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FULL RESEARCH PAPER
Health policy

Estimating the health impact of menu calorie labelling policy and sugar-sweetened beverage taxation in two European countries: a microsimulation study

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Aims To estimate and compare the impacts of mandatory menu calorie labelling policy and sugar-sweetened beverage (SSB) taxation on reducing obesity prevalence, cardiovascular disease (CVD) mortality, and equity-related impacts, in Belgium and Germany.

Methods and results We used microsimulation models over a 20-year simulation horizon (2022–2041). We modelled the impacts through assumed changes in energy intake due to consumer responses and food industry reformulation. Scenarios of partial (in 'large' out-of-home food businesses; ≥ 250 employees) and full (in all out-of-home food businesses) implementation for menu calorie labelling and different tax rates for SSBs (10%, 20%, 30%) were simulated. Compared with the counterfactual scenario, assuming effects on both consumer and industry behaviour, menu calorie labelling applied to all out-of-home food businesses was estimated to reduce obesity prevalence by 3.61 [95% uncertainty interval-UI: (2.78, 4.30)] and 4.28 [95% UI: (3.64, 5.06)] percentage points and prevent 1600 [95% UI: (400, 3800)] and 30 000 [95% UI: (10 000, 58 000)] CVD deaths in Belgium and Germany over 20 years, respectively. The 30% SSB tax was estimated to reduce obesity prevalence by 0.27 [95% UI: (0.17, 0.43)] and 0.27 [95% UI: (0.17, 0.39)] percentage points and postpone 2500 [95% UI: (800, 5200)] and 16 000 [95% UI: (7500, 28 000)] CVD deaths in Belgium and Germany, respectively. In both countries, SSB taxation had a larger impact on CVD deaths for lower (vs. higher) education groups, whereas menu calorie labelling prevented more CVD deaths for higher (vs. lower) education groups.

Conclusion Menu calorie labelling and SSB taxation have substantial impacts on reducing obesity prevalence and preventing CVD deaths in Belgium and Germany. Implementing both policies will be important to tackle obesity and CVD burden.

Lay summary This study estimated and compared the potential public health impacts of mandatory menu calorie labelling policy and SSB taxation on reducing obesity prevalence and cardiovascular disease deaths in two European countries (Belgium and Germany).

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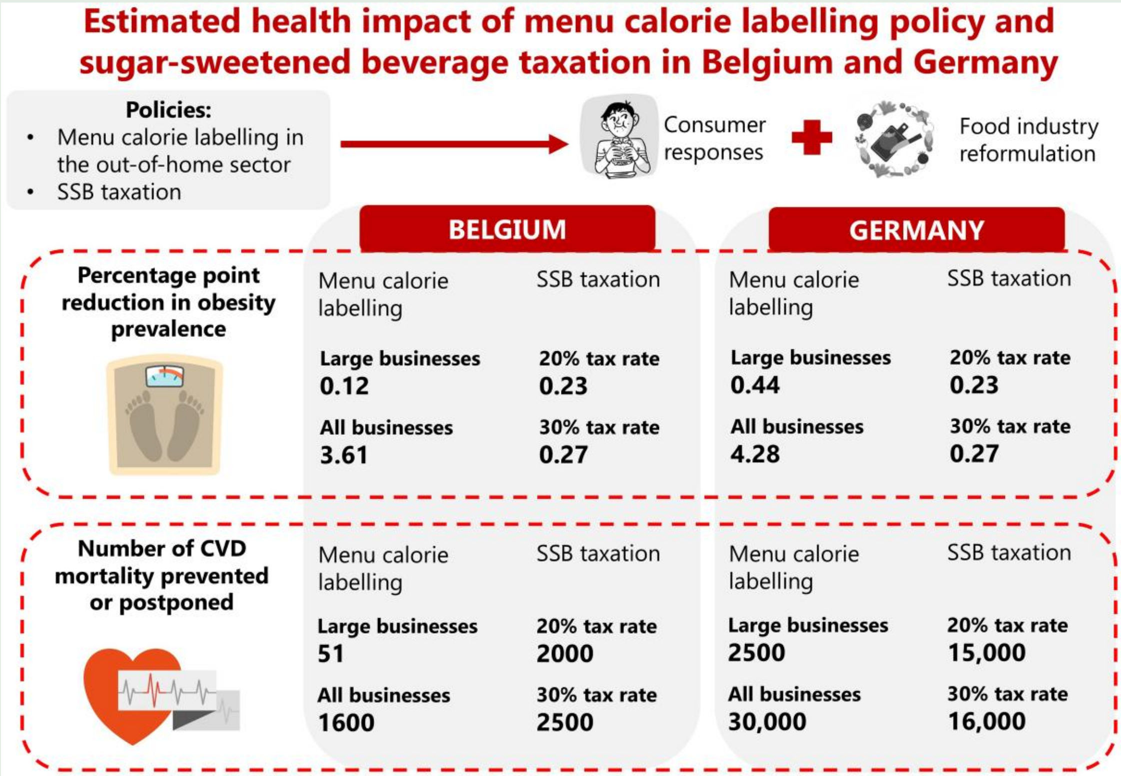
Graphical Abstract



Pictures used in this graphical abstract were downloaded/designed by Freepik.com; CVD = cardiovascular disease; SSB = sugar-sweetened beverage

Keywords Simulation modelling • Policy evaluation • Food policies • Public health policies • Europe

Key findings

- In both Belgium and Germany, implementing the mandatory menu calorie labelling policy in all out-of-home food businesses may have greater benefits in reducing obesity prevalence than sugar-sweetened beverage (SSB) taxation. The impact of SSB taxation on cardiovascular disease mortality was estimated to be greater than the mandatory calorie labelling policy in Belgium but smaller in Germany.
- Mandatory menu calorie labelling policy and SSB taxation need to be seen as complementary policy instruments and implementing both as part of the public health efforts will yield greater benefits in addressing diet-related diseases in both countries.

Introduction

In Europe, more than half of adults live with overweight or obesity, with over 20% attributed to obesity alone.[1] Obesity and its associated physical health burden [e.g. non-communicable diseases (NCDs)][2] are estimated to have substantial economic impacts in many European countries.[3] Food environments have been shown to play an important role in influencing diets and the subsequent risk of developing obesity.[4,5] In line with this, the out-of-home food sector is thought to be a key contributor to the obesity epidemic because eating out is now more commonplace, and out-of-home food and non-alcoholic beverages (hereafter: food) are characterized by being high in energy.[6,7] Therefore, public health policies targeting the out-of-home food businesses are important in addressing obesity and its adverse health impacts without widening current health inequalities.

Menu calorie labelling, designed to empower consumers to make healthier choices by providing calorie information at the point of purchase when dining out, has been mandatorily implemented for the first time in Europe, in large out-of-home food businesses (i.e. ≥250 employees) in England since 2022.[8,9] This policy has also been implemented in major chain restaurants with 20 or more outlets in the US[10,11] and large chain food businesses in an Australian state.[12] Based on some previous simulation modelling studies,[9–11] mandatory menu calorie labelling potentially has population-level impacts in reducing obesity prevalence and NCDs through changing consumer behaviour and inducing industry reformulation. In the US, simulation studies indicate that the implementation of menu calorie labelling in major chain restaurants could prevent 27 646 cardiovascular disease (CVD) deaths[10] and 16 700 cancer deaths over the lifetime of the population.[11] Full implementation of menu calorie labelling policy in all out-of-home food businesses in England was estimated to potentially reduce obesity prevalence by 2.65% points and prevent 9200 CVD deaths over 20 years without widening health inequalities, whereas, at present, the policy is only implemented in large out-of-home food businesses.[9] Given these projected impacts, mandatory menu calorie labelling should be considered for implementation in other European countries as part of comprehensive prevention efforts targeting the out-of-home food sector alongside other public health policies like sugar-sweetened beverage (SSB) taxation.

SSB taxation has been adopted in many European countries (e.g. Belgium, France, Ireland, and UK) to decrease SSB consumption by increasing the prices and encouraging businesses to reformulate products to reduce sugar content.[13] This policy was reported to be promising in preventing obesity and NCDs based on simulation modelling studies from many countries, including Germany, the UK, the USA, and Australia.[14,15] However, a review of studies estimating the impacts of SSB taxation based on simulation modelling approaches concluded that there is limited evidence of (i) the equity-related impacts of SSB taxation across socioeconomic status (SES) groups and (ii) the extent to which SSB taxation may offer greater benefits in reducing obesity and CVD mortality compared to other policies,[15] such as the mandatory menu calorie labelling.

There is a dearth of studies estimating the impacts of different public health policies in improving population health and assessing impacts on health inequalities. Assessments between different public health policies will be important for policymakers to consider multiple evidence-based policy options and prioritize resources for implementation.[15] Although structural-based policies (e.g. SSB tax) have been hypothesized to be more effective overall and in reducing health inequality than agency-based policies, which rely on individual motivation and nutrition literacy (e.g. menu calorie labelling),[14,16,17] this may not apply widely. For example, menu calorie labelling policy does not have differential impacts across SES groups based on two meta-analyses[18,19] and does not seem to widen health inequalities according to a simulation modelling study in England.[9]

In the present study, for the first time, the likely overall population-level impacts across SES groups (defined by education level) of implementing menu calorie labelling and SSB taxation were estimated in two European countries with large differences in population size, Belgium and Germany, where the prevalence of obesity (defined as body mass index—BMI $\geq$ 30 kg/m^2) is high (around 22% for each country[1]) and projected to peak around 30% by 2041.[20] Menu calorie labelling has not yet been implemented in either Belgium or Germany. While Germany currently does not impose a tax on SSBs, Belgium has a SSB tax in place before 2016. There is limited evidence from both countries on the potential impacts of mandatory menu calorie labelling and how much greater these impacts might be compared to SSB taxation. We aimed to estimate and compare the potential health impacts of implementing menu calorie labelling and varying SSB tax rates in countries with different current policy implementations.

Methods

We extended a previous simulation model of the menu calorie labelling policy in England[9] to estimate and compare the impacts of mandatory menu calorie labelling and SSB taxation on obesity prevalence and CVD (defined by coronary heart disease and stroke) mortality in Belgium and Germany. The model,[9] originally adapted from the IMPACT Food Policy Model,[21] is a dynamic, stochastic, discrete-time, and open-cohort microsimulation. Under alternative policy scenarios compared to their corresponding counterfactuals (see below), the model simulates the subsequent impact of the policies on relevant exposures (i.e. energy, SSB intake), changes in risk factor (BMI), and mortality risk throughout individuals' life course. We simulated the effects of the two policies over 20 years from 2022 to 2041. We simulated the models from 2022, as this is when the menu calorie labelling policy was mandatorily implemented for the first time in England.[8,9] We conducted the simulation separately in Belgian and German populations aged 30 to 89 years, using a synthetic population that mimics the real demographic characteristics, BMI, energy and SSB intakes, and disease-related mortality trends based on national data sources (see Section 'Creating synthetic population' in supplementary materials).

Our scenarios for modelling the impacts of mandatory menu calorie labelling policy in Belgium and Germany followed the current implementation of this policy in England that requires 'large' out-of-home food businesses ($\geq$250 employees) to display calorie information for non-prepacked food and drinks.[8,9] In Belgium and Germany, large businesses represented 3% and 9% of the number of outlets in the out-of-home food sector and 10% and 21% of this sector turnover in 2019–2020, respectively.[22] Following a previous simulation study,[9] we assumed that the proportions of different businesses are equivalent to the proportions of out-of-home calories consumed from those businesses (as the coverage of the policy) (see Section 'Mandatory menu calorie labelling' in supplementary materials). We estimated the impacts of mandatory menu calorie labelling policy based on two main scenarios: (i) 'partial implementation' scenario, which refers to the implementation in large out-of-home food businesses only (3% and 9% for the number of outlets or 10% and 21% for the sector turnover in Belgium and Germany, respectively) and (ii) 'full implementation' scenario which refers to the implementation in every out-of-home food business (100% for Belgium and Germany; see *Table 1*). For SSB taxation, we modelled different scenarios based on reported changes in SSB consumption following the implementation of the taxation reported by a previous meta-analysis[23] (see *Table 1*).

For both policies, we compared each scenario with a corresponding counterfactual 'baseline' scenario that refers to the current situation or legislation. In Belgium and Germany, 'no intervention' served as the counterfactual scenario for modelling mandatory menu calorie labelling as this policy has not yet been implemented. While there is no SSB tax in Germany, Belgium enacted volumetric SSB taxes of €0.03/L before 2016, €0.07/L from 2016, and €0.12/L from 2018.[24] Our counterfactual scenarios for modelling SSB taxes were 'no policy' for Germany and an implemented 'SSB tax of €0.03/L' for Belgium because we used SSB consumption data in 2014 (see Section 'SSB tax' in supplementary materials).

Menu calorie labelling effects

We estimated the impact of mandatory menu calorie labelling on energy intake through (i) consumer response (i.e. customers opt for lower-calorie options) and (ii) retailer response (i.e. food reformulation of out-of-home food businesses) based on two main scenarios: partial and full implementations (e.g. as in[9]; see *Table 1*, *Figure 1*).

Effect on consumer response

Following two simulation studies in USA[10,11] using the findings from a meta-analysis by Shangguan *et al.*,[25] we assumed that exposure to menu calorie labelling would reduce calorie intake by 7.3% [95% CI: (−10.1%, −4.4%)] for each out-of-home meal. This effect is similar to a reduction of 7% relative to the average baseline calories purchased reported in a Cochrane meta-analysis by Crockett *et al.*[26] (see Section 'Mandatory menu calorie labelling' in supplementary materials). We considered a possible calorie compensation of 26.5% (averaging estimates from two meta-analyses at 42%[27] and 11%[28]) throughout the day as individuals may consume additional food due to fewer out-of-home calories consumed. Sensitivity analyses with 11% and 42% compensation were conducted. We assumed no differences in the effects of menu calorie labelling across sociodemographic characteristics following the current literature.[18,19]

Reformulation effect

Similar to previous simulation studies,[10,11] we assumed that calorie labelling would lead to a reduction of 5% in menu options offered by the food businesses. This is based on empirical data of reformulation observed in US chain restaurants.[11] This reformulation effect based on US data aligns with a reduction of 4% in the calorie content of menu items (15 kcal out of 400 average baseline calories) reported in a meta-analysis of 41 studies

Table 1 Scenarios and key assumptions

Mandatory menu calorie labelling	
Consumer response	
Partial implementation	Based on consumer response (7.3%) and compensation (26.5%) with calorie labelling implemented in large out-of-home food businesses (3% in Belgium and 9% in Germany)
Full implementation	Based on consumer response (7.3%) and compensation (26.5%) with calorie labelling implemented in all out-of-home food businesses (100% in both Belgium and Germany)
Reformulation	
Partial implementation (Reformulation)	Based on reformulation (5%) with calorie labelling implemented in large out-of-home food businesses (3% in Belgium and 9% in Germany)
Full implementation (Reformulation)	Based on reformulation (5%) with calorie labelling implemented in all out-of-home food businesses (100% in both Belgium and Germany)
Combined	
Partial implementation	Based on consumer response (7.3%), compensation (26.5%), and reformulation (5%) with calorie labelling implemented in large out-of-home food businesses (3% in Belgium and 9% in Germany)
Full implementation	Based on consumer response (7.3%), compensation (26.5%), and reformulation (5%) with calorie labelling implemented in all out-of-home food businesses (100% in both Belgium and Germany)
SSB taxation	
Consumer response	
10% tax	A decrease in SSB consumption by 13.04% [a 10% increase in price based on a pass-through rate (82%) and a demand price elasticity (−1.59)]
20% tax	A decrease in SSB consumption by 26.08% [a 20% increase in price based on a pass-through rate (82%) and a demand price elasticity (−1.59)]
30% tax	A decrease in SSB consumption by 39.11% [a 30% increase in price based on a pass-through rate (82%) and a demand price elasticity (−1.59)]
Reformulation	
30% decrease in sugar	30% lower sugar content due to industry reformulation, independent of changes in consumer behaviour
Combined	
Combination of consumer response and reformulation	Each of the scenarios of consumer response above combined with reformulation

SSB, sugar-sweetened beverage.

by Zlatevska *et al.*[29] (see Section 'Mandatory menu calorie labelling' in supplementary materials). We assumed the effect was consistent across different menu items due to an absence of contradictory evidence.

SSB tax effects

We also estimated the impact of the SSB taxes through consumer response and reformulation (see *Table 1*, *Figure 1*), even though these two pathways were derived from different SSB tax designs (ad valorem tax and tiered tax, respectively).

Effect on consumer response

We developed scenarios for SSB taxation following the findings from a recent meta-analysis by Andreyeva *et al.*[23] Based on a pass-through rate of 82% [95% CI: (66%, 98%)] and a demand price elasticity (i.e. % change in sales or consumption due to % change in price) of −1.59 [95% CI: (−2.11, −1.08)],[23] we modelled SSB ad valorem taxes of 10%, 20%, and 30% (see Section 'SSB tax' in supplementary materials). We assumed no compensation or substitution as findings from a high-quality meta-analysis indicated no substitution to non-SSBs or untaxed beverages due to increased SSB prices.[23] Our scenario of a 20% ad valorem tax on SSBs follows a previous modelling study and is based on scientific recommendations.[14,23,30] We conducted sensitivity analyses using reductions of 6.7% [95% CI: (−10.4, −3.1%)] and 10.0% [95% CI: (−14.7, −5.0)] due to a 10% increase in SSB price reported by Afhsin *et al.*[31] and Teng *et al.*,[32] respectively. We assumed a similar effect of SSB taxes across SES groups due to mixed evidence across study settings.[23]

Reformulation effect

We assumed that the SSB tax would lead to a reduction of the sugar content of liable beverages by 30% (e.g. as in[14]) based on the observed effect of the soft drinks industry levy in the UK reported by two studies: a 29% decrease in the sugar content of all SSB products sold,[33] and a 30% decrease in the sugar volume from soft drinks sold.[34]

Data sources

We created a synthetic population for both countries (see Section 'Creating synthetic population', Supplementary material online, *Appendix Tables S1, S2,* and *S3*). We used population projections from Statbel, the Belgian Statistical Office and projected mortality trends based on the CVD deaths observed from 2012 to 2020. The population projections for Germany were from the German Federal Statistical Office and we projected mortality trends based on the CVD deaths observed from 1991 to 2019. For the exposures (BMI, energy, SSB intakes), we used nationally representative surveys: the National Food Consumption Survey (FCS) 2014–2015 for Belgium and *Kooperative Gesundheitsforschung in der Region Augsburg* (KORA) S4, F4, FF4 (1999, 2007, 2014) and *Nationale Verzehrstudie* (NVS) II (2006) for Germany. We fitted generalized additive models for location, shape, and scale (GAMLSS) models to estimate BMI distribution conditional on year (for Germany only), age, sex, and

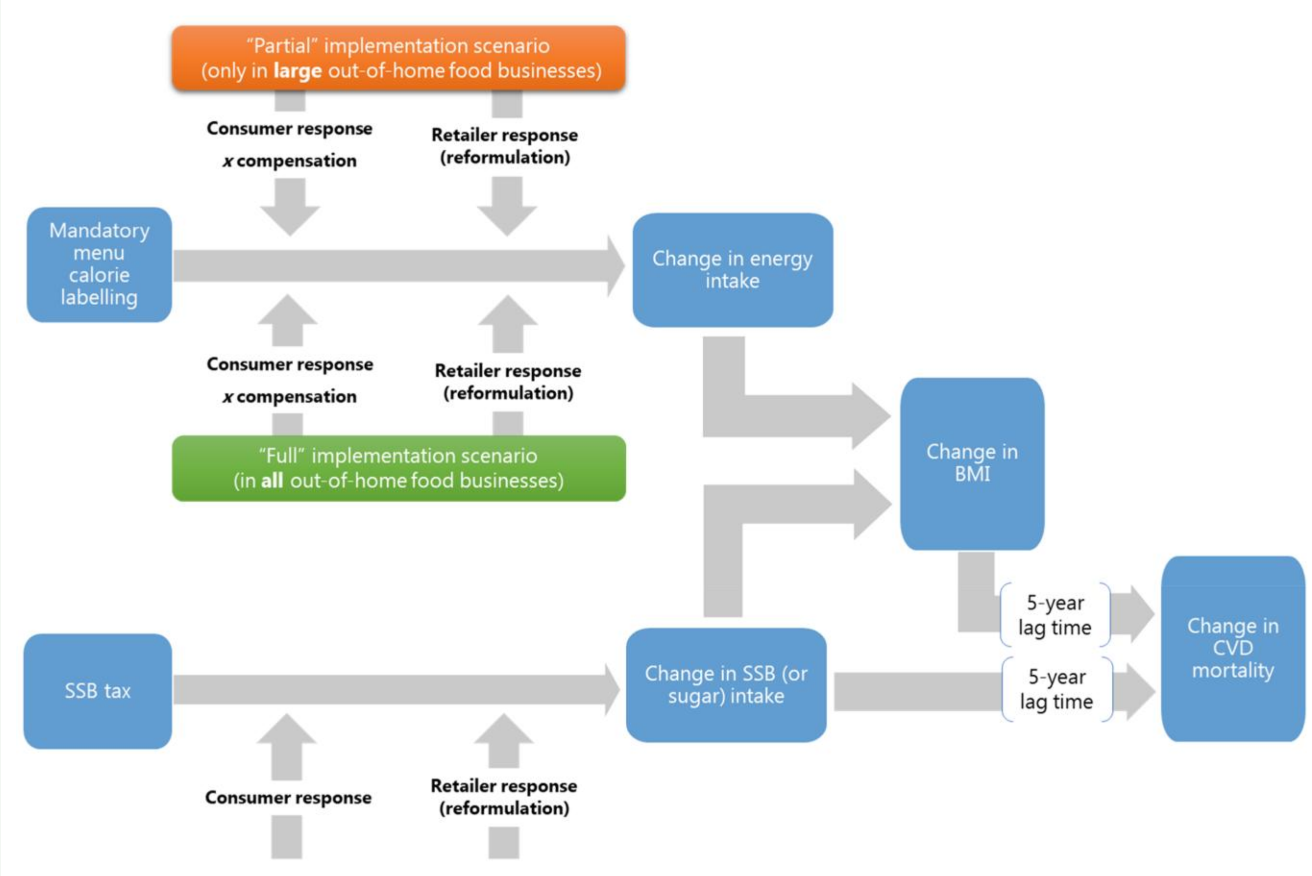


Figure 1 Logic diagram of the impact of mandatory menu calorie labelling and sugar-sweetened beverage taxation on obesity and cardiovascular disease mortality (adapted from Colombet *et al.*[9]). BMI, body mass index; CVD, cardiovascular disease; SSB, sugar-sweetened beverage.

education (as a measure of SES). Energy and SSB intake distributions were conditional on year (for Germany only), age, sex, education, and BMI (e.g. as in[14]). We calculated out-of-home energy intake by multiplying average daily energy intakes by the proportion of out-of-home consumption. This approach was also used to calculate non-diet SSB intake (see Section 'Creating synthetic population' in supplementary materials). All data management and statistical analyses were conducted using R Studio. For code see https://github.com/zoecolombet/MenuEnergyLabelling_code_Europe.

Model engine

We modified a framework for simulation modelling of mandatory menu calorie labelling in England.[9] We hypothesized that mandatory menu calorie labelling (partial or full) implementation would immediately reduce the population's out-of-home energy intake, which has further impacts on changes in CVD mortality risk through a reduction in BMI (see *Figure 1*, and Section 'Estimating the effect of change in energy and SSB intake on BMI and CVD mortality' in supplementary materials). Changes in energy intake were computed by subtracting post-intervention energy from baseline energy intake every year. The Christiansen and Garby prediction formula[35] guided how the changes in energy intake were transformed into equivalent changes in body weight before being converted into BMI changes (see Sub-section 'Estimating the effect of change in energy intake on BMI' in supplementary materials). Using BMI changes, we estimated subsequent change (or reduction) in obesity prevalence (BMI $\geq$ 30 kg/m^2) and the 5-year lag-time changes (e.g. as in[36]) in CVD mortality risk. Based on this information, new mortality rates and the number of deaths were projected. For menu calorie labelling, we modelled the policy's impact solely through a reduction in calories (see *Figure 1*), as a meta-analysis used to inform the effect on calorie intake indicates no statistically significant effects of menu calorie labelling on the reduction in other dietary components (e.g. sugar, sodium).[25]

We also adopted the calorie labelling framework for estimating the impacts of SSB taxation. The effect of SSB taxation on BMI informed changes in obesity prevalence. For the impacts of SSB taxation on CVD mortality, we estimated the simultaneous effects of reduced SSB intake through two pathways: (i) changes in BMI (or BMI-mediated pathway; indirect effect) and (ii) without BMI pathway (direct effect; see *Figure 1* and Sub-section 'Estimating the effect of change in SSB intake on BMI and CVD mortality' in supplementary materials). We assumed that SSB intake has an immediate effect on BMI, and we followed the menu calorie labelling framework in modelling the subsequent effect of BMI changes on CVD mortality risk. For the direct pathway, we assumed the same 5-year lag time for the effect of SSB intake on CVD mortality risk. We also reported the indirect effect of SSB taxation on CVD mortality through BMI as part of the sensitivity analyses. Because we assumed a 5-year lag time, the policies impact the CVD outcomes in the population from 2027 through the simulation period ending in 2041.

Model outputs

For every scenario in each policy, changes in obesity prevalence and the total number of CVD deaths prevented or postponed (DPPs) were simulated in adults aged 30–89 years separately in Belgium and Germany. To assess the equity-related impacts of both these policies based on SES, we presented the outputs stratified by educational level and compared the DPP rates between low- and high-education groups. We presented the findings to two significant digits for DPPs and to two decimal places for changes in prevalence.

Table 2 Estimated impacts of mandatory menu calorie labelling on changes in obesity prevalence and cardiovascular disease mortality in Belgium and Germany (2022–2041)

Scenarios	Belgium		Germany	
	Percentage point changes in obesity prevalence	Number of CVD DPPs	Percentage point changes in obesity prevalence	Number of CVD DPPs
Consumer response				
Partial implementation	−0.06 (−0.10, −0.03)	27[a] (0, 200)	−0.23 (−0.33, −0.14)	1200 (0, 4500)
Full implementation	−1.96 (−2.69, −1.08)	800 (0, 2200)	−2.35 (−3.22, −1.63)	16 000 (4500, 32 000)
Reformulation				
Partial implementation	−0.06 (−0.08, −0.04)	27[a] (0, 200)	−0.22 (−0.25, −0.19)	1500 (0, 4000)
Full implementation	−1.83 (−1.97, −1.70)	800 (200, 2000)	−2.25 (−2.36, −2.15)	15 000 (5000, 27 000)
Combined				
Partial implementation	−0.12 (−0.17, −0.08)	51[a] (0, 400)	−0.44 (−0.54, −0.34)	2500 (500, 6500)
Full implementation	−3.61 (−4.30, −2.78)	1600 (400, 3800)	−4.28 (−5.06, −3.64)	30 000 (10 000, 58 000)

The first 20 years from the policy implementation (2022 to 2041) with the population-level impacts observed from 2027 to 2041 due to a 5-year lag time. Estimates are presented as median and 95% uncertainty intervals (UIs), unless otherwise specified.
CVD, cardiovascular disease; DPPs, deaths prevented or postponed.
[a]Estimates are presented as mean because the median is 0 (zero).

Estimating model uncertainty

We ran 200 iterations using a Monte Carlo method to obtain the uncertainty of model parameters and then reported the results as median values and 95% uncertainty intervals (UIs). See 'Estimating model uncertainty' in supplementary materials for detailed information on possible sources of uncertainty.

Results

Mandatory menu calorie labelling

Table 2 presents the estimated impacts of mandatory menu calorie labelling on obesity prevalence and preventing or postponing CVD deaths in Belgium and Germany. In both countries, estimated impacts through consumer response were similar to retailer reformulation. We estimated higher impacts on obesity prevalence and CVD mortality for Germany than Belgium when the full scenario of mandatory menu calorie labelling was implemented.

In Belgium, the partial implementation (3% of the total number of outlets) and considering consumer response and reformulation, was estimated to reduce obesity prevalence by 0.12% points [absolute, 95% UI: (0.08, 0.17)] and prevent 51 CVD deaths [95% UI: (0, 400)] over 20 years. However, the full implementation was estimated to have markedly larger impacts on reductions in obesity prevalence [3.61% points; 95% UI: (2.78, 4.30)] and CVD mortality [1600 DPPs; 95% UI: (400, 3800)]; which is around 0.90% [95% UI: (0.24, 1.88)] of the total expected CVD deaths.

In Germany, the partial implementation (9% of the total number of outlets) accounting for both consumer response and reformulation would result in a 0.44%-point decline [95% UI: (0.34, 0.54)] in obesity prevalence and 2500 CVD DPPs [95% UI: (500, 6500)] over 20 years. The full implementation in Germany was estimated to reduce obesity prevalence by 4.28 [95% UI: (3.64, 5.06)] percentage points. The reduction in CVD mortality was estimated to be 12 times more than that achieved by implementing this policy in large out-of-home sector businesses only: 30 000 CVD deaths [95% UI: (10 000, 58 000)], around 1.14% [95% UI: (0.51, 1.87)] of the total expected CVD deaths.

Under the full mandatory menu calorie labelling scenario in both countries, we estimated greater changes in obesity prevalence among low and middle education groups than in high education one (*Table 3*). Comparing rates of CVD DPPs per 100 000 population between low and high education groups, we estimated median ratios of 0.86 and 0.76 for Belgium and Germany, respectively (see Supplementary material online, Appendix *Table S4*). This indicates that menu calorie labelling implemented in all out-of-home businesses may prevent fewer CVD deaths in low than high education groups in both countries.

Our sensitivity analyses produced comparable findings. Larger impacts were estimated when using minimum (11%) than maximum (42%) compensation (see Supplementary material online, Appendix *Table S5*) and using turnover than the proportion of outlets for the partial implementation scenario (see Supplementary material online, Appendix *Table S6*).

SSB tax

The likely population-level impacts of SSB taxation on obesity prevalence and CVD mortality through consumer response increased in line with the higher tax rates implemented (*Table 4*). The reformulation effect (sugar content reduced by 30%) alone was estimated to have similar impacts to implementing a 20% SSB tax. The estimated changes in obesity prevalence resulting from SSB taxation were similar between Belgium and Germany.

In Belgium, consumer response to 20% and 30% tax rates would reduce obesity prevalence by 0.12 [95% UI: (0.07, 0.23)] and 0.18 [95% UI: (0.10, 0.34)] percentage points and prevent 1200 [95% UI: (200, 2800)] and 1700 [95% UI: (400, 4200)] CVD deaths over two decades. Reformulation alone was estimated to result in a 0.14% point [95% UI: (0.09, 0.22)] decline in obesity prevalence and 1200 CVD DPPs [95% UI: (400, 3600)]. Combining both consumer response and reformulation would result in bigger estimated impacts. For example, a 30% tax rate combined with reformulation was estimated to decrease obesity prevalence by 0.27 [95% UI: (0.17, 0.43)] percentage points and postpone 2500 deaths [95% UI: (800, 5200)] or around 1.46% [95% UI: (0.54%, 3.07%)] of the expected CVD deaths.

Table 3 Estimated impacts of mandatory menu calorie labelling accounting for combined consumer response and reformulation on obesity prevalence and cardiovascular disease mortality by educational level in Belgium and Germany (2022–2041)

Scenarios	Belgium		Germany	
	Obesity prevalence	CVD	Obesity prevalence	CVD
Counterfactual	**Predicted**	**Predicted CVD mortality**	**Predicted**	**Predicted CVD mortality**
Low education	33.54 (32.72, 34.29)	82 000 (48 000, 130 000)	26.01 (25.38, 26.73)	300 000 (200 000, 420 000)
Middle education	32.24 (31.44, 32.97)	52 000 (31 000, 76 000)	20.61 (20.27, 20.87)	1 500 000 (960 000, 2 200 000)
High education	18.79 (18.11, 19.42)	37 000 (22 000, 61 000)	14.80 (14.48, 15.09)	790 000 (520 000, 1 100 000)
Partial implementation	**Percentage point changes**	**DPPs**	**Percentage point changes**	**DPPs**
Low education	−0.12 (−0.20, −0.07)	25[a] (0, 200)	−0.51 (−0.67, −0.39)	280[a] (0, 1000)
Middle education	−0.13 (−0.21, −0.09)	17[a] (0, 200)	−0.43 (−0.54, −0.34)	1500 (0, 4500)
High education	−0.10 (−0.15, −0.05)	9[a] (0, 200)	−0.38 (−0.48, −0.28)	500 (0, 3000)
Full implementation	**Percentage point changes**	**DPPs**	**Percentage point changes**	**DPPs**
Low education	−3.70 (−4.54, −2.85)	600 (0, 1600)	−5.05 (−6.13, −4.20)	2800 (500, 6500)
Middle education	−4.11 (−4.85, −3.13)	600 (0, 1400)	−4.23 (−5.03, −3.60)	16 000 (5000, 32 000)
High education	−2.96 (−3.53, −2.37)	400 (0, 1200)	−3.58 (−4.23, −3.03)	10 000 (2500, 21 000)

Estimates are presented for 20 years from the policy implementation (2022 to 2041) with the population-level impacts observed from 2027 to 2041 due to a 5-year lag time. Estimates are presented as median and 95% uncertainty intervals (UIs), unless otherwise specified.
CVD, cardiovascular disease; DPPs, deaths prevented or postponed.
[a]Estimates are presented as mean because the median is 0 (zero).

Table 4 Estimated impacts of sugar-sweetened beverage tax on changes in obesity prevalence and cardiovascular disease mortality in Belgium and Germany (2022–2041)

Scenarios	Belgium		Germany	
	Percentage point changes in obesity prevalence	Number of CVD DPPs	Percentage point changes in obesity prevalence	Number of CVD DPPs
Consumer response				
10% tax	−0.06 (−0.11, −0.03)	600 (0, 2000)	−0.06 (−0.10, −0.03)	4500 (1000, 9500)
20% tax	−0.12 (−0.23, −0.07)	1200 (200, 2800)	−0.12 (−0.20, −0.06)	8500 (3000, 16 000)
30% tax	−0.18 (−0.34, −0.10)	1700 (400, 4200)	−0.18 (−0.30, −0.10)	12 000 (4500, 22 000)
Reformulation				
30% decrease in sugar	−0.14 (−0.22, −0.09)	1200 (400, 3600)	−0.14 (−0.20, −0.09)	10 000 (3500, 18 000)
Combined				
10% tax	−0.19 (−0.30, −0.12)	1800 (600, 4200)	−0.18 (−0.27, −0.12)	12 000 (4500, 22 000)
20% tax	−0.23 (−0.37, −0.15)	2000 (800, 4800)	−0.23 (−0.32, −0.14)	15 000 (6500, 26 000)
30% tax	−0.27 (−0.43, −0.17)	2500 (800, 5200)	−0.27 (−0.39, −0.17)	16 000 (7500, 28 000)

The first 20 years from the policy implementation (2022 to 2041) with the population-level impacts observed from 2027 to 2041 due to a 5-year lag time. Estimates are presented as median and 95% uncertainty intervals (UIs), unless otherwise specified.
CVD, cardiovascular disease; DPPs, deaths prevented or postponed; SSB, sugar-sweetened beverage.

In Germany, consumer response to the implementation of SSB taxes would yield a 0.12-percentage point [95% UI: (0.06, 0.20)] decline in obesity prevalence and 8500 [95% UI: (3000, 16 000]) CVD DPPs for the 20% SSB tax and a 0.18-percentage point [95% UI: (0.10, 0.30)] decline in obesity prevalence and 12 000 CVD DPPs [95% UI: (4500, 22 000)] for the 30% SSB tax. The reformulation alone would decline obesity prevalence by 0.14% points [95% UI: (0.09, 0.20)] and reduce CVD deaths by 10 000 [95% UI: (3500, 18 000)]. We estimated bigger impacts from combining consumer response and reformulation with a decline in obesity prevalence by 0.27% points (95% UI: 0.17, 0.39) and a reduction in CVD deaths by 16 000 (95% UI: 7500, 28 000), around 0.62% [95% UI (0.27%, 0.97%)] of the predicted deaths if a 30% SSB tax would be implemented.

Table 5 Estimated impacts of the sugar-sweetened beverage tax accounting for combined consumer response and reformulation on obesity prevalence and cardiovascular disease mortality by educational level in Belgium and Germany (2022–2041)

Scenarios	Belgium		Germany	
	Obesity prevalence	CVD	Obesity prevalence	CVD
Counterfactual	**Predicted**	**Predicted CVD mortality**	**Predicted**	**Predicted CVD mortality**
Low education	33.54 (32.72, 34.29)	82 000 (48 000, 130 000)	26.01 (25.38, 26.73)	300 000 (200 000, 420 000)
Middle education	32.24 (31.44, 32.97)	52 000 (31 000, 76 000)	20.61 (20.27, 20.87)	1 500 000 (960 000, 2 200 000)
High education	18.79 (18.11, 19.42)	37 000 (22 000, 61 000)	14.80 (14.48, 15.09)	790 000 (520 000, 1 100 000)
10% tax	**Percentage point changes**	**DPPs**	**Percentage point changes**	**DPPs**
Low education	−0.23 (−0.37, −0.13)	800 (200, 2200)	−0.27 (−0.42, −0.16)	2200 (500, 5500)
Middle education	−0.24 (−0.39, −0.15)	800 (0, 1800)	−0.16 (−0.23, −0.10)	7000 (2000, 13 000)
High education	−0.09 (−0.14, −0.03)	200 (0, 800)	−0.12 (−0.18, −0.07)	3500 (990, 7000)
20% tax	**Percentage point changes**	**DPPs**	**Percentage point changes**	**DPPs**
Low education	−0.28 (−0.46, −0.17)	1000 (200, 2600)	−0.34 (−0.50, −0.19)	2500 (990, 6000)
Middle education	−0.30 (−0.47, −0.18)	800 (200, 2000)	−0.19 (−0.28, −0.12)	8000 (3000, 15 000)
High education	−0.11 (−0.18, −0.05)	200 (0, 1000)	−0.15 (−0.22, −0.09)	3500 (1000, 8000)
30% tax	**Percentage point changes**	**DPPs**	**Percentage point changes**	**DPPs**
Low education	−0.34 (−0.54, −0.20)	1200 (200, 2800)	−0.39 (−0.62, −0.24)	3000 (1000, 6500)
Middle education	−0.35 (−0.57, −0.21)	1000 (200, 2200)	−0.23 (−0.34, −0.15)	8800 (3000, 16 000)
High education	−0.13 (−0.21, −0.06)	200 (0, 1000)	−0.17 (−0.26, −0.10)	4000 (1500, 8500)

Estimates are presented for 20 years from the policy implementation (2022 to 2041) with the population-level impacts observed from 2027 to 2041 due to a 5-year lag time. Estimates are presented as median and 95% uncertainty intervals (UIs), unless otherwise specified.
CVD, cardiovascular disease; DPPs, deaths prevented or postponed; SSB, sugar-sweetened beverage.

We estimated greater changes in obesity prevalence in low than in higher education groups in Belgium and Germany (*Table 5*). We compared rates of CVD DPPs of implementing a 30% SSB tax considering both consumer response and reformulation per 100 000 population between low and high education groups. We estimated median ratios of 3.46 and 2.00 for Belgium and Germany, respectively, and the probability of the ratios > 1 was higher than 50% (see Supplementary material online, Appendix *Table S4*). This indicates that the policy may prevent more CVD deaths in low than high education groups in both countries.

Sensitivity analyses using effect sizes from different meta-analyses showed similar findings to the primary analyses of the same 10% SSB tax rate (see Supplementary material online, Appendix *Table S7*). We found small impacts when the effect of SSB taxes on a reduction in CVD mortality was only estimated through changes in BMI (see Supplementary material online, Appendix *Table S8*).

Discussion

To inform future food policy in Europe, we modelled the likely population impacts of implementing mandatory menu calorie labelling and SSB taxation on obesity prevalence and CVD mortality in two European countries (2022–2041). In both countries, we estimated the impact of menu calorie labelling on obesity prevalence to be greater than SSB taxation when implemented in every out-of-home food business. However, implementing menu calorie labelling in all out-of-home food businesses is estimated to postpone or prevent more CVD deaths than the highest SSB tax rate (30%) in Germany (1.14% vs. 0.62% of the total expected CVD deaths) but not in Belgium (0.90% vs. 1.46%). Under the assumption that the policies have the same effect across ages, sexes, and SES groups,[9] we estimated that SSB taxation may have equitable impacts as the policy tended to prevent more CVD deaths in low than high education groups. However, menu calorie labelling may not have equitable impacts as more CVD DPPs were estimated in high than low education groups.

Mandatory menu calorie labelling would have a higher impact across the studied countries if the policy were implemented for all out-of-home food businesses, rather than just large businesses, as is currently the case in England.[9] Our findings are consistent with a previous simulation modelling in England,[9] suggesting large impacts of implementing mandatory menu calorie labelling in all out-of-home food sectors with obesity prevalence reduced by 2.65% points. This study also estimated 9200 CVD DPPs or around 1.10% (95% UI 0.71–1.60) relative to the expected CVD deaths,[9] which is similar to our estimates in Belgium (0.90%) and Germany (1.14%).[9] Our results are also consistent with previous modelling in USA.[10] For example, our full scenario without reformulation (a compensation level of 26.5%) would result in 16 000 CVD DPPs in Germany compared to 27 646 CVD DPPs in USA (a higher compensation of 50% with a much larger population size).[10] In addition, our research echoes their finding that adding the reformulation doubles the mortality benefits.[10]

Our findings for SSB taxation are also similar to those of previous simulation modelling in Germany.[14] Under the same scenario of 20%

SSB tax without reformulation assumed, our estimates of 8500 CVD DPPs are half of 17 000 all-cause DPPs (combined CVD and non-CVD deaths) reported by the previous modelling (findings on CVD deaths only are not presented).[14] A handful of studies have simulated the impact of sugary drink policies across different study contexts and reported consistent results.[15] For example, a study from the US with a larger population size estimated 31 000 CVD DPPs in the next 15 years from implementing a 10% SSB tax.[21] It is important to note that the likely impacts on CVD mortality estimated through BMI only (see Supplementary material online, Appendix *Table S8*) were similarly modest in size compared to the previous modelling estimates.[14] In line with this, the benefits of reducing obesity prevalence were much smaller than the estimates for mandatory calorie labelling, indicating that the SSB tax may largely impact CVD mortality through a pathway not involving changes in BMI as discussed in a previous simulation modelling study.[14]

We estimated that mandatory menu calorie labelling implemented in all out-of-home food businesses may have greater population-level impacts than SSB taxation in reducing obesity prevalence in both countries, and in preventing CVD deaths in Germany but not in Belgium. Greater impacts of menu calorie labelling on reducing obesity prevalence may be because energy intake from out-of-home has more direct and substantial impacts on weight gain, particularly due to larger portion sizes (volume) and high in fat and overall calorie content.[6,7,37,38] In line with this, a study of UK Biobank participants reported that BMI has stronger associations with total energy and energy from fat than sugar.[39] The greater CVD mortality-related benefits of SSB taxes compared to menu calorie labelling in Belgium, but not in Germany, may be explained by higher SSB intake in Belgium (see Supplementary material online, Appendix *Table S3*). Importantly, the evidence used to inform our model suggests that these policies may impact CVD mortality through different pathways that involve changes in BMI for mandatory menu calorie labelling and other BMI-independent mechanisms for SSB taxation. These policies need to be seen as complementary policy instruments as menu calorie labelling will affect all products on menus while SSB taxation will only affect SSBs. Implementing both as part of the public health efforts in addressing diet-related diseases will yield greater benefits in both countries.

It is important to note that menu calorie labelling may not have equitable impacts in Belgium and Germany, as the policy tends to postpone more CVD deaths in high than low education groups. This may be explained by our estimated exposure data, which shows higher out-of-home energy intake in high compared to low education groups (see Supplementary material online, Appendix *Table S3*) and thus higher potential effect of the policy in those with high education. Proportions of daily out-of-home energy intake were not available by education level in Belgium nor in Germany; we estimated out-of-home energy intake by sex and age groups only. However, our estimations align with findings from a previous study suggesting more frequent eating out in middle and high than low education groups in Belgium.[37] Future modelling studies in other settings are warranted to provide more insights on the relevance of this assumption. Meanwhile, SSB intake is higher in low and/or middle-education groups in both countries compared to high education group, and therefore, more CVD deaths attributable to SSB intake can be prevented in these groups.

The present study has some strengths. To our knowledge, this is the first comparison of likely health impact of mandatory menu calorie labelling and SSB taxation in a European setting. Our findings are particularly robust as we used a validated model that has previously been exercised to estimate the menu calorie labelling in England and other dietary-specific policies in the US.[9,21] Scenarios were informed from current policy practices (e.g. mandatory menu calorie labelling in England). Our estimates are supported by rigorous sensitivity analyses that account for uncertainties in modelling assumptions and are consistent with findings from previous studies,[9,10,14,15,21] increasing confidence in the results. Two different policies were examined using the same model framework, addressing the current gaps highlighted by a scoping review[15] on a dearth of evidence on the impacts of SSB policy compared to other policies.

The present study also has some limitations. First, we used a proportional effect estimate (7.3% reduction) from a meta-analysis[25] for the main analysis. Even though this estimate has been used in previous simulation modelling studies[10,11] and similar to findings from another meta-analysis,[26] the effect may not be transferable to the population in Belgium and Germany. While there is an absence of evidence for Belgium and Germany, observational studies showed that implementation of menu calorie labelling in a single fast food chain across three US states was associated with a purchase reduction per customer of 82 calories,[40] but no such reduction in calories per transaction was observed in England from a recent pre-post comparison study.[41] Similarly, the reformulation due to menu labelling was based on US data[11] and supported by a recent study,[29] but this may not fully reflect the potential reformulation within the European context due to differences in food industry practices. For instance, the average energy content of restaurant meals in the US is 1088 kcal[42] and much higher than in Germany where it is approximately 792 kcal.[43] This limitation also applies to the effect estimates (consumer response, reformulation) used for simulating the effects of SSB taxation. Evidence based on empirical impacts of the policies in both countries would improve the precision of modelling the long-term policy impacts. We assumed the effects of policies remained stable throughout the simulation period due to the absence of contrasting evidence. However, the effect of policies may change due to behavioural adaptation (e.g. decrease due to habituation to information, or increase due to increased awareness and policy campaign) over time,[9] policy amendments, and market shifts (e.g. introduction of new products). We also did not consider the cumulative effects of out-of-home energy and SSB intakes over the life course.

Our exposures (i.e. BMI, energy and SSB intakes) were based on the most recent available representative surveys in 2014 or earlier, and we assumed the patterns have continued since then. Similarly, the proportions of out-of-home energy intake were derived from studies conducted in early 2000s, assuming no subsequent changes by age groups and sex. While these sources are the best available, dietary habits may have changed in response to the COVID-19 pandemic[44] and recent economic downturns.[45] Our model also did not account for potential changes and future trends in immigration that may affect dietary patterns. Therefore, outdated baseline consumption data may also potentially introduce bias to some extent. However, our findings are more likely to underestimate rather than overestimate policy impacts. In the context of the menu calorie labelling policy, eating out may now be more common, reflected by the increased number of out-of-home food retailers in the last 20 years in both countries.[22] Future modelling studies will benefit from using more recent data. For Belgium, we used the €0.03/L tax (before 2016) as the counterfactual scenario because we used SSB consumption data in 2014. SSB intake may have decreased due to a new tax of 0.12/L implemented in 2018. We assumed this price increase, from €0.03/L to €0.12/L, is approximately equivalent to a 10% SSB tax (see Section 'SSB tax' in supplementary materials). Therefore, implementing higher SSB taxes (20% or 30%) would result in greater impacts than the current implemented SSB tax rate (€0.12/L). Furthermore, we did not consider cross-border shopping which could diminish the effectiveness of SSB taxation. In Belgium, there is evidence that this may indeed be an issue.[46] However, in Germany, despite no available data, cross-border shopping is unlikely due to taxes in many neighbouring countries. Cross-border shopping may also contribute to heterogeneity in the policy effect, with lower-SES individuals more likely to engage in cross-border shopping.[24]

We modelled the impacts specific to the population aged 30–89 years, and therefore, the results do not capture potential policy benefits related to peak SSB consumption in younger ages,[47] nor do the results account for changes in obesity from childhood to young adulthood. We modelled the exposures conditional on education level, and we estimated the policy impacts across these education groups. Consequently, we excluded individuals with no information ('unknown', 'not applicable') on education level in Belgium, and this is a limitation. We assumed no differential effects of the policies (i.e. the effect of menu calorie labelling, price elasticity due to SSB taxation) by sociodemographic characteristics (e.g. education level). This is supported by findings from previous meta-analyses suggesting no differences in the effects of menu calorie labelling across sociodemographic characteristics, including SES[18,19] and mixed evidence on price elasticity by SES.[23] However, such differences may still plausibly exist. For instance, low SES group may benefit more from SSB taxes as they tend to be more responsive to price increases.[48] More evidence on heterogeneity in policy effects in general and specifically in Belgium and Germany is needed. We were also not able to consider potential differential effects of menu labelling policy by types of out-of-home food business (e.g. fast food, fine dining) due to a lack of available evidence in this regard, and no available data on the number of outlets by food business types in Belgium and Germany.

Our model accounted for calorie labelling reductions in energy intake during out-of-home food sector visits being partially offset by increased energy intake later in the day (calorie compensation). For SSB taxation, we assumed no compensation or substitution supported by a high-quality meta-analysis indicating no significant substitution to non-SSBs or untaxed beverages due to increased SSB prices.[23]

While our definition of obesity based on BMI ($\geq$ 30 kg/m^2) is internationally acceptable, BMI does not account for body fat distribution. Future research will benefit from including other anthropometric measures (e.g. waist circumference) and considering other newly developed obesity definitions.[49]

The wide UIs in long-term projections indicate a broad plausible range of estimated policy impacts and appropriately reflect the uncertainty in the underlying data. Non-zero lower bounds of the UIs for full implementation of menu calorie labelling and higher SSB tax rates suggest that these policies are likely to yield meaningful benefits in improving modelled health outcomes. Therefore, our findings provide new evidence that implementing mandatory menu calorie labelling across all out-of-home food establishments and applying higher tax rates (e.g. 30%) on SSBs would yield substantial public health benefits by reducing obesity prevalence and preventing CVD deaths. Each of the policies has also been demonstrated to be cost-effective by previous studies.[11,14] In Belgium, implementing mandatory menu calorie labelling in all out-of-home sectors together with higher tax rates is recommended to maximize public health efforts to tackle diet-related diseases. As neither of the policies has been adopted in Germany, our results emphasize the need for the government to take ambitious steps towards implementing both mandatory menu calorie labelling policy in all-out-home businesses and SSB tax at higher rates for greater public health benefits. The introduction of menu calorie labelling as a new policy in Belgium and Germany may require education campaigns to maximise its effectiveness and equity. Implementing SSB taxation in Germany or increasing the current SSB tax rate in Belgium would benefit from public campaigns explaining its rationale, as previously done in the UK.[50] More importantly, these policies need to be seen as complementary approaches, and with additional measures across the food system, highlighting the fact that no single policy will be enough to significantly reduce the burden of unhealthy diets in populations.

Conclusion

This study provides the first evidence of population-level benefits of implementing national level mandatory menu calorie labelling policy and SSB taxes in Belgium and Germany. Implementing both policies is needed in order to tackle obesity and CVD burden in both countries.

Supplementary material

Supplementary material is available at *European Journal of Preventive Cardiology*.

Author contribution

I.G.N.E.P., M.O., E.R., Z.C. designed the study. I.G.N.E.P., C.K., Z.C. developed the model. M.O., C.K., and Z.C. supervised I.G.N.E.P. M.S.V. and K.M.F.E.-F. did the GAMLSS fitting for exposure data in Belgium and Germany, respectively. N.B. and A.P. acquired the survey data for Belgium and Germany, respectively. I.G.N.E.P. and Z.C. did the analysis and drafted the initial manuscript. R.E. and Z.C. verified the results from the analysis. All the authors contributed to the data interpretation and revised the manuscript draft. All the authors approved and accept responsibility to submit for publication.

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Conflict of interest: none declared.

Data availability

We used data from different sources. For Belgium, population projection and census data are available online on the official website of Statbel, the Belgian Statistical Office. Projected mortality data are available upon request from Statbel. Exposure data (BMI, energy and SSB intakes) are from the National Food Consumption Survey, available upon request to the data custodian (Sciensano). For Germany, population projection, census, and mortality data are available online on the German Federal Statistical Office's website. Exposure data are from KORA (https://www.helmholtz-munich.de/en/epi/cohort/kora) and NVS surveys available with the permission from the data custodian. R script to generate the results presented in this study is publicly available at https://github.com/zoecolombet/MenuEnergyLabelling_code_Europe.

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