that introduced GHG-weighted consumption taxes on foods could have on emissions and human health. Employing the International Model for Policy Analysis of Agricultural Commodities and Trade and an additional health assessment framework, they examined the proposed measures for 62 food commodities in 150 areas across the globe with agricultural data retrieved from FAOSTAT. Accordingly, results indicate that not only health could be promoted but diet-related GHG emissions additionally diminished by almost 10% if a tax of $52 per ton CO_2-equivalent was imposed. This applied especially to high and middle-income regions but also most of the considered low-income countries. Within this context, reduced beef weighs particularly heavy given its high carbon impact.

Within the EU27, Wirsenius et al. (2010) analysed the possible GHG reduction potential of emission-based consumption taxes for various animal products as the earliest study to raise the topic. Under usage of pre-estimated elasticities and yearly per capita consumption and expenditure data provided by FAOSTAT and EUROSTAT, they concluded that differentiated taxes of €60 per ton CO_2-equivalent could reduce agricultural emissions by around 7%. Particularly, decreases in the consumption of ruminant meat accompanied by substitution to other meat products such as poultry had the biggest effect. Oppositely to that, Jansson & Säll (2018) found very different results for the EU. Elasticity estimations with the Common Agricultural Policy Regionalised Impact Model yielded much lower values with rather inelastic demand. Accordingly, price changes showed a smaller effect on food demand and relatively high charges would be needed for the policy measure to be effective. In fact, the authors yielded smaller mitigation levels with a tax five times as high as Wirsenius et al. (2010) imposed. Despite very low price sensitivity values, those findings are more in line with the results of similar studies.

An analysis of such taxes on a national level was performed by Bonnet et al. (2018) in France, who examined the potential of different tax schemes to modify household demand and correspondingly environmental effects. To do so, they applied a Random Coefficient Logit Model and Discrete Choice Model to analyse food purchases and preferences, based on panel data of 25766 households in 2010. In accordance with the findings of Jansson & Säll (2018), also this simulation resulted in low elasticity values, indicating a possible GHG emission decrease of 6% with a tax level of €200 per ton CO_2-equivalent. The authors additionally agreed that high charges on beef seemed to be most effective.

Other findings however were found in the study performed by Edjabou & Smed (2013) who considered emission-based taxes for 23 food products in Denmark. By establishing a linear Almost Ideal Demand System (AIDS), they analysed monthly panel data of 2000 representative Danish households. In contrast, results indicated that the most effective tax scenario, 3.5-6.9 DKK per kg CO_2-equivalent, could lead to an average carbon reduction of 10.4-19.4% per household. Besides, they attributed beneficial effects on overall diets, further confirming the positive assessment of the tax scenario.

One of the few relevant studies additionally considering food subsidies conducted Abadie et al. (2016). Targeting Norway, they simulated a mixed policy approach with ad valorem taxes on unfavourable food groups and subsidies on recommended goods. The application of varying levels on different products allowed them to estimate the best fit for defined GHG mitigation levels. While doing so, the lowest societal costs and average calorie intake levels were considered. Also in this study, the authors employed a linear AIDS model relying on data from the yearly Norwegian consumer expenditure survey. Findings indicated promising potential as reduced emissions of up to 10% were possible if all considered products were taxed besides few exceptions with subsidies up to 40% of initial levels. The authors therewith confirmed moderate but important changes towards more sustainable dietary choices.

For what concerns Sweden, Säll & Gren (2015) who assessed the emission reduction potential of an environmental tax on meat and dairy products found mixed results. Emissions, in this case, corresponded not only to GHG but also ammonia, phosphorus and nitrogen. Hence, they estimated an AIDS model based on per capita consumption data and prices from 1980 to 2012. Tax levels between 8.9% and 33.3% of initial prices resulted in demand alterations of 1.8-13.1%, depending on the product considered. Following this, Säll et al. (2020) worked on a more comprehensive analysis of climate taxes for Sweden under usage of a QAIDS model, including 52 representative food products. Both studies agree in their findings that meat in general, but especially measures towards beef were most efficient. Besides that, the researchers resumed that approximately 10-12.1%, namely from the livestock sector, could be conserved if the corresponding prices were increased according to external effects (1.2 SEK per kg CO_2-equivalent). Yet, the authors point out the lack of information regarding plant-based meat substitutes and the need to conduct a more thorough analysis of the measures once replacement goods are considered.

To our knowledge, only Ritchie et al. (2018) thematize mitigation possibilities of meat substitutes, together with possible health improvements for high-income countries. Utilizing successively increased subsidies on plant-based alternatives, tested against various social acceptability scenarios, they projected substitutions from meats to plant-based for 2020. To do so, they applied a joined ecological and health modelling procedure, based on retrieved elasticities of US consumers. Since data on meat substitutes was unavailable, they used chicken was as an alternative – posing a heavy limitation. Their findings indicate potential for substitution and thus possible GHG reductions and health enhancements, yet heavily dependent on both: prices and consumers' acceptability. No emission savings were noticeable with subsidies below 10%, while price decreases of 75% evoked reductions between 5-61%, depending on substitutes' acceptability.

The outlined studies show that taxes, especially carbon-adapted, and subsidies hold potential to change dietary patterns and reach reductions in GHG releases. This can be based on their promoting effect of reduced meat – especially ruminant – consumption on the one side and possible switches towards more sustainable – meat-free – goods on the other side. However, it also became apparent that consideration of plant-based substitutes is missing or deeply restrained due to lacking real data. Their role in such schemes, specifically for meat substitution, and the resulting mitigation effect therefore remains unclear – providing support and emphasizing the need to work on the objective of this study.

4. Data

In the following section, we explain the supermarket instore data on minced products as well as its handling prior to the analysis. Thereafter, we present descriptive statistics and the determination of the products' GHG emission impacts while we conclude this chapter with data limitations.

ICA Maxi in Stockholm Nacka, Sweden, provided the daily instore data on the minced products. The supermarket itself performed the collection over thirty days in January 2020 via the scanning records. They gathered daily information on the number of packaged goods sold, their weight and their VAT-exempted prices. Data capture in this supermarket was especially particular, as ICA Maxi entails a vast assortment of commodities and great variety among similar products. Further, the owners approved to conduct the data gathering which was a prerequisite for this study. During that time a daily average of 4048 people visited the store. According to this store, tendentially richer households of the surrounding municipality frequent this ICA.

4.1. Data Handling

Before the data could be analysed, we had to perform various steps. First, we assembled all daily Excel files into one single sheet for a better overview. By then, the list included 73 minced products. Second, we removed returned goods and outliers (products only sold one to three times). As it was important for the study to grasps substitution effects among minced goods of different origins, we categorized the products accordingly. Those that could not be assigned to a group (e.g. mixed minced meat) were also excluded. 42 products remained that we could use in the analysis. What followed was the calculation of a weighted price/unit per group. Therefore, we accounted for the VAT rate of 12% levied on Swedish food goods and the amount of the specific products sold within the category of origin. In the end, the data set was aggregated into the five groups of minced products (beef, plant, poultry, wild/lamb, pork) with corresponding average units sold and average prices.

4.2. Descriptive Statistics

Table 1 provides a descriptive overview of the quantities and prices of the average aggregated packaged products. Thirty observations, referring to the collection period, are available for every group. Minced beef was sold most with 349 packages per day on average. Customers purchased the plant-based substitutes as well as those from poultry approximately 40 and 39 times a day while wild/lamb and pork were consumed less with 22 and 8 packages sold per day on average. The relatively high standard deviations for all groups can be based on the spikes the data reveals. Those peaks result from the fact that more people do their groceries on the weekend than during the week. Correspondingly, the minimum and maximum values vary greatly.

Regarding the prices of the chosen commodities, packaged meat products were generally sold more expensive than plant-based products, except pork. Among those, beef packages are sold with the highest average price of 87.3 SEK per average unit. Wild/lamb goods range after, followed by poultry goods for 75 and 53 SEK on average. Pork packages are sold the cheapest for 33 SEK per unit. Plant-based goods reveal an approximate price of 47 SEK per unit sold. The standard deviations for all commodity groups are relatively low as the range between minimum and maximum values is small. Accordingly, prices fluctuated only slightly, despite the high spikes in quantities.

Table 1. Descriptive statistics of minced products.
Source: Based on ICA data.

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
Qbeef	30	348.7333	114.2514	183	562
Qplant	30	39.66667	18.42475	13	90
Qpoultry	30	39.13333	19.02944	13	93
Qwild/lamb	30	21.73333	11.33482	3	48
Qpork	30	8.466667	4.93917	0	22
Pbeef	30	87.35427	6.645988	74.743	106.645
Pplant	30	46.5667	5.226911	37.273	56.537
Ppoultry	30	53.32443	5.88718	44.346	63.921
Pwild/lamb	30	75.32987	6.892777	59.758	88.54
Ppork	30	32.5128	.5417086	31.298	32.95

It has to be noted that not only its meat or plant origin but also the varying average package weights determine the price. The average unit sold weighted 0.840 kg for beef, 0.560 kg for plant-based goods, 0.590 kg for poultry, 0.500 kg for wild/lamb and 0.500 kg for pork. Accordingly, per kg prices differ, where wild/lamb is most expensive with 150.66 SEK per kg, followed by beef and poultry for 96.56 and

76.58 SEK per kg on average. Plant goods value 69.88 SEK per kg, only pork is sold cheaper with an average of 65.03 SEK per kg.

4.3. GHG Emission Impact

To estimate the effect of different tax and subsidy levels on consumption and therewith connected GHG releases, we required data on the goods' emissions. Considering the different animal and plant origins, we consulted two consecutive sources to obtain standardized and most recent life cycle assessment (LCA) data on CO_2-equivalents for Sweden: Moberg et al. (2019) computed the climate impact for meats and Potter et al. (2020) provided information on plant-based goods. For the latter, we retrieved numbers for soya as the majority of included plant-based products is soya-based. As data availability on such a specific product type as minced meat is scarce, we used values for generally packaged meat.

Moberg et al. (2019) base their calculations on different LCA scenarios while considering a more amplified emission scheme, e.g. including those stemming from land use and respective changes. Potter et al. (2020) rely on a brought review of representative and relevant studies on the current Swedish production system as the starting point for their calculations and follow an approach oriented to the one of Moberg et al. (2019). Accordingly, both calculation procedures are harmonized, account for all transmissions up to the retail gate and rely on the Global Warming Potential for 100 years to weigh differing GHG.

Table 2 shows the CO_2-equivalents per kg that we applied for the product groups in this study. Ruminant meat exhibits the highest climate impact with a value of 23.5 for beef and 22.3 for wild/lamb. Pork and poultry have much smaller impacts with values of 4.6 and 4.2. The plant-based version has the lowest climate impact with 2.2. Considering the differing product weights, we calculated CO_2-equivalents per average products which we used for the final analysis. Those lie at 19.7 for beef, 1.2 for plant-based goods, 2.5 for poultry, 10.8 for wild/lamb and 2.3 for pork.

Table 2. CO_2-equivalents for minced products, per kg and average unit.
Source: Based on ICA data, Potter et al. (2020) and Moberg et al. (2019).

Product	CO_2-equivalent/kg	CO_2-equivalent/average unit sold
Beef	23.5	19.7
Plant	2.2	1.2
Poultry	4.2	2.5
Wild/lamb	22.3	10.8
Pork	4.6	2.3

4.4. Limitations

Certain limitations the data entails have to be kept in mind throughout this work. The instore data was only provided by one single supermarket. Accordingly, it does not give a representative picture of all supermarkets in the country, but only reflects consumer and price patterns for this specific location. As the store is situated close to Stockholm, consumer behaviour might differ significantly e.g. in the countryside or another area of the city. This also includes the customer base in the ICA Nacka which has limited expressiveness as people are wealthier on average and therefore do not speak for lower-income households. Moreover, the data was gathered daily over one month. Hence, spikes in quantities, e.g. because of increased grocery shopping during the weekend, weigh heavier than in an aggregated, longer data set. The consideration of a longer time frame with monthly or yearly data would therefore have been desirable. However, as this gathering was the first trial, no longer period was set. For the same reason, solely minced products were considered, limiting data availability on a specific good and therefore also the scope of this work.

Regarding the numbers on GHG emissions, we did not use a single source due to the lack of availability for the specific products and the required national scope. However, we tried to overcome this problem by selecting two sources that build on each other, i.e. researchers overlap and sequential methods are used, and therefore are as similar as possible.

5. Methods

In this section, we outline the methodological approach underlying the empirical analysis conducted in this work. First, we explain the steps to estimate consumers' price sensitivity. This includes a thorough explanation on the assumption of the two-stage demand system, the QAIDS model and elasticity estimations. Following this, we indicate the approach to analyse the proposed policy scenarios by providing an overview on the determination of tax and subsidy levels with associated changes in demand and GHG emissions.

5.1. Two-stage Demand System

The multitude of available commodities and therewith connected challenges such as excessive data quantities or technological requirements aggravate the examination of consumption structures and requires facilitations within the actual existing demand system. Accordingly, preliminary assumptions concerning consumers' preferences are needed to overcome those problems. Following Edgerton (1997), multistage budgeting systems with the condition of weak separability are a suitable approach, with consumers being viewed as utility-maximizing individuals. We followed the same concept with a two-stage budgeting process also in this work and integrated it into the QAIDS model.

Hence, the weak separability condition allows food goods to be separately grouped, "where a change in the price of a commodity in one group affects the demand for all commodities in another group in the same manner" (ibid.). According to the author, the different budgeting stages allow independent allocations in two steps. First, food expenditure is distributed between aggregated groups under consideration of prices. Irrespective of this, a further reallocation of expenses takes place again within these groups. Thus, consumers can directly compare similar products of the same group and allocate their available budget respectively. *Figure 2* provides an overview of the utility tree associated with the budgeting process of this work.

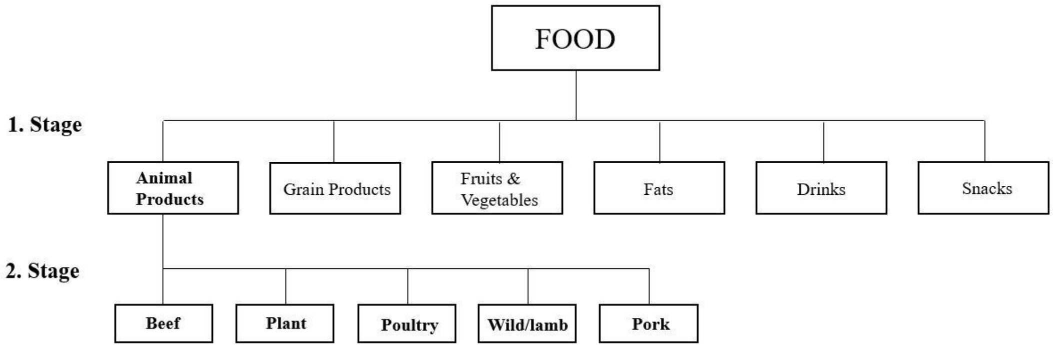

Figure 2. Utility tree for minced products.
Source: Own illustration, based on Edgerton (1997) & Säll et al. (2020).

Accordingly, the first stage of *Figure 2* represents a demand system of six aggregated food groups, where consumers decide on how much of their total food expenditure they spend on each broad category. Among those, animal products are relevant for this work. The second stage determines the further distribution within this group, referring to meats of beef, poultry, wild/lamb and pork, but also meat substitutes from plant-based origins. The inclusion of the different stages thus allows not only to estimate consumption changes within the same category as a reaction to price increases but also to account for switches to other aggregated food groups and thus determine final elasticities.

Considering the data available for this work, we retrieved estimates for aggregated animal products in the first stage from Säll et al. (2020) who followed the same estimation steps as outlined in this work.

5.2. Quadratic Almost Ideal Demand System

The Almost Ideal Demand System, to estimate income and demand elasticities, was set up as proposed by Deaton & Muellbauer (1980) and supplemented by the quadratic extension of Banks et al. (1997). Even though various models exist to estimate demand system, e.g. the Rotterdam or Translog Model, special attention was particularly assigned to the AIDS model in its different variants (van Oordt, 2016). This can be attributed to its flexible application possibilities and its numerous eligible properties. According to Xi et al. (2004) and Deaton & Muellbauer (1980), it is easy to conduct, provides estimates of the demand system arbitrarily to first order and fulfils the theoretical principle of rational choice. Further, its reliance on price-independent generalized logarithmic (PIGLOG) preferences, a class of preferences that typifies consumer demand as the result of rational acting individuals, assures ideal aggregation among consumers. The test of restrictions such as symmetry and homogeneity is also possible. Our choice specifically for the quadratic form of the model can be justified in its congruence with actually observed patterns in consumer expenditures (Banks et al., 1997). Thus, the best possible realistic representation of demand can be secured. As established by the authors, the interaction of household income and expenditure, defined by Engel curves, needs to be represented differently based on extended PIGLOG preferences. While the standard AIDS model relies on curvatures that are linear in the logarithm of total expenditure, demand observations showed that its quadratic term fit reality better. The QAIDS model was thus defined as follows:

$$s_i = \propto_i + \sum_{j=1}^{m} \gamma_{ij}\, lnp_j + \beta_i(lnX - lnP) + \frac{\mu_i}{Q}(lnX - lnP)^2 \qquad \textbf{1)}$$

with $i = 1, \ldots, n$ representing the respective good within a group and $j = 1, \ldots, m$ all commodities within the specific group of goods. Parameters are α, β, μ and γ. S_i represents the budget share for good i, regressed on logarithmic prices of all considered goods, lnp_j, and logarithmic total expenditure X. X is accordingly defined as $\sum_{i=1}^{n} p_i\, q_i$ and shares are thus $s_i = p_i q_i / X$. Share i in the case of this analysis refers to 1-5 for the goods beef, plant, poultry, wild/lamb and pork.

P indicates the aggregated price index for the AIDS model in its non-linear version.

$$lnP = \alpha_0 + \sum_{i=1}^{n} \alpha_i lnp_i + \frac{1}{2}\sum_{i}^{n}\sum_{j}^{n} \gamma_{ij} ln(p_i + p_j) \qquad \textbf{2)}$$

Q as price aggregator is described by:

$$Q = \prod_{i}^{n} p_i^{\beta_i} \qquad \textbf{3)}$$

Hence, equation **1)-3)** provide a suitable framework to be in accordance with the theory of demand. To assure that the specific model properties hold, parameters need to fulfil the following restrictions:

Adding up:

$$\sum_{i=1}^{n} \alpha_i = 1 \quad \sum_{i=1}^{n} \beta_i = 0 \quad \sum_{i=1}^{n} \mu_i = 0 \qquad \textbf{4)}$$

Adding up restrictions require that the share of initial consumption in logarithmic form, α_i, needs to add to 1. Moreover, β_i, which describes responses to changes in total expenditure, sums to 0. Correspondingly, the parameter for the quadratic term, μ_i, also sums to 0.

Homogeneity:

$$\sum_{i=1}^{n} \gamma_{ij} = 0 \qquad \textbf{5)}$$

The homogeneity condition implies that γ_{ij} adds to 0 with γ_{ij} indicating the response to price changes in budget shares.

Symmetry:

$$\gamma_{ij} = \gamma_{ij} \quad \textbf{6)}$$

Accordingly, symmetry means that variations in the price of commodity i lead to the same marginal effect on the expenditure share of commodity j as does a variation in the price of commodity j on the marginal change of expenditure share of commodity i.

We apply equation **1)-3)** for every commodity within the group of animal products in the second stage. During the estimation process, the fulfilment of restrictions **4)-6)** is assured. By fulfilling those conditions, total expenditure adds up to 1 within the system of demand functions ($\sum s_i = 1$). Accordingly, a situation is provided in which expenditure shares are constant if real expenditures (x/P) and relative prices are kept unchanged. Thus, an appropriate starting point is created to measure changes in demand in response to price and income changes (Deaton & Muellbauer, 1980).

5.3. Income and Expenditure Elasticities

To assess relative changes in consumption as a response to income and price alterations, income and expenditure elasticities are estimated. To do so, Green & Alston (1990), as well as Edgerton (1997), serve as the orientation in their definitions and calculations for multilevel demand systems. Accordingly, compensated elasticities are first calculated for each of the two stages and thereafter used to determine final uncompensated elasticities. The latter take the whole demand system into account and thus include changes among goods within the same group as well as switches between aggregated groups. Correspondingly, we follow the concept of Edgerton (1997) and fulfil its imposed conditions to capture the effects throughout the whole commodity range.

To assess the effect of price variations, most popularly Hicksian and Marshallian elasticities can be determined. While Hick's computations solely consider price/substitution effects on consumption choices and consider how to achieve the highest utility level with different prices and lowest expenditure, Marshallian calculations additionally take income effects into account and imply utility maximization under a budget constraint (Edgerton, 1996, pp. 56). Consequently, the determination of Marshallian elasticities provides a more suitable approach given the objectives of this work. By doing so, the impact of the proposed policy scenarios on demand with respect to income, price and substitution can be thoroughly analysed. The corresponding equations are as follows:

$$\varepsilon_i^I = 1 + \beta_i / s_i \quad \textbf{7)}$$

$$\varepsilon_{i,j}^M = \left[\left(\gamma_{i,j} - \beta_i s_j\right) / s_i\right] - \delta_{i,j} \quad \textbf{8)}$$

Where I denotes income elasticity and M Marshallian elasticity for each separated stage. Kronecker delta δ is one if $i = j$, otherwise it is zero. To fulfil homogeneity, the following conditions must hold: $\varepsilon_i^I + \sum_{j=1}^{m} \varepsilon_{i,j}^M = 0$. By applying equation **7)** and **8)** to every good within an aggregated group of every stage, uncompensated final elasticities can be obtained according to Edgerton (1997). To do so, equation **9)** and **10)** are used:

$$\varepsilon_i^{I*} = \varepsilon_j^I \varepsilon_r^I \quad \textbf{9)}$$

$$\varepsilon_{i,j}^{M*} = \delta_{r,u} \varepsilon_{i,j}^M + \varepsilon_i^I s_j \left(\delta_{r,u} + \varepsilon_{r,u}^M\right) \quad \textbf{10)}$$

Subscripts r and u denote the main groups of goods, while i and j represent the commodities within one group.

5.4. Tax and Subsidy Levels

The tax levels for *Scenario 1*, the taxation of external effects, were determined for each commodity i as illustrated in **11):**

$$tax_i = ADC_i \times e_i \quad \textbf{11)}$$

Accordingly, we multiplied the average damage cost of each good i (ADC_i) by the average emissions of i per package. For the ADC_i we used the current Swedish Carbon tax of 1.2 SEK per kg CO_2-equivalent (Government Offices of Sweden, 2021) and adapted all calculations to the average packages considered.

In *Scenario 2*, the mixed approach, we taxed the external effects of meat products according to **11)** with a subsidy S_i of 10%, placed on initial prices, p_{i0}, according to equation **12):**

$$subsidy_i = p_{i0} + (p_{i0} \times S_i) \quad \textbf{12)}$$

5.5. Changes in Demand and GHG Emissions

We simulated the impact of the different tax scenarios on consumption and connected GHG emissions using a linear demand curves system of own and cross prices that we established for each commodity i (see Varian, 2010, pp. 274). The setup of this framework has the advantage that it represents the relationship between a goods' price and the quantity consumers are willing to pay at a certain point in time while considering the price and income elasticities. Additionally, commodity-related GHG emissions and changes in their releases can be included. We decided to use linear forms because of their simplicity.

To determine changes in demanded quantities q_i per product unit, linear demand equations based on own and cross-price elasticities as in equation **13)** found the basis for our calculation:

$$q_i = \frac{\Delta q_i}{\Delta pj} \times \mathrm{p}_i + a_i + \Delta h_i \qquad \textbf{13)}$$

where q_i is the quantity demanded of commodity i, a_i denotes the initial intercept, $\frac{\Delta q_i}{\Delta pi}$ represents the slope, p_i the price in SEK per unit and Δh_i the summed effect of shifters accrued by the price variation.

Previously estimated final Marshallian elasticities ($\varepsilon_{i,j}^{M*}$) and initial prices and quantities (p_{i0} and q_{i0}) served as the starting point to establish the equation. We rearranged equation **14)**, the expression for final Marshallian elasticities, to determine the slope values $\Delta q_i/\Delta \mathrm{p}_j$. Slopes were estimated for every commodity, including the substitution effects the remaining goods j have on the respective commodity i.

$$\varepsilon_{i,j}^{M*} = (\Delta q_i/\Delta \mathrm{p}_j) \times (p_{j0}/q_{i0}) \qquad \textbf{14)}$$

As the next step, we plugged obtained values for slope coefficients into equation **13)** and allowed us to obtain values for the initial intercept a_{i0}, shown in **15)**. Accordingly, we considered a situation before tax and subsidy introduction, thus Δh_i was zero and final own-price elasticities were used.

$$a_{i0} = q_0 - p_{i0} \times \left(\frac{\varepsilon_{i,j}^{M*} \times q_{i0}}{p_{i0}}\right) \qquad \textbf{15)}$$

Thereafter it was possible to determine all substitution effects as a response to price variations of the remaining goods j within the group. This indicates to which extent the initial intercept a_{i0} shifts and where the new intercept a_{i1} lies. Thus, by summing all cross-price elasticities, we could obtain Δh_i (see equation **16)**.

$$\Delta h_i = \sum \Delta \mathrm{p}_j \times \frac{\varepsilon_{i,j}^{M*} \times q_{i0}}{p_{j0}}$$ **16)**

Following this, we could calculate new consumed quantity levels under usage of final own-price elasticities, the new price, and the new intercept. Consequently, the difference in demand per commodity before and after the intervention, Δq_i, could be determined. Equation **17)** expresses the indicated step.

$$q_{i1} = \varepsilon_{i,j}^{M*}(p_{i0} + \Delta p_i) + a_{i1}$$ **17)**

We obtained the total effect of the intervention on consumption by summing the changes across all commodities j in the group. After obtaining new consumption levels and the differences in demand, we estimated corresponding changes in GHG emissions. The CO_2 emissions for every unit per commodity (e_i) were multiplied with the change in total quantity demanded. Accordingly, the total effect of the measures on emissions could then be calculated as the difference in GHG emissions before and after tax or subsidy implementation.

6. Results & Analysis

The subchapters below provide an overview of the estimated results of consumers' price sensitivity and the proposed policy scenarios based on the methodology outlined in Chapter 5. The former analysis has been conducted with the statistical software TSP and STATA. However, TSP results are prioritized due to the higher reliability of the program's estimation technique with QAIDS. The estimation in STATA posed problems due to low transparency and a non-robust estimation technique. For the latter analysis, Excel was used.

6.1. Consumers' Price Sensitivity

This subchapter shows the results based on the two-stage budgeting process as explained in Chapter 5.1. We retrieved first stage demand system results on aggregated animal products from Säll (2020). Those include meat, other (plant-based) protein sources and dairy. Though plant-based substitutes are missing – data was not available so far – this product range represents the closest the goods analysed in this work. The author's estimated price elasticity amounts to -0.606 and is found to be rather inelastic while its income elasticity with 1.150 categorizes the products as luxurious.

We applied the methodology outlined in Chapter 5.2 on the QAIDS model to all second stage commodities. Accordingly, we estimated four models which built the basis for the 5^{th} model approximation. By using lagged variables we ensured consumers' coherence with previous purchases. Additionally, we included an autocorrelation term. Given the short length of the period considered, we dropped the control for a time trend. Accordingly, 11 out of 23 parameters were significant at least at 10% level. Models obtained R^2 with values between 0.02 and 0.48, indicating lower to moderate statistical fits. Yet, Wooldridge (2013, pp. 38) argue that the importance of R^2 should not be overestimated. Performed Lagrange Multiplier (LM) tests for all demand system equations confirm that no autocorrelation prevails. Detailed test results are listed in *Table A1* and *Table A2* in the Appendix. *Table 3* below shows consecutively estimated Marshallian compensated within group elasticities between second stage minced products, final uncompensated elasticity estimations including all stages, as well as the corresponding income elasticities. We calculated final elasticities manually following equations **9)** and **10)**. Values for standard errors and significance levels therefore are only available for compensated elasticities.

Regarding the compensated within group results, all own-price elasticities are negative. This is in line with theoretical specifications of consumer demand as price increases of a good should lead to reductions in its demand (Edgerton, 1996, pp. 61). Their levels vary widely and indicate inelastic values for pork and plant between 0 and -1, an almost unitary elastic value for beef close to -1 and highly elastic values for poultry and wild/lamb less than -1. Levels of cross-price elasticities indicate low to medium-strong price sensitivity – with exceptions – and in majority show positive values. This indicates that most goods are substitutes, except for poultry and pork, and beef and pork. Especially distinctive is the finding of beef and plant-based products being complements. Accordingly, price increases of beef go hand in hand with demand decreases of plant-based goods. Substitutability between the remaining meats and plant-based products, however, got confirmed. Compensated income elasticities show that beef and plant-based goods are luxury goods within the group, as their values lie above 1. Wild/lamb is on the edge, while poultry and pork are categorized as normal goods with values below 1. Nine out of 25 values are found to be statistically significant[1].

Final uncompensated elasticities differ from the compensated ones, which is in line with theory as total elasticities take all stages of the demand system into account (Edgerton, 1997). Deviations however are small and own-price, as well as cross-price elasticities, hold in similar levels. Hence, the fact that plant-based goods are substitutes to most meats but complements to beef remains. Solely the smaller own-price elasticity for beef proves its demand to be inelastic. Further, generally higher levels of income elasticities categorize wild/lamb as luxury goods besides beef and plant-based products. Poultry and pork remain normal goods, though their values increase. Accordingly, the more income consumers have the more they spend on the former goods while expenditure on the latter remains relatively constant.

For both compensated and final uncompensated price elasticities, most estimated values lie within the overall expected range, even though price effects are generally very high in comparison. The analysis of Säll & Gren (2015) on yearly per capita data resulted in similar values for beef, pork and poultry. This is in overall congruence with the final elasticity estimations of Säll et al. (2020), though their cross-findings on wild/lamb and beef as well as beef and poultry differ in direction. On the other hand, Bonnet et al. (2018), found comparable levels of own-price elasticities for poultry as well as ruminants, and matching effects between meat

[1] It should be mentioned that non-significant values do not necessary mean that results are untrue, but the true values could be close to zero.

products, considering monthly household data. However, certain estimated cross-price elasticities found in our study, between beef and plant (-1.034), beef and poultry (1.280) as well as poultry and pork (-1.628) strongly exceed expected and previously estimated levels. Though, Säll & Gren (2015) also found relatively higher results for the latter. Considering plant-based goods, this does not only reveal complementarity but also strongly tight price and demand reactions to beef. The opposite counts for poultry, while poultry and pork behave similarly. The fact that customers of this area are tendentially richer would speak for lower price elasticities. However, the high weekend spikes combined with the short length of the dataset are possible explanations for generally higher and striking price effects. A longer, aggregated dataset, e.g. on monthly or yearly data, would allow to smoothen those effects and probably lead to normally ranging results. Moreover, the lack of quantitatively analysed data on plant-based products makes it difficult to draw further conclusions. However, the fact that we categorized plant-based goods with meats in one aggregated group, rather than two separated ones could be decisive for the magnitude of cross-price effects and their relationship to other meats, i.e. the complementarity to beef.

Table 3. Compensated and final uncompensated elasticity estimations.
Source: Own calculations, based on ICA data.

Compensated elasticities, within group						
	Beef	Plant	Poultry	Wild/lamb	Pork	**Income**
Beef	**-0.978***** **(0.132)**	-0.139** (0.048)	0.091 (0.073)	0.019 (0.047)	-0.012 (0.031)	1.019*** (0.035)
Plant	-1.390** (0.480)	**-0.454** **(0.321)**	0.100 (0.299)	0.385 (0.205)	0.159 (0.154)	1.201*** (0.140)
Poultry	1.081 (0.739)	0.145 (0.299)	**-2.072***** **(0.560)**	0.528** (0.255)	-0.355** (0.168)	0.673** (0.231)
Wild/lamb	0.319 (0.806)	0.705 (0.365)	0.917** (0.454)	**-3.141***** **(0.539)**	0.200 (0.330)	1.000*** (0.200)
Pork	-0.325 (1.360)	0.759 (0.700)	-1.628** (0.756)	0.518 (0.840)	**-0.119** **(1.435)**	0.799** (0.296)
Final uncompensated elasticities						
	Beef	Plant	Poultry	Wild/lamb	Pork	**Income**
Beef	**-0.675**	-0.108	0.139	0.037	-0.010	1.173
Plant	-1.034	**-0.417**	0.156	0.406	0.161	1.380
Poultry	1.280	0.165	**-2.040**	0.540	-0.355	0.774
Wild/lamb	0.616	0.736	0.964	**-3.123**	0.201	1.150
Pork	-0.088	0.783	-1.591	0.532	**-0.118**	0.916

Standard errors in parenthesis (1%, 5%, 10% significance level).

6.2. Policy Scenario Analysis

Table 4 below shows the findings for the proposed scenarios in detail and indicates how the demanded quantities of every good within the supermarket's assortment and the corresponding GHG emissions react as a response to the intervention. We further determined the products' market shares. Those amount to 75% for beef, 10% for plant while remaining meats additionally lie below 12%.

Table 4. Policy analysis estimations.
Source: Own calculations, based on ICA data.

Scenario 1								
	dP	% dP	Q_0	Q_1	% dQ	GHG Q_0	GHG Q_1	%-share of dGHG
Beef	19.9	22.7	183.0	156.1	-14.7	3605.1	3074.5	-101.0
Plant	0.8	2.1	19.0	15.3	-19.5	22.8	18.3	-0.8
Poultry	1.8	4.1	29.0	36.1	24.3	72.1	89.6	3.3
Wild/lamb	6.5	8.7	11.0	10.3	-6.8	118.8	110.8	-1.5
Pork	1.4	4.2	1.0	1.0	-2.7	2.3	2.2	-0.0
Total								-13.8

Scenario 2								
	dP	% dP	Q_0	Q_1	% dQ	GHG Q_0	GHG Q_1	%-share of dGHG
Beef	19.9	22.7	183.0	158.5	-13.4	3605.1	3121.7	-98.8
Plant	-3.7	-10.0	19.0	16.3	-14.5	22.8	19.5	-0.7
Poultry	1.8	4.1	29.0	35.5	22.3	72.1	88.2	3.3
Wild/lamb	6.5	8.7	11.0	9.3	-15.7	118.8	100.2	-3.8
Pork	1.4	4.2	1.0	0.9	-12.2	2.3	2.0	-0.1
Total								-12.8

Concerning *Scenario 1*, emission-adapted taxes per average package are highest for beef within the considered assortment. Respective price increases for all goods range between 22.7% and 2.1%. In reaction, demanded quantities decrease by 14.7% for beef whereat plant-based products experience the highest relative reduction within the product range of 19.5%. Oppositely, the demand for poultry goods increases by 24.3% while wild/lamb and pork goods decrease less by 6.8% and 2.7%. While most of those findings seem reasonable, especially responses towards plant-based but also poultry products might be counter-intuitive. Given the low taxation of plant-based goods and the relatively increased financial attractiveness, minimal decreases or increases due to substitution might be anticipated. However, recalling the estimated elasticities, we found plant-based products to be very strong complements to beef. This strong relationship therefore undermines any positive consumption effect from the remaining products and leads to the heavy decrease in its consumption connected to the relatively strong taxation of beef. As indicated previously, an increase in the prices of beef entails diminishing demand effects for plant-based products. For poultry, on the other hand, resulting purchase decreases might be expected. However, as poultry is a substitute for most goods with especially high cross-effects to beef, it benefits from substitution effects. Accordingly, instead of switching to plant-based products as a response to stronger price increases for meats, consumers rather substitute with minced poultry while additionally reducing the demand for replacement goods.

Following the changes in quantities, an overall reduction in GHG emissions of 13.8% results. Given the sales data of the supermarket – with beef taking a significant share of 75% – most emission reductions stem from the product. Accordingly, its demand reduction of 14.7% accounts for more than 100% of total GHG savings. Given the low share in which plant-based goods are sold, 10%, their high decrease of 19.5% solely accounts for 0.8% among all reduced emissions. The same applies to the remaining products, where the 24.3% increase in demand for poultry goods offsets a share of 3.3% among the whole mitigation.

For *Scenario 2*, we applied the same tax levels for meats as in *Scenario 1* and subsidized prices of replacement goods by 10%. Following this, relative reductions in beef demand slightly diminish to 13.4% while those for plant-based goods fall to 14.5%. Previously forecasted relatively strong increased poultry purchases are being slowed down to 22.3%, the remaining meats experience higher demand decreases of 15.7% and 12.2% once meat analogues are promoted. As outlined previously, the strong complementarity between beef and plant-based goods but also the substitutability between replacement and other meat products, provide an explanation for those findings. The strong cross-price effect to beef also in this case offsets any potential achievements in terms of higher plant-based quantities sold. This effect however is increasingly softened the higher a subsidy is placed. In hand with that, given the effects' reciprocity, the demand for beef experiences a diminished reduction effect. Meanwhile, the fact that remaining meats experience enforced purchase decreases can be mainly based on their substitutional relationship to beef. Though, the strong cross-effects especially between beef and poultry keep the latter as a possible choice of substitute for consumers.

In terms of GHG emissions, *Scenario 2* results in lower reduction achievements compared to *Scenario 1*, of 12.8%. Mainly responsible for the reduced mitigation potential is the subsidy's effect on beef. The lower reduction in demand of 13.4% reduces its share in mitigation to 98.8%. Even though plant-based products are relatively consumed more, and other meats less compared to *Scenario 1*, effects on GHG reductions are minor considering its low sales portions. The relative increase in replacement products of 5% barely affects its GHG reduction share, by 0.1%, while changes in poultry demand remain unnoticed. Additionally, the stronger reductions in wild/lamb and pork demand of 15.7% and 12.2% increase its share solely to 3.8% and 0.1%. Accordingly, the relative higher purchases of beef as the main emitter weighs heavy in released emissions.

With regards to the obtained results, both scenarios indicate that a reduction of GHG emissions could be reached. Yet, given the existing cross-effects, *Scenario 1* is the more effective measure as higher savings in emissions are possible. Mitigation achievements due to a consumption shift from meats to plant-based however, is not reached. Given the complementarity between plant-based goods and beef, any relative increase of the former goods comes hand in hand with an increase of the latter – provoking an increase in GHG emissions given its high sales dominance.

When comparing the results to the study of Säll et al. (2020), the composition of how GHG can be reduced differs widely. Although results are consistent in that beef contributes significantly, they find remaining meats to be more important. Accordingly, beef takes a share of 75%, while the others contribute between 5% and 10% each. On the one hand, imposed tax levels differed from this work as the authors considered per kg units rather than smaller and differing average package sizes. Thus, all price alterations clearly exceeded those applied in this study. The relative price increases for beef however were lower in comparison, while those for the remaining goods were significantly higher. Given those differences, higher demand reductions with effects on GHG emissions resulted for all products though slightly for beef with 15.6%, 14% for chicken, 10% for wild/lamb and 4.1% for pork. On the other hand, the difference in sales data plays a significant role in the composition of GHG reductions. In comparison to a 75% market share for beef in our study, it solely amounts to 30% in the one of Säll et al. (2020), while pork and chicken also take large shares with 39% and 26%. Bonnet et al. (2018) even find beef to have a share of solely 14.5% among meats, while pork and chicken take 57% and 14.5%. Yet, they also confirm the highest reduction potential for beef though more balanced among all commodities. In this context, the consideration of a highly specialized commodity and a relatively rich consumer clientele in this study must be re-emphasized whose predominant preferences for minced beef determine the composition of sales data. Besides that, both studies find much lower cross-elasticities than those – especially the striking ones – estimated in this work. This is due to the prevailing spikes in the dataset. Accordingly, the lower values reduce the impact on the demand for other goods, thus inducing differing effects on GHG. This difference in cross-price elasticities additionally explains the finding that both studies found reductions in poultry demand, even though poultry was indicated as a substitute to beef. The fact that the authors of both studies considered a broader range of product categories to determine cross effects, yet without considering plant-based goods, additionally comes into play when determining the emission scheme. Given those differences, also the overall estimated mitigation potential differs. Säll et al. (2020) find a potential of 10.5% when all goods are taxed with meat being responsible for 88% in reductions. Mainly the higher price elasticities, but also the high share of beef is responsible for the relatively larger share estimated in this work.

Though no comparable studies on mixed approaches with real market data on meat analogues exist, it is highly reasonable that the mentioned aspects influence the findings for *Scenario 2* similarly. Especially the great market share of beef, combined with its strong cross-effects on poultry and plant-based goods determine the effect of quantities demanded and GHG reductions. Our findings on substitutes as complements to beef however contradict the assumption of Ritchie et al. (2018), who approximated plant-based goods to chicken as substitutes to all meats – resulting in very different effects on demand changes as well as GHG releases.

6.3. Sensitivity Analysis

By conducting a sensitivity analysis, we aim at assessing one of the uncertainties exerted on our final estimated results: the striking cross-price elasticities. To do so, we set the values between beef and plant, beef and poultry as well as pork and poultry to zero, to test their effect on the policy findings. To this end, *Table A3* in the Appendix provides a detailed listing while *Figure 3* and *Figure 4* below illustrate the shares in GHG reductions for both Scenarios (SA) compared to the original cases (Base).

Considering *Scenario 1*, decisive alterations in relative demanded quantities are noticeable. Accordingly, rather than experiencing reductions of 19.5%, plant-based demand increases by 3.9%. For minced poultry, previous augmentations of 24.3% turn into reductions of 4.7% while pork products are demanded 3.8% more instead of declining by 2.7%. Values for beef and wild/lamb decline unchanged. Despite the relative changes in demand, barely any modifications in released GHG emissions are noticeable. Slightly higher mitigation potential results, 14.2%, as poultry consumption decreases by 0.6% instead of contributing. Yet, almost no emission increases occur from plant-based as well as pork goods, 0.2% and 0.0%.

For *Scenario 2*, the relative demand for plant-based meats rises further to 9%, compared to the previous 14.5% decreases. Minced poultry experiences additional reductions of 6.8% instead of 22.3% increases, and minced pork demand falls by 5.7% compared to reductions of 12.1% before. Again, ruminants remain decreasing unchanged. In terms of GHG emissions, overall reductions amount to 13.2%. However, solely slight changes are noticeable as plant-based goods add to releases by 0.4% instead of marginally contributing to mitigation, while poultry goods take a share of 1% in reductions compared to previous small contributions. For pork, no effect is perceptible.

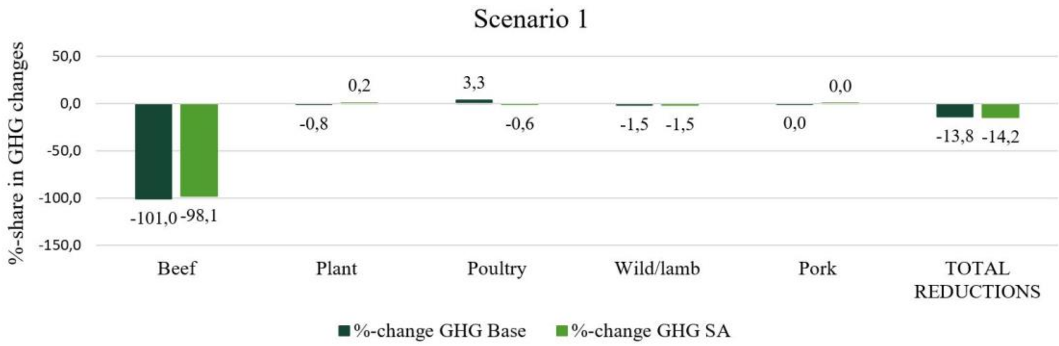

Figure 3. Shares in GHG changes Base compared to SA case for Scenario 1.
Source: Own illustration, based on ICA data.

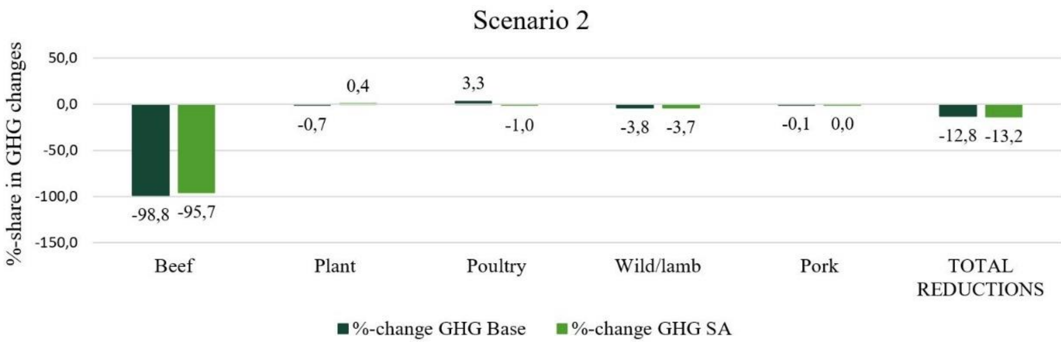

Figure 4. Shares in GHG changes Base compared to SA case for Scenario 2.
Source: Own Illustration, based on ICA data.

The performed sensitivity analysis shows that the striking cross-elasticities indeed impact the relative demanded quantities heavily. The results for both interventions indicate consumption changes towards increased demand for plant-based goods and reduced meat consumption, except for pork in *Scenario 1*. However, despite the transition from rather higher-emitting meats to low-emitting plant-based goods, almost no differing effect on the release of GHG emissions compared to the original scenarios is observable. Instead, the findings confirm the previous results that demand alterations of the respective goods – even though in line with transition achievements – only have marginal effects as long as minced beef is heavily dominating the sales while remaining, i.e. plant-based, goods have low purchasing shares.

7. Discussion & Conclusion

In view of defined mitigation targets, it was the aim of this study to further analyse the potential lying in consumption-based policies while addressing the increasingly important role of plant-based substitutes. Specifically, we investigated if taxes and subsidies across differentiated minced products could increase people's plant-based consumption in place of meat, to reduce GHG emissions. Based on estimated consumers' price sensitivity, we tested two policy scenarios intended to increase the relative attractiveness of plant-based goods as a dietary choice: a taxation according to external effects in *Scenario 1* and a mixed approach with an additional subsidy on plant-based goods in *Scenario 2*. Findings to our research question indicated that both scenarios promoted a shift in consumers' consumption patterns, leading to reduced GHG emissions. *Scenario 1* resulted in bigger savings, 13.8% within the considered assortment, compared to 12.8% in *Scenario 2.* However, a decline in meat in favour of replacement goods to mitigate emissions could not be reached in either of the scenarios. Although estimated elasticities indicated that sample consumers might perceive meat analogues as substitutes to most meats, decisively determining this scheme was the strong complementarity found to beef. This was pivotal as the analysis of our sample has shown that purchases of beef heavily dominate customers' choices while many do not perceive plant-based substitutes as valid food product, given its highly limited demand.[2] The discussed scenarios therefore either lead to a strong reduction in the relative demand for plant-based goods connected to the high taxation of beef in *Scenario 1* or additionally benefit beef consumption with a subsidy in *Scenario 2*. Thus, rather than buying more replacement goods considered consumers even prefer to reduce their consumption in case of strong beef taxation to sustain their meat purchases or use additional budget margins on further beef purchases in case of a subsidy. The corresponding effect exerted on the demand for minced beef thereby determines the emissions, whereat subsidies even induce undesired impacts on GHG releases. On the other hand, demand alterations of replacement goods were barely noticeable. Sensitivity results further emphasize their marginal effects on emissions as long as low purchasing shares prevail. Hence, significant GHG reductions for minced

[2] At this point it shall be noted that although we have looked at other meats, we focus on beef due to its strong dominance. However, numerous studies show that other meat products are consumed in similar quantities (Säll et al. (2020) or Bonnet et al. (2018) as beef, thus we neglect their low shares compared to plant-based.

goods solely can be achieved by diminished beef demand, however, not by the dietary transition towards more sustainable consumption.

The key finding that can be drawn from the scenario analysis is that price-based measures could only play an important role in stimulating people' willingness to substitute and furthering sustainable dietary switches once the average consumer accepts plant-based substitutes as a substantial food product. However, as the state is today – with only low purchasing shares – their potential is limited. In fact, Siegrist & Hartmann (2019) confirm that only few people, namely those with an increased environmental and health awareness, buy them regularly while Lemken et al. (2019) state that they remain disregarded by the majority. We therefore argue that a switch in consumers' preferences is necessarily needed as the first step to acknowledge plant-based products as a valid meat alternative in their consumption basket. The fact that meat consumption is deeply entangled in western cultures thereby comes heavily into play. In this regard, Michel et al. (2021) concluded that substitutes were perceived rather negatively compared to meats, often related to disgust or low social acceptance. Oppositely, they found the latter being sensed as a beneficial food product associated with high social acceptance, status and good health. However, Hartmann & Siegrist (2017) point out that many European consumers are not aware of the adverse environmental impacts connected to meat products – and thus the advantages plant-based products could provide – contributing to an additional lower willingness to alter their demand behaviour. Resultingly, we deduce that much more information to raise the public's awareness, change entrenched social and cultural paradigms, and increase plant-based substitutes' popularity needs to be provided. On the one side, this includes clarification on the environmental problems connected to meats. On the other side, the benefits of plant-based products need to be highlighted. For this purpose, knowledge-based policies are required. Röös et al. (2021) emphasize their potential, e.g. of labelling, information campaigns as well as nudging tools where various examples indicate prospects of success to raise awareness. Until then, while preferences are shifting, our findings indicate, that consumption-based taxes on meat – especially beef – could be used to decrease diet-related GHG emissions in Sweden, in line with those of Säll et al. (2020) and Säll & Gren (2015).

An evaluation of the suitable mitigation policy solely based on this work would, however, be precipitous. Certain restrictions constrain the results that need further consideration, though also reveal possible fields for future research. Among those, the highly restricted context with data tailored exclusively on minced meats, dominated by beef, but also to the specific clientele of the supermarket ICA Nacka limits the expressiveness of the obtained findings. Studies, e. g. of Hoek et al. (2011) and Lemken et al. (2019) show that consumers' perception of replacement products and among customer types differ thus further examination is needed.

Besides, an analysis within a comprehensive demand system is indispensable to account for policy effects among a conclusive food range. In this context, Boer et al. (2020) point to the role of fish as an alternative replacement good to meat for the promotion of sustainable diets. Not only the extent to which the intervention schemes address fish but also its interaction with plant-based analogues remains to be tested. Finally, the high and partly exceeding results based on consumption spikes in the dataset need further analysis. A longer, aggregated dataset could provide a remedy for this. This would probably also allow to perform the examination on a kg basis and thus simplify comparisons to other studies.

Research in this field is still in its infancy, just as consumers are gradually changing their behaviour. However, multiple essential starting points for the future are provided. Certain is, the way we consume must change given defined GHG mitigation targets where plant-based substitutes as a more sustainable food source could play a significant role. It is the task of future research to further explore an effective way of policymaking to contest the path of re-thinking our consumption choices and finally alter demand patterns.

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Appendix

Table A1. Test results for the second stage products.
Source: Own calculation, based on ICA data.

	Equation: EQAIDS1 Dependent variable: S1	Equation: EQAIDS2 Dependent variable: S2
Mean of dep. var.	.760809	.086211
Std. dev. of dep. var.	.047482	.020493
Sum of squared residuals	.046077	.928805E-02
Variance of residuals	.164560E-02	.331716E-03
Std. error of regression	.040566	.018213
R-squared	.281027	.184048
LM het. test	.516217 [.472]	.978432E-03 [975]
Drubin-Watson	1.09502	2.43008
	Equation: EQAIDS3 Dependent variable: S3	Equation: EQAIDS4 Dependent variable: S4
Mean of dep. var.	.084471	.048642
Std. dev. of dep. var.	.029726	.019564
Sum of squared residuals	.024808	.548265E-02
Variance of residuals	.886015E-03	.195809E-03
Std. error of regression	.029766	.013993
R-squared	.022371	.477528
LM het. test	1.60812 [.205]	.879468 [.348]
Drubin-Watson	.693597	1.48389

Note: The final equation in the estimation dropped.

Table A2. Estimates for parameter values of the second stage.
Source: Own calculation, based on ICA data.

Number of observations = 28 Log likelihood = 313.644 Schwarz B.I.C. = -259.382

Parameter	Estimate	Standard Error	t-statistic	P-value
C11	.028212	.091405	.308649	[.758]
C12	-.105077	.036769	-2.85778	[.004]
C13	.070672	.056286	1.25559	[.209]
C14	.015176	.035515	.427311	[.669]
C22	.047794	.027503	1.73780	[.082]
C23	.993328E-02	.025528	.389113	[.697]
C24	.033496	.617458	1.91871	[.055]
C33	-.093437	.048024	-1.94563	[.052]
C34	.043588	.621741	2.00486	[.045]
C44	-.101753	.025636	-3.96922	[.000]
B1	.014546	.026515	.548586	[.583]
B2	.017036	.011905	1.43102	[.152]
B3	-.027798	.019654	-1.41438	[.157]
B4	.152633E-04	.948971E-02	.160840E-02	[.999]
A1	.764001	.012258	62.3270	[.000]
A2	.080489	.554062E-02	14.5271	[.000]
A3	.083644	.902608E-02	9.26690	[.000]
A4	.055350	.425648E-02	13.0037	[.000]
RH0	-.021171	.055197	-.383551	[.701]
D1	-.026583	.104384	-.254666	[.799]
D2	.062827	.047313	1.32789	[.184]
D3	.799409E-02	.077058	.103741	[.917]
D4	-.080025	.036491	-2.19298	[.028]

Table A3. Policy analysis estimations for SA.
Source: Own calculation, based on ICA data.

Scenario 1								
	dP	% dP	Q0	Q1	% dQ	GHG Q0	GHG Q1	%-share of dGHG
Beef	19.9	22.7	183.0	156.1	-26.9	3605.1	3074.5	-98.1
Plant	0.8	2.1	19.0	19.8	0.8	22.8	23.7	0.2
Poultry	1.8	4.1	29.0	27.6	-1.4	72.1	68.7	-0.6
Wild/lamb	6.5	8.7	11.0	10.3	-0.7	118.8	110.8	-1.5
Pork	1.4	4.2	1.0	1.0	0.0	2.3	2.4	0.0
Total								-14.2
Scenario 2								
	dP	% dP	Q0	Q1	% dQ	GHG Q0	GHG Q1	%-share of dGHG
Beef	19.9	22.7	183.0	158.5	-13.4	3605.1	3121.7	-95.7
Plant	-3.7	-10.0	19.0	20.7	9.0	22.8	24.9	0.4
Poultry	1.8	4.1	29.0	27.0	-6.8	72.1	67.2	-1.0
Wild/lamb	6.5	8.7	11.0	9.3	-15.7	118.8	100.2	-3.7
Pork	1.4	4.2	1.0	0.9	-5.7	2.3	2.2	-0.0
Total								-13.2