Could taxes on foods high in fat, sugar and salt (HFSS) improve climate health and nutrition in Scotland?

Amarachi, Nneli; Revoredo-Giha, C; Dogbe, Wisdom

Published in:
Journal of Cleaner Production

DOI:
10.1016/j.jclepro.2023.138564

First published: 01/10/2023

Document Version
Publisher's PDF, also known as Version of record

Journal of Cleaner Production 421 (2023) 138564

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Could taxes on foods high in fat, sugar and salt (HFSS) improve climate health and nutrition in Scotland?

Amarachi Nneli [a], Cesar Revoredo-Giha [b], Wisdom Dogbe [c,*]

[a] School of Geosciences, University of Edinburgh, Edinburgh, United Kingdom
[b] Scotland's Rural College (SRUC), Peter Wilson Building, King's Buildings, West Mains Road, Edinburgh, EH9 3JG, United Kingdom
[c] The Rowett Institute, University of Aberdeen, Foresterhill, Aberdeen, AB25 2ZD, United Kingdom

ARTICLE INFO

Handling Editor: Giovanni Baiocchi

Keywords:
Foods high in fats
Sugar and salt (HFSS)
EASI demand
Scotland
CO_2-Eq emission
Revenue-neutral tax

ABSTRACT

Foods high in fats, sugar and salt (HFSS) have a significant impact on public health, the climate and the economy. As such, it is critical to ascertain how pricing policies could help reduce their consumption in Scotland. This study analysed secondary data of 3260 households from Kantar Worldpanel, which comprised 18 food categories consumed in Scotland. The primary objective was to simulate the implications of an excise tax imposed on HFSS food purchases on climate health and consumer welfare using uncompensated own- and cross-price elasticities estimated from the Exact Affine Stone Index demand model. Two policy scenarios were considered: taxing all HFSS while the prices of the remaining foods remain unchanged; and taxing HFSS while subsidising fruit and vegetables with the revenue generated. The results from the study indicate that imposing taxes on HFSS would reduce their consumption due to price effects. A 10% tax on HFSS food groups while subsidising fruit and vegetables with the tax revenues simultaneously brought about a 5–9% decline in the consumption of HFFS and an 11% and 7% rise in vegetable and fruit consumption respectively. Weekly per capita greenhouse gas emissions could increase by 2% if fruit and vegetables were subsidised with the tax revenues, while decreasing by 3% when only HFSS food groups were taxed. Taxing HFSS without a subsidy policy in place was more regressive on consumers than when fruit and vegetables were subsidised. In conclusion, imposing a revenue-neutral HFSS tax policy would result in a trade-off between dietary, welfare and environmental goals. The policy scenario adopted by the government would depend on the national goal being pursued.

1. Introduction

The consumption of foods high in fat, sugar and salt (HFSS) is one of the leading causes of non-communicable diseases (NCDs) such as ischaemic heart disease (IHD), stroke, certain cancers and type 2 diabetes (Rayner and Scarborough, 2005). Hypertension, a risk factor for cardiovascular disease, is caused by a high intake of salt (Strazzullo et al., 2009). Similarly, excess sugar intake, a major cause of being overweight, is a significant risk factor for diabetes and many cancers (Lauby-Secretan et al., 2016; Te Morenga et al., 2012). High-fat diets are reported to increase oxidative stress in a variety of tissues. According to Hu et al. (2001), coronary heart disease risk can be best reduced by replacing saturated fats with unsaturated fats as well as cutting down the total dietary fat.

Koengkan et al. (2023b) found a positive correlation between unhealthy food production and the prevalence of obesity, which inevitably pollutes the environment through increased fossil fuel consumption (Koengkan et al., 2023a, 2023c). The high consumption of HFSS has put a strain on economic activities, population health and the living standards of the world population. One in five deaths are attributed to the intake of energy-dense foods (Vos et al., 2017). Encarnação et al. (2016) further estimated that obesity, one of the major risk factors for non-communicable diseases (NCDs) in Europe, accounted for 40% of deaths, approximately 17 million deaths in 2012. Koengkan et al. (2023a) found that the obesity epidemic is a major driver of increased CO_2-eq emissions in Latin America.

In Scotland, 65% of adults and 28% of children are living with obesity and related conditions like type 2 diabetes, various types of cancer and heart diseases (Butland et al., 2020). Decreased consumption of fruit and vegetables, fibre and oil-rich foods among the Scottish population predisposes consumers to health problems. Diet is the main contributory factor in the prevalence of overweight and obesity as well

* Corresponding author.
E-mail addresses: A.E.Nneli@sms.ed.ac.uk (A. Nneli), wisdom.dogbe@abdn.ac.uk (W. Dogbe).

https://doi.org/10.1016/j.jclepro.2023.138564
Received 10 March 2023; Received in revised form 18 August 2023; Accepted 22 August 2023
Available online 25 August 2023

as non-communicable diseases (Food Standard Scotland, 2018a).

In 2016, a total of 6697 and 2181 deaths were recorded due to coronary heart disease and stroke. In addition, 31% of children had dental decay whilst 29% of the population had high blood pressure (Food Standard Scotland, 2018b). Non-communicable diseases such as heart disease, cancer, diabetes, stroke and liver and lung diseases are the leading causes of death in Scotland, accounting for almost two thirds of all deaths in 2020. However, studies have shown that one in five of these deaths could be prevented through public health action on unhealthy food and drinks as well as tobacco and alcohol. Estimates suggest that ill health and disability caused by tobacco, alcohol and unhealthy food and drink costs the Scottish economy between £5.6 and £9.3 billion every year (ASH Scotland, 2010; Castle, 2015; National Records of Scotland, 2020). In 2014/15 the National Health Service (NHS) spent £6.1 billion on treating obesity-related ill health. According to Public Health England, this figure is expected to increase to £9.7 billion per year by the end of 2050 (Holmes, 2021). These statistics demand that policymakers engage with the food system to address these problems.

The planet is operating almost beyond a level that is safe for humanity. Empirical studies elsewhere suggest that discretionary foods (HFSS) have a large impact on greenhouse gas emissions (Forbes et al., 2021). Therefore, there is a need to adopt climate-neutral foods to keep our planet safe. Ridoutt et al. (2021) suggest that the dietary climate footprint averages 3.4 kg CO_2-eq per person per day. Hadjikakou (2017) further notes that foods high in fat, sugar and salts (discretionary foods) account for 33–39% of the food-related climate footprint in Australia. Hendrie et al. (2016) found there to be a significant contribution of discretionary foods to GHGe in the average diet when compared to the recommended dietary requirement in Australia. These statistics reveal that the impact of food choices does not only affect personal health but also climate health and goals. Currently, no empirical estimates indicate the impact of HFSS (discretionary) on the climate in Scotland. It is believed that the figure will be similar to that of Australia however. Shifts in dietary patterns can therefore potentially provide benefits for both the environment and health. As a result, the United Nations' sustainable development goals (SDGs) highlight the need for a multifaceted, coordinated effort to limit global temperature rise to 1.5–2 °C and prevent the catastrophic effects of climate change (United Nations, 2022). This presents opportunities for current food policies to be broadened to include HFSS, which contributes to the national agricultural greenhouse gas emissions.

In recent years, there has been political interest in adopting fiscal policies as a strategy to reduce the consumption of health-damaging and carbon-intensive foods. For instance, Ludbrook (2019) suggests that taxes, food campaigns, pledges and subsidy interventions could be an economic opportunity for promoting healthy food consumption across the globe. More importantly, taxes have been described as the most efficient tool that can be used to achieve minimal consumption of HFSS foods such as sugar-sweetened beverages (SSBs), confectionery, cakes, biscuits etc. (Hagenaars et al., 2017). As a result, countries such as the USA, Denmark, Mexico, France, South Africa, Hungary and the United Kingdom etc. Have imposed taxes on different kinds of HFSS. Empirical studies assessing the effectiveness of various taxes on HFSS to reduce the consumption of SSBs, fat products and salty confectionaries have been carried out in these countries to highlight the environmental, economic and health benefits. For instance, in January 2012, France implemented a soda tax, which saw a price increase on drinks with added sugar or sweeteners, and a consequent drop in sales. Smed et al. (2016) assessed the effect of the saturated fat tax on food and nutrient intake in Denmark and found a 4% decrease in saturated fat purchases. Bødker et al. (2015) concluded that the total sale of foodstuffs decreased by 0.9%. In Mexico, Barrientos-Gutierrez et al. (2017) found that the sweetened beverage tax resulted in an average BMI reduction of 0.15 kg/m2 per person, which translates into a 2.54% reduction in obesity prevalence. In the UK (Scotland), the soft drinks industry levy (SDIL) has resulted in over 50% of manufacturers reducing the sugar content of drinks since it was announced in March 2016 – the equivalent of 45 million kilograms of sugar every year (HM Treasury, 2018).

Although many studies and reviews are addressing the implications of reducing HFSS on health (Bandy et al., 2020; Blakely et al., 2020a; Chouinard et al., 2007; Dogbe and Revoredo-Giha, 2022; Jensen and Smed, 2018; Popkin et al., 2021; Scarborough et al., 2020), to the best of our knowledge the impact of HFSS taxes on climate health is understudied. Modelling studies by Grout et al. (2022) in New Zealand concluded that taxing junk foods and sugar-sweetened beverages could improve climate health. Scotland has set an ambitious target to achieve net zero emissions of all greenhouse gas (Scottish Government, n.d.). This means that all avenues to reduce greenhouse gas emissions must be considered to meet the target.

This study differs from previous works in the UK and elsewhere as it assesses the impact of HFSS taxes on both health and the environment using rich consumer panel data. We are the first to consider the seven main types of HFSS consumed in Scotland: take-home confectionery; biscuits; take-home savouries; cakes, pastries and sugar morning; total puddings and desserts; take-home sugary drinks; and edible ice and ice cream. We also went a step further by linking the food categories in our datasets with the carbon footprint dataset to estimate the environmental implications of the policy simulations. We estimated elasticities for 18 foods and a numeraire consumed in Scotland using an Exact Affine Stone Index (EASI) demand model. The EASI demand model is the most advanced existing demand model that does not impose restrictions on the estimate Engel curves. The model also allows for the incorporation of unobserved household heterogeneity in the calculation of consumer welfare. Both own- and cross-price elasticities derived from the EASI demand model were used to simulate the effect of a 10% increase in the price of HFSS in our data. The changes in quantities were converted into changes in weekly CO_2-equivalent emissions. Finally, we designed two tax policy scenarios: 1) all HFSS were taxed whilst the remaining food groups were untaxed; and 2) all HFSS were taxed, and the revenue generated was used to subsidise fruits and vegetables consumed by 15% in our data.

2. Methods

2.1. Data

The data for this study was from Kantar Worldpanel (KWP), which was collected across 3260 households in Scotland from January to December in 2017 and 2018. Studies estimating food demand models like ours usually rely on price and quantity data and in some cases socioeconomic data. For instance, Dogbe and Gil (2018), Etilé et al. (2018), Guerrero-López et al. (2017), Liu et al. (2014), Ludbrook (2019) and Powell and Leider (2020) relied on the price and quantities of food purchased by consumers to estimate the implications of fiscal policies. Incorporating socio-demographic characteristics in the model also allows researchers to analyse the distributional impact of fiscal policies. For instance, Dogbe and Revoredo-Giha (2022) incorporated demographic characteristics into their demand model in order to compare the distributional impact of the SDIL and a tax on soft drinks in Scotland.

Following previous studies, this study used household purchase data of 18 food categories (including prices and quantities of purchases) collected over 52 weeks in Scotland. The analysis only includes the sample that remained for a minimum of 40 weeks during the data collection period. Per capita, weekly averages were used for the estimation. Factors such as household size were considered during the selection of household samples, as well as socio-demographic characteristics like the number of children and adults, age, sex, marital status and total expenditure per capita.

18 food categories were included in the analysis, along with a column for all other expenditures. These food categories were divided into discretionary and non-discretionary foods. Discretionary foods in the data include take-home confectionery, biscuits, take-home savouries,

cakes, pastries, sugar morning goods, total puddings and desserts, take-home sugary drinks, edible ices and ice cream. Dairy products, meat and fish, fats and eggs, fruit, vegetables, grains, prepared ready-to-eat foods, sugar and preserves, condiments and sauces, low-calorie soft drinks and juices and alcoholic beverages represent the non-discretionary foods, and there is a single category representing all other food and non-food products. All quantities of the food and food products were weighted/ represented in kilograms, and prices were recorded in pounds to ensure homogeneity or uniformity.

2.2. Descriptive statistics

Table 1 shows a list of food categories purchased by the average household, along with their mean budget shares and mean prices. The total mean budget share for discretionary foods is 16%, while that of non-discretionary foods was up to 70% with all other expenditures representing 14% of the mean budget share. This suggests that consumers in Scotland spent more on healthy foods in 2018, even though the prices are approximately three times higher than the discretionary food groups.

In this regard, take-home confectionery had the highest budget share of about 4% among discretionary foods, while total puddings and desserts, and edible ice and ice cream had budget shares of about 1%. Among the non-discretionary foods, sugar and preserves had the lowest budget share of 1%, while meat and fish and all other expenditure had the highest budget share of 14%.

The 'all other expenditures' category has the highest mean price of £13.44, which falls within a similar range to most non-discretionary foods, while take-home sugary drinks have the lowest mean price of £1.18. This shows that healthy foods are generally more expensive than their counterparts.

Table 2 represents the percentage of Scottish households that did not purchase the food aggregates in the data. Alcoholic beverages seem to be the least consumed foods since they have the highest percentage of about 9.29%. Grains and all other expenditures represent the most purchased products (0%), followed by prepared ready-to-eat foods and low-calorie soft drinks and juices at 2%. This shows that the foods with the least non-consuming percentages are mostly essential foods and nutrients that households use regularly and these are also easily accessed. Most of the foods with higher percentages are discretionary foods while non-discretionary foods have the lowest percentages.

The mean value, standard deviation and percentages of the socio-demographic components (age, number of children, number of adults, total expenditure per capita, marital status of the household heads and sex) are represented in Table 3. The mean value depicts the average number of household samples. As shown, age has a mean value of 49.80 and a standard deviation of 12.98. Similarly, the number of children in the household sample has a mean of 0.54 while 0.90 is the standard deviation. The number of adults is at a 2.09 mean value with a standard deviation of 2.38. The average total expenditure per capita, which demonstrates the average of the total expenditure of households over 52 weeks is 27.96, while the deviation from the sample mean is 15.00.

Table 1
Descriptive statistics (means of budget share, log prices) of each of the food categories.

Food categories	Mean budget shares (%)	Mean prices (£)
Take-home confectionery	0.04	3.40
Biscuits	0.03	5.84
Take-home savouries	0.02	8.06
Cakes, pastries and sugar morning	0.03	1.43
Total puddings and desserts	0.01	5.87
Take-home sugary drinks	0.02	1.18
Edible ice and ice cream	0.01	3.72
Dairy products	0.08	3.77
Meat and fish	0.14	8.26
Fats and eggs	0.03	3.12
Fruit	0.06	4.10
Vegetables	0.06	2.65
Grains	0.05	2.91
Prepared ready-to-eat foods	0.11	5.92
Sugar and preserves	0.01	6.19
Condiments and sauces	0.02	10.61
Low-calorie soft drinks and juices	0.05	8.30
Alcoholic beverages	0.09	10.65
All other expenditures	0.14	13.44

Source: Author's computation based on KWP dataset

Table 2
The percentage of non-consuming food households.

Food categories	Percentage of non-consuming household
Take-home confectionery	0.43%
Biscuits	0.37%
Take-home savouries	1.35%
Cakes, pastries and sugar morning	0.09%
Total puddings and desserts	2.67%
Take-home sugary drinks	2.82%
Edible ice and ice cream	8.47%
Dairy products	0.09%
Meat and fish	0.28%
Fats and eggs	0.15%
Fruit	0.52%
Vegetables	0.09%
Grains	0.00%
Prepared ready-to-eat foods	0.06%
Sugar and preserves	1.07%
Condiments and sauces	0.15%
Low-calorie soft drinks and juices	0.06%
Alcoholic beverages	9.29%
All other expenditures	0.00%

Source: Author's computation based on the KWP dataset

2.3. CO_2 equivalent emission estimation

The emission estimates for this research study were obtained from the SHARP Indicator Database (SHARP-ID). This was used to calculate the environmental impact of the observed 18 food categories in Scotland and the methodology was based on the life cycle analysis principle considering current production practices (De Valk et al., 2000). The construction of the SHARP ID was based on a total of 182 primary products from four European countries, using various publicly accessible data sources such as agri-footprint, Europe (BV, 2015); coinvent, Global Swiss Confederation (Weidema et al., 2013); and primary production reports (Kool et al., 2012) combined with European production, trade and transport data (Fausto, BACI World Trade Database and GTAP).

Fig. 1 presents the average CO_2-eq estimates for the food groups considered. Among the discretionary food groups, cakes, pastries and sugar morning have the highest average CO_2 equivalent emission per kilogram of food (6.70) with take-home sugary drinks emitting the lowest CO_2 equivalent in the category. Overall, meat and fish in the non-discretionary category have the highest average CO_2 (16.02) and take-home sugary drinks (0.51) average the lowest CO_2 equivalent emission estimate. Clune et al. (2017) found similar results when conducting a meta-analysis on red meat. The average estimate shows that dairy products, fats and eggs, and prepared ready-to-eat foods categories are in the medium range of average CO_2 equivalent emissions. Other

Table 3
Mean values and standard deviations of socio-demographic characteristics of households (%).

Variables	Mean	Standard deviation
Age	49.80	12.98
Total expenditure per capita	27.96	15.00
Number of children	0.54	0.90
Number of adults	2.09	2.38

Source: Author's computation based on the KWP dataset

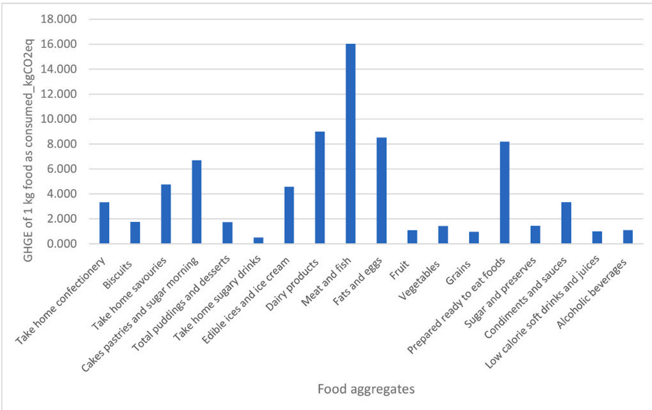

Fig. 1. Average CO_2-e (kg) per kg of food. Source: Author's computation.

remaining food categories were found to contribute less than 5g of CO_2 equivalent emission per kilogram of food.

2.4. Empirical analysis

The study used the Exact Affine Stone Index (EASI) demand model comprising real total expenditures, demographic characteristics and budget shares to estimate price and expenditure elasticities. The EASI model is an improvement on the Almost Ideal Demand System, which has been used extensively to study household demand as well as the welfare impact of fiscal policies. The major limitations of the AIDS model are that it estimates linear Engel curves and does not incorporate unobserved household heterogeneity. However, Lewbel and Pendakur's (2009) EASI demand encompasses all the advantages of the AIDS model plus allowing the Engel curve to take any form and incorporating unobserved heterogeneity in welfare estimates. Following this, Dogbe and Gil (2018), Reaños and Wölfing (2018) and Zhen et al. (2013) used the EASI demand model to simulate the policy implications of fiscal policies in Spain, Germany and the United States. Following these studies, the own-price and cross-price elasticities were estimated from an EASI demand model for Scotland. These were subsequently used to simulate the impact of HFSS value added taxes (VAT) on food purchases, consumer welfare and greenhouse gas emissions. The estimation procedure is summarised in the conceptual framework below (see Fig. 2).

2.4.1. EASI demand model

In much verifiable research, the Almost Ideal Demand System (AIDS) and its variants are used extensively because they are utility-based and can have approximate versions estimated through linear regression (Deaton and Muellbauer, 1980). Researchers have demonstrated that the AIDS model has outstanding properties and can estimate the specific preferences of consumers (Lee et al., 1994). There are, however, some limitations to the Almost Ideal Demand System. The Engel curves of the AIDS model, for instance, are linear in real expenditures (Zhen et al., 2013) unlike the EASI demand model, which can have any shape over real expenditures (Lewbel and Pendakur, 2009).

There are several advantages to the Exact Affine Stone Index (EASI) demand model, in addition to the fact that it possesses all the superior properties of AIDS. EASI budget share error terms, unlike the AIDS model, can be interpreted as unobserved heterogeneity or random utility parameters. EASI demand functions can be estimated using nonlinear three-stage least squares (3LS) and the Generalised Method of Moments (GMM) (Hansen, 1982) using the R statistical software. Lewbel and Pendakur (2009) conclude that the best demand model for demand analysis is the EASI demand model due to its various commendable properties. Literature shows that the linear approximation of the EASI demand model produces similar price elasticities to the full model (Lewbel and Pendakur, 2009).

The linear approximate EASI demand system relates to the budget shares w^j, to real food expenditure y^r, demographic characteristics z, and food prices p

$$w^j = {}_r^R = {}_0 b_r y^r + Cz + \sum_{k=1}^{j} Ap + \varepsilon \tag{1}$$

where b^r is a vector of parameters ($r = 0,1,2,3,..,5$) that control the shape of the Engel curve. y is the real expenditure deflated by the Stone index: $y = log\,(x) - (p)w'$ and x is nominal quarterly household weekly per capita expenditure; w represents the vector of mean budget shares. The matrices of parameters to be estimated are A, C and b_r. ε is the vector of error terms, which accounts for unobserved preference heterogeneity; this is important when performing welfare analysis. Table 2 shows that non-consuming households in the data range from 0 to 9.5%. Due to the low number of non-consuming households, a Tobit form of the EASI demand model where the latent budget share W^*_h is related to observed budget share w^j according to $w^j \equiv max\,(0, w^{j^*})$ was estimated. The final model was estimated using iterative 3SLS with all the conditions of symmetry, adding up homogeneity imposed on the demand model. To

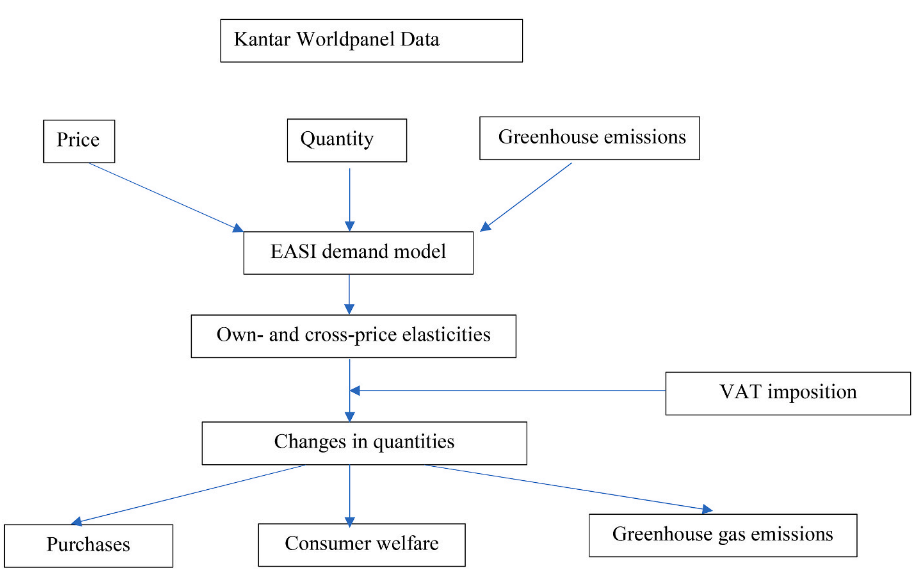

Fig. 2. A conceptual framework for assessing the impact of an HFSS tax.

correct the expenditure endogeneity in our model, Lewbel and Pendakur (2009) proposed instrumenting for the real food expenditure (y) using $\bar{y}$ defined as $\bar{y} = log(x) - log(p)\varpi'$.

2.4.2. Elasticities

Expenditure elasticities and Hicksian and Marshallian price elasticities were derived from (1) following Castellón et al. (2015) and Lewbel and Pendakur (2009). The compensated Hicksian price elasticity of demand for good k with respect to the price of the good j was derived by

$$\varepsilon = \varpi^{-1}(B) + \Omega\varpi - I \quad (2)$$

where ε is an $n\ x\ n$ matrix of compensated demand elasticities, ϖ is an identity matrix where the ones have been replaced by the group budget shares, Ω is an $n\ x\ n$ matrix of ones and I is an identity matrix.

The vector of expenditure elasticities ϑ were subsequently derived by

$$\vartheta = (\varpi)^{-1}(1 + Ap')^{-1}A + 1_n \quad (3)$$

where ϑ is the $J\ X\ 1$ vector of estimated expenditure elasticities, A is the expenditure semi-elasticity coefficients which are $\Sigma^{5}{}_{r=0}A_r y^r$, p is a vector of mean prices and 1_j is a $J \times 1$ vector of ones.

The matrix of uncompensated Marshallian elasticities was derived from the Slutsky equation given by $\varepsilon = \varepsilon - \varpi\vartheta$.

2.5. Simulation

The goal of the present study is to estimate the impact of a 10% price increase on the purchases of HFSS considering both own and cross-price elasticities. The changes in purchases were subsequently used to estimate the effect of the policy on average weekly per capita greenhouse gas emissions. Two policy scenarios were considered: 1) imposing a 10% VAT on all HFSS whilst the prices of the remaining food categories were unchanged; and 2) imposing the 10% VAT on all HFSS but subsidising the purchases of fruit and vegetables using the revenue generated from HFSS taxes (See Table 4).

Table 4
Simulation scenarios.

Food groups	CO_2-eq tax on all HFSS	CO_2-eq tax on all HFSS plus subsidy on fruit and vegetables
Take-home confectionery	T	T
Biscuits	T	T
Take-home savouries	T	T
Cakes, pastries and sugar morning	T	T
Total puddings and desserts	T	T
Take-home sugary drinks	T	T
Edible ice and ice cream	T	T
Dairy products		
Meat and fish		
Fats and eggs		
Fruit		S
Vegetables		S
Grains		
Prepared ready-to-eat foods		
Sugar and preserves		
Condiments and sauces		
Low-calorie soft drinks and juices		
Alcoholic beverages		

T = 10% VAT; S = subsidy.
Source: Author's computation

3. Results and discussion

3.1. Price and expenditure elasticities

Appendix A presents the own-price and cross-price elasticities of the food categories. All own price elasticities were found to be negative and significant at a 5% level. The own-price elasticities indicate that to increase the price of the product, holding all other factors constant would decrease the quantity demanded. Three of the 18 food categories were found to be elastic: take-home confectionery, take-home savouries, and low-calorie soft drinks and juices. This means that a unit change in price for these food products would lead to more than proportionate changes in the quantity demanded.

The remaining 15 food categories were found to be inelastic since their absolute values are less than unity. The implication is that fiscal policies aimed at decreasing or increasing consumption need to be relatively high to achieve an appreciable level of impact. Tiffin et al. (2011) also found vegetables and fruits to be inelastic, although fruits were more responsive to price changes than vegetables. This further buttresses the need to impose excise taxes on HFSS food groups and use the revenue realised to subsidise healthy food groups like fruit and vegetables.

Cross-price elasticities are off-diagonal estimates that reflect how changes in the price of one food group affect demand in other food groups (Andreyeva et al., 2010). Relationships between two products can be substitutionary or complementary. In our result, 200 complementarities and 142 substitutions were observed among the food categories. Complimentary commodities are purchased and consumed together while substitute goods can be replaced easily by other goods with the same or similar utility. All compliments have negative cross-price elasticities while the positive cross-price elasticities are the substitutes. Appendix A shows that cross-price elasticities can be elastic, inelastic and unit elastic depending on how consumers react to price changes.

For example, total puddings and desserts, take-home sugary drinks, vegetables, prepared ready-to-eat foods, sugar and preserves, and condiments and sauces were found to be substitutes for fruits, whilst the rest were complements. This is reasonable because meat and fish are complementary to fruit. Grains are also complementary to fruits, indicating that consumers buy these categories together. Therefore, an increase in the price of fruit could lead to a reduction in purchases of grains, meat and fish etc.

All expenditure elasticities were found to be positive and significant at the 1% level. Expenditure elasticities measure the degree of responsiveness of consumers to expenditure changes. Expenditure elasticities serve as a tool to classify foods or goods as necessities or luxuries in demand analysis (Pawlowski and Breuer, 2013). Appendix A shows the expenditure elasticities of all 18 food categories and a numeraire estimated at the variable means. The study found all the HFSS foods to be elastic, indicating that they are luxury goods in the consumers' budget. This shows that Scottish households do not consider these foods vital for their wellbeing. All non-discretionary food groups are inelastic in demand except for low-calorie soft drinks and juices (1.010). The reason for this could be that most of the foods in the non-discretionary categories are considered staple foods necessary to keep the body functioning. Therefore, household budgets were perhaps spent on these food groups. However, it is interesting to note that Scottish households consider fruits (0.919) and vegetables (0.935) as necessities in the food basket, although this is almost likened to being unit elastic and as such subsidies on such healthy food groups would encourage healthy diets in Scottish households. These findings are similar to those of Ecker and Qaim (2008) who found fruits (0.424) and other vegetables (0.432) to be normal goods. Overall, take-home sugary drinks (1.221) react most to food expenditure changes, while alcoholic beverages (0.883) are less likely to be responsive to food expenditure changes.

3.2. Impact of HFSS excise tax on food purchases

The negative effect of HFSS consumption has prompted policymakers and researchers to explore policy instruments to encourage healthy diets. This could be achieved by increasing the prices of HFSS foods through excise taxes and applying subsidies on healthy foods. Fig. 3 shows the impact of the fiscal policy on the 18 food categories. First, taxes were imposed on all HFSS whilst the prices of non-taxed foods remained the same. From the graph, it can be observed that a 10% excise tax on HFSS food groups results in a reduction of HFSS consumption in households in Scotland. HFSS reduced by 6–10% after taxes; edible ices and ice cream had the lowest reduction, whilst total puddings and desserts and take-home sugary drinks had the highest reduction. The policy had unintended effects on non-taxed foods. For instance, the consumption of fruits and vegetables was reduced by 2 and 5% respectively. On the other hand, the demand for dairy products and grains increased by 2%. Reductions in the remaining food groups are between 0 and 5%.

However, the second policy scenario shows that taxing HFSS whilst subsidising the prices of fruit and vegetables with the revenue generated led to a significant impact on the consumption of both HFSS and non-discretionary foods. Again, Fig. 3 shows a decline in the consumption of HFSS by 5–9% after subsidies were imposed. A 15% subsidy on fruits and vegetables resulted in an increase in the quantities demanded by 11% and 7% respectively. Although dairy products, meat and fish, grains, fats and eggs and alcoholic beverages experienced higher demand, there was an insignificant change in the consumption rate of condiments and sauces, and sugar and preserves after imposing HFSS taxes and subsidies.

3.3. Impact on CO_2 equivalent emission (CO_2-eq) tax on food demand

This section assesses the change in CO_2 equivalent emissions after the tax imposition. Fig. 4 shows that this study simulated two different policy scenarios – the impact of the policy on weekly per capita greenhouse gas emissions when all HFSS are taxed versus when all HFSS are taxed while fruits and vegetables are subsidised.

From the analysis, it can be deduced that a food policy where all HFSS food groups are taxed would be more effective in cutting down CO_2 equivalent emissions from household food sources. The graph represents the average percentage change in weekly emissions in Scottish households across a 52-week period.

On average, the government could reduce emissions by about 3% when all HFSS are taxed and the prices of the remaining food categories are unchanged. However, government policy that seeks to increase the price of HFSS through taxes while subsidising fruit and vegetables would increase overall weekly per capita emissions by approximately 2%. This suggests that to achieve better climate health, there would be a trade-off resulting in less consumption of fruit and vegetables – a negative impact on nutrition. It is therefore important for governments and stakeholders to consider which of these goals are most pressing and pursue their policy goals wisely.

3.4. Impact of CO_2-eq tax on consumer welfare

Taxation of less healthy foods and subsidisation of fruit and vegetables are seen as a multidimensional strategy to improve health outcomes in Scotland and the UK at large. However, it is critical to ascertain the impact of such policies on consumer welfare considering the current economic crisis in Scotland due to Covid-19 and the Russian invasion of Ukraine.

Fig. 5 shows the impact of the policies on consumer welfare. Consumer welfare was estimated using the log of living cost index proposed by Pendakur and Lewbel (2009). The figure shows the increase in expenditure required for the consumer to consume the same basket of goods before the implementation of the fiscal policies. When all HFSS are taxed while prices of untaxed foods remain the same, the average consumer would expect about a 16% increase in expenditure to meet his/her previous consumption. This means that taxing HFSS impacts the total food expenditure of a household because a price increase due to taxes does not warrant an increase in household income. However, when HFSS are taxed and fruit and vegetables are subsidised, consumers

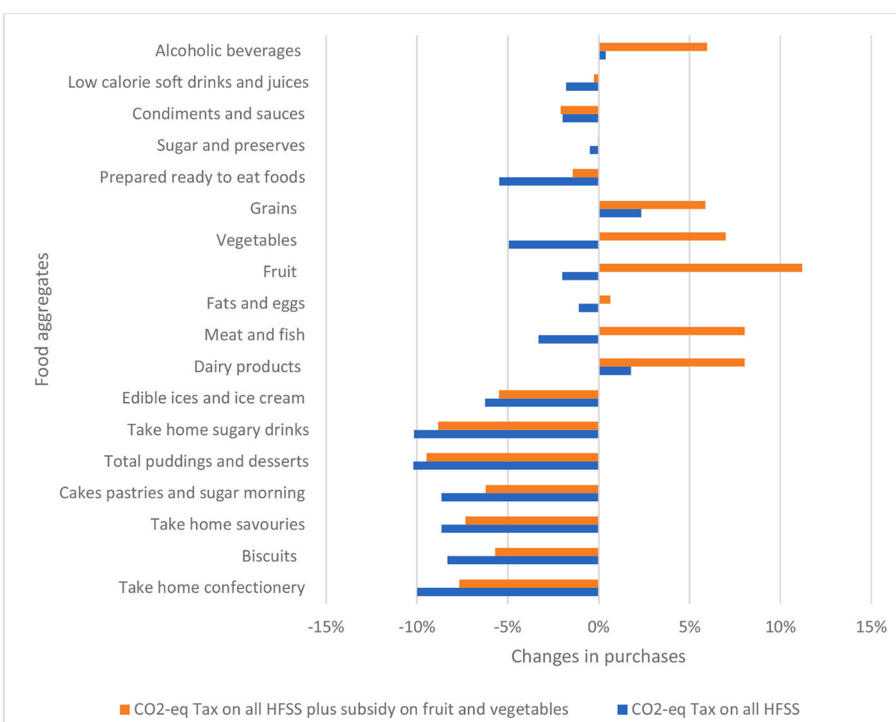

Fig. 3. Impact of fiscal policy on food purchases. Source: Author's computation.

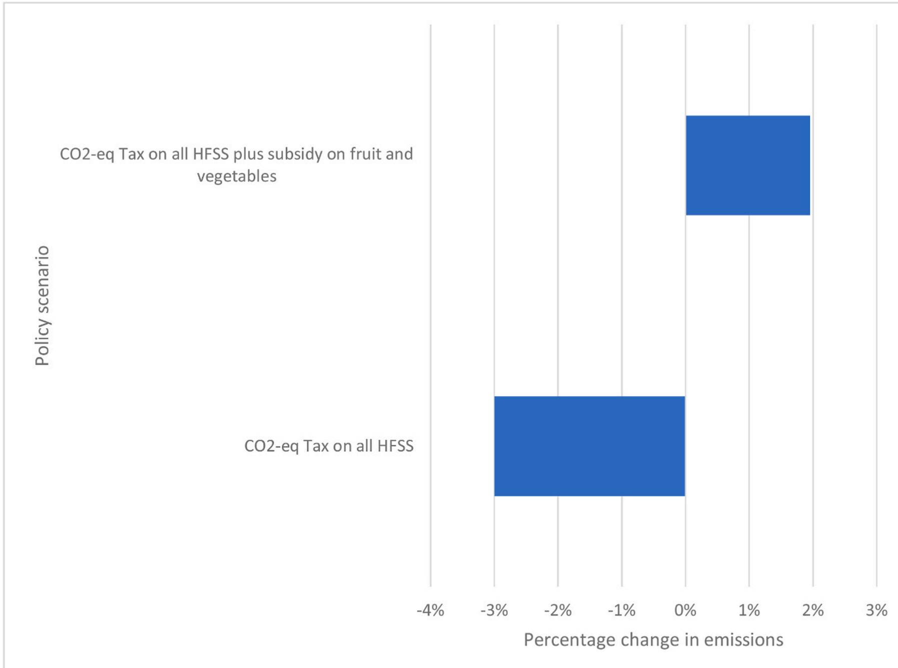

Fig. 4. Percentage change in weekly emissions. Source: Author's computation.

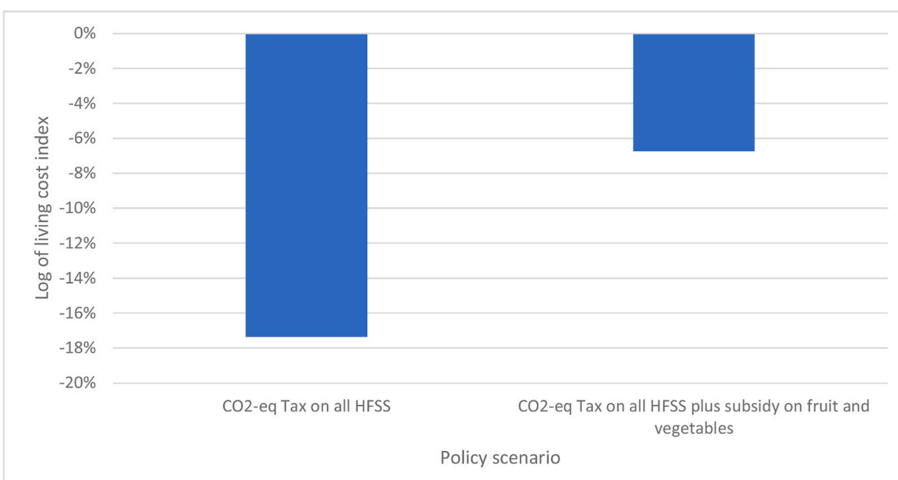

Fig. 5. Impact of policies on consumer welfare.
Source: Author's computation

require an additional 6% increase in expenditure to meet their initial consumption. In summary, consumers are worse off when all HFSS are taxed and there are no subsidies. Implementing both tax policies and subsidising consumers with the income from such policies is a less regressive public policy (Broeks et al., 2020).

3.5. Discussion

The results show that taxing HFSS reduces their purchase for the average consumer. This result is confirmed in previous studies in other countries. For instance, Blakely et al. (2020b) found that an 8% tax on junk foods could improve health and result in health expenditure savings through reduced consumption. Bíró (2015) also found that the Hungary junk food tax made Hungarians healthy by reducing their consumption of junk foods. In our analysis, consumers were expected to increase their consumption of fruits and vegetables even though they were not the focus of the policy.

Fernandez and Raine (2019) suggest that to maximise the impacts of SSB taxation, it should be combined with interventions that increase access to non-sweetened beverages. As a result, the second policy scenario combined the HFSS tax with subsidies on fruit and vegetables. The impact of this policy scenario was higher on both HFSS (lower intake) and fruit and vegetable purchases (high intake) than in the first scenario. This potentially translates into a higher impact on population health. This is confirmed by Saha et al. (2021) who found that a combination of VAT and subsidy is more effective than VAT or subsidy alone. Similarly, Cobiac et al. (2017) found that combining both subsidies and taxes is more effective in improving population health and lowering expenditure on health. However, these previous studies did not account for the welfare and the environmental impact of the policies.

Our study shows that taxing HFSS alone is more regressive on consumers than when both taxes and subsidies are used. Previous studies assessing the welfare impact of food and/or nutrient taxes include Batis et al. (2016), Bíró (2015), Colchero et al. (2017), Etilé et al. (2018), Phulkerd et al. (2020) and Teng et al. (2021). These authors found that taxing junk foods harms welfare, especially among lower-income households. A study by Dogbe and Gil (2018) is also similar to ours; the authors found that combining both taxes and subsidies reduces the impact on consumer welfare.

Our results also suggest that taxing HFSS has the potential to reduce the environmental footprint of household food consumption. Although the food groups and study area differ, Grout et al. (2022) confirmed that taxing junk foods led to decreases in GHG emissions from baseline diets in their study.

The potential trade-offs between diet quality, welfare and environmental footprints resulting from HFSS taxes have not been captured in previous studies. The magnitude and the directions of the trade-offs are incomparable. However, the strong trade-offs between welfare and environmental gains are found in aquaculture (Macaulay et al., 2022) and technical efficiency studies (Ait Sidhoum et al., 2022), indicating that one-size-fits-all policies do not exist in the real world.

4. Conclusion

This study aims to estimate the impact of excise taxes on foods high in fats, sugar and salt (HFSS) on CO_2-equivalent emissions and consumer welfare in Scotland. The paper applied the Exact Affine Stone Index Implicit Marshallian demand system to estimate the demand elasticities for seven HFSS food categories purchased in Scotland.

From the analysis, it is deduced that households in Scotland spend more on healthy foods (80%) than foods high in fats, sugar and salt (HFSS) (16%) even when their prices are higher than HFSS food groups.

From the simulation analysis, this study calculated the impact of introducing an HFSS excise tax on the 18 food categories while considering two policy scenarios: a 10% tax on HFSS and zero tax on non-discretionary food groups; and a 10% excise tax on HFSS and a revenue-neutral subsidy on fruit and vegetables.

In the first policy scenario, the excise tax reduced the purchases of HFSS but had an unintended effect on non-taxed foods i.e., the consumption of fruit and vegetables reduced by 2% and 5% respectively. The second policy scenario not only reduced HFSS consumption in Scottish households by 5–9% but also resulted in an 11% and 7% increase in the consumption of fruit and vegetables respectively.

The impact of the excise tax on greenhouse emissions could be positive or negative depending on the policy scenario adopted by the government. Taxing HFSS without any subsidy policy in place could reduce CO_2-eq emissions by 3%. However, taxing HFSS whilst subsidising fruits and vegetables would result in about a 2% increase in CO_2-eq emissions.

In the welfare context, in the scenario without the subsidy, consumers would require a 16% increase in their food expenditure to meet previous household food consumption, while they would only require about a 6% (10% less) increase in their expenditure if both the excise tax and subsidies were applied. The policy adopted by the government would imply a trade-off between environmental, dietary and welfare goals.

4.1. Policy recommendations

First, our results suggest that taxing HFSS reduces consumption. It is therefore recommended that government and policymakers consider fiscal policy as a tool to change consumer behaviour, especially regarding unhealthy foods. This can be adopted as a VAT, tiered tax or excise tax. Second, the current research found that imposing both taxes and subsidies could achieve greater results than when taxes are used alone. We recommend that the government consider adopting a revenue-neutral tax policy when tackling the consumption of unhealthy foods for maximum impact. Targeting the most vulnerable groups, the revenue generated from the tax could be given as a subsidy i.e., vouchers for fruit and vegetables, to encourage their consumption. Finally, the current work shows that imposing a revenue-neutral tax policy could result in a trade-off between welfare and climate goals. This indicates that a one-size-fits-all policy cannot work. We recommend that stakeholders consider the national goals before adopting either of the policy scenarios proposed in this paper. For instance, where the goal of the government is to raise revenues or decrease emissions, the government could adopt policy scenario one, but where the goal is to improve health or shift consumption towards healthy foods, the second policy scenario works better.

4.2. Limitations and recommendations for future research

The research had limitations that should be explored when conducting future research in this area. The simulation in the current research work is based on long-run demand elasticities. This has the potential to bias the results from the simulation. Future research should either consider using short-run demand elasticities or compare the results from the two types of elasticities. The study also used data from Scotland, and as such the results should be interpreted with caution as consumers in different geographical areas may react differently to pricing policies. The CO_2-eq emission was derived from the SHARP Indicator Database, which is averaged from EU countries. Food ingredients and manufacturing processes differ from country to country. As a result, the CO_2-eq data may not be a true reflection of foods purchased in Scotland. Future research should consider using CO_2-eq data from foods manufactured in Scotland to give a true reflection of emission levels from foods. The current research assumed that the government fiscal policy does not affect the supply of HFSS. However, this may not be true when suppliers react to the policy by decreasing production or shifting towards the production of untaxed products. This would offset the magnitude of the impact of the policy. Future research could consider the interaction between demand and supply when estimating the impact of fiscal policies. Finally, the current research does not take into account food-away-from-home (FAFH), and so it potentially underestimates the effect of the policy on both consumer welfare and greenhouse gas emissions per capita. We therefore recommend that future research considers using both food-at-home (FAH) and FAFH to assess the impact of the policy.

Funding

This paper derives from work under Topics B4 (Food supply and security) and B5 (Food and Drink Improvement), which are part of the Scottish Government—Rural and Environment Science and Analytical Services Division (RESAS) as part of their Strategic Research Programme 2022-27.

CRediT authorship contribution statement

Amarachi Nneli: Writing – original draft, Writing – review & editing. **Cesar Revoredo-Giha:** Data curation. **Wisdom Dogbe:** Conceptualization, Methodology, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

Appendix A. Price and expenditure elasticities

	1	2	3	4	5	6	7	8	9	10
Take-home confectionery (1)	**−1.022**	−0.024	−0.064	0.031	0.056	−0.004	0.028	0.006	−0.023	0.008
	(0.018)	(0.016)	(0.018)	(0.014)	(0.025)	(0.024)	(0.031)	(0.009)	(0.009)	(0.013)
Biscuits (2)	−0.021	**−0.792**	0.071	0.062	−0.101	0.005	−0.055	0.006	0.008	−0.020
	(0.011)	(0.041)	(0.035)	(0.02)	(0.042)	(0.026)	(0.052)	(0.01)	(0.009)	(0.018)
Take-home savouries (3)	−0.042	0.062	**−1.081**	0.030	0.088	−0.022	0.100	0.047	−0.015	0.014
	(0.011)	(0.03)	(0.051)	(0.02)	(0.043)	(0.027)	(0.054)	(0.01)	(0.009)	(0.018)
Cakes, pastries and sugar morning (4)	0.022	0.074	0.042	**−0.984**	−0.039	−0.003	0.023	0.001	−0.014	−0.021
	(0.011)	(0.023)	(0.027)	(0.025)	(0.035)	(0.026)	(0.044)	(0.01)	(0.009)	(0.016)
Total puddings and desserts (5)	0.014	−0.042	0.042	−0.015	**−0.987**	0.026	−0.058	−0.011	0.023	−0.014
	(0.007)	(0.017)	(0.02)	(0.012)	(0.036)	(0.017)	(0.032)	(0.006)	(0.006)	(0.011)
Take-home sugary drinks (6)	−0.003	0.007	−0.017	−0.001	0.050	**−0.979**	−0.073	0.046	−0.017	0.027
	(0.013)	(0.02)	(0.024)	(0.017)	(0.032)	(0.038)	(0.04)	(0.01)	(0.009)	(0.016)
Edible ice and ice cream (7)	0.007	−0.020	0.046	0.008	−0.053	−0.036	**−0.577**	−0.006	−0.007	−0.024
	(0.008)	(0.02)	(0.024)	(0.015)	(0.03)	(0.02)	(0.052)	(0.007)	(0.007)	(0.013)
Dairy products (8)	−0.006	0.013	0.156	−0.008	−0.080	0.164	−0.061	**−0.963**	0.034	0.022
	(0.019)	(0.029)	(0.034)	(0.025)	(0.046)	(0.04)	(0.058)	(0.021)	(0.014)	(0.023)
Meat and fish (9)	−0.119	0.025	−0.108	−0.089	0.262	−0.159	−0.142	0.052	**−0.745**	−0.091
	(0.03)	(0.047)	(0.054)	(0.04)	(0.073)	(0.063)	(0.092)	(0.024)	(0.031)	(0.036)
Fats and eggs (10)	−0.002	−0.023	0.014	−0.023	−0.035	0.030	−0.069	0.006	−0.017	**−0.789**
	(0.009)	(0.018)	(0.021)	(0.014)	(0.027)	(0.021)	(0.034)	(0.008)	(0.007)	(0.018)
Fruit (11)	−0.030	−0.039	−0.046	−0.073	0.051	0.027	−0.091	−0.092	−0.023	−0.044
	(0.021)	(0.028)	(0.033)	(0.025)	(0.045)	(0.041)	(0.056)	(0.016)	(0.015)	(0.023)
Vegetables (12)	−0.037	−0.154	0.007	−0.056	−0.120	−0.114	−0.021	−0.024	−0.102	−0.004
	(0.017)	(0.03)	(0.035)	(0.025)	(0.047)	(0.037)	(0.058)	(0.014)	(0.013)	(0.022)
Grains (13)	−0.002	0.010	0.151	0.044	−0.023	0.096	−0.041	−0.055	−0.057	−0.017
	(0.013)	(0.029)	(0.034)	(0.021)	(0.043)	(0.03)	(0.054)	(0.011)	(0.01)	(0.019)
Prepared ready-to-eat foods (14)	−0.059	−0.082	−0.137	−0.007	−0.002	−0.093	−0.168	−0.076	0.087	−0.046
	(0.029)	(0.049)	(0.057)	(0.041)	(0.077)	(0.063)	(0.096)	(0.024)	(0.022)	(0.038)
Sugar and preserves (15)	0.007	−0.028	0.009	−0.011	−0.027	0.023	−0.022	0.007	−0.015	0.032
	(0.006)	(0.014)	(0.016)	(0.01)	(0.021)	(0.015)	(0.026)	(0.006)	(0.005)	(0.009)
Condiments and sauces (16)	−0.025	−0.043	−0.076	−0.008	0.001	−0.036	−0.011	0.041	0.010	0.043
	(0.007)	(0.015)	(0.018)	(0.012)	(0.023)	(0.017)	(0.029)	(0.006)	(0.006)	(0.011)
Low-calorie soft drinks and juices (17)	−0.063	0.028	−0.074	−0.003	−0.018	−0.059	0.009	0.051	−0.007	0.036
	(0.012)	(0.014)	(0.016)	(0.013)	(0.022)	(0.022)	(0.028)	(0.008)	(0.008)	(0.012)
Alcoholic beverages (18)	0.069	−0.024	0.016	−0.001	−0.023	−0.033	0.035	−0.006	−0.011	0.019
	(0.021)	(0.02)	(0.022)	(0.019)	(0.031)	(0.033)	(0.039)	(0.013)	(0.012)	(0.017)
Others (19)	0.096	0.001	−0.003	−0.017	−0.022	−0.034	0.030	−0.027	−0.050	−0.084
	(0.02)	(0.023)	(0.023)	(0.021)	(0.014)	(0.021)	(0.017)	(0.032)	(0.054)	(0.017)

Appendix APrice and expenditure elasticities cont'd

	11	12	13	14	15	16	17	18	19	Expenditure
Take-home confectionery (1)	−0.008	−0.014	0.008	−0.011	0.030	−0.040	−0.045	0.044	0.032	1.218
	(0.014)	(0.011)	(0.01)	(0.01)	(0.018)	(0.016)	(0.01)	(0.009)	(0.02)	0.025
Biscuits (2)	−0.014	−0.067	0.008	−0.017	−0.050	−0.057	0.017	−0.002	−0.001	1.049
	(0.012)	(0.014)	(0.016)	(0.012)	(0.026)	(0.022)	(0.008)	(0.006)	(0.023)	0.023
Take-home savouries (3)	−0.015	0.004	0.076	−0.026	0.016	−0.092	−0.036	0.009	−0.002	1.060
	(0.013)	(0.014)	(0.017)	(0.012)	(0.026)	(0.022)	(0.008)	(0.006)	(0.023)	0.026
Cakes, pastries and sugar morning (4)	−0.032	−0.025	0.033	0.003	−0.019	−0.006	0.001	0.007	−0.003	1.121
	(0.013)	(0.013)	(0.014)	(0.011)	(0.023)	(0.02)	(0.008)	(0.007)	(0.021)	0.022
Total puddings and desserts (5)	0.010	−0.022	−0.005	0.000	−0.021	0.002	−0.004	−0.001	−0.003	1.023
	(0.008)	(0.009)	(0.01)	(0.007)	(0.016)	(0.014)	(0.005)	(0.004)	(0.014)	0.036
Take-home sugary drinks (6)	0.015	−0.035	0.046	−0.012	0.037	−0.034	−0.022	0.000	−0.003	1.221
	(0.014)	(0.013)	(0.013)	(0.011)	(0.022)	(0.019)	(0.01)	(0.007)	(0.021)	0.038
Edible ices and ice cream (7)	−0.013	−0.002	−0.007	−0.013	−0.014	−0.004	0.004	0.007	0.002	1.164
	(0.01)	(0.01)	(0.012)	(0.009)	(0.019)	(0.016)	(0.006)	(0.004)	(0.017)	0.045
Dairy products (8)	−0.115	−0.028	−0.090	−0.052	0.044	0.185	0.086	0.004	−0.023	0.998
	(0.021)	(0.019)	(0.019)	(0.017)	(0.032)	(0.028)	(0.014)	(0.012)	(0.032)	0.016
Meat and fish (9)	−0.050	−0.236	−0.166	0.103	−0.160	0.075	−0.032	−0.007	−0.068	0.967
	(0.034)	(0.03)	(0.03)	(0.028)	(0.05)	(0.044)	(0.023)	(0.019)	(0.054)	0.015
Fats and eggs (10)	−0.019	−0.002	−0.010	−0.012	0.063	0.064	0.019	0.008	−0.021	0.947
	(0.01)	(0.01)	(0.011)	(0.009)	(0.018)	(0.016)	(0.007)	(0.005)	(0.017)	0.020
Fruit (11)	**−0.714**	0.050	−0.047	0.029	0.066	0.026	−0.006	−0.034	−0.016	0.919
	(0.032)	(0.02)	(0.019)	(0.018)	(0.031)	(0.028)	(0.016)	(0.015)	(0.034)	0.026
Vegetables (12)	0.050	**−0.635**	−0.044	0.023	0.013	0.204	0.065	−0.006	−0.033	0.935
	(0.019)	(0.025)	(0.019)	(0.016)	(0.031)	(0.027)	(0.013)	(0.011)	(0.031)	0.019
Grains (13)	−0.036	−0.035	**−0.754**	0.010	0.009	0.042	−0.001	−0.007	−0.017	0.948
	(0.015)	(0.015)	(0.024)	(0.013)	(0.028)	(0.023)	(0.009)	(0.007)	(0.025)	0.016

(*continued on next page*)

(*continued*)

	11	12	13	14	15	16	17	18	19	Expenditure
Prepared ready-to-eat foods (14)	0.060	0.046	0.026	**−0.822**	−0.192	−0.322	−0.079	−0.018	−0.048	0.974
	(0.033)	(0.031)	(0.031)	(0.038)	(0.052)	(0.045)	(0.022)	(0.018)	(0.055)	0.017
Sugar and preserves (15)	0.015	0.002	0.002	−0.024	**−0.872**	0.027	0.027	0.006	−0.008	0.939
	(0.007)	(0.007)	(0.008)	(0.006)	(0.019)	(0.012)	(0.005)	(0.004)	(0.012)	0.026
Condiments and sauces (16)	0.007	0.062	0.015	−0.055	0.035	**−0.973**	0.006	0.002	−0.007	0.889
	(0.009)	(0.009)	(0.009)	(0.007)	(0.015)	(0.018)	(0.006)	(0.004)	(0.014)	0.023
Low calorie soft drinks and juices (17)	−0.001	0.054	0.002	−0.031	0.092	0.019	**−1.056**	0.019	0.003	1.010
	(0.013)	(0.01)	(0.009)	(0.009)	(0.016)	(0.014)	(0.013)	(0.009)	(0.018)	0.021
Alcoholic beverages (18)	−0.055	−0.016	−0.020	−0.023	0.028	0.006	0.024	**−0.904**	−0.020	0.883
	(0.022)	(0.016)	(0.014)	(0.014)	(0.023)	(0.02)	(0.017)	(0.036)	(0.035)	0.039
Others (19)	−0.011	−0.055	−0.030	−0.042	−0.049	−0.020	0.022	−0.001	**−0.861**	1.085
	(0.034)	(0.031)	(0.025)	(0.055)	(0.012)	(0.014)	(0.018)	(0.035)	(0.683)	0.040

References

Ait Sidhoum, A., Dakpo, K.H., Latruffe, L., 2022. Trade-offs between economic, environmental and social sustainability on farms using a latent class frontier efficiency model: evidence for Spanish crop farms. PLoS One 17 (1), e0261190. https://doi.org/10.1371/journal.pone.0261190.

Andreyeva, T., Long, M.W., Brownell, K.D., 2010. The impact of food prices on consumption: a systematic review of research on the price elasticity of demand for food. Am. J. Publ. Health 100 (2), 216–222. https://doi.org/10.2105/AJPH.2008.151415.

ASH Scotland, 2010. Up in Smoke: tobacco economic cost of tobacco in Scotland. https://www.ashscotland.org.uk/media/4634/Up_in_smoke_Nov2010_web.pdf.

Bandy, L.K., Scarborough, P., Harrington, R.A., Rayner, M., Jebb, S.A., 2020. Reductions in sugar sales from soft drinks in the UK from 2015 to 2018. BMC Med. 18 (1), 20. https://doi.org/10.1186/s12916-019-1477-4.

Barrientos-Gutierrez, T., Zepeda-Tello, R., Rodrigues, E.R., Colchero-Aragonés, A., Rojas-Mart\`\inez, R., Lazcano-Ponce, E., Hernández-Ávila, M., Rivera-Dommarco, J., Meza, R., 2017. Expected population weight and diabetes impact of the 1-peso-per-litre tax to sugar sweetened beverages in Mexico. PLoS One 12 (5), e0176336.

Batis, C., Rivera, J.A., Popkin, B.M., Taillie, L.S., 2016. First-year evaluation of Mexico's tax on nonessential energy-dense foods: an observational study. PLoS Med. 13 (7), e1002057 https://doi.org/10.1371/JOURNAL.PMED.1002057.

Bíró, A., 2015. Did the junk food tax make the Hungarians eat healthier? Food Pol. 54, 107–115. https://doi.org/10.1016/J.FOODPOL.2015.05.003.

Blakely, T., Cleghorn, C., Mizdrak, A., Waterlander, W., Nghiem, N., Swinburn, B., Wilson, N., Ni Mhurchu, C., 2020a. The effect of food taxes and subsidies on population health and health costs: a modelling study. Lancet Public Health 5 (7), e404–e413. https://doi.org/10.1016/S2468-2667(20)30116-X.

Blakely, T., Cleghorn, C., Mizdrak, A., Waterlander, W., Nghiem, N., Swinburn, B., Wilson, N., Ni Mhurchu, C., 2020b. The effect of food taxes and subsidies on population health and health costs: a modelling study. Lancet Public Health 5 (7), e404–e413. https://doi.org/10.1016/S2468-2667(20)30116-X.

Bødker, M., Pisinger, C., Toft, U., Jørgensen, T., 2015. The Danish fat tax—effects on consumption patterns and risk of ischaemic heart disease. Prev. Med. 77, 200–203. https://doi.org/10.1016/j.ypmed.2015.03.031.

Broeks, M.J., Biesbroek, S., Over, E.A.B., Van Gils, P.F., Toxopeus, I., Beukers, M.H., Temme, E.H.M., 2020. A social cost-benefit analysis of meat taxation and a fruit and vegetables subsidy for a healthy and sustainable food consumption in The Netherlands. BMC Publ. Health 20 (1), 1–12.

Butland, B., Jebb, S., Kopelman, P., McPherson, K., Thomas, S., Mardell, J., Parry, V., 2020. Foresight. tackling obesities: future choices. Project Report 2, 1–164. Foresight. Tackling Obesities: Future Choices. Project Report. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/287937/07-1184x-tackling-obesities-future-choices-report.pdf.

Bv, B.A.F., 2015. Agri-footprint 2.0–Part 1: Methodology and Basic Principles, vol. 34. Gravin Beatrixstraat, Netherlands, p. 2805.

Castellón, C.E., Boonsaeng, T., Carpio, C.E., 2015. Demand system estimation in the absence of price data: an application of Stone-Lewbel price indices. Appl. Econ. 47 (6), 553–568.

Castle, A., 2015. Obesity in Scotland. http://archive2021.parliament.scot/ResearchBriefingsAndFactsheets/S4/SB_15-01_Obesity_in_Scotland.pdf.

Chouinard, H.H., Davis, D.E., LaFrance, J.T., Perloff, J.M., 2007. Fat taxes: big money for small change. Forum Health Econ. Pol. 10 (2).

Clune, S., Crossin, E., Verghese, K., 2017. Systematic review of greenhouse gas emissions for different fresh food categories. J. Clean. Prod. 140, 766–783.

Cobiac, L.J., Tam, K., Veerman, L., Blakely, T., 2017. Taxes and subsidies for improving diet and population health in Australia: a cost-effectiveness modelling study. PLoS Med. 14 (2), e1002232 https://doi.org/10.1371/journal.pmed.1002232.

Colchero, M.A., Rivera-Dommarco, J., Popkin, B.M., Ng, S.W., 2017. In Mexico, evidence of sustained consumer response two years after implementing a sugar-sweetened beverage tax. Health Aff. 36 (3), 564–571.

De Valk, H., Vaillant, V., Goulet, V., 2000. Epidemiology of human Listeria infections in France. Bull. Acad. Natl. Med. 184 (2), 267.

Deaton, A., Muellbauer, J., 1980. An almost ideal demand system. Am. Econ. Rev. 70 (3), 312–326.

Dogbe, W., Gil, J.M., 2018. Effectiveness of a carbon tax to promote a climate-friendly food consumption. Food Pol. 79 https://doi.org/10.1016/j.foodpol.2018.08.003.

Dogbe, W., Revoredo-Giha, C., 2022. Industry levy versus banning promotion on soft drinks in Scotland: a distributional analysis. Food Pol. 106, 102191 https://doi.org/10.1016/J.FOODPOL.2021.102191.

Ecker, O., Qaim, M., 2008. Income and Price Elasticities of Food Demand and Nutrient Consumption in Malawi.

Encarnação, R., Lloyd-Williams, F., Bromley, H., Capewell, S., 2016. Obesity prevention strategies: could food or soda taxes improve health? J. Roy. Coll. Phys. Edinb. 46 (1), 32–38.

Etilé, F., Lecocq, S., Boizot-Szantai, C., 2018. The incidence of soft-drink taxes on consumer prices and welfare: evidence from the French " soda tax.". https://halshs.archives-ouvertes.fr/halshs-01808198.

Fernandez, M.A., Raine, K.D., 2019. Insights on the influence of sugar taxes on obesity prevention efforts. Curr. Nutr. Rep. 8 (4), 333–339. https://doi.org/10.1007/s13668-019-00282-4.

Food Standard Scotland, 2018a. Situation Report: the Scottish Diet: it Needs to Change. 2018 Update, pp. 1–36. Aberdeen. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.foodstandards.gov.scot/downloads/Situation_report_-_the_Scottish_diet_-_it_needs_to_change_-_2018_update_FINAL.pdf.

Food Standard Scotland, 2018b. Situation Report: the Scottish Diet: it Needs to Change, pp. 1–36. https://www.foodstandards.gov.scot/downloads/Situation_report_-_the_Scottish_diet_-_it_needs_to_change_-_2018_update_FINAL.pdf.

Forbes, S., Bicknell, E., Guilovica, L., Wingrove, K., Charlton, K., 2021. A rapid review of the environmental impacts associated with food consumption in Australia and New Zealand. Curr. Nutr. Rep. 10 (4), 334–351. https://doi.org/10.1007/s13668-021-00374-0.

Grout, L., Mizdrak, A., Nghiem, N., Jones, A.C., Blakely, T., Ni Mhurchu, C., Cleghorn, C., 2022. Potential effect of real-world junk food and sugar-sweetened beverage taxes on population health, health system costs and greenhouse gas emissions in New Zealand: a modelling study. BMJ Nutr. Prev. Health 5 (1), 19–35. https://doi.org/10.1136/bmjnph-2021-000376.

Guerrero-López, C.M., Unar-Munguía, M., Colchero, M.A., 2017. Price elasticity of the demand for soft drinks, other sugar-sweetened beverages and energy dense food in Chile. BMC Publ. Health 17 (1), 1–8. https://doi.org/10.1186/s12889-017-4098-x.

Hadjikakou, M., 2017. Trimming the excess: environmental impacts of discretionary food consumption in Australia. Ecol. Econ. 131, 119–128.

Hagenaars, L.L., Jeurissen, P.P.T., Klazinga, N.S., 2017. The taxation of unhealthy energy-dense foods (EDFs) and sugar-sweetened beverages (SSBs): an overview of patterns observed in the policy content and policy context of 13 case studies. In: Health Policy, vol. 121. Elsevier Ireland Ltd, pp. 887–894. https://doi.org/10.1016/j.healthpol.2017.06.011. Issue 8.

Hansen, L.P., 1982. Large sample properties of generalized method of moments estimators. Econometrica: J. Econom. Soc. 1029–1054.

Hendrie, G.A., Baird, D., Ridoutt, B., Hadjikakou, M., Noakes, M., 2016. Overconsumption of energy and excessive discretionary food intake inflates dietary greenhouse gas emissions in Australia. Nutrients 8 (11), 690.

Holmes, J., 2021. Tackling Obesity: the Role of the NHS in a Whole-System Approach. The King's Fund, London, UK.

Hu, F.B., Stampfer, M.J., Solomon, C.G., Liu, S., Willett, W.C., Speizer, F.E., Nathan, D.M., Manson, J.E., 2001. The impact of diabetes mellitus on mortality from all causes and coronary heart disease in women. Arch. Intern. Med. 161 (14), 1717. https://doi.org/10.1001/archinte.161.14.1717.

Jensen, J.D., Smed, S., 2018. State-of-the-art for food taxes to promote public health. Proc. Nutr. Soc. 77 (2), 100–105.

Koengkan, M., Fuinhas, J.A., Tavares, A.I.P., Gonçalves Silva, N.M.B., 2023a. 10 - the increase of CO2 emissions by obesity epidemic in Latin American and Caribbean countries. In: Koengkan, M., Fuinhas, J.A., Tavares, A.I.P., Gonçalves Silva, N.M.B. (Eds.), Obesity Epidemic and the Environment. Academic Press, pp. 275–298. https://doi.org/10.1016/B978-0-323-99339-5.00006-6.

Koengkan, M., Fuinhas, J.A., Tavares, A.I.P., Gonçalves Silva, N.M.B., 2023b. 8 - the consequences of the obesity epidemic on food production: empirical evidence from Latin American and Caribbean countries. In: Koengkan, M., Fuinhas, J.A., Tavares, A.I.P., Gonçalves Silva, N.M.B. (Eds.), Obesity Epidemic and the

Environment. Academic Press, pp. 219–240. https://doi.org/10.1016/B978-0-323-99339-5.00010-8.

Koengkan, M., Fuinhas, J.A., Tavares, A.I.P., Gonçalves Silva, N.M.B., 2023c. 9 - does the obesity epidemic increase the consumption of fossil fuels in Latin America and Caribbean countries? In: Koengkan, M., Fuinhas, J.A., Tavares, A.I.P., Gonçalves Silva, N.M.B. (Eds.), Obesity Epidemic and the Environment. Academic Press, pp. 241–273. https://doi.org/10.1016/B978-0-323-99339-5.00004-2.

Kool, A., Marinussen, M., Blonk, H., 2012. LCI Data for the Calculation Tool Feedprint for Greenhouse Gas Emissions of Feed Production and Utilization. GHG Emissions of N, P and K Fertiliser Production.

Lauby-Secretan, B., Scoccianti, C., Loomis, D., Grosse, Y., Bianchini, F., Straif, K., 2016. Body fatness and cancer—viewpoint of the IARC Working Group. N. Engl. J. Med. 375 (8), 794–798.

Lee, J.-Y., Brown, M.G., Seale Jr., J.L., 1994. Model choice in consumer analysis: Taiwan, 1970–89. Am. J. Agric. Econ. 76 (3), 504–512.

Lewbel, A., Pendakur, K., 2009. Tricks with Hicks: the EASI demand system. Am. Econ. Rev. 99 (3), 827–863.

Liu, Y., Lopez, R.A., Zhu, C., 2014. The impact of four alternative policies to decrease soda consumption. Agric. Resour. Econ. Rev. 43 (Issue 1). https://ageconsearch.umn.edu/record/164593/.

Ludbrook, A., 2019. Fiscal measures to promote healthier choices: an economic perspective on price-based interventions. Publ. Health 169, 180–187. https://doi.org/10.1016/j.puhe.2019.02.008.

Macaulay, G., Barrett, L., Dempster, T., 2022. Recognising trade-offs between welfare and environmental outcomes in aquaculture will enable good decisions. Aquacult. Environ. Interact. 14 https://doi.org/10.3354/aei00439.

National Records of Scotland, 2020. Vital events - deaths. https://www.nrscotland.gov.uk/statistics-and-data/statistics/statistics-by-theme/vital-events/deaths.

Pawlowski, T., Breuer, C., 2013. Expenditures on sport products and services. In: Routledge Handbook of Sport Management. Routledge, pp. 354–372.

Phulkerd, S., Thongcharoenchupong, N., Chamratrithirong, A., Soottipong Gray, R., Prasertsom, P., 2020. Changes in population-level consumption of taxed and non-taxed sugar-sweetened beverages (SSB) after implementation of SSB excise tax in Thailand: a prospective cohort study. Nutrients 12 (11). https://doi.org/10.3390/nu12113294.

Popkin, B.M., Barquera, S., Corvalan, C., Hofman, K.J., Monteiro, C., Ng, S.W., Swart, E. C., Taillie, L.S., 2021. Towards unified and impactful policies to reduce ultra-processed food consumption and promote healthier eating. The Lancet Diabetes \& Endocrinology 9 (7), 462–470.

Powell, L.M., Leider, J., 2020. The impact of Seattle's Sweetened Beverage Tax on beverage prices and volume sold. Econ. Human Biol. 37, 100856 https://doi.org/10.1016/j.ehb.2020.100856.

Rayner, M., Scarborough, P., 2005. The burden of food related ill health in the UK. J. Epidemiol. Community Health 59 (12), 1054–1057.

Reaños, M.A.T., Wölfing, N.M., 2018. Household energy prices and inequality: evidence from German microdata based on the EASI demand system. Energy Econ. 70, 84–97.

Ridoutt, B., Baird, D., Hendrie, G.A., 2021. Diets within environmental limits: the climate impact of current and recommended Australian diets. Nutrients 13 (4). https://doi.org/10.3390/nu13041122.

Saha, S., Nordström, J., Scarborough, P., Thunström, L., Gerdtham, U.-G., 2021. In search of an appropriate mix of taxes and subsidies on nutrients and food: a modelling study of the effectiveness on health-related consumption and mortality. Social Sci. Medicine 287, 114388. https://doi.org/10.1016/j.socscimed.2021.114388.

Scarborough, P., Adhikari, V., Harrington, R.A., Elhussein, A., Briggs, A., Rayner, M., Adams, J., Cummins, S., Penney, T., White, M., 2020. Impact of the announcement and implementation of the UK Soft Drinks Industry Levy on sugar content, price, product size and number of available soft drinks in the UK, 2015-19: a controlled interrupted time series analysis. PLOS Medicine 17 (2), e1003025. https://doi.org/10.1371/journal.pmed.1003025.

n.d Scottish Government. *Climate change*. Energy and climate change directorate, Retrieved July 27, 2023, from. https://www.gov.scot/policies/climate-change. /#:~:text=Scotland's ambitious climate change legislation,economy and society is required.

Smed, S., Scarborough, P., Rayner, M., Jensen, J.D., 2016. The effects of the Danish saturated fat tax on food and nutrient intake and modelled health outcomes: an econometric and comparative risk assessment evaluation. European J. Clinical Nutr. 70 (6), 681–686. https://doi.org/10.1038/ejcn.2016.6, 2016 70:6.

Strazzullo, P., D'Elia, L., Kandala, N.-B., Cappuccio, F.P., 2009. Salt intake, stroke, and cardiovascular disease: meta-analysis of prospective studies. Bmj 339.

Te Morenga, L., Mallard, S., Mann, J., 2012. Dietary sugars and body weight: systematic review and meta-analyses of randomized controlled trials and cohort studies. BMJ 346 (jan15 3), e7492–e7492.

Teng, A., Buffière, B., Genç, M., Latavao, T., Puloka, V., Signal, L., Wilson, N., 2021. Equity of expenditure changes associated with a sweetened-beverage tax in Tonga: repeated cross-sectional household surveys. BMC Public Health 21 (1), 149. https://doi.org/10.1186/s12889-020-10139-z.

Tiffin, R., Balcombe, K., Salois, M., Kehlbacher, A., 2011. Estimating Food and Drink Elasticities. University of Reading, Reading.

Treasury, H.M., 2018. Soft drinks industry levy comes into effect. GOV.UK. https://www.gov.uk/government/news/soft-drinks-industry-levy-comes-into-effect.

United Nations, 2022. In: The Sustainable Development Goals: Report 2022 (Department of Economic and Social Affairs. Department of Economic and Social Affairs.

Vos, T., Abajobir, A.A., Abate, K.H., Abbafati, C., Abbas, K.M., Abd-Allah, F., Abdulkader, R.S., Abdulle, A.M., Abebo, T.A., Abera, S.F., others, 2017. Global, regional, and national incidence, prevalence, and years lived with disability for 328 diseases and injuries for 195 countries, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016. The Lancet 390 (10100), 1211–1259.

Weidema, B.P., Bauer, C., Hischier, R., Mutel, C., Nemecek, T., Reinhard, J., Vadenbo, C. O., Wernet, G., 2013. Overview and Methodology: Data Quality Guideline for the Ecoinvent Database Version 3.

Zhen, C., Finkelstein, E.A., Nonnemaker, J.M., Karns, S.A., Todd, J.E., 2013. Predicting the effects of sugar-sweetened beverage taxes on food and beverage demand in a large demand system. Am. J.Agricu. Econom. 1–25.