True costs of food: Valuing health impacts of food consumption

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Developed as part of 'The True Cost of Food: Alternative mechanisms to support local food procurement by public agencies in NYS' project

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The True Cost of Food: Alternative mechanisms to support local food procurement by public agencies in NYS

This publication was supported by 'The True Cost of Food: Alternative mechanisms to support local food procurement by public agencies in NYS' project (Cornell CALS, n.d.). This project aimed to quantify the true cost of food procured by state agencies in New York and develop a mechanism to transparently adjust procurement bids to account for these costs. The project aimed to correct this cost imbalance through three stages of integrated working streams:

1. Estimate the environmental, health and other spillover costs of food procured by NYS agencies.
2. Develop a framework for adjusting food vendors' bids to incorporate these multipliers and spillover costs.
3. Engage with NYS agencies and food vendors in implementing true costs in public food procurement.

This publication describes a method to estimate the health spillover costs of food, which was, to the authors' knowledge, unavailable at the time. The publication serves as a proof of concept within the context of the larger project, specifically for food procured by NYS public agencies. Therefore, the method was described in the demographic and dietary context of New York State. However, the authors believe that the method, with minor adjustments, can be applied in the broader context of true cost estimations, so beyond the context of food procurement by NYS public agencies only.

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Summary

Unhealthy diets are a major challenge in the US. In New York State, public agencies spend more than $1.2 billion a year on food procurement. Quantifying the health and environmental impacts of food procurement can inform better decision-making. This report presents a method to calculate the health costs and benefits of the consumption of food. Results are shown to illustrate the method, focusing on three product categories of political relevance in New York State: fruits, vegetables and sugar-sweetened beverages (SSBs).

A comparative risk assessment, following the approach by Springmann et al. (2019), is used to estimate two health effects: (1) current average consumption against no consumption of sugar-sweetened beverages on heart disease and diabetes, and (2) the health benefit of an additional serving of fruits and vegetables on heart diseases and stroke in New York State (for the adult population over 25 years old). The model includes official demographic data, disease outcomes and food consumption levels from the Global Burden of Disease study (GBD 2019). Two different sources of relative risks are compared (Micha et al. 2017a; GBD, 2019) which both allow to quantify attributable disease burden as mortality and disability-adjusted life years . Two different valuation approaches were included: the value of statistical life (VSL), based on willingness to pay for mortality risk reductions, and cost of illness (CoI), which is based on the direct (healthcare) and indirect (productivity loss) economic costs.

The remaining part of this summary includes results from one source of relative risks (GBD, 2019)[1]. Cost/benefits are provided as: USD based on VSL[2] (USD based on CoI). An additional 100g serving added to the reference diet for the New York State population showed USD 4.35 (0.15) benefits for fruit and USD 4.55 (0.17) benefits for vegetables. The costs of the current intake of sugar-sweetened beverages (against no consumption) are USD 2.85 (0.24) per additional 100g serving. The estimated health costs/benefits are substantial compared to the consumer price for these food products.

Incorporating the true costs of food consumption on consumer health in (political) decision making could result in important health and economic benefits. These true cost estimates can incentivise decision makers (such as public agencies) to adjust their food procurement aiming to pursue positive or prevent negative human health effects. This document provides a framework building on publicly available data to estimate the true health costs of food, highlighting the importance of different input parameters.

[1] The appendices provide results for all combinations of risk rates and valuation approaches.

[2] The VSL value from the US Environmental Protection Agency (EPA) of 11.4 million US$ in 2022 was used, which is higher than the value from the Organisation for Economic Co-operation and Development (OECD) (approximately 3.7 million international $ 2022 per statistical life). See section 2.3 for more details on the monetary valuation applied.

1 Introduction

New York state agencies spend more than $1.2 billion a year on food for schools, hospitals, prisons and other government institutions. Currently, public agencies are required to buy from the lowest bidder. A better understanding of the true cost of food products would allow New York agencies to adjust their food vendors based on hidden costs to society rather than financial costs only.

The process of assessing true, or hidden, costs is called True Cost Accounting (TCA). The field of TCA is rapidly evolving. Specifically, no harmonized approach to include the health costs of food consumption exists to account for the costs of individual products. However, such an approach would allow for better informed and sustainable procurement decisions and consequently contribute to a more healthy and sustainable New York state society.

The true cost of food takes into account positive and negative externalities created during production and consumption. Negative health effects from unhealthy diets are a major contribution to the negative externalities. Several studies estimate this effect for the population as a whole, based on their entire diets, but these studies do not yet take into account the consumption of specific products.

Globally, a study by the scientific group of the United Nations Food Systems Summit estimated that the current externalities of the global food systems are almost double (19.8 trillion USD) the current total financial value of global food consumption (9 trillion USD) (Hendriks et al., 2021). In this study, approximately 11 trillion USD were attributed to costs to human life linked to unhealthy diets. A background study of the 2023 United Nations State of Food and Agriculture in the World (SOFA) report, also shows the biggest hidden costs (8–10 trillion 2020 $PPP) are driven by unhealthy diets (Lord, 2023). A study in the US, found hidden food system costs are three times as large (2.1 trillion USD per year) as the current food expenditures (Rockefeller Foundation, 2021). In this report, human health impacts are the biggest contributors to hidden costs, with the majority of the costs — 604 billion — attributable to healthcare costs related to diet-related diseases (see Figure 1).

Indeed, unhealthy diets are a major challenge in the US. A 2017 study by Micha et al. (2017a) estimated that nearly half of all deaths from heart disease, stroke and type 2 diabetes in the US are attributable to unhealthy diets. Diet-related diseases represent a significant financial burden in the US. Heart disease cost the US almost USD 240 billion from 2018 to 2019, including direct health care and medication costs and indirect loss of productivity due to death (American Heart Association, 2023).

New York State, like many parts of the United States, has been grappling with a rising obesity epidemic. Nearly two thirds of New York adults are overweight or obese, with these two conditions affecting over 8.4 million people (BRFSS, 2021). Furthermore, health disparities persist, with obesity affecting some cultural groups more than others.

According to data from the 2019 Global Burden of Disease study (GBD, 2019), in New York State approximately 522,000 disability-adjusted-life-years (DALYs)[3] were attributable to dietary risks. Figure 2 shows that Ischemic heart disease alone contributed to more than half of this burden.

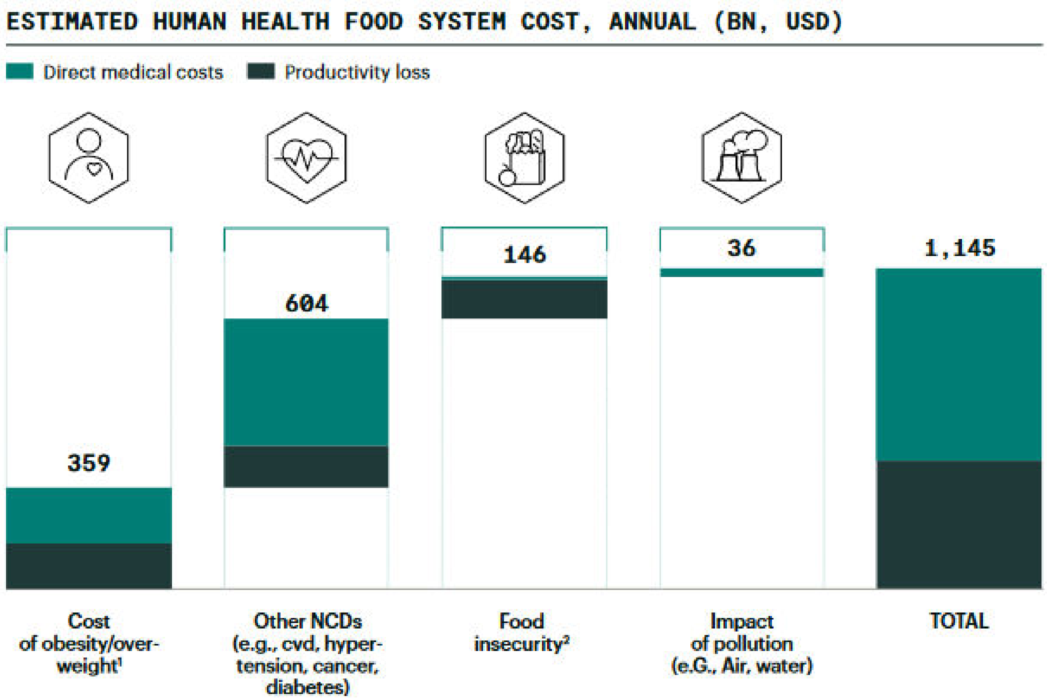


Figure 1: Breakdown of the external costs of human health impacts in the US food system. Image from The Rockefeller Foundation (2021).

[3] The World Health Organization (WHO) defines a DALY as: 'One DALY represents the loss of the equivalent of one year of full health. DALYs for a disease or health condition are the sum of the years of life lost to due to premature mortality (YLLs) and the years lived with a disability (YLDs) due to prevalent cases of the disease or health condition in a population.' (WHO, n.d.)

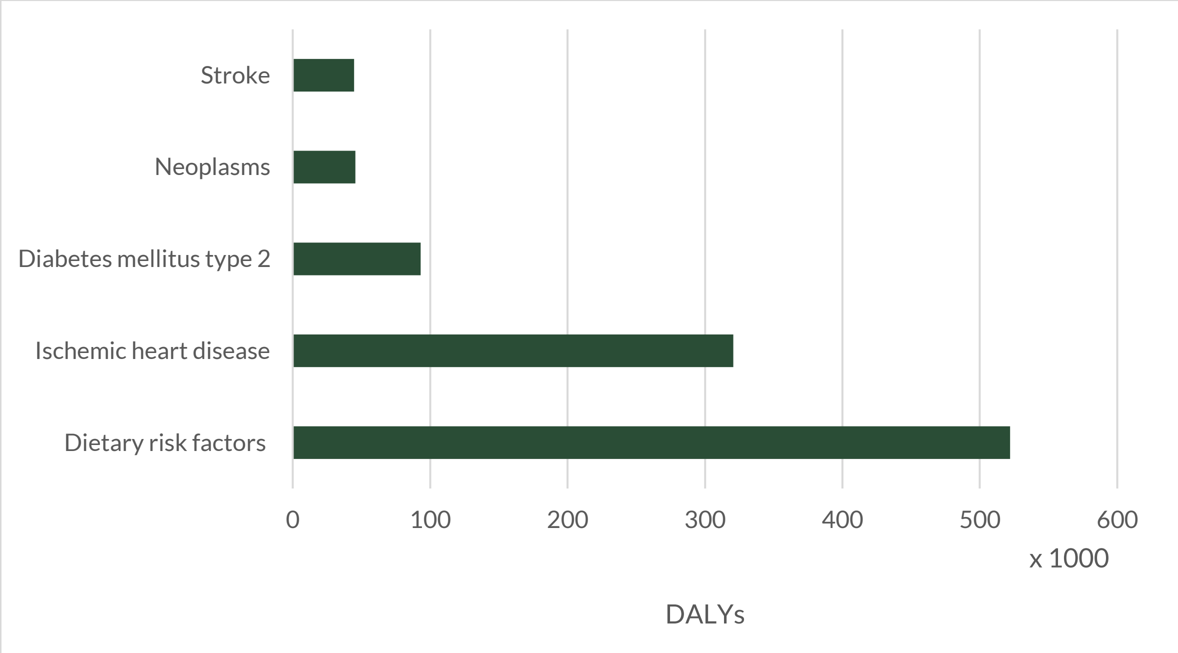


Figure 2: Burden of diseases (in Disability Adjusted Life Years (DALYs)) in New York State attributable to dietary risk factors. Source: GBD (2019).

New York State's health improvement plan or "Prevention Agenda 2019-2024: Prevent Chronic Diseases Action Plan" includes diet-related objectives. Specifically, under Focus Area 1 (Healthy Eating and Food Security), Objectives 1.7 and 1.9 (see Table 1), focused on increasing intakes of fruits and vegetables and decreasing intakes of sugar-sweetened beverages. These targets align with the 2020-2025 Dietary Guidelines for Americans, which also recommend limiting food and beverages higher in added sugars.

Table 1: New York State Prevention Agenda (2019-2024) dietary intake targets

Objective	Description	Baseline 2016	2024 target
1.7	Decrease the percentage of adults who consume one or more sugary drinks per day (among all adults)	23.2%	22.0%
1.9	Decrease the percentage of adults who consume less than one fruit and less than one vegetable per day (among all adults)	31.2%	29.6%

Source: Behavioural Risk Factor Surveillance System (BRFSS), New York State (2021).

Both the burden of disease and the recommendations for dietary change highlight the importance that true cost accounting assessments in NYS, and the US in general, incorporate human health effects from food consumption. However, different approaches to quantifying health costs have been developed (see Appendix D) and challenges remain in assessing health impacts from consumption at the product level and its monetary valuation.

This paper presents an approach to estimating the true costs of food consumption. Firstly, a comparative risk assessment and potential impact fraction was applied to quantify the health effect of an additional serving of fruit and vegetables, as well as to quantify the disease burden attributable to current sugar-sweetened beverage (SSB) consumption. These health effects were based on the annual burden of coronary heart disease, stroke and diabetes. Secondly, two monetary valuation approaches were applied to highlight the difference between using a VSL and CoI approach.

2 Methods

2.1 Approach

Springmann et al. (2018) considered the negative health effect of an additional serving of meat over a reference diet to calculate optimal meat taxes. Following this approach, we assessed the positive change in diet-related disease burden of an additional serving of fruit and vegetables for the entire New York State population (adults 25 years and older). In addition, we examined the disease burden of current SSBs consumption against a zero intake reference.

Our estimation of health costs related to the consumption of food products consisted of a quantification of the disease burden followed by a monetary valuation of that burden. The burden of disease quantification was based on a comparative risk assessment (CRA) to determine the attributable health effects related to a change in dietary pattern. See Figure 3 for a schematic overview of the approach.

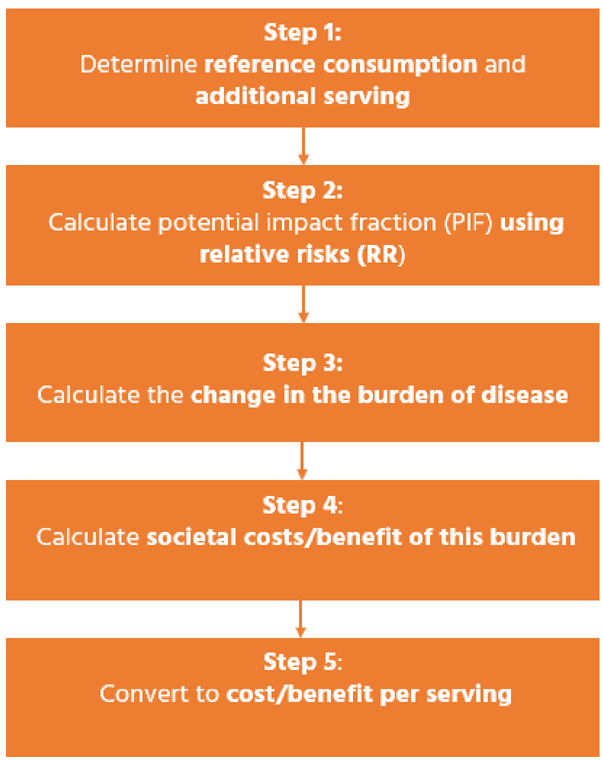


Figure 3: Approach to calculate health benefits and costs from an additional serving of foods.

A CRA framework allows to estimate the burden of disease that is attributable to a risk factor. For this purpose, CRA incorporates independently derived inputs and parameters on demographics, risk factors, their etiologic effect (i.e., what is likely to cause or contribute to causing a disease) and disease incidence (O'Hearn et al., 2023). Within a CRA framework, relative risks (RRs) represent 'a ratio of the risk of occurrence of a disease or death among two population groups, such as those exposed to a risk factor and those not exposed' (Lopez et al., 2006). Derived from these relative risks, the potential impact fraction (PIF), as presented in Murray et al. (2003), describes the relative contribution of a risk factor to the disease burden and represents the percentage of each cause-specific death or DALY due to a change in a given risk factor. In this study, the burden in a population due to the observed exposure distribution (i.e., a reference intake) was compared to the burden from another exposure distribution (i.e., reference intake plus additional serving).

We included risk factors for dietary categories of political relevance in New York State: fruits, vegetables and SSBs (see Table 1). We limited the diseases included to coronary heart disease, stroke and diabetes based on the availability of RRs in Micha et al. (2017a) and GBD (GBD, 2019). Relative risks were obtained from two different sources to illustrate variability in outcomes of this approach (see Table 2). Micha et al. (2017a) provides disease and risk associations for a wide range of food groups and coronary heart disease, stroke and diabetes. Relative risk estimates from Micha et al. (2017a) incorporate evidence from published or de novo meta-analyses (prospective cohorts or randomized clinical trials) evaluating associations of dietary factors with CHD, stroke, or type 2 diabetes. We also included relative risk estimations for twelve risk categories from the Global Burden of Disease project (GBD, 2019). For each disease-risk associations, GBD uses data from published meta-analyses of prospective observational studies to estimate the relative risk (Afshin et al., 2019).

Table 2: Relative risks for disease-risks associations included in this study

Dietary risk factor and disease	**Micha et al. (2017a)***		**GBD (2019)****	
	RR	Unit	RR	Unit
Diet low in fruits				
CHD	0.94	Per 100 g/day	0.96	Per 100 g/day
Ischemic stroke	0.88	Per 100 g/day	0.95	Per 100 g/day
Haemorrhagic stroke	0.73	Per 100 g/day	Intracerebral haemorrhage – 0.91 Subarachnoid haemorrhage – 0.91	Per 100 g/day
Diet low in vegetables				
CHD	0.95	Per 100 g/day	0.94	Per 100 g/day
Ischemic stroke	0.83	Per 100 g/day	0.97	Per 100 g/day
Haemorrhagic stroke	0.83	Per 100 g/day	Intracerebral haemorrhage – 0.95 Subarachnoid haemorrhage – 0.95	Per 100 g/day
Diet high in sugar-sweetened beverages				
CHD	1.21 (CHD-BMI adjusted)	Per 8 oz (1 serving)/day	1.06	Per 240 g/day
Diabetes type 2	1.22 (Diabetes-BMI adjusted)	Per 8 oz (1 serving)/day	1.13	Per 240 g/day

*RRs values for the age group 55-64.
**RRs values for the age group 55-59, CHD = coronary heart disease, also known as ischemic heart disease in GBD data.

2.2 Burden of disease quantification

We estimated the mortality attributable to dietary risk factors by calculating age-specific PIFs, given the relative risks for a specific population. A PIF represents the proportional disease burden that would be avoided or added to the total burden when the dietary risk exposure changes from a reference diet to a counterfactual diet. Using the PIF, the burden prevented by (in case of a positive health effect) or attributable to (in case of a negative health effect) the dietary change was obtained from the total burden of the disease in New York State's population. The prevented or attributable burden was converted to a burden per serving by dividing the burden by the number of servings consumed within the population in one year. Figure 4 provides a visual representation of the comparative risk assessment (including monetary valuation, see Section 2.3), while Appendix A provides further details on the comparative risk assessment.

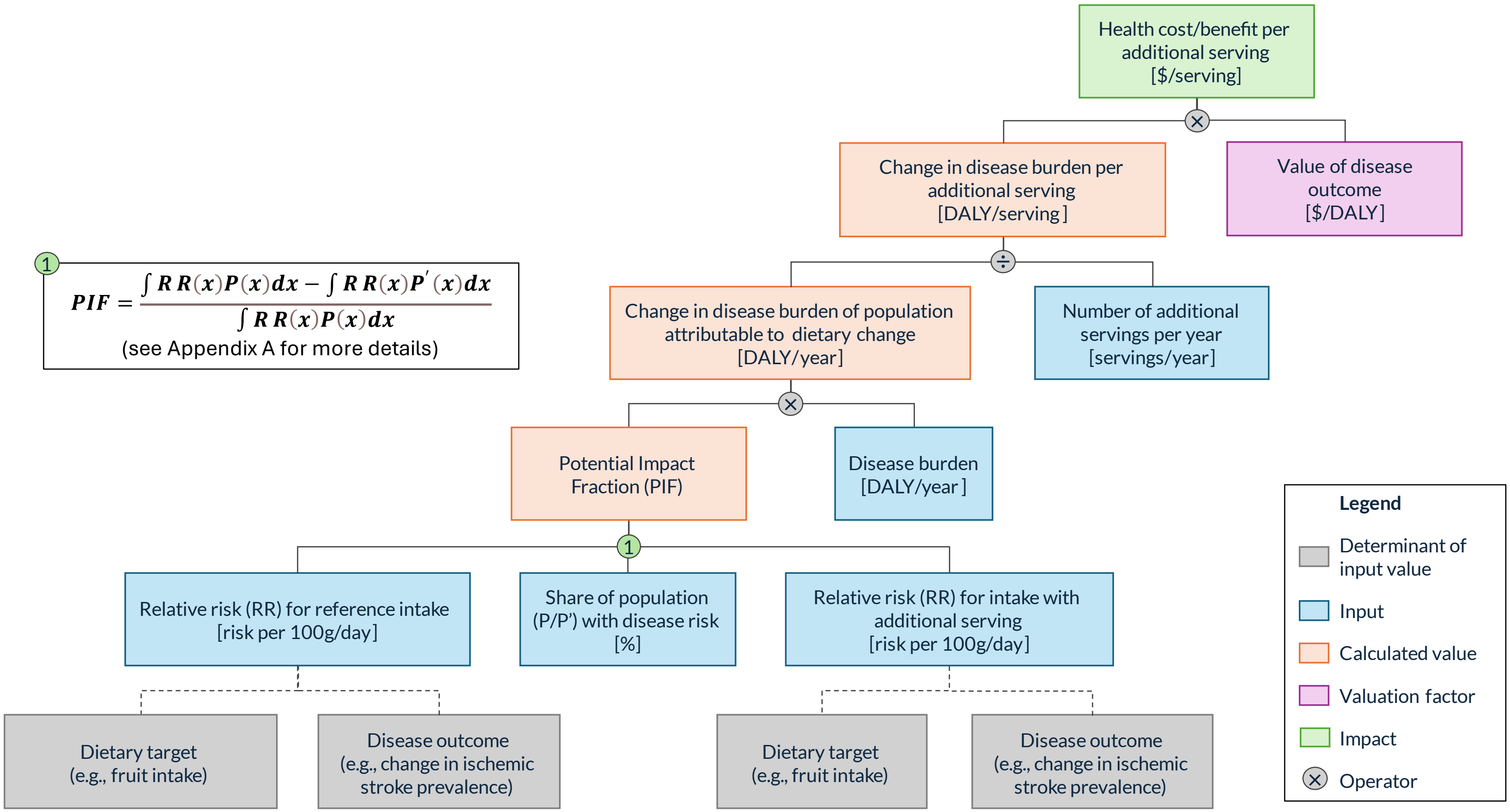


Figure 4: Calculation tree for the comparative risk assessment of health cost/benefit per additional serving of a food product. The effect is expressed as the change in disease burden compared to the burden from a reference intake. One assessment is done for a combination of a disease outcome and a dietary target. A calculation tree is a visual representation of a calculation that starts with the variables at the bottom line. The intermediate result of an applied operator is shown on the line above. Consequentially, the result of the total calculation is shown at the top.

The current average diet in the US was used as the reference diet and served as a proxy for the diet of New York State's population. The counterfactual diet depended on the food group. For food groups with a health benefit (fruits and vegetables), the counterfactual diet was the reference diet plus one additional serving of the food group. For food groups with a negative health effect (SSBs in case of this study), the counterfactual scenario was the reference diet from which all consumption of the food group in scope was removed. It is important to note that in the case of benefits from and additional intake of fruits and vegetables the food intake increased while for the SSBs the food intake decreased. We did not take into account substitution effects or health effects due to changes in total caloric intake.

For both scenarios, the relative risks of the related consumption level were calculated. Relative risks from two different sources were applied (Micha et al., 2017a and GBD, 2019). Both sources provide multiple relative risks for each disease-food group combination dependent on age groups (from 25 years old and above). For each age group, the relative risks were linearly interpolated and extrapolated to all consumption levels, assuming a piecewise linear dose-response relation, and capped at the relative risk corresponding to a maximum consumption level. The relative risk exposure was capped for Micha et al. (2017a) at 300 g/day for fruits and 400 g/day for vegetables. For GBD (2019), RRs were capped at 300 g/day for both fruits and vegetables.

2.3 Monetary valuation

Studies that monetarily value health effects on populations often use two approaches that range from societal preference to economic effects: a value-of-statistical-life (VSL) or a cost-of-illness (CoI) approach, respectively (Springmann et al., 2016). These two approaches provide different perspectives: VSL represents stated preferences of mortality risks reductions, while CoI represents the economic burden of a specific disease to society, through projected health-care expenditure (direct costs) and/or productivity loss (indirect costs).

We included CoI values that differ per disease and account for both direct and indirect costs (Table 3). CoI for heart disease and stroke were obtained from the American Heart Association (AHA, 2023) and for diabetes from the American Diabetes Association (ADA, 2017). The costs for diabetes were inflated from the year 2017 to year 2019 using consumer price index data from the US Bureau of Labour Statistics. These costs were divided by the total burden of disease in the US in 2019 to obtain an estimated cost per death and cost per DALY. The health costs for non-fatal cases were also included in the total costs, but attributed to fatal cases.

A VSL of 11.4 million USD/death in 2022 from the USDA based on EPA was used in this study (USDA, 2023). This VSL value is relatively high compared to 3.7 million international $ 2022 as provided by the Organisation for Economic Co-operation and Development (OECD). More information about EPA's is available in Appendix B of the EPA's Guidelines for Preparing Economic Analyses (EPA, 2010).

Table 3: Costs of illness for different diseases

Disease	Annual cost (USD)	Cost per death (USD)	Cost per DALY (USD)	Year	Source
Heart Disease	240 bn	430,199	26,810	2018-2019	American Heart Association (2023)
Stroke	57 bn	298,222	14,766	2018-2019	American Heart Association (2023)
Diabetes	327 bn	4,207,467	76,186	2017	American Diabetes Association (2017)

Note: data for diabetes have been inflated to 2019 values.

3 Results

In this study, the true costs of consumer health effects were calculated for three food groups (fruits, vegetables, and SSBs) and three diseases (heart disease, stroke, and type 2 diabetes) in scope. The health effects were quantified with two different sources of relative risks (Micha et al. (2017a) and GBD (2019)) and for both source of RRs the burden was expressed in mortality (for results in DALYs, see Appendix C). The monetary values were obtained using two different valuation approaches (VSL and CoI).

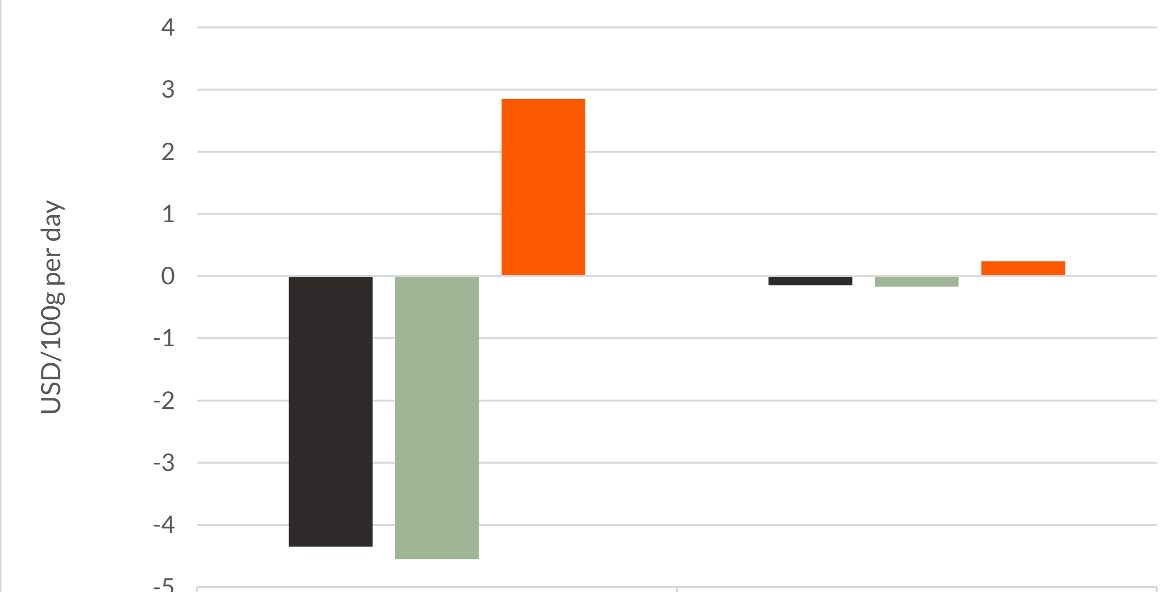
Table 4 shows a selection of true costs given RRs from GBD (2019) and a mortality burden. Appendix C provides the true costs for each combination of model parameters. As expected, different parameters led to different true costs, as shown in Table 4 and Figure 5 below. Especially, the true costs based on VSL were higher than those based on CoI. For example, an additional serving of fruit (100 g) per day for the whole NYS population led to an expected decrease in disease burden equivalent to prevented costs per 100 g of USD 4.35 when using VSL and USD 0.15 when using CoI. If current NYS SSBs intake would go down to zero (from current average of 252 g per person per day), approximately 2,718 deaths per year from CHD could be avoided, resulting in prevented true costs per 100g serving of USD 2.50 using VSL and USD 0.09 when using CoI. An additional 427 deaths from diabetes could be avoided, resulting in USD 0.40-0.14 per 100 g serving when using VSL and CoI valuation, respectively.

Overall, the largest true cost (in absolute values) was obtained for an additional serving of vegetables using VSL valuation: USD 4.55 per 100 g serving per person. When comparing results with the CoI valuation, the largest cost (in absolute values) was obtained for the current intake of SSBs: USD 0.24 per 100g serving. Note that the diseases in scope for different food products affected both the estimate of disease burden and the monetary value for CoI per unit of burden, while the VSL value per unit of burden was unaffected by a change in diseases in scope.

Table 4: True costs of consumer health effects in New York State for selected dietary risk factors, based on an additional serving of fruits and vegetables and reduced consumption of SSBs to zero.

Food group	Reference intake (g/person/day)	Counterfactual intake (g/person/day)	Current burden (deaths/year)	Attributable burden (deaths/year)	True cost - VSL (USD/100 g serving)	True cost - COI (USD/100g serving)
Fruits	147.7	247.7	48,385	-1,904	-4.35	-0.15
CHD			40,197	-1,517	-3.47	-0.13
Ischemic Stroke			4,451	-195	-0.45	-0.01
Haemorrhagic stroke			3,737	-191	-0.44	-0.01
Vegetables	197.3	297.3	48,385	-1,993	-4.55	-0.17
CHD			40,197	-1,771	-4.05	-0.15
Ischemic Stroke			4,451	-124	-0.28	-0.01
Haemorrhagic stroke			3,737	-97	-0.22	-0.01
SSBs	252	0	43,911	-3,145	2.85	0.24
CHD			40,197	-2,718	2.46	0.09
Diabetes			3,714	-427.3	0.39	0.14

Notes: Results estimated using relative risks sourced from the Global Burden of Disease (GBD 2019). NYS=New York State. SSBs: sugar-sweetened beverages. BMI: body mass index.



	True cost - VSL (USD/100g serving)	True cost - COI (USD/100g serving)
Fruits	-4.35	-0.15
Vegetables	-4.55	-0.17
SSBs	2.85	0.24

Figure 5: True cost estimates using CoI and VSL valuation of consumer health effects of an additional serving of fruits and vegetables and of a reduced consumption of SSBs to zero. VSL: value of statistical life. CoI: cost of illness. SSBs: sugar-sweetened beverages.

4 Discussion

This study has shown that true costs of consumer health effects for selected food groups and diet-disease associations can be estimated using information that is fully available in the public domain. This provides an opportunity to inform policy design by New York State's decision makers using True Cost Accounting.

When taking fruit consumption as an example, our results showed that an additional serving of fruit for the NYS population can lead to a reduction of CHD, ischemic stroke and haemorrhagic stroke mortality, equivalent to prevented costs of 0.15 USD/100 g serving when using CoI. To put this potential in perspective, one should look at the economic costs of feeding the NYS population (13.6 million people of 25 years old and above) an additional serving of fruit per day. Assuming the average retail price in 2020 for one kilogram of apples was approximately USD 3.30 (or USD 0.33 per 100 g), this represents a 45% return/savings on apples through a reduction in true costs (direct and indirect cost of illness).

However, different model parameters led to different results. Particular attention needs to be given to the selection of relative risks, disease burden (mortality or DALYs) and valuation approaches.

The comparative risk assessment, as applied in this study, was potentially affected by confounding factors, particularly related to clustering dietary components, which might lead to an overestimation of relative risks linked to individual dietary components compared to their effects within overall dietary patterns (Micha et al., 2017b). The choice of risk factors included in a CRA strongly affects its results and should ensure the assessment serves its purpose when informing (policy) decisions. We considered only a limited amount of risk factors, because the current study served as a proof of concept.

Results using VSL valuation expectedly led to higher (prevented) true costs for the selected dietary risk factors and associated diseases, which aligns with another study (Springmann et al., 2016). The different valuation approaches provide a different perspective (economic costs versus societal preference) and serve a different purpose. Therefore, decision makers should be transparent about how the chosen valuation approach affected and/or supported their decision.

When using VSL, true costs for fruits and vegetables are higher than for SSBs, while for CoI, compared across the dietary risk factors, the true costs from current SSBs intake surpass the prevented costs potential from additional intake of fruits and vegetables. This depends on the high economic costs associated with diabetes, as approximately 1 of USD

4 in US health care costs is spent on caring for people with diabetes (American Diabetes Association, 2017).

The chosen unit for disease burden (DALYs or mortality) was also shown to affect true cost estimations. The choice does not only affect the estimated attributable burden, but indirectly also affects the valuation. When quantifying disease burden in DALYs, 'the value of a statistical life year' needs to be derived from the value of a statistical life. To do so, the total value of a statistical life has to be distributed over the (remaining) expected life years of participants in the VSL study. It can be expected that the number of life years lost due to diet-related diseases is lower than the average expected life years of participants in a VSL study. As a result, the total VSL value allocated to the statistical value of a life year is distributed over more years than quantified life years lost to diseases. Ultimately, this leads to a lower true cost when quantifying disease burden in life years lost rather than mortality. In theory, true costs based on burden quantification in life years lost (such as DALYs) are likely to be more accurate, but burden quantification might be less accurate or not always available.

5 Limitations

The temporal element from observational studies is a limitation in this approach. While the health effects of dietary patterns are expected to have a time lag, this approach combines current dietary data with burdens in the same year. The relative risks (RRs) used in this study are derived from meta-analyses but it is important to take precautions when interpreting association as causation. As noted by Micha et al. (2017a), evidence from randomized trials is not available, and relying on observational studies presents risks of confounding biases. In nutrition and medical research, conducting experimental studies is often limited due to ethical reasons. The evidence linked to vegetables and fruits on diet-related diseases appears less contested. For the impacts of SSBs, recent research has focused on measuring mediated effects through body-mass-index (BMI) adjustments. For this reason, it is recommended that future studies align with the latest scientific evidence and with country or state-specific recommendations and targets.

We limited the scope of this study to three dietary risk factors of political relevance in New York State (fruits, vegetables and SSBs). Within the fruit and vegetables categories, potentially important distinctions in nutritional value might result in different health impacts, e.g. no distinction is made between a broccoli and a tomato or between an apple and a banana. Furthermore, in this study, we focused on quantifying and valuating the human health effects associated with three diseases: heart disease, stroke, and type 2 diabetes. For future studies, more diseases can be included, as long as sufficient evidence and data on associations to specific dietary risk factors is available.

A limitation related to the above is the effect of potential confounding effects by including multiple diseases. This can lead to a potential overestimation of total burden, as diseases tend to be correlated (Micha et al., 2017b). This could be countered by taking the maximum health cost or benefit between different diseases, but this would likely be an underestimation.

This study considered the average dietary intake for the general adult population (25 years and older) and no distinction was made between different groups with different dietary needs (e.g. children, adolescents, elderly, pregnant women). Furthermore, the results presented consider the average intake of the general US adult population, which might not be an accurate representation of New York state. For future studies, it is recommended that New York State-specific dietary intake data is used when available. Furthermore, there is no distinction in this model among the different settings that New York State agencies procure, e.g. hospitals, schools, prisons, etc.

The way of interpolating the relative risks can have a significant effect on the result. We applied a linear dose-response relation, such that every additional serving led to the same difference in relative risk as long as the maximum consumption level was not reached. Some sources (like the GBD) show non-linear dose-response relations, where an additional serving has more effect at lower consumption levels than at higher consumption levels. Other tools take a non-linear dose-response relationships for fruits and vegetables, and nuts and seeds (WHO, 2023). Future work should incorporate non-linear dose-response relations if sufficient scientific evidence about the form of these relations is established.

Different approaches to monetary valuation exist. Each approach provides different insights, but also comes with its own assumptions and limitations. For example, when using cost-of-illness valuation, a choice needs to be made whether or not to include costs of non-fatal health effects. Separating fatal from non-fatal for health burden (typically in number of deaths or DALYs, respectively), but also in terms of economic costs is not trivial, but affects the results. Additional choices also depend on availability of more specific data. In this study, we assumed costs of illness to be equal for some diseases (e.g. same cost for haemorrhagic stroke and intracerebral haemorrhage). Also, US level cost-of-illness data were used rather than New York state specific costs. Similarly, suitability of VSL valuation is dependent on context. For example, the socio-economic situation of respondents affects the results of a stated preference study from which the value of a statistical life is determined. Ultimately, the preferred valuation approach depends on the consideration of both purpose and data availability.

6 Conclusion

The majority of TCA studies addressed the environmental costs and benefits of food, while limited approaches included consumer health-related costs (Hendriks et al., 2021; Rockefeller Foundation, 2021). Even fewer included the costs associated with single foods or nutrients (Seidel et al., 2023). In this paper, we extended an existing comparative risk assessment approach by Springmann et al. (2018) to include the consumer health effects in a true cost accounting assessment.

Consumer health effects of different food products were quantified based on one additional serving of foods associated with a positive health effect (fruits and vegetables) and the current average intake of food products associated with a negative health effect (SSBs). For fruits and vegetables, we estimated the prevented burden of diet-related diseases, expressed in mortality or life years lost. For SSBs, we estimated the diet-related disease burden attributed to a population's current average intake compared to a zero intake. Valuation was based on value-of-statistical-life and cost-of-illness valuation, covering a wide range of valuation approaches. Irrespective of the choice of risk factors and valuation approach, the estimated health costs/benefits are substantial compared to the consumer price of the corresponding food product.

It is important to note that the estimated true costs reflect the health effect of an additional serving in a diet over a prolonged period of time. As such, it is conceptually different from the costs associated with one specific serving of fruits or vegetables. Nonetheless, these true cost estimates can incentivise decision makers (such as public agencies) to adjust their food procurement aiming to pursue positive or prevent negative human health effects. For example, true cost estimates can be used to internalise health costs in procurement prices, used for agency-specific of state-level target setting to reduce external costs and/or increase health benefits and inform more sustainable decision making.

The true costs presented here are estimates on a product level and not a vendor or supplier-specific estimate. Therefore decision makers should not use these costs to discriminate among different vendors.

For future developments, it is important to ensure the approach is aligned with the latest New York State and US dietary guidelines, as well as with up-to-date scientific knowledge. Preferably, information from meta-analysis are used to identify diet-related disease associations. In the future, this model can be adjusted with New York State specific data. For example, more specific food consumption and cost of illness data can be included, for which we relied on average data from the US.

Appendices

A. Comparative risk assessment

For calculating PIFs, we used the general formula:

$$\boldsymbol{PIF} = \frac{\int \boldsymbol{RR}(\boldsymbol{x})\boldsymbol{P}(\boldsymbol{x})\boldsymbol{dx} - \int \boldsymbol{RR}(\boldsymbol{x})\boldsymbol{P}'(\boldsymbol{x})\boldsymbol{dx}}{\int \boldsymbol{RR}(\boldsymbol{x})\boldsymbol{P}(\boldsymbol{x})\boldsymbol{dx}}$$

where RR(x) is the relative risk of disease for a risk factor level x, P(x) is the number of people in the population with risk factor level x in reference scenario, and P'(x) is the number of people in the population with risk factor level x in the counterfactual scenario. The different risk levels can represent different age groups. In this approach we assume a linear relationship in changes in relative risks.

The attributable deaths linked to the change in risk exposure was calculated by multiplying the PIF by the disease-specific mortality rates in New York State or DALYs.

Change in attributable deaths/DALYs is calculated as the product of the PIF and the disease burden (mortality/DALYs).

B. Input data

Table B.1 provides an overview of the input data required for the comparative risk assessment and their respective sources. We use average dietary intake data and mortality data from GBD 2019. The relative risk estimates linked to the different diseases were also adopted from GBD. Alternative relative risks were adopted from Micha et al. (2017a), which includes meta-analysis for different cardiovascular diseases, food and nutrient risks (see Table B.1). This study only includes data for adults 25 years and older.

Table B.1: Overview of comparative risk assessment data.

Input data	Value	Source
Mortality rates or DALYs	Depends on disease (burden per year)	GBD (2019)
Average intake (fruits, vegetables, SSBs)	Depends on the food group (g/per person/ per day)	GBD (2019)
Demographics	Population >25 years in NYS Population >25 years in the US	US Census
RRs (age-specific)	Depends on the exposure and risk combination	Micha et al. (2017a) & GBD (2019)
Value of Statistical life (VSL)	Willingness to pay for mortality risk reductions ($/death)	EPA, OECD
Cost of illness (CoI)- (Heart disease:, Stoke, Diabetes)	Direct and indirect economic costs	AHA (2023), ADA (2017)

C. True cost estimates

Table C.1: True cost estimates for selected dietary risk factors based on mortality and DALYs and different relative risks

Food group	Reference intake (g/person/day)	Counterfactual intake (g/person/day)	NYS Disease burden (deaths/year)	NYS Change in deaths (deaths/year) – GBD (2019)	NYS Change in deaths (deaths/year) – Micha et al. (2017a)	VSL True cost (USD/100g serving) - GBD (2019)	COI True cost (USD/100g serving) - GBD (2019)	VSL True cost (USD/100g serving) - Micha et al. (2017a)	COI True cost (USD/100g serving) - Micha et al. (2017a)
Fruits	**147.7**	**247.7**	**48,385**	**1,904**	**-5,605**	**-4.35**	**-0.15**	**-12.80**	**-0.41**
CHD			40,197	-1,517	-2,900	-3.47	-0.13	-6.62	-0.25
Ischemic Stroke			4,451	-195	-745	-0.45	-0.01	-1.70	-0.04
Haemorrhagic stroke			3,737	-191	-1960	-0.44	-0.01	-4.48	-0.12
Vegetables	**197.3**	**297.3**	**48,385**	**-1,993**	**-4,932**	**-4.55**	**-0.17**	**-11.26**	**-0.36**
CHD			40,197	-1,771	-2,491	-4.05	-0.15	-5.69	-0.22
Ischemic Stroke			4,451	-124	-1,327	-0.28	-0.01	-3.03	-0.08
Haemorrhagic stroke			3,737	-97	-1,114	-0.22	-0.01	-2.55	-0.07
SSBs	**252**	**0**	**43,911**	**-3,145**	**-9,426**	**2.85**	**0.24**	**8.54**	**0.57**
CHD (CHD-BMI adjusted for Micha)			40,197	-2,718	-8,597	2.46	0.09	7.79	0.23
Diabetes (Diabetes-BMI adjusted for Micha)			3,714	-427.3	-829	0.39	0.14	0.75	0.28

Notes: VSL mortality valuation from EPA. NYS=New York State. SSBs= sugar-sweetened beverages. BMI=body mass index

Table C.2: True cost estimates for selected dietary risk factors based on mortality and DALYs and different relative risks.

Food group	Reference intake (g/person/day)	Counterfactual intake (g/person/day)	NYS disease burden (DALYs/year)	NYS Change in deaths (DALYs/year) – GBD (2019)	NYS Change in deaths (DALYs/year) – Micha et al. (2017a)	VSL True cost (USD/100g serving) – GBD (2019)	COI True cost (USD/100g serving) – GBD (2019)	VSL True cost (DALYs/100g serving) - Micha et al. (2017a)	COI True cost (DALYs/100g serving) - Micha et al. (2017a)
Fruits	**147.7**	**247.7**	**756,571**	**-30,227**	**-100,271**	**-0.64**	**-0.14**	**-2.14**	**-0.40**
CHD			582,169	-21,975	-41,999	-0.47	-0.12	-0.89	-0.23
Ischemic Stroke			92,944	-4,080	-15,562	-0.09	-0.01	-0.33	-0.05
Haemorrhagic stroke			81,458	-4,172	-42,711	-0.09	-0.01	-0.91	-0.13
Vegetables	**197.3**	**297.3**	**756,571**	**-30,364**	**-88,077**	**-0.65**	**-0.15**	**-1.88**	**-0.35**
CHD			582,169	-25,654	-36,071	-0.55	-0.14	-0.77	-0.19
Ischemic Stroke			92,944	-2,599	-27,716	-0.06	-0.01	-0.59	-0.08
Haemorrhagic stroke			81,458	-2,111	-24,290	-0.04	-0.01	-0.52	-0.07
SSBs	**252**	**0**	**820,408**	**-66,773**	**-182,164**	**0.56**	**0.25**	**1.54**	**0.62**
CHD (CHD-BMI adjusted for Micha et al. (2017a))			582,169	-39,365	-124,515	0.33	0.08	1.05	0.27
Diabetes (Diabetes-BMI adjusted for Micha et al. (2017a))			238,239	-27,408	-57,650	0.23	0.17	0.49	0.35

Notes: VSL valuation for DALYs from the OECD/True Price Monetisation Factors. NYS=New York State. SSBs= sugar-sweetened beverages. BMI=body mass index

D. Overview of existing approaches

With the development of the true cost accounting field and more evidence regarding the negative impacts of food systems on diets and health outcomes, existing methods aiming to quantify health effect have been developed. Table D.1 provides an overview of existing approaches that have been reviewed to support this study.

Table D.1: Existing approaches to monetize the human health impacts of food consumption at the product level.

Food categories	Approach	Valuation	Source
Packaged foods	Individuals reached multiplied by the prevalence of disease and change in risk	Associated medical and productivity costs	IWA (2021)
Processed meat	Comparative risk assessment	Cost of illness (direct medical costs and indirect productivity costs)	Springmann et al. (2018)
Foods	The marginal contribution of a food product to the overall overconsumption of harmful ingredients	Cost of illness (direct medical costs)	Manouchehrabadi et al. (2022)
Packaged foods	Quantity standardized health-costs relative to optimal intakes	Cost of illness	Seidel et al. (2023)

The Impact-Weighted Accounts (IWA) project developed a consumer packaged foods framework to estimate the monetized impacts of companies portfolios. The "effectiveness" dimension estimates the nutrient quality captured by the level of nutrients with an established relationship with health outcomes (trans fat, added sugar, sodium, whole grains and fibre). According to the Impact-Weighted Accounts team at Harvard (HBS, n.d.), investment professionals (The Calvert) used the product impact frameworks for consumer packaged food to highlight where an organization could improve the nutritional quality of its portfolio.

The consumer health module for the assessment of the true price of an agricultural product, within the PPS 'Echte en Eerlijke Prijs' developed by True Price and Wageningen Economic (Manouchehrabadi et al., 2022) considers the difference between the recommended consumption level and the actual consumption level. However, data on recommended intakes is required. Similarly, Seidel et al. (2023) use GBD data and recommended intakes to derive true cost estimates.

Overall, the comparative risk assessment framework is commonly used to quantify and monetize health impacts and using cost-of-illness approaches. In 2023, Springmann worked on a tool published by WHO (2023) ‘Diet Impact Assessment’ model (DIA) which quantifies the health, environmental and affordability implications of dietary changes in the EU. The valuation approach followed in this WHO tool is the value of statistical life based on a comprehensive global meta-analysis of stated preference surveys of mortality risk valuation from the Organisation for Economic Co-operation and Development (OECD).

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