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Long-term impact of a sugar-sweetened beverage tax and increased physical activity on obesity and diabetes burden in Central and Eastern European Countries: a microsimulation model

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ABSTRACT

Aims: This study models the potential health impacts of combining fiscal and behavioral policies, specifically, sugar-sweetened beverage (SSB) taxation and increases in physical activity (PA), across six Central and Eastern European (CEE) countries.

Methods: We simulated the effects of a 20 % SSB tax combined with a 15 % increase in PA on obesity, type 2 diabetes mellitus (T2DM), and mortality over 30 years in Bulgaria, Czechia, Hungary, Poland, Romania, and Slovakia. Sensitivity analyses examined alternative scenarios, including SSB substitution with water, a 30 % fruit and vegetable subsidy.

Results: Combined SSB taxation and PA increases would have a significant impact on low-income adults aged 15–49 in Czechia, Hungary, and Romania, whereas high-income groups benefit most in Bulgaria, Poland, and Slovakia. It could prevent between 7,344 (95 % UI: 4,520, 10,168) T2DM cases in Slovakia and 24,142 (95 % UI: 18,809, 29,474) in Poland. Obesity reductions are projected to peak in the early to mid-2030 s, with T2DM and mortality benefits accruing more gradually.

Conclusions: Integrating fiscal and behavioural policies could reduce the burden of obesity, T2DM, and related inequalities in CEE countries, supporting strategies aligned with the WHO and Sustainable Development Goals.

1. Introduction

Diabetes mellitus (diabetes hereafter) poses a major public health concern in Europe, affecting both population health and healthcare systems. In 2024, one in ten adults aged 20 to 79 in Europe has diabetes, with cases projected to rise by 10 % to 72.4 million by 2050; related healthcare costs are estimated at USD 193 billion, accounting for 19 % of global diabetes expenditure [1]. Prevalence of diabetes varies regionally, with higher rates observed in Central and Eastern Europe (CEE) and Southern Europe. In CEE, the prevalence affects about 7.16 % of the adult population, with a higher burden among women (7.69 %) compared to men (6.48 %) [2].

Type 2 diabetes mellitus (T2DM) is the predominant form of diabetes in adults, accounting for approximately 90 % of all cases [3]. The condition arises from a combination of pancreatic β-cell dysfunction and peripheral insulin resistance, and is strongly associated with overweight and obesity [3]. In the European Union, T2DM was responsible for an estimated 109,000 deaths and 5.3 million disability-adjusted life years (DALYs) in 2019 [3]. A considerable proportion of this burden is attributable to modifiable lifestyle factors: insufficient consumption of fruits, whole grains, nuts, and seeds, together with high intake of sugar-sweetened beverages (SSBs) and red or processed meats, contributed to 36 % of deaths and 37 % of DALYs attributable to T2DM. Elevated body-mass index (BMI > 21–$23\ kg/m^2$) accounted for 41 % of deaths and 57 % of DALYs [3]. Mortality associated with diabetes-related risk factors, including physical inactivity and high SSB consumption, has increased

Abbreviations: BMI, body mass index; BG, Bulgaria; CEE, Central and Eastern European; CZ, Czechia; DALYs, disability-adjusted life years; EHIS, European health interview survey; EU, European Union; GAPPA, global action plan on physical activity; GBD, global burden of disease; HU, Hungary; MET, metabolic equivalent of task; NCD, noncommunicable diseases; PA, physical activity; PL, Poland; QARMM, quality assessment reporting for microsimulation models; RO, Romania; SK, Slovakia; SSB, sugar-sweetened beverages; T2DM, type 2 diabetes mellitus; UI, uncertainty interval; USD, United States Dollar; VAT, value-added tax; WHO, world health organization.

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steadily from 1990 to 2021 in countries such as Bulgaria, Czechia, Hungary, Poland, Romania, and Slovakia [4].

SSB intake, in particular, promotes obesity, insulin resistance, and the development of T2DM [5,6]. SSB consumption is especially high among younger adults in CEE; for example, Hungarian adults consume an average of 46.1 g of added sugars per day, equivalent to 7.6 % of total energy intake [7]. Evidence supports that SSB taxation effectively raises prices, reduces sales, and lowers sugar intake [8]. The World Health Organization (WHO) recommends the implementation of SSB taxation as part of its Global Action Plan for the Prevention and Control of Noncommunicable Diseases (NCDs) 2013–2030, to improve public health and promote health equity [9]. In response to these trends, the WHO recommends imposing a tax on SSB products of at least 20 % [10]. Fiscal policies on sugar-sweetened beverages vary across CEE countries. Czechia imposes a 13.04 % value-added tax (VAT) on SSBs, while Romania and Slovakia apply VAT rates of 8.26 % and 16.67 %, respectively [8]. Hungary and Poland levy volume-based excise taxes on sugar-sweetened drinks, in addition to VAT, resulting in total tax rates measured as a percentage of the price of an internationally comparable brand of about 24.6 % and 28.6 %, respectively [8]. Recent data on Bulgaria's taxation of SSBs is unavailable [8]. However, there remains limited evidence on how these fiscal policies impact diabetes outcomes.

Physical inactivity is a major contributor to the growing T2DM burden in Europe. Individuals in CEE and Southern Europe are significantly more likely to be physically inactive, with adjusted odds ratios of 0.64 (95 % CI: 0.55–0.74) and 0.61 (95 % CI: 0.52–0.71), respectively [11]. In CEE countries, the prevalence of complete physical inactivity is particularly high, with rates in Bulgaria exceeding 50 % [12]. As a result, many adults in these regions do not meet the WHO recommendation of 150–300 min of moderate-intensity, or 75–150 min of vigorous-intensity aerobic physical activity per week, or an equivalent combination [13]. To address this gap, efforts must be intensified to increase physical activity levels by at least 15 % by 2030, in line with the Global Action Plan on Physical Activity (GAPPA) target [14,15]. Reducing these disparities is crucial, as increasing physical activity can substantially lower the incidence of obesity and diabetes [16].

Given the dual burden of unhealthy dietary habits and physical inactivity, integrating fiscal measures such as SSB taxation with public health initiatives that promote physical activity could yield synergistic benefits in reducing the incidence of diabetes [8]. However, to evaluate the impact of these two interventions on disease burden, long-term observation is needed. Therefore, simulations such as microsimulation are a key method for assessing the long-term effects of health programs or policies on population health outcomes [17]. Microsimulation is a powerful modelling technique that simulates the life courses of individuals within a population to estimate the long-term impact of interventions or policies. By utilizing individual-level data and probabilistic rules, microsimulation effectively captures heterogeneity in risk factors, behaviors, and outcomes, enabling detailed projections of health impacts and cost-effectiveness across diverse subgroups. This approach is particularly valuable for chronic diseases, such as diabetes, where an individual's history and risk profile significantly influence future disease progression and response to interventions. Moreover, microsimulation enables the evaluation of complex, combined policy scenarios and their long-term effects on population health, which would be difficult to assess through traditional epidemiological methods or randomized trials alone. As such, it offers a cost-effective and flexible tool for informing evidence-based public health policy and optimizing resource allocation [17].

Previous studies have employed microsimulation models to assess the impact of SSB taxes on obesity and non-communicable diseases, including diabetes, primarily in Western European countries such as Belgium [18] and Germany [19], as well as in Southern European countries like Portugal [20]. Physical activity interventions have also been modelled in the United Kingdom [21]. However, no prior study has examined the combined effects of these strategies in CEE countries. Therefore, this study is the first to use microsimulation modelling to estimate the long-term impact of increased physical activity and SSB taxation on obesity and diabetes burden in the CEE region.

2. Materials and methods

We developed a discrete-time stochastic microsimulation model to project the long-term impact of public health policies on obesity, T2DM, and T2DM-attributable mortality in six CEE countries. The model evaluated a combined policy scenario including a 20 % tax on SSBs and a 15 % increase in physical activity, in line with the WHO recommendation [10] and GAPPA target [14]. Outcomes were stratified by sex and income level. The analysis included Bulgaria (n = 7,540), Czechia (n = 7,993), Hungary (n = 5,603), Poland (n = 19,959), Romania (n = 16,186), and Slovakia (n = 5,527) [22]. Baseline T2DM incidence and mortality were sourced from the Global Burden of Disease (GBD) 2019 study. Each simulated individual was assigned a sex, an age group (15–49, 50–74, or ≥ 75 years), and an income category according to national population distributions from the European Health Interview Survey (EHIS) 2019. We categorised income level in EHIS as low (first and second quintiles), middle (third quintile), and high (fourth and fifth quintiles). Baseline bodyweight status was determined using age- and income-specific prevalence estimates from the same source. Bodyweight categories were defined as normal weight (BMI 18.5–24.9 kg/m^2), overweight (BMI 25.0–29.9 kg/m^2), and obese (BMI ≥ 30.0 kg/m^2) [23]. All individuals were assumed to be alive and free of T2DM at model entry. Detailed baseline characteristics are presented in Table 1.

Transitions between these states were updated annually using estimated transition probabilities derived from published epidemiological evidence. Normal-weight individuals could progress to overweight, obese, or diabetic states. Overweight individuals could advance to obesity or develop T2DM, and obese individuals are at risk of developing T2DM. Once individuals became diabetic, they remained in that state and were subject to an elevated annual mortality risk. The baseline year was 2019, and the model simulated outcomes from 2020 to 2050 (Supplementary 1).

The microsimulation model allowed for heterogeneous risk trajectories and the inclusion of multiple interventions, consistent with frameworks previously applied in non-communicable disease policy modelling [24]. A main scenario was composed of two policy interventions targeting obesity that were introduced in the second year of the simulation. The first involved implementing a tax on SSBs, represented as a proportional increase in excise duties on SSB products, modelled to generate an annual probability of weight reduction among individuals with obesity [25]. In this study, SSBs were defined as beverages containing added caloric sugars, including soft drinks, energy drinks, sports drinks, and lemonades, but excluding fruit juice, milk products, unsweetened beverages such as coffee or tea, and artificially sweetened drinks [25]. The effect of the tax was modelled using income-specific price elasticities of demand. This approach was grounded in standard economic theory, which holds that higher prices lead to lower consumer demand. Country-specific estimates of price elasticity were obtained from published studies; in the absence of national data, pooled estimates from global systematic reviews were used. Changes in SSB consumption were calculated using a constant-elasticity model that links proportional tax increases to corresponding reductions in consumption. These changes in SSB intake were then translated into health outcomes using established relationships between SSB consumption, obesity, and T2DM incidence. Income-specific effects were incorporated by adjusting elasticities to account for greater price responsiveness among lower-income groups and lower responsiveness among higher-income groups. Detailed estimates of the price elasticity of demand and its application in this analysis are provided in Supplementary 2.

The intervention modelled a 15 % relative increase in baseline physical activity levels. The increase applied to moderate-to-vigorous non-work-related activities, including walking, cycling, and

Table 1
Baseline Sociodemographic and health characteristics by country and age group.

Baseline characteristic	Bulgaria	Czechia	Hungary	Poland	Romania	Slovakia	Source
Sample size (n)	7,540	7,993	5,603	19,959	16,186	5,527	EHIS 2019
Age, %							
15–49	50.0	53.6	53.8	50.4	55.2	56.1	EHIS 2019
50–74	39.4	37.2	36.7	40.0	35.1	36.5	
75+	10.6	9.3	9.5	9.7	9.6	7.4	
Sex (male), %							
15–49	51.4	51.3	51.4	46.7	51.1	51.2	EHIS 2019
50–74	45.8	47.6	45.1	43.3	47.3	47.6	
75+	35.2	37.1	33.5	32.6	36.8	34.2	
Income level, %							
Low	30.5	40.0	40.0	32.8	40.0	37.1	EHIS 2019
Middle	21.0	20.0	20.0	18.0	18.7	20.0	
High	48.5	40.0	40.0	49.1	41.3	43.0	
Body weight by age group and income level, %							
Low income							
15–49							
Normal weight	62.7	56.0	51.8	54.9	54.2	59.7	
Overweight	29.1	27.6	27.7	29.5	39.8	30.0	
Obese	8.2	16.4	20.5	15.6	6.1	10.3	
50–74							
Normal weight	31.4	28.0	26.4	32.4	27.8	27.7	
Overweight	49.1	42.4	37.9	40.7	54.2	43.5	
Obese	19.6	29.6	35.7	26.9	18.0	28.9	
75+							
Normal weight	37.4	34.8	29.8	34.4	39.6	28.3	
Overweight	47.3	45.0	42.3	42.6	47.3	49.7	
Obese	15.3	20.2	27.8	22.9	13.1	22.0	
Middle income							
15–49							
Normal weight	59.0	51.1	50.2	48.9	53.9	49.9	
Overweight	31.5	35.2	31.9	36.9	40.7	36.5	EHIS 2019
Obese	9.5	13.7	17.9	14.2	5.4	13.6	
50–74							
Normal weight	29.9	25.9	27.2	25.0	28.0	27.3	
Overweight	51.9	45.4	36.5	46.4	55.1	42.0	
Obese	18.2	28.7	36.3	28.6	16.9	30.7	
75+							
Normal weight	35.7	36.4	36.0	30.9	37.0	25.0	
Overweight	54.1	44.2	40.8	42.7	49.1	46.4	
Obese	10.2	19.4	23.2	26.4	13.8	28.6	
High income							
15–49							
Normal weight	59.6	52.3	54.4	53.6	56.3	51.2	
Overweight	32.9	34.6	31.3	34.5	38.1	34.7	
Obese	7.5	13.0	14.3	11.9	5.6	14.1	
50–74							
Normal weight	32.4	29.6	29.8	30.4	26.6	26.8	
Overweight	48.0	49.2	41.4	43.5	57.2	46.4	
Obese	19.6	21.3	28.8	26.0	16.2	26.8	
75+							
Normal weight	42.0	32.4	35.3	32.3	33.5	26.2	
Overweight	43.3	48.2	44.4	37.9	50.3	43.5	
Obese	14.6	19.4	20.3	29.9	16.2	30.3	
T2DM incidence (n)							
15–49	5,222	6,874	5,449	39,455	10,184	2,994	
50–74	21,736	34,359	24,204	163,146	39,563	11,848	GBD 2019
75+	630	1,032	720	3,051	959	244	
Total	27,588	42,265	24,980	205,652	50,706	15,086	
Mortality due to T2DM (n)							
15–49	55	53	56	246	70	22	
50–74	888	1,412	1,155	3,979	1,237	394	GBD 2019
75+	1,034	3,003	1,692	5,876	1,431	410	
Total	1,977	4,468	8,296	10,101	2,738	826	
Physical activity level							
Total MET-minutes/week, EU 28: 1940 (1884–1996)	1,524 (1,381–1,668)	1,883 (1,714–2,053)	2,173 (1,976–2,370)	1,542 (1,365–1,718)	1,614 (1,440–1,788)	1,935 (1,749–2,120)	[11]

Note: Normal weight (BMI 18.5–24.9 kg/m^2); overweight (BMI 25.0–29.9 kg/m^2); obesity (BMI ≥ 30.0 kg/m^2). T2DM incidence and mortality are based on actual GBD data per 100,000 individuals for comparison purposes; however, the model is initialized with non-diabetic individuals. Abbreviations: BMI, Body Mass Index; EHIS, European Health Interview Survey; EU, European Union; GBD, Global Burden of Disease; MET, Metabolic Equivalent of Task; T2DM, Type 2 Diabetes Mellitus.

recreational sports, expressed as Metabolic Equivalent of Task (MET) minutes per week, based on published evidence [11]. We assumed that physical activity levels increased equally across all age groups and sexes. This change was modelled to reduce the annual probability of transitioning from normal weight or overweight to obesity. Our approach followed established methodological frameworks [26], in which theoretical interventions promoting vigorous physical activity were represented by adjusting the probability of participation in vigorous activity during each simulation cycle [26]. Both baseline and policy scenarios were modelled in parallel. Primary outcomes included annual and cumulative numbers of obesity cases, incident T2DM, and deaths attributable to T2DM. Differences between the baseline and policy scenarios represented the estimated cases and deaths averted. Results are stratified by sex, age group, and income level, and the model structure is presented in Supplementary 3 Fig. S1 and S2.

The model was further extended to include two dietary interventions: a 30 % subsidy on fruits and vegetables and replacement of SSBs with water. These interventions were selected based on evidence of their effectiveness in reducing obesity and were incorporated into the model to capture their potential impact on obesity trends. The fruit and vegetable subsidy has been associated with a 0.2 % reduction in obesity prevalence by increasing consumption of nutrient-dense foods and displacing less healthy alternatives, with particularly cost-effective benefits for low-income populations [27]. Replacing an 8-ounce serving of SSBs (equivalent to approximately 237 mL) with water was linked to a 0.3 % reduction in obesity prevalence through decreased calorie intake from added sugars and improved hydration [28]. The extended model was simulated in a single country, Hungary.

Model performance was assessed through internal validation owing to data limitations, as no comparable external datasets were available for the study population. Internal consistency checks confirmed model stability, and reproducibility was ensured by using a fixed random seed. For external face validity, we compared the SSB-only scenario with observed post-tax changes in purchases and obesity following the UK Soft Drinks Industry Levy and Mexico's excise tax, noting contextual differences in tax design, baseline intake, and substitution patterns to demonstrate alignment without overfitting to GBD data.

Following best practices for stochastic microsimulation modelling, we conducted 1,000 Monte Carlo replications to ensure stability and precision in the estimated outcomes. Previous studies indicate that 1,000 replications are generally sufficient to stabilize key outputs and generate robust uncertainty intervals [29]. Our model produced consistent incidence estimates with narrow 95 % uncertainty intervals across replications. The model was developed based on adaptations of existing models and published literature [25,26,30,31]. Further details of the modelling framework, including all code and parameter inputs, are available at https://github.com/nafanabdu/microsimulation. All simulations and analyses were conducted using R version 4.4.0. Ethical approval complies with EHIS Regulation (EC) No. 1338/2008 of the European Parliament and Council (16 December 2008). The EHIS Wave 3 followed Commission Regulation (EU) No. 2018/255. Participants provided informed consent before participating. We followed the modelling guidelines outlined in the Quality Assessment Reporting for Microsimulation Models (QARMM) checklist (Supplementary 4) [32].

3. Results

Implementing a 20 % SSB tax combined with a 15 % increase in physical activity between 2020 and 2050 is estimated to yield substantial health gains across six CEE countries. The cumulative number of prevented obesity cases ranged from 8,525 (95 % UI 6,397, 10,654) in Slovakia to 27,949 (95 % UI 23,842, 32,056) in Poland. Corresponding estimates for T2DM cases averted ranged from 7,344 (95 % UI 4,520, 10,168) to 24,142 (95 % UI 18,809, 29,474), and deaths averted ranged from 2,617 (95 % UI 394, 4,839) to 8,699 (95 % UI 4,526, 12,872). In Bulgaria, projections show 10,806 (95 % UI 8405, 13206) obesity cases prevented, 9,002 (95 % UI 5,764, 12,239) T2DM cases averted, and 3,180 (95 % UI 659, 5,702) deaths averted. In Czechia, the expected benefits are 10,905 (95 % UI 8414, 13,396) obesity cases, 9,444 (95 % UI 6226, 12,662) T2DM cases, and 3,380 (95 % UI 792, 5,969) deaths averted. In Hungary, the intervention is projected to prevent 8,864 (95 % UI 6732, 10,997) obesity cases, 7,721 (95 % UI 4,912, 10,530) T2DM cases, and 2,870 (95 % UI 634, 5,105) deaths. Across all six countries, the intervention could prevent 90,778 (95 % UI 83,683, 97,873) obesity cases, 77,798 (95 % UI 68,411, 87,185) T2DM cases, and 27,751 (95 % UI 20,393, 35,109) deaths by 2050. (See Fig. 1 and Supplementary 5).

The most considerable projected impact of the SSB tax and increased physical activity is among low-income individuals aged 15–49 in Czechia, Hungary, and Romania. In Czechia, low-income males aged 15–49 are estimated to prevent 1,176 (95 % UI 647, 1,750) obesity cases, 1,014 (95 % UI 286, 1,722) T2DM cases, and 351 (95 % UI −222, 957) deaths. In Hungary, males of the same age and income group are projected to benefit slightly more, with 980 (95 % UI 503, 1,470) obesity cases, 842 (95 % UI 204, 1,467) T2DM cases, and 306 (95 % UI −198, 765) deaths averted. Similarly, in Romania, low-income males aged 15–49 are estimated to prevent 2,655 (95 % UI 1,840, 3,489) obesity cases, 2,180 (95 % UI 1,105, 3,315) T2DM cases, and 749 (95 % UI −67, 1,602) deaths.

In contrast, in Bulgaria, Poland, and Slovakia, higher-income groups are projected to experience the most significant benefits. High-income females aged 50–74 in Bulgaria are expected to prevent 1,163 (95 % UI 605, 1,752) obesity cases, 1,006 (95 % UI 274, 1,797) T2DM cases, and 383 (95 % UI −217, 961) deaths. In Poland, high-income females aged 15–49 are projected to prevent 3,385 (95 % UI 2,282, 4,477) obesity cases, 2,772 (95 % UI 1,270, 4,225) T2DM cases, and 957 (95 % UI −66, 1,991) deaths. In Slovakia, males aged 15–49 are expected to experience the largest benefits, with 906 (95 % UI 391, 1,436) obesity cases, 776 (95 % UI 86, 1,433) T2DM cases, and 270 (95 % UI −219, 790) deaths averted. Overall, benefits declined with age, with the 15–49 and 50–74-year groups contributing most cases prevented, while estimates among individuals aged 75 years and older were smaller. (See Table 2).

The model projects that the number of obesity cases prevented will peak in the early to mid-2030 s across most countries, before gradually declining toward 2050. In contrast, T2DM cases and deaths averted are projected to continue increasing throughout the period. In Hungary, obesity prevention peaks around 2031 at 399 cases, then declines to 146 by 2050, while T2DM cases and deaths averted rise to 347 and 243, respectively. Similar trends are projected in Czechia, Poland, and Slovakia, with obesity cases prevented reaching 488, 1,246, and 381 around 2032, followed by gradual declines, while T2DM cases and deaths averted continue to grow, reaching 440 and 291 in Czechia, 1,121 and 748 in Poland, and 338 and 227 in Slovakia by 2050. Romania and Bulgaria peak slightly later, around 2033, with 1,057 and 476 obesity cases prevented, respectively, before declining, while T2DM cases and deaths averted continue to rise, attaining 981 and 620 in Romania and 445 and 281 in Bulgaria by 2050 (Fig. 2).

In a sensitivity analysis, the combined SSB tax and increased physical activity produced larger projected reductions in obesity, T2DM, and deaths than the alternative intervention scenarios. Under this main scenario, an estimated 8,864 (95 % UI: 6,732, 10,997) obesity cases and 7,721 (95 % UI: 4,912, 10,530) T2DM cases would be prevented, with 2,870 (95 % UI: 634, 5,105) deaths averted in Hungary. By comparison, the model projects that substituting SSBs with water would prevent 5,770 (95 % UI: 3,576, 7,965) obesity cases, 4,979 (95 % UI: 2,194, 7,765) T2DM cases, and 1,762 (95 % UI: −469, 3,993) deaths, while a 30 % subsidy on fruits and vegetables is projected to prevent 4,011 (95 % UI: 1,736, 6,287) obesity cases, 3,528 (95 % UI: 743, 6,313) T2DM cases, and 1,214 (95 % UI: −1,059, 3,488) deaths. A similar pattern was observed in Bulgaria, Czechia, Poland, Romania, and Slovakia, although varied by age group and income level. Overall, the combined SSB tax and increased physical activity scenario is projected to avert approximately 50 % more cases of obesity and T2DM than the SSB substitution scenario and more than twice the impact of the fruit and vegetable

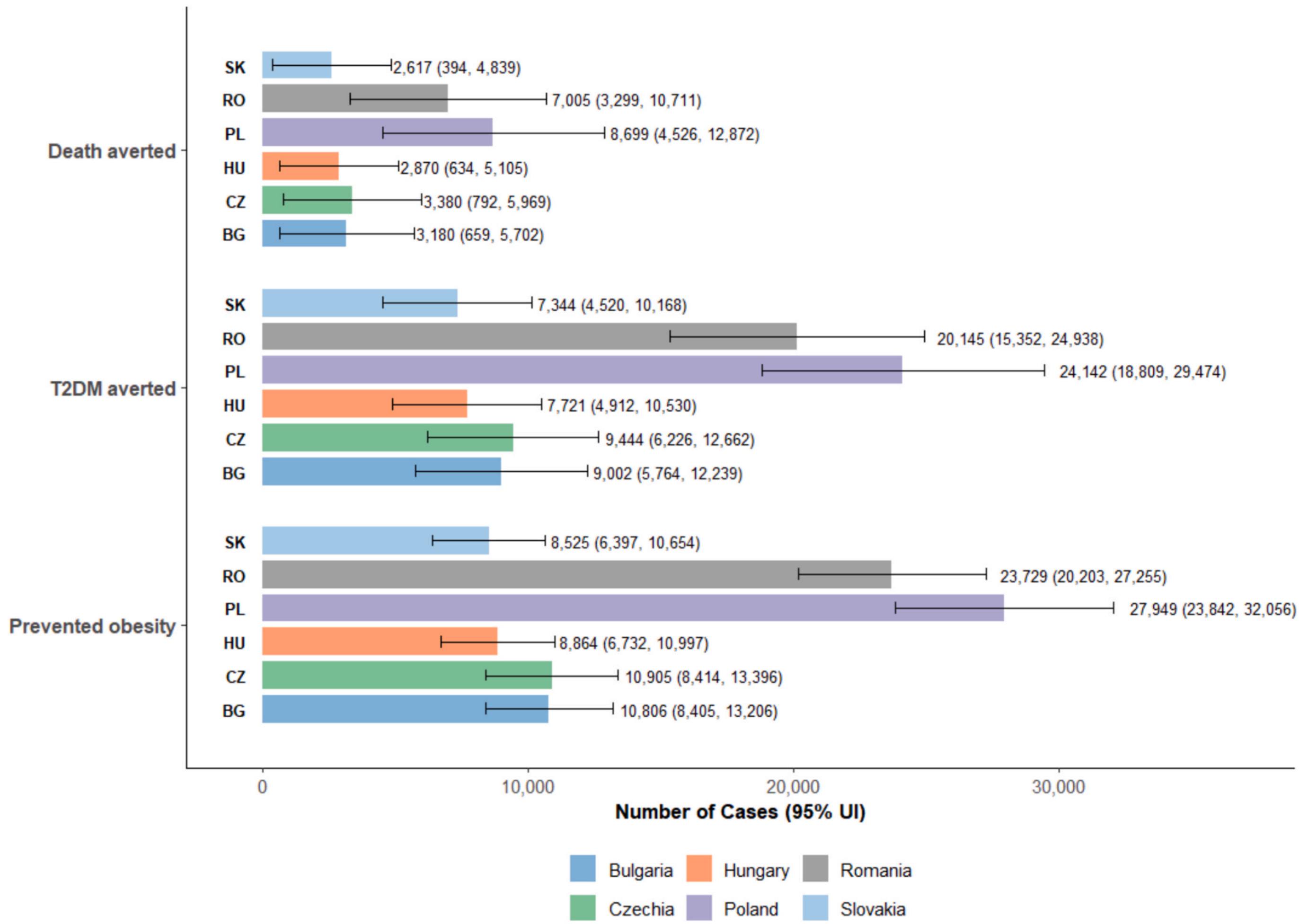

Fig. 1. Total estimated cases of prevented obesity, type 2 diabetes (T2DM) averted, and deaths averted in six Central and Eastern European countries (BG: Bulgaria, CZ: Czechia, HU: Hungary, PL: Poland, RO: Romania, SK: Slovakia). Error bars represent 95 % confidence intervals.

subsidy scenario (Table 3, and Supplementary 6).

4. Discussion

This study is the first to estimate the combined long-term effects of fiscal policy, specifically SSB taxation and public health promotion through increased physical activity, on obesity and T2DM incidence in CEE countries. The model suggests that implementing a combined intervention comprising a 20 % tax on SSBs and a 15 % increase in population-level physical activity could prevent nearly 91,000 obesity cases, 78,000 T2DM cases, and 27,000 deaths over 30 years in six CEE countries. These projections are consistent with modelling studies from Western Europe, such as Ireland [33] and the United Kingdom [34], which estimated reductions in SSB consumption and reported meaningful declines in obesity and T2DM following the introduction of SSB taxation. The findings also align with previous evidence showing that fiscal measures targeting SSBs can encourage product reformulation and shift consumption towards lower-sugar alternatives by raising the relative price of high-sugar products [35].

Increasing physical activity also contributed to reductions in the burden of obesity and diabetes. CEE countries could begin by targeting a 15 % reduction in physical inactivity through stronger national policies. However, policy implementation remains uneven across the region, with gaps between planning and execution. Hungary, for example, has adopted measures across all six domains of the WHO's MOVING framework but demonstrates moderate implementation, particularly in out-of-school activities, workplace programs, and urban design [8]. Slovakia developed a national action plan for 2017–2020, although further efforts in monitoring and follow-up would strengthen its impact [8]. In Czechia and Poland, physical activity guidelines have been issued, and school-based interventions introduced; however, opportunities remain to develop more comprehensive strategies and enhance intersectoral coordination [8]. Romania and Bulgaria have launched awareness campaigns and issued recommendations, but these initiatives have generally remained short-term and have faced constraints in funding and integration [8]. To achieve the WHO GAPPA 2030 targets, countries must shift from individual-focused approaches to systemic ones that strengthen school and community programs, improve infrastructure, secure sustainable funding, and enhance cross-sector collaboration. Targeted actions for vulnerable populations, including rural and socioeconomically disadvantaged groups, are essential to reduce health inequities [14].

The inclusion of increased physical activity in our model represents a novel contribution, as most previous analyses have focused solely on taxation or dietary policy. Evidence from *meta*-analyses indicates that moderate increases in population-level physical activity can substantially reduce the risk of obesity, T2DM, and premature mortality [36]. Reinvesting tax revenues into preventive health initiatives and coupling fiscal measures with effective communication campaigns can enhance behaviour change and public support. Allocating SSB tax revenues to support physical activity infrastructure and promotion may help overcome structural and financial barriers, particularly in countries with underfunded public health strategies [10].

Our analysis indicates substantial heterogeneity in intervention

Table 2
Projected averted cases of obesity, T2DM, and deaths under the main scenario of a 20 % SSB tax and a 15 % increase in physical activity, 2020–2050, in six Central and Eastern European countries.

Output	Bulgaria			Czechia			Hungary		
	Prevented obesity Mean (95 % UI)	T2DM averted Mean (95 % UI)	Death averted Mean (95 % UI)	Prevented obesity Mean (95 % UI)	T2DM averted Mean (95 % UI)	Death averted Mean (95 % UI)	Prevented obesity Mean (95 % UI)	T2DM averted Mean (95 % UI)	Death averted Mean (95 % UI)
Female									
Low income									
15–49	794 (390, 1,238)	619 (26, 1,207)	230 (−237, 700)	1114 (592, 1,679)	944 (198, 1,611)	340 (−199, 887)	932 (483, 1,423)	796 (174, 1,399)	281 (−201, 787)
50–74	859 (387, 1,281)	752 (162, 1,372)	272 (−246, 758)	1011 (512, 1,543)	907 (254, 1,580)	349 (−199, 901)	863 (443, 1,290)	780 (173, 1,406)	306 (−158, 774)
75+	261 (15, 524)	227 (−115, 581)	88 (−180, 370)	286 (22, 568)	250 (−83, 586)	78 (−222, 358)	251 (−4, 503)	234 (−79, 560)	86 (−175, 341)
Middle income									
15–49	536 (157, 901)	411 (−97, 902)	141 (−228, 531)	530 (122, 926)	442 (−76, 975)	159 (−259, 542)	432 (88, 783)	371 (−74, 837)	127 (−235, 498)
50–74	559 (150, 960)	494 (−43, 993)	169 (−265, 591)	476 (125, 839)	423 (−38, 854)	166 (−207, 544)	406 (89, 718)	368 (−23 770)	137 (−228, 491)
75+	170 (−26, 389)	140 (−130, 411)	50 (−162, 260)	126 (−62, 324)	117 (−120, 379)	41 (−169, 246)	118 (−41, 304)	96 (−128, 315)	38 (−146, 208)
High income									
15–49	1,049 (482, 1,613)	788 (−28, 1,531)	254 (−323, 817)	987 (407, 1,553)	814 (114, 1,574)	268 (−291, 820)	766 (291, 1,246)	648 (56, 1,236)	231 (−238, 681)
50–74	1,163 (605, 1,752)	1,006 (274, 1,797)	383 (−217, 961)	837 (319, 1,334)	754 (71, 1,434)	262 (−267, 776)	712 (276, 1,173)	621 (21, 1,211)	258 (−228, 723)
75+	355 (42, 648)	298 (−94, 724)	106 (−224, 427)	251 (−18, 499)	211 (−106, 602)	83 (−220, 374)	208 (−47, 441)	183 (−138, 495)	70 (−182, 324)
Subtotal	5,746 (4,508, 6,983)	4,736 (3,067, 6,404)	1,692 (389, 2,995)	5,617 (4,346, 6,888)	4,862 (3,215, 6,508)	1,746 (444, 3,048)	4,688 (3,591, 5,785)	4,098 (2,658, 5,538)	1,534 (383, 2,684)
Male									
Low income									
15–49	844 (388, 1,276)	665 (23, 1,290)	213 (−274, 688)	1,176 (647, 1,750)	1,014 (286, 1,722)	351 (−222, 957)	980 (503, 1,470)	842 (204, 1,467)	306 (−198, 765)
50–74	721 (338, 1,154)	642 (90, 1,198)	245 (−203, 699)	931 (464, 1,409)	830 (199, 1,483)	310 (−226, 831)	704 (294, 1,092)	633 (88, 1,165)	253 (−153, 663)
75+	142 (−49, 340)	118 (−132, 345)	47 (−136, 231)	173 (−28, 384)	148 (−107, 413)	47 (−169, 259)	129 (−41, 317)	121 (−130, 260)	46 (−147, 232)
Middle income									
15–49	537 (144, 940)	459 (−45, 974)	155 (−240, 543)	554 (143, 971)	480 (−64, 970)	164 (−234, 589)	464 (133, 820)	386 (−47, 848)	133 (−244, 488)
50–74	463 (125, 822)	414 (−55, 874)	158 (−233, 508)	426 (94, 775)	396 (−36, 851)	149 (−259, 531)	337 (47, 614)	297 (−92, 687)	102 (−220, 443)
75+	91 (−54, 249)	76 (−122, 276)	28 (−123, 189)	83 (−64, 232)	64 (−141, 250)	27 (−129, 199)	57 (−65, 188)	52 (−109, 212)	19 (−106, 145)
High income									
15–49	1,102 (532, 1,658)	846 (91, 1,675)	264 (−311, 833)	1,031 (435, 1,607)	859 (136, 1,586)	282 (−302, 861)	812 (310, 1,292)	680 (12, 1,345)	242 (−272, 733)
50–74	967 (466, 1,513)	885 (170, 1,535)	316 (−238, 880)	768 (309, 1,248)	661 (32, 1,260)	261 (−227, 753)	588 (186, 986)	522 (16, 1,023)	198 (−259, 625)
75+	192 (−44, 435)	162 (−137, 459)	64 (−172, 327)	145 (−62, 361)	130 (−131, 390)	44 (−189, 265)	105 (−76, 283)	89 (−139, 306)	36 (−146, 218)
Subtotal	5,060 (3,897, 6,223)	4,266 (2,697, 5,836)	1,489 (270, 2,708)	5,288 (4,068, 6,508)	4,582 (3,011, 6,154)	1,634 (348, 2,921)	4,177 (3,140, 5,213)	3,623 (2,254, 4,992)	1,336 (252, 2,420)
Total	10,806 (8,405, 13,206)	9,002 (5,764, 12,239)	3180 (659, 5,702)	10,905 (8,414, 13,396)	9,444 (6,226, 12,662)	3,380 (792, 5,969)	8,864 (6,732, 10,997)	7,721 (4,912, 10,530)	2,870 (634, 5,105)

Output	**Poland**			**Romania**			**Slovakia**		
	Prevented obesity Mean (95% UI)	**T2DM averted**Mean (95% UI)	**Death averted**Mean (95% UI)	**Prevented obesity**Mean (95% UI)	**T2DM averted**Mean (95% UI)	**Death averted**Mean (95% UI)	**Prevented obesity**Mean (95% UI)	**T2DM averted**Mean (95% UI)	**Death averted**Mean (95% UI)
Female									
Low income									
15–49	2,611 (1,771, 3,479)	2,208 (1,034, 3,314)	774 (−143, 1,638)	2,567 (1,675, 3,307)	2,101 (1,011, 3,262)	715 (−117, 1,543)	811 (365, 1,264)	673 (39, 1,316)	220 (−267, 652)
50–74	2,216 (1,463, 2,957)	1,926 (928, 2,956)	745 (−84, 1,534)	2,089 (1,393, 2,797)	1,884 (891, 2,856)	666 (−72, 1,458)	725 (310, 1,124)	655 (107, 1,241)	235 (−250, 661)
75+	723 (314, 1,158)	635 (86, 1,210)	240 (−237, 673)	635 (225, 1,012)	37 (1,093, 269)	199 (−212, 636)	175 (−22, 383)	157 (−119, 440)	63 (−166, 284)

(continued on next page)

Table 2 (*continued*)

Output	Poland Prevented obesity Mean (95% UI)	T2DM averted Mean (95% UI)	Death averted Mean (95% UI)	Romania Prevented obesity Mean (95% UI)	T2DM averted Mean (95% UI)	Death averted Mean (95% UI)	Slovakia Prevented obesity Mean (95% UI)	T2DM averted Mean (95% UI)	Death averted Mean (95% UI)
Middle income									
15–49	1,379 (750, 2024)	1141 (300, 1978)	422 (−227, 1,071)	1,110 (541, 1,681)	899 (169, 1,676)	309 (−203, 842)	440 (99, 786)	363 (−86, 812)	134 (−230, 495)
50–74	1,167 (588, 1799)	1058 (358, 1843)	396 (−231, 997)	898 (399, 1,399)	803 (138, 1,417)	299 (−245, 819)	371 (66, 687)	325 (−68, 707)	123 (−193, 457)
75+	378 (58, 720)	345 (−96, 786)	129 (−216, 468)	283 (29, 546)	244 (−102, 624)	92 (−181, 367)	92 (−60, 265)	87 (−113, 281)	28 (−145, 196)
High income									
15–49	3,385 (2,282, 4477)	2772 (1270, 4225)	957 (−66, 1,991)	2,268 (1,486, 3,062)	1,816 (727, 2,914)	589 (−230, 1,479)	871 (404, 1,349)	717 (37, 1,382)	253 (−272, 787)
50–74	2,883 (1,935, 3792)	2576 (1373, 3810)	931 (−71, 1,919)	1,860 (1,105, 2,574)	1,657 (680, 2,638)	592 (−172, 1,384)	725 (271, 1,170)	644 (24, 1248)	242 (−221, 721)
75+	991 (445, 1560)	889 (173, 1538)	322 (−246, 877)	587 (189, 1,009)	529 (−29, 1,061)	198 (−231, 625)	188 (−48, 436)	168 (−129, 444)	65 (−173, 329)
Subtotal	15,733 (13,559, 17,907)	13,551 (10,682, 16,420)	4,915 (2,694, 7,137)	12,277 (10,465, 14,090)	10,487 (8,023, 12,951)	3,659 (1,760, 5,558)	4,399 (3,334, 5,464)	3,767 (2,335, 5,239)	1,363 (222, 2,504)
Male									
Low income									
15–49	2,300 (1,480, 3119)	1936 (927, 2921)	664 (−120, 1,505)	2,655 (1,840, 3,489)	2,180 (1,105, 3,315)	749 (−67, 1,602)	861 (413, 1,329)	697 (74, 1,341)	241 (−250, 726)
50–74	1,673 (957, 2361)	1500 (624, 2411)	565 (−117, 1,248)	1,888 (1,191, 2,526)	1,674 (787, 2,610)	603 (−121, 1,287)	657 (229, 1,074)	598 (96, 1,085)	218 (−197, 638)
75+	355 (40, 664)	303 (−92, 712)	119 (−184, 454)	372 (69, 682)	314 (−103, 698)	113 (−212, 420)	91 (−57, 230)	83 (−128, 281)	32 (−128, 1,960)
Middle income									
15–49	1,195 (607, 1755)	1022 (200, 1779)	362 (−270, 959)	1,166 (605, 1,718)	938 (220, 1,661)	333 (−266, 904)	459 (113, 838)	386 (−101, 830)	129 (−230, 502)
50–74	890 (410, 1404)	806 (182, 1501)	309 (−221, 838)	815 (358, 1,291)	722 (98, 1,345)	255 (−231, 726)	343 (53, 636)	296 (−76, 684)	104 (−201, 393)
75+	188 (−37, 412)	161 (−138, 458)	62 (−188, 294)	168 (−34, 371)	144 (−127, 426)	40 (−170, 255)	48 (−61, 166)	42 (−95, 181)	15 (−96, 134)
High income									
15–49	2,953 (1,929, 3,916)	2,452 (1,234, 3,774)	849 (−176, 1,753)	2,341 (1,560, 3,122)	1,909 (778, 3,038)	613 (−224, 1,514)	906 (391, 1,436)	776 (86, 1,433)	270 (−219, 790)
50–74	2,188 (1,351, 3,037)	1,983 (942, 3,057)	697 (−202, 1,555)	1,699 (1,047, 2,358)	1,474 (572, 2,348)	532 (−153, 1,239)	659 (245, 1,117)	591 (25, 1,142)	213 (−237, 682)
75+	474 (83, 855)	427 (−69, 902)	155 (−231, 573)	347 (38, 695)	303 (−77, 722)	107 (−216, 467)	101 (−67, 278)	88 (−123, 315)	31 (−142, 209)
Subtotal	12,216 (10,283, 14,149)	10,591 (8,127, 13,055)	3,784 (1,832, 5,735)	11,452 (9,738, 13,165)	9,658 (7,329, 11,986)	3,346 (1,539, 5,153)	4,126 (3,062, 5,190)	3,557 (2,185, 4,929)	1,254 (172, 2,336)
Total	27,949 (23,842, 32,056)	24,142 (18,809, 29,474)	8,699 (4,526, 12,872)	23,729 (20,203, 27,255)	20,145 (15,352, 24,938)	7,005 (3,299, 10,711)	8,525 (6,397, 10,654)	7,344 (4,520, 10,168)	2,617 (394, 4,839)

Note: Based on data from the European Health Interview Survey, income level was divided into low (first and second quintiles), middle (third quintile), and high (fourth and fifth quintiles). Abbreviations: T2DM, Type 2 Diabetes Mellitus; UI, Uncertainty Interval.

impact across countries, age groups, and income levels. The largest relative benefits would be expected among younger and lower-income individuals in Czechia, Hungary, and Romania. Younger populations may be more affected, as they tend to consume more SSBs and energy-dense foods; their behaviours are likely more responsive to price and incentive changes. Early adoption of healthier behaviours in these groups may yield cumulative lifetime benefits. This pattern mirrors empirical findings from Mexico [37] and the United Kingdom [34], where lower-income groups, who typically consume more SSBs due to lower cost, greater accessibility, and targeted marketing, showed the greatest reductions in purchase and consumption following SSB taxation. As a result, SSB taxes tend to have a greater relative impact on consumption among younger, lower-income individuals, which can translate into larger health benefits, including reductions in obesity prevalence, within these groups.

Conversely, in Bulgaria, Poland, and Slovakia, projected benefits were more pronounced among higher-income groups. One possible explanation for this simulated trend is that high-income groups, with greater resources, may have more opportunities to respond to price changes (e.g., by substituting SSBs for healthier options), leading to larger absolute reductions. However, in reality, low-income groups could experience "regressive" effects from taxes, where the same percentage price increase imposes a greater burden, potentially leading to larger relative reductions if behavior change is modelled differently [38]. These differences highlight the importance of tailoring SSB and physical activity interventions to the socio-economic and cultural contexts of diverse populations.

Across all six countries, these trends suggest that obesity prevention yields more immediate short- to medium-term benefits, peaking in the early to mid-2030 s before gradually declining as the intervention

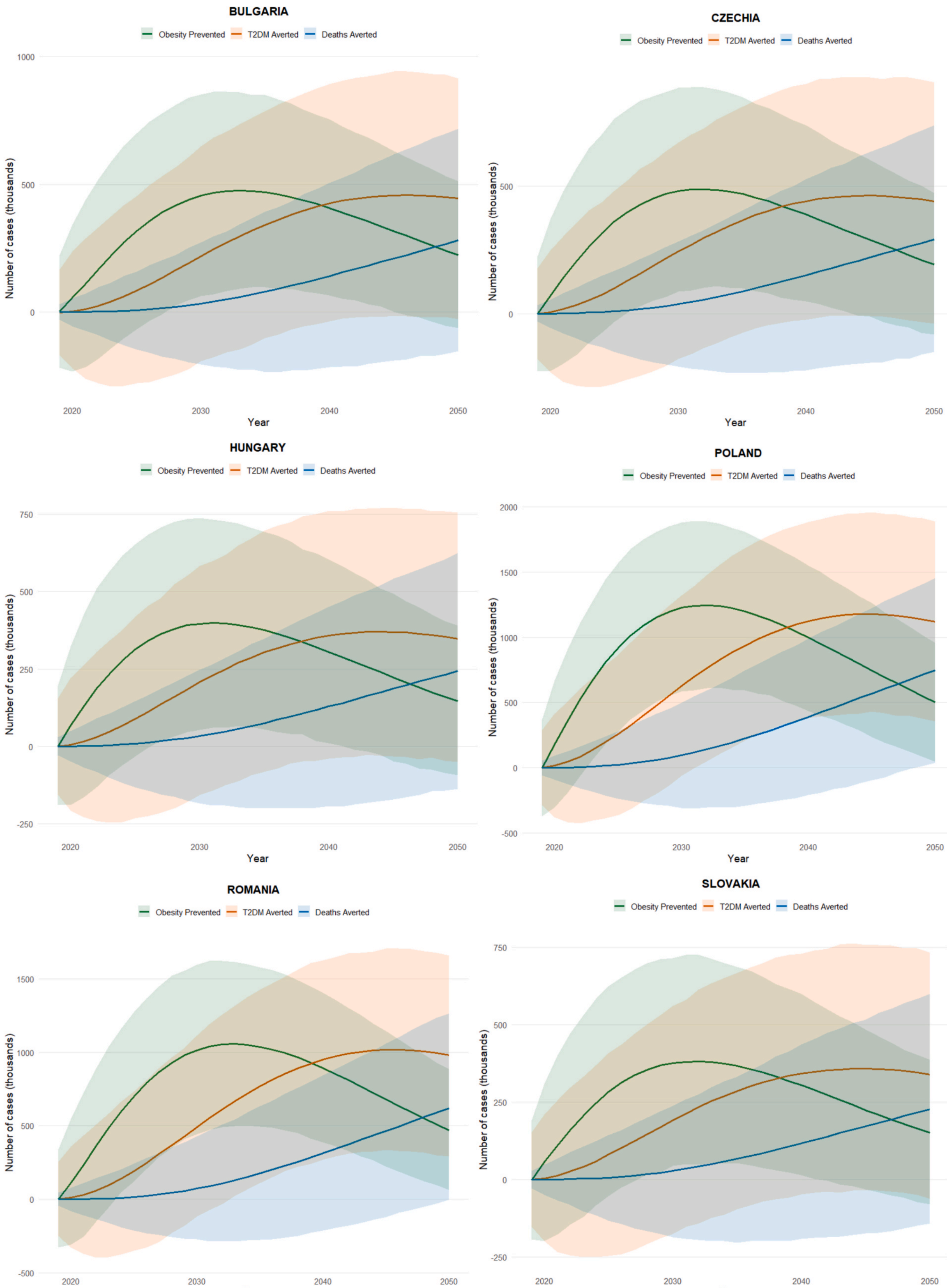

Fig. 2. Projected impacts of a 20 % SSB tax combined with a 15 % increase in physical activity on obesity, T2DM, and mortality in Central and Eastern European countries, 2020–2050. Solid lines represent mean projections, and shaded areas denote 95 % uncertainty intervals.

Table 3
Estimated averted cases of obesity, T2DM, and deaths under three policy scenarios in six Eastern and Central European Countries, 2020–2050.

Scenarios	Bulgaria Prevented obesity Mean (95 % UI)	T2DM averted Mean (95 % UI)	Death averted Mean (95 % UI)	Czechia Prevented obesity Mean (95 % UI)	T2DM averted Mean (95 % UI)	Death averted Mean (95 % UI)	Hungary Prevented obesity Mean (95 % UI)	T2DM averted Mean (95 % UI)	Death averted Mean (95 % UI)
20 % SSB Tax + 15 % PA	10,806 (8405, 13,206)	9002 (5764, 12,239)	3180 (659, 5702)	10,905 (8,414, 13,396)	9,444 (6,226, 12,662)	3,380 (792, 5,969)	8,864 (6,732, 10,997)	7,721 (4,912, 10,530)	2,870 (634, 5,105)
Substituting SSBs with water	7,042 (4,573, 9,510)	5,878 (2,714, 9,042)	2,004 (−500, 4,509)	7,558 (4,983, 10,133)	6,466 (3,205, 9,728)	1,113 (−156, 2383)	5,770 (3,576, 7,965)	4,979 (2,194, 7,765)	1,762 (−469, 3,993)
30 % subsidy on fruits and vegetables	4,963 (2,386, 7,539)	4,061 (909, 7,213)	1,425 (−1,098, 3,947)	5,275 (2,673, 7,877)	4,560 (1,385, 7,735)	1,573 (−1,014, 4,161)	4,011 (1,736, 6,287)	3,528 (743, 6,313)	1,214 (−1059, 3,488)

Scenarios	Poland Prevented obesity Mean (95% UI)	T2DM averted Mean (95% UI)	Death averted Mean (95% UI)	Romania Prevented obesity Mean (95% UI)	T2DM averted Mean (95% UI)	Death averted Mean (95% UI)	Slovakia Prevented obesity Mean (95% UI)	T2DM averted Mean (95% UI)	Death averted Mean (95% UI)
20% SSB Tax + 15% PA	27,949 (23,842, 32,056)	24,142 (18,809, 29,474)	8,699 (4,526, 12,872)	23,729 (20,203, 27,255)	20,145 (15,352, 24,938)	7,005 (3,299, 10,711)	8,525 (6,397, 10,654)	7,344 (4,520, 10,168)	2,617 (394, 4,839)
Substituting SSBs with water	20,132 (16,065, 24,199)	17,062 (11,830, 22,294)	6,069 (1,899, 10,238)	15,492 (11,798, 19,186)	12,906 (8,202, 17,610)	4,383 (666, 8,101)	5,532 (3,356, 7,707)	4,760 (1,986, 7,534)	1,674 (−546, 3,893)
30% subsidy on fruits and vegetables	14,113 (9,903, 18,323)	11,822 (6,61, 16,984)	4,158 (−20, 8,337)	10,800 (7,032, 14,568)	8,888 (4,190, 13,587)	3,039 (−740, 6,818)	3,887 (1,626, 6,147)	3,309 (609, 6,010)	1,154 (−1,089), 3,397)

Abbreviations: PA, Physical Activity; SSB, Sugar-Sweetened Beverage; T2DM, Type 2 Diabetes Mellitus; UI, Uncertainty Interval.

reaches saturation among the high-risk population. In contrast, reductions in T2DM and deaths accrue more slowly, reflecting the delayed downstream effects of improved weight status on chronic disease incidence and mortality. Population-level interventions that reduce energy intake, increase physical activity, and slow weight gain might produce the largest impact in the early years, when many individuals remain at risk of transitioning to obesity. Over time, as the prevalence of obesity is suppressed, fewer new individuals remain at high risk, shrinking the "pool" of susceptible persons and reducing the incremental number of obesity cases prevented annually. Modelling studies of adult obesity indicate that the epidemic may plateau or even decline when successive birth cohorts enter healthier environments or historic weight-gain trajectories slow. Similar modelling suggests that obesity prevalence across 18 European countries may peak around 2037 before stabilising [39]. Thus, the decline in prevented obesity cases likely reflects both a reduction in incidence, with fewer individuals transitioning to obesity, and a shift in the remaining population toward those already obese or beyond the point of prevention.

Meanwhile, T2DM and deaths averted continue to accumulate, as risk reduction manifests later. Even as obesity prevention plateaus, the cumulative pool of people protected from T2DM grows, with sustained benefits in later decades [40]. Sustained implementation is therefore critical: while obesity prevention yields short-term gains, long-term benefits in T2DM and mortality reinforce the enduring value of population-level interventions. Preventing obesity in younger cohorts generates larger downstream benefits, given their higher lifetime risk of diabetes and death. Declining annual numbers of prevented obesity cases should not be interpreted as intervention failure; instead, they reflect saturation effects and sustained long-term gains in chronic disease outcomes.

Sensitivity analyses confirmed that combining a 20 % SSB tax with a 15 % increase in physical activity would deliver substantial health gains. However, the feasibility and cost-effectiveness of implementation require careful consideration. Industry opposition and public resistance to SSB taxes highlight the need for strategic communication, phased implementation, and complementary measures such as incentives for healthier choices [41]. Alternative scenarios, including SSB substitution with water and a 30 % fruit and vegetable (F&V) subsidy, generated smaller but complementary benefits. The impact of SSB taxation may depend on substitution patterns. In Hungary, replacing SSBs with water would avert 5,770 obesity cases and 4,979 T2DM cases. Replacing SSBs with water reduces caloric intake and glycaemic load, particularly among adolescents and low-income adults who are major consumers of sugary drinks. Evidence from Mexico, a 10 % SSB tax reduced sales by 12 % while untaxed beverages, mainly bottled plain water, rose by 4 % [34], and similar trends were observed in the UK after the Soft Drinks Industry Levy [42]. Policies that facilitate access to safe and affordable drinking water, such as public fountains, school hydration programmes, and front-of-pack water promotion, can reinforce these effects.

A 30 % F&V subsidy addresses affordability barriers, especially for low-income populations. Evidence suggests that a 10 % subsidy can increase F&V intake by approximately 14 % in adults, supporting the notion that combined fiscal measures, including taxes and subsidies, can improve diet quality and health outcomes at the population level [43]. Overall, no single intervention is sufficient to reverse obesity and T2DM trends. A national strategy integrating SSB taxation, water substitution, F&V subsidies, and physical activity promotion could yield synergistic health and equity gains, while reinvesting revenues in healthy food access and activity infrastructure may reduce socioeconomic disparities [44].

5. Strengths and limitations

This study provides a structured projection of the potential health impact of SSB taxation and increased PA interventions, offering a valuable tool for policy planning in Central and Eastern European contexts. The microsimulation approach accounts for individual-level heterogeneity and captures dynamic interactions between interventions and health outcomes over time. However, several limitations should be acknowledged. The model relies on idealized assumptions that may not fully capture the complex and evolving nature of real-world settings, including shifts in consumer behaviour, industry responses, and variations in policy implementation across countries. Baseline data from the EHIS are self-reported, introducing the potential for reporting bias. The use of fixed annual transition probabilities to model movement between health states may overestimate disease progression. These probabilities were derived from published epidemiological studies conducted in diverse populations and time periods, which may not fully capture temporal trends, preventive health interventions, or individual risk behaviors. Consequently, these estimates may not precisely reflect disease progression dynamics within each CEE country and should be interpreted with caution.

Our model assumes that the effects of SSB taxation and physical activity on T2DM risk operate primarily through reductions in BMI. Although this approach aligns with existing economic models, it may not fully capture the complex metabolic pathways by which SSB consumption influences diabetes risk. Emerging evidence suggests that high sugar intake can impair insulin sensitivity and β-cell function independently of obesity [45]. Similarly, SSB consumption may affect glucose metabolism beyond its impact on adiposity [46]. Physical activity has also been shown to enhance insulin sensitivity independent of weight loss, through mechanisms such as increased skeletal-muscle glucose uptake and greater translocation of glucose transporters to the cell surface [47]. Excluding these direct metabolic effects could therefore underestimate the potential impact of SSB taxation and physical activity on diabetes risk. Future modelling studies should incorporate both weight-dependent and weight-independent pathways to provide a more comprehensive assessment of the effects of SSB taxation.

Due to computational constraints, we simulated synthetic populations based on representative baseline characteristics rather than using detailed individual-level data, which may limit the precision of individual risk predictions. Similarly, the extended model used for the sensitivity analysis, which introduced two additional scenarios, a 30 % subsidy on fruits and vegetables and the replacement of SSBs with water, was simulated for Hungary only. Future studies could expand this analysis to other countries in Central and Eastern Europe to assess the generalisability of these findings and their potential impact across the region. Additionally, further research could simulate the effects of higher SSB tax rates, especially considering the WHO's recent initiative urging countries to raise sugary drink prices by at least 50 % by 2035 through taxation [49]. Future research could examine cost-effectiveness across different socioeconomic groups and explore strategies to enhance the equity, reach, and sustainability of both fiscal and behavioural interventions. It will be essential to consider local socioeconomic conditions and assess potential co-benefits, including reductions in cardiovascular disease and other obesity-related conditions. While the model provides important insights, its real-world application must consider country-specific constraints, such as policy inertia, public acceptance, and administrative capacity. Future studies should aim to integrate dynamic feedback loops (e.g., substitution effects in diet or changes in physical activity behavior) and, where possible, validate predictions against longitudinal cohort data. Moreover, health equity implications should be explored, particularly whether such fiscal and behavioral interventions disproportionately benefit or burden low-income populations. These steps would enhance the model's relevance and policy utility.

While the model incorporated socioeconomic stratification, it may not fully capture the dynamic interplay between income, education, and urban–rural differences. Furthermore, our model does not explicitly account for potential industry responses, such as product reformulation or marketing shifts, nor cross-border purchasing, all of which could influence the real-world impact of taxation. We also did not directly calculate SSB consumption, instead relying on price elasticity estimates from the published literature. Additionally, the analysis assumes a uniform 15 % increase in physical activity across populations, which may not occur equally across income groups. In practice, implementation could exacerbate inequalities if environments that promote physical activity remain less accessible in lower-income areas. Future empirical and microsimulation studies should explore these structural modifiers in greater depth.

6. Conclusion

As Central and Eastern European countries continue to face growing NCD burdens, integrating fiscal and behavioural health policies could substantially improve population health, particularly by reducing obesity, T2DM, mortality, and associated health inequalities. Policymakers should prioritise comprehensive approaches that include implementing or strengthening SSB taxation, ensuring access to safe and affordable drinking water, increasing the availability of fruits and vegetables, and expanding opportunities for physical activity, particularly among younger and lower-income populations. Evidence from this modelling study can also inform regional health strategies aligned with the WHO European Programme of Work and the Sustainable Development Goals.

Consent for publication

Not applicable.

Generative AI disclosure

The first author used AI (ChatGPT) and Grammarly to enhance the readability and language of the manuscript during the drafting process. Following its use, all authors reviewed and edited the content as necessary and take full responsibility for the final version of the publication.

CRediT authorship contribution statement

Abdu Nafan Aisul Muhlis: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **Orsolya Varga:** Writing – review & editing, Validation, Supervision, Methodology, Funding acquisition, Conceptualization.

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Declaration of Competing Interest

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

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.diabres.2025.113002.

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