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FEDERAL RESEARCH PROGRAMME ON DRUGS

SUBOD

Improved monitoring of the disease burden attributable to substance use

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Contract - DR/94/SUBOD

FINAL REPORT

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1. INTRODUCTION

This is the final report of the research project "SUBOD: Improved monitoring of substance use in Belgium." The project was developed in response to the growing recognition that tobacco and alcohol use are among the leading behavioural risk factors for ill health and premature death. Previously, the Belspo-funded SOCOST project has assessed the social cost of legal and illegal drugs in Belgium, highlighting the need for a more sustainable, tailored, and integrated monitoring of the societal impact of substance use. Building on this, the SUBOD project aimed to perform the necessary methodological developments to integrate the burden attributable to tobacco and alcohol use into the Belgian national burden of disease study (BeBOD), coordinated by Sciensano, and to initiate an improved and routine monitoring of these impacts.

The burden of tobacco and alcohol use were assessed using advanced epidemiological methods. The project quantified the economic cost of tobacco and alcohol use through causal inference models, applied to the HISLink dataset, which links Belgian Health Interview Survey (HIS) data with healthcare use data from the Intermutualistic Agency (IMA). Additionally, the disease-specific burden of tobacco and alcohol use was estimated using the comparative risk assessment framework. This approach defines the burden of risk factors as the sum of the attributable burdens of different causally related diseases. For each risk-outcome pair, the attributable burden is determined by integrating data on exposure (consumption levels) with the relative risks associating consumption with disease incidence or mortality.

Using quantitative data, the SUBOD project addresses three key dimensions: data quality and monitoring, methodological refinement, and policy translation. Specifically, the project aims to examines (1) the availability and reliability of data sources on tobacco and alcohol consumption and sales in Belgium, to establish a methodology for accurate monitoring, (2) a scoping review of relative risks for tobacco and alcohol use and their associated diseases, leveraging both scientific and grey literature to create an open-access repository of best-evidence relative risks, and (3) the extension of the Belgian national burden of disease study to include additional causally associated health outcomes, allowing for a comprehensive quantification of the burden of tobacco and alcohol use in terms of attributable deaths, Years of Life Lost (YLL), Disability-Adjusted Life Years (DALY), and costs, disaggregated by age, sex, region, and year. Knowledge translation and policy transfer are central to the SUBOD project. The research has been conducted in close collaboration with key policy stakeholders, leveraging existing networks and interactions to ensure policy relevance and practical applicability. Through proactive project communication, SUBOD also aims to enhance the visibility and accessibility of data collections related to tobacco and alcohol use.

The SUBOD project directly contributes to the objectives of Belgium's federal tobacco and alcohol plans, which explicitly call for improved monitoring of tobacco and alcohol use and their respective impacts. It also lays the groundwork for future studies evaluating the effectiveness and cost-effectiveness of interventions aimed at reducing the burden of tobacco and alcohol use. Furthermore, the project aligns with Sciensano and Gent University's strategic priorities, reinforcing its mission to provide scientific expertise and policy advice to health authorities. By engaging with international collaborations such as the European Burden of Disease Network, chaired by the project coordinator, SUBOD ensures that Belgium remains at the forefront of burden of disease research and evidence-based policy development.

In this final report, we present the state of the art, highlighting key issues related to tobacco and alcohol consumption. We discuss the different methods used to calculate attributable burden (AB) and costs, such as critical appraisal of data sources, time series analysis, the use of comparative risk assessment, and AB. Next, we discuss the results of the SUBOD project and compare them with international results. Finally, policy recommendations are presented and discussed, which is an important part of the project objectives. An overview of all project results: reports, scientific publications, press releases,

1.1. State of the art and problem statement

Alcohol and tobacco use are major public health challenges worldwide, significantly affecting both health and economic welfare. According to the Global Burden of Disease Study 2021, tobacco use accounted for approximately 1.5 million deaths and 33 million DALYs in 2021. Harmful alcohol consumption was responsible for over 1.8 million deaths in 2021 (Brauer et al., 2024). The causal relationship between these substances and increased morbidity and mortality has been well documented (Rehm et al., 2003; Freedman et al., 2018), with significant economic consequences due to healthcare costs and lost productivity.

Social cost studies serve as an economic tool to evaluate alcohol and tobacco policies, guiding resource allocation based on the economic burden attributable to substance use (Bhattacharya, 2017; Ritter et al., 2015). However, methodological inconsistencies in disease burden and cost-of-illness studies raise concerns regarding the reliability of such estimates, potentially leading to over- or underestimations (Bogdanovica et al., 2011; Kilian et al., 2020; Stockwell et al., 2018). A systematic review highlighted the complexity of incorporating all consequences of substance use into social cost studies, emphasizing the need for methodological rigor (Verhaeghe et al., 2016).

A 2016 Belspo-funded study, SOCOST, estimated the social costs of legal and illegal drugs in Belgium, identifying gaps in data availability and methodological robustness (Lievens et al., 2017; Verhaeghe et al., 2016). It underscored the necessity for a more sustainable and integrated monitoring system for assessing the societal impact of substance use. Building on these insights, the current research aims to refine national burden estimates for tobacco and alcohol use in Belgium.

To promote population health and guide policy decisions effectively, comprehensive and reliable information on the health status of the population is essential. Beyond the mere presence or absence of diseases, burden of disease (BoD) methodologies offer a robust and comparable framework to quantify the physical and psychosocial impact of diseases, injuries, and risk factors (Devleesschauwer et al., 2014). A critical component of many BoD studies is the attribution of disease burden to specific risk factors, providing insights into their relative contributions and enabling priority setting for preventive measures (C. J. Murray et al., 2003).

Currently, the Global Burden of Disease (GBD) study provides international estimates of the health impact of alcohol and tobacco use. However, while the GBD study integrates diverse datasets into a sophisticated statistical framework, its estimates are not always grounded in sufficient local data, potentially leading to overgeneralization and limited reproducibility. Consequently, various countries, including Australia, Scotland, and the Netherlands, have developed national burden of disease studies to produce more accurate, country-specific estimates.

Recognizing the need for transparent, locally rooted estimates, Sciensano launched the BeBOD study in 2016 (Devleesschauwer, 2018). The first results, published in 2022, included DALY estimates for 37 health outcomes, alongside fatal burden estimates for 137 causes of death and non-fatal burden estimates for 56 cancer types (De Pauw et al., 2023). Current developments focus on integrating economic impact estimates and risk factors attributable burden. Stakeholder consultations have repeatedly emphasized the need for risk factor inclusion in the BeBOD framework, requiring further methodological advancements in data integration for quantifying the attributable burden of substance use.

2. METHODS

This chapter outlines the methodological framework used to estimate the burden of tobacco and alcohol use in Belgium, following a structured progression from data appraisal to burden estimation. The approach aligns with the Comparative Risk Assessment (CRA) framework (Figure 1), a widely established method for quantifying the impact of risk factors on disease burden. Originally developed by the GBD study, CRA compares current exposure levels to a theoretical minimum risk exposure level (TMREL), allowing the estimation of the Population-Attributable Fraction (PAF) (C. J. Murray et al., 2003; Plass et al., 2022). BeBOD applies this method to assess the risk factor-attributable burden from 2013 to the most recent reference year (2021), disaggregated by region, sex, and age group.

The methodological framework consists of three key components:

- **Critical Appraisal of Data Sources**: A systematic assessment of local data sources is conducted to model the true extent of tobacco and alcohol use in Belgium. This involves evaluating data completeness, quality, and comparability, as well as identifying gaps that may affect burden estimation. Robust data selection and processing are ensured through standardized criteria.
- **Time Series Analysis of Exposure Data**: Trends in tobacco and alcohol consumption are examined using statistical modeling to capture historical and current patterns. This enables an understanding of changes in exposure over time and supports more precise burden estimation.
- **Burden and Cost Estimation**: The final stage quantifies the health and economic burden of tobacco and alcohol use. Disease burden is measured in DALYs, incorporating both mortality and morbidity. Additionally, economic burden estimation accounts for direct healthcare costs, productivity losses, and broader societal impacts.

The methodological approach is structured into work packages (WPs) to ensure a systematic and integrated analysis. WP1 focuses on data appraisal and modeling of substance use prevalence, WP2 synthesizes evidence on risk factor-disease associations, and WP3 quantifies both the health and economic burden. WP4 ensures project coordination and reporting, WP5 manages data governance and integration, and WP6 facilitates dissemination and application of findings.

The CRA method follows a stepwise approach to attribute disease burden, involving five sequential steps, as illustrated in Figure 1. Steps 1 and 2 focus on exposure assessment and risk quantification, forming the foundation for calculating attributable burden.

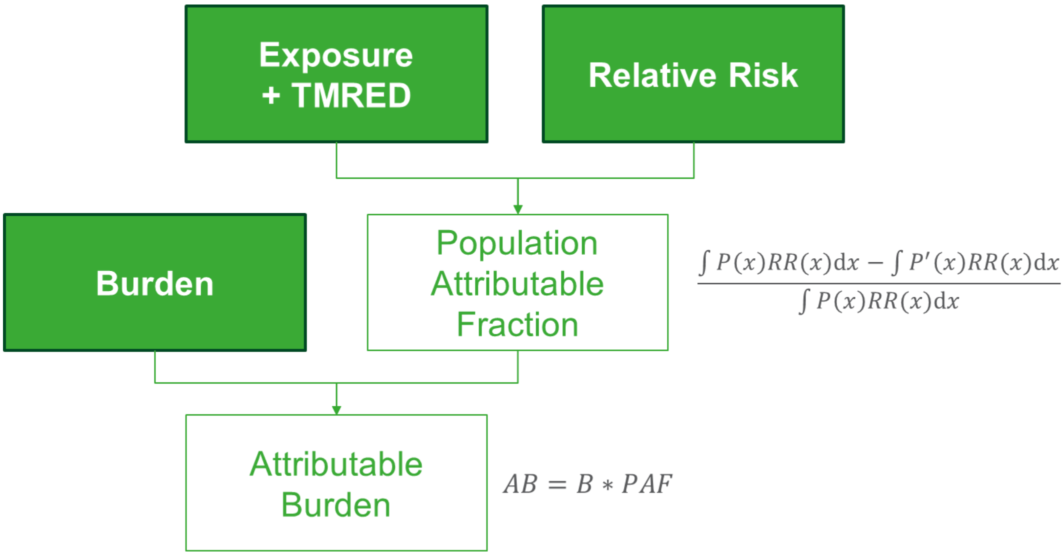

Figure 1: Stepwise approach for calculating the attributable burden of disease through comparative risk assessment

2.1. Critical appraisal of data sources

BOD and the CRA methodology rely on consistency in definition, units of the exposure data, and the exposure-response functions to calculate the PAF (Plass et al., 2022). These exposure indicators are essential as they provide information on the exposure that increases the risk of developing a certain disease that will be needed further in the PAF calculation. The indicators are different depending on data availability and study settings, national or global efforts.

To accurately assess the prevalence and impact of any risk factor, multiple data sources must be considered and critically appraised. The methodology involves identifying, evaluating, and integrating relevant data sources, beginning with self-reported survey estimates and extending to alternative sources such as administrative records, sales data, or biomarker-based measurements.

This exposure assessment is a crucial step in estimating the burden of disease, as it quantifies how much of a population is exposed to a specific risk factor and the distribution of that exposure. The methods for estimating exposure can vary widely depending on the risk factor in question and the type of data available within the relevant context (Ezzati et al., 2002; Plass et al., 2022). This step requires careful consideration of the data sources, potential biases, and adjustments needed to ensure the exposure estimates are both accurate and representative. In this section, we explore the key principles and approaches to exposure assessment (Ezzati et al., 2002).

2.1.1. Search strategy for data sources

Data related to the selected risk factor were extracted from various national and international sources, utilizing heterogeneous methodologies. The sources identified were chosen based on their potential relevance to the study. While some data sources may have been missed, this review aims to provide an overview of those deemed most applicable.

Estimating population exposure to risk factors has traditionally relied on self-reported measures from surveys (e.g., behavioural risk factor surveillance systems). However, to obtain a comprehensive assessment, data sources incorporating objective measures such as biomarkers, sales data, and administrative records were also considered. These additional sources help address limitations such as underestimation due to self-report bias, recall bias, and sampling issues. Triangulation methods between multiple data sources can enhance the accuracy and reliability of estimates.

2.1.2. Search strategy for alternative data sources

To reduce the limitations of individual survey and administrative data, initiatives that integrate available information were explored. Alternative data sources were identified through literature reviews, consultations with experts, and the examination of grey literature, such as industry reports and government registries. For instance, global monitoring, such as WHO and OECD databases, often provide harmonized estimates that integrate multiple data sources

2.1.2.1. Inclusion criteria

Available datasets for monitoring the selected risk factor over the past two decades were identified and critically assessed to determine their suitability. Sources were identified through an unstructured literature review and expert consultations.

2.1.2.2. Quality assessment and inclusion criteria

To select high-quality data, we established a list of quality criteria adapted from existing epidemiological assessment frameworks. Each identified source was evaluated based on the following criteria:

- Frequency
- Bias assessment
- Type of survey
- International comparability
- Consistency over time (methodology changes YES/NO)
- Representativeness of the sample
- Level of aggregation: EU, national, regional, provincial

Table 1. Overview of the criteria used for the quality assessment of available data sources on alcohol use and sales

Quality criteria	Rationale	Assessment
Frequency	Support the development of a time series on alcohol use.	Frequency of data collection and reporting
Bias assessment	To minimize underestimation and produce results representative of the general population	Evaluation of the sampling frame, response rates, reporting methods, and likelihood of impacts on the estimates
Data collection	Minimize bias in the data collection process	Preference for self-completed, self-reported collection with little interference from interviewers
International comparability	To be able to compare to other BoD studies estimates	Comparison of overall methods to other studies or multi-country data sources
Consistency over time (methodology changes YES/NO)	To have an accurate estimation of the data over time	Evaluation of the methods applied from one year to the next and whether there were any changes and how those impact validity
Representativeness of the sample	Nationally representative sample with details by age, sex, and region	Reach of the sample and how well it can represent the distribution of drinking geographically

Age groups	To have multiple age categories to ensure a broader overview of the data by considering various age groups	Description in the sample of the age groups included
Level of aggregation: EU, national, regional, provincial	Detailed data at various levels of aggregation	Strata with multiple levels of aggregation
Frequency	Support the development of a time series on alcohol use.	Frequency of data collection and reporting

The critical assessment of these identified data sources was performed by testing the data sources to the list of pre-defined criteria. The final dataset is selected as the best available data source for the next steps of the project.

2.2. Time series of exposure data

One possible data source for exposure indicators is repeated cross-sectional surveys. However, these surveys are often not conducted annually and therefore may not provide a continuous time series. When an existing time series is unavailable, methodologies can be developed to address gaps in the data and ensure a consistent representation over time. For instance, in the BeBOD study, where the goal is to present a time series of risk factor attributable estimates from 2013 to the most recent reference year, a methodology was developed to be able to fill the gaps in the years between data (De Pauw et al., 2024).

2.2.1. General methodology

To interpolate missing years of data, BeBOD relies on implementing a Bayesian Generalised linear models (GLM) methodology to predict the frequency of specific exposures by making use of Integrated Nested Laplace Approximations (INLA). INLA is a method designed for approximate Bayesian inference in latent Gaussian models, which encompasses a wide array of statistical models used across various scientific disciplines (Lindgren & Rue, 2015). INLA is particularly effective for models that are computationally demanding to fit using traditional Markov Chain Monte Carlo techniques due to its efficiency and speed. The method focuses on latent Gaussian models where the observed data are linked to latent Gaussian variables via a likelihood function, applicable to models like generalized linear mixed models, spatial models, and more. INLA relies on the Laplace approximation to estimate the marginal posterior distributions of the latent variables and model parameters swiftly, with less computational overhead than conventional Bayesian methods, while also allowing for the computation of uncertainty. INLA uses a nested approach where it initially approximates the marginal posterior distributions of the hyperparameters, then, based on these approximations, computes the marginal distributions of the latent field and other parameters. The methodology includes a strategy to select the "best-fitted model" to create a time series. This model was the best at taking into account interactions between and across independent variables (e.g. year, sex, region, and age groups). In BeBOD, estimations via INLA are done by using the R-INLA package (version 24.05.10).

General model

GLM are used to model the exposure variables in function of time and other possible covariates. Different statistical families and link functions are required to account for different types of data distributions.

Binomial model (for prevalence data):

The general model to forecast the prevalence of an exposure can be described as

$$\log\left(\frac{\pi_C}{1-\pi_C}\right) = \beta_0 + \beta_1 X_{year} + \beta_j X_j + \varepsilon,$$

Whereby π_C represents the exposure prevalence, β_0 the intercept of the model, β_1 the coefficient associated with the prevalence (π_C) and the year (X_{year}) in which the data were observed, β_i the coefficient associated with the prevalence (π_C) and a socio-demographic predictor (X_j), and ε the residual term. The term $\log\left(\frac{x}{1-x}\right)$ is the logit-link function that is implemented to model a binomial process.

Poisson or Quasi-Poisson Models (for count data):

These models are appropriate for variables representing counts or rates that are non-negative.

$$\log(\mu) = \beta_0 + \beta_1 X_{year} + \beta_j X_j + \varepsilon,$$

Where μ is the expected count (or rate). The log-link function ensures the predictions remain non-negative.

Gamma Models (for positively skewed continuous data):

Used for data that are positive and continuous, such as rates or durations.

$$\log(\mu) = \beta_0 + \beta_1 . X_{year} + \beta_j . X_j + \varepsilon$$

In BeBOD, a total of 5 different models are considered including different combinations of the independent variables year, sex, age, and region. Each model is composed of different interactions between those independent variables where the model with the higher number of interactions takes into account lower-grade interactions from the previous model.

Model 1: Fixed effects model

$$y = \beta_0 + \beta_1 * YEAR + \beta_2 * SEX + \beta_3 * AGE + \beta_4 * REGION + \varepsilon$$

Model 2: Two-way interaction model with year

$$y = \beta_0 + \beta_{12} * YEAR * SEX + \beta_{12} * YEAR * SEX + \beta_{13} * YEAR * AGE + \beta_{14} * YEAR * REGION + \varepsilon$$

Model 3: Two-way interaction model among all included factors

$$y = \beta_0 + \dots + \beta_{12} * YEAR * SEX + \beta_{13} * YEAR * AGE + \beta_{14} * YEAR * REGION + \beta_{23} * SEX * AGE + \beta_{34} * AGE * REGION + \beta_{24} * SEX * REGION + \varepsilon$$

Model 4: Three way interaction model among all included factors

$$y = \beta_0 + \ldots + \beta_{123} * YEAR * SEX * AGE + \beta_{124} * YEAR * SEX * REGION + \beta_{234} * SEX * AGE * REGION + \beta_{123} * YEAR * AGE * REGION + \varepsilon$$

Model 5: Four way interaction model among all included factors

$$y = \beta_0 + \ldots + \beta_{1234} * YEAR * SEX * AGE * REGION + \varepsilon$$

The formal model-building process includes three consecutive steps. In an initial step, the different models were built and their goodness of fit values were saved into a table. The model with the best goodness-of-fit (lowest Watanabe-Akaike information criterion (WAIC), was identified as the prime candidate to construct the final model.

The most suitable model is selected based on the Watanabe–Akaike information criterion (WAIC), whereby a lower WAIC is associated with a better fit of the model to the data. Therefore, the model with the lowest WAIC is selected for the imputation. After model selection, the estimated prevalence estimates and their surrounding 95% uncertainty intervals for the years with no information on the prevalence are extracted from the posterior distribution of the Bayesian model fitted with INLA by age, sex, and region. In addition, we also use the estimated and smoothed prevalence rate derived from the most suitable model for the years in which data are available, to allow for a coherent time series.

2.2.2. Imputation

In BeBOD, only missingness in the response variable is considered (forecasting) given the selected final model. More specifically, projected exposure estimates are obtained by imputing the missing outcomes for unobserved years (i.e., from 2018 to 2021). Given that the distribution of the response variable is part of the model, it is possible to predict the missing values by computing their predictive distribution.

2.2.3. Normalization of categorical exposure data

For categorical exposure variables, a normalization process is applied that aims to standardize the categorical exposure values across the different categories of risk factors, ensuring that they sum to 100%. The steps below outline a general approach applicable to any risk factor.

For each risk factor, the total exposure is calculated by summing the values across all relevant categories. Each category is then normalized by dividing its value by the total exposure, ensuring that the sum of the normalized exposures equals 100%. The normalized values are verified to confirm they total 100%, ensuring the accuracy of the normalization process. Finally, these normalized values are used for the next steps.

2.3. Disease-specific deaths using comparative risk assessment

2.3.1. Identification and quantification of risk-outcome-pairs association

A fundamental step in estimating the burden of disease attributable to risk factors is identifying the health outcomes causally linked to specific exposures. Establishing these risk-outcome associations is essential for ensuring the validity and robustness of CRA results (Zheng et al., 2022). Risk-outcome pairs must be based on strong causal evidence to ensure that the estimated burden accurately represents true public health impacts rather than false associations (Plass et al., 2022).

This section will explain the process of identifying and quantifying risk-outcome associations, using evidence standards that support this step.

2.3.1.1 Identification of risk-outcome pairs

The process of identifying these associations relies on robust epidemiological principles, with causality assessments often guided by frameworks such as the Bradford Hill criteria (Hill, 1965):

- **Strength**: The larger the effect size, the more likely that the association is causal.
- **Consistency**: The more independent studies producing similar findings, the more likely that the association is causal.
- **Specificity**: The more specific exposure and outcome are defined, the more likely that the association is causal.
- **Temporality**: The outcome has to occur after the exposure, possibly after some delay.
- **Biological gradient**: Higher exposure should be associated with more cases of the outcome, indicative of a dose-response relationship.
- **Plausibility**: There should be a plausible mechanism between exposure and outcome.
- **Coherence**: The fewer contradictory findings in other fields of study, the more likely that the association is causal.
- **Experiment**: Do changes in exposure, for example through preventive action, have an effect on the frequency of the outcome?
- **Analogy**: A causal relationship is supported if there are similar risk-outcome pairs.

These criteria are key elements in establishing causality.

Furthermore, the GBD also performed causality assessments to decide on the inclusion of risk-outcome pairs in previous cycles (Murray et al., 2020), which are based on the grading system of the World Cancer Research Fund (Wiseman, 2008). Where they have categorize risk-outcome associations based on the strength of available evidence, from "convincing" and "probable" to "possible" or "insufficient" (Murray et al., 2020; Wiseman, 2008). Such frameworks ensure transparency and consistency in deciding which risk-outcome pairs to include in CRA analyses. These categories are defined as follows:

- **Convincing evidence**: Convincing evidence is evidence based on epidemiological studies showing consistent associations between exposure and disease and includes little or no evidence to the contrary. The available evidence is based on a substantial number of studies including prospective observational studies and, where relevant, randomized controlled trials (RCT) of sufficient size, duration, and quality that show consistent effects. The association should be biologically plausible.
- **Probable evidence**: Probable evidence is evidence based on epidemiological studies showing fairly consistent associations between exposure and disease, but for which perceived shortcomings in the available evidence exist or some evidence to the contrary precludes a more definite judgment. Shortcomings in the evidence may be any of the following: insufficient duration of trials (or studies); insufficient trials (or studies) available; inadequate sample sizes; or incomplete follow-up. Laboratory evidence is usually supportive. The association should be biologically plausible.

- **Possible evidence**: Possible evidence is evidence based mainly on findings from case-control and cross-sectional studies. Insufficient RCT, observational studies, or non-randomized controlled trials are available. Evidence based on non-epidemiological studies, such as clinical and laboratory investigations, is supportive. More trials are needed to support the tentative associations, which should be biologically plausible.
- **Insufficient evidence**: Insufficient evidence is evidence based on findings of a few studies that are suggestive but insufficient to establish an association between exposure and disease. Little or no evidence is available from RCTs. More well-designed research is needed to support the tentative association.

In summary, the identification of risk-outcome pairs is a critical step in Comparative Risk Assessment, as it ensures that the estimated burden is based on robust and causal evidence (Plass et al., 2022; Zheng et al., 2022). Since the GBD 2021, the introduction of the burden of proof risk function methodology has further strengthened this process. This approach evaluates risk-outcome pairs using a star-rating system, where those receiving at least one star are considered for inclusion. By analyzing the relative risk (RR) estimate and its 95% uncertainty interval, the methodology ensures that risk-outcome pairs are only included if their uncertainty interval does not cross the null value of 1, even when unexplained between-study heterogeneity is not accounted for (Brauer et al., 2024; Zheng et al., 2022).

2.3.1.2 Selection of dose-response functions

For the selected risk-outcome pairs, a dose-response or exposure-response function is required to translate exposure to the risk factor into the relative risk for the associated health outcome. The selection of these functions is a critical step, as it directly impacts the accuracy and reliability of the burden estimates.

To ensure consistency and transparency, the following criteria can be used to evaluate epidemiological studies serving as the source of a dose-response function. These criteria also help document the rationale for selecting one function over potential alternatives:

Accessibility

Can the information be easily extracted?

- From the article text?
- From the supplementary materials?
    - Pdf
    - Document
    - Spreadsheet

In the context of BeBOD, this is essential for maintaining the study's relevance and ensuring the findings can be revised as new evidence emerges

Transparency

Are the methodology and underlying data clearly described?

- Which health data is used?
- How is the health outcome defined?
- How is exposure assessed?

- Which information is available for the study's subjects? For example:
    - Age and sex
    - Socio-economic status
    - Smoking behaviour
    - Body Mass Index
    - Physical activity level
- Is the information on subjects on the level of the individual or area level?
- Which confounding factors are taken into account?
- In case of a systematic review and meta-analysis:
    - Is the search strategy documented?
    - What are the inclusion and exclusion criteria?
    - Which studies are included in the review?
    - Which information is extracted?

Transparency is crucial in the BeBOD study to ensure that the study findings can be verified and reproduced.

Reliability
Is the analysis methodology sound and appropriate?

- Is exposure assessment unbiased?
- Is the outcome definition appropriate?
- Are analyses performed for relevant subgroups?
- Is the relationship adjusted for all possible confounding factors?
- Are single or multiple exposure models used?
- In case of a systematic review and meta-analysis:
    - Was there publication bias detected?
    - How high is the heterogeneity of the results between the studies?

Ensuring reliability is essential to establish confidence in the estimates, as they inform decision-making by policymakers and public health stakeholders. This is a key objective of the BeBOD study.

Evidence
Is the quality and quantity of the data used in the analysis sufficient?

- What is the sample size?
- Is the sample representative of the population?
- What is the study design?
    - Systematic review
    - RCT
    - Cohort study
    - Case-control study
    - Ecological study
- In case of a systematic review and meta-analysis:
    - Are all included studies relevant?
    - Are all relevant studies included?
    - Does the review consider the most recent evidence?

In BeBOD, reliance on robust evidence ensures that the study's results are scientifically valid and can withstand scrutiny from both scientific and policy perspectives.

Relevance
Are the findings representative of the (Belgian) population and relevant?

- Do the health outcome definitions match?
- Does the definition of exposure match?
- Are the population characteristics similar?
- What is the geographical extent of the study?
- What is the observed exposure range?

For BeBOD, ensuring relevance is critical to producing estimates that accurately capture the burden of disease in Belgium and address country-specific public health priorities.

2.3.2 Exposure definition

For BeBOD, a critical appraisal of national data sources is performed to identify the "best available" dataset for each risk factor/exposure, as mentioned above.

2.3.3 Calculation of the attributable burden of risk factors

The attributable burden quantifies the proportion of a disease burden that can be linked to one risk factor. This calculation builds on the foundations laid by Step 1 (identification of risk-outcome pairs) and Step 2 (exposure assessment), as these complementary steps provide the critical components required for the PAF equation and the resulting attributable burden (AB) estimates (Figure 1). The estimates are generated by year, age, sex, and region.

2.3.3.1 Theoretical Minimum Risk Exposure Level (TMREL)

To estimate the impact of the increased risk from an exposure, a baseline level of exposure must be defined as a counterfactual. This baseline, known as the TMREL, represents the exposure level that would result in the lowest possible population risk, regardless of whether it can realistically be achieved in practice (Murray et al., 2003).

To guide the choice of the TMREL, Murray et al. (2003) presented different natures of the counterfactual based on the type of risk factor:

- **Physiological Risk Factors**: These include essential physiological parameters like blood pressure. The theoretical minimum here would be a non-zero level based on empirical evidence, representing the point where risk is minimized without disrupting vital functions.
- **Behavioural Risk Factors**: For habits like smoking or alcohol use, the theoretical minimum is usually zero or the point where benefits outweigh risks, depending on the exposure-response relationship. Protective behaviours, like physical activity, also have a theoretical minimum at the highest sustainable levels of benefit.
- **Environmental Risk Factors**: These involve harmful exposures like pollution, where the theoretical minimum is the lowest achievable level, typically the natural background concentration (e.g., the lowest level of particulate matter that can be achieved in the environment).

- **Socioeconomic Risk Factors**: These factors, like income and education, have complex, context-dependent effects. The theoretical minimum varies by context and is assessed relative to policy interventions aimed at reducing disparities.

2.3.3.2 Population attributable fraction (PAF)

The PAF represents the proportion of a disease that can be attributed to exposure to a specific risk factor and thus quantifies its impact on the disease burden (as a percentage). This is calculated by estimating the excess prevalence of disease in the population. This can be represented mathematically and is drawn from Murray et al. (2003). Note that different formulas exist depending on the nature of the exposure variable (i.e. binary, categorical, or continuous).

For a binary exposure (presence/absence), the PAF formula is as follows:

$$PAF = \frac{P(RR-1)}{P(RR-1)+1}$$

where P is the prevalence of exposure in the population and RR is the relative risk of exposure to the outcome.

For categorical risk factors, the formula can be represented as:

$$PAF = \frac{\sum_{i=1}^{n} P_i RR_i - \sum_{i=1}^{n} P'_i RR_i}{\sum_{i=1}^{n} P_i RR_i}$$

In this equation, P_i represents the observed prevalence of exposure class *i*, P'_i refers to the counterfactual prevalence of exposure class *i*, and RR_i denotes the relative risk associated with exposure class *i*, relative to the reference class. Where $\sum_n$ is the sum of n exposure categories. Each category has its RR in this case and the TMREL is assumed to be a relative risk of 1.

For continuous risk factors, the formula can be represented as:

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

Where $P(x)$ represents the observed exposure distribution, $P'(x)$ denotes the counterfactual exposure distribution, and $RR(x)$ refers to the relative risk at a specific point on the dose-response function.

Note that risk factor-specific considerations regarding PAF calculations will be addressed in their respective annexes.

1.4.2.1 Estimating the attributable burden of disease

Estimating the attributable burden of disease requires estimates of that burden (e.g. DALY, YLL, YLD, or number of deaths) and was drawn from the available dataset generated by the BeBOD study. For this, a PAF for YLD and a PAF for YLL are estimated and multiplied by the YLD and YLL. Mathematically this can be written as:

$$Attributable\ Burden\ (AB) PAF * BURDEN$$

The attributable burden of disease is estimated by multiplying the PAF by the burden estimate at the most disaggregated level (5-year age group, sex, region, year combination). This provides an attributable burden estimate in absolute numbers that is then aggregated to different levels (e.g., all sexes, all regions, all ages). These aggregated values are divided by the aggregate estimate of the total burden to re-estimate the PAFs for aggregate levels. This process captures the variation in burden by age and sex at the most detailed level. Rates and age-standardized rates are calculated for the attributable burden estimates after aggregation, and DALYs are calculated as the final step. Aggregated PAF estimates was based on the attributable burden values divided by the total absolute values (not rates) and was considered as another estimate of the metric (like rates and numbers).

2.4 Direct and indirect costs

To calculate the global attributable cost of tobacco and alcohol use, a distinction was made between direct costs and indirect costs. Direct costs refer to costs used to deal with the use of tobacco and alcohol and its proximate effects, such as hospitalisation. Indirect costs refer to secondary effects of tobacco and alcohol misuse such as productivity loss (Moore & Caulkins, 2006).

2.4.1 Data sources

To calculate direct and indirect costs related to tobacco and alcohol use, the Linkage of Health Interview Survey Data with Health Insurance Data (HISLink) dataset was used. The HISLink dataset merges data from the Belgian Health Interview Survey (HIS) with the Mandatory Health Insurance (MHI) data collected by the Intermutualistic Agency (IMA). The linkage of the data from the two databases occurred through the national registry numbers.

2.4.1.1 Belgian Health Interview Survey

In the HIS, the aim is to provide an overall picture of the health status of the Belgian population. The survey allows us to identify the main health problems, as well as the social and behavioural factors that influence them. Data on sociodemographic background characteristics, health status, lifestyle, and medical consumption of a representative sample of the general Belgian population has been collected. The HIS questionnaire is a face-to-face interview and a self-complete questionnaire. To date, the HIS has been organised in Belgium in 1997, 2001, 2004, 2008, 2013, and 2018. For the SUBOD project, the HIS2013 and HIS2018 datasets were used.

2.4.1.2 Compulsory health insurance database

Alongside the HIS, the IMA administrative database includes information on reimbursed care and medication for the population covered by compulsory health insurance (~99% of the total population in Belgium). The compulsory health insurance partly or in some cases fully covers the costs of a wide range of medical, and paramedical services, and pharmaceuticals. The IMA database includes information on reimbursed health care and medication for the population covered by the compulsory health insurance (about 99% of the total population in Belgium). The IMA database comprises reimbursed total health care costs for every payment modality (directly paid by the health insurance, patients out-of-pocket, and supplements). These expenditures include (1) ambulatory care (over-the-counter pharmaceuticals excluded), (2) hospital care, and (3) reimbursed medicines purchased through pharmacies (Intermutualistisch Agentschap, n.d.) Information on reimbursed healthcare costs was available from 2018-2020 for all HIS participants. Healthcare costs include hospital care, ambulatory care (including pharmaceuticals), and reimbursed medicines purchased through public pharmacies.

1.4.3 Methods

1.4.3.1 G-Computation – Causal Inference

Since it is not possible to directly assess the costs related to alcohol and tobacco use, it is necessary to compute the incremental cost attributable to alcohol and tobacco use. Therefore, multivariable regression models with negative binomial distribution and log link were used to explore the extent to which both outcomes (direct and indirect costs) are associated with the concerned risk factors. The regression models included socio-demographic characteristics and lifestyle factors such as age, gender, educational level, and socioeconomic status based on preferential reimbursement status. Missing values were excluded from the analyses. This model is repeated for each risk factor separately.

Average healthcare cost ~ Smoking class [Different classification] + confounders

Average healthcare cost ~ Alcohol class [Different classification] + confounders

In the first phase, attributable (or incremental) costs were estimated at the individual level using g-computation (direct standardization), which allows to estimate the marginal effect of the concerned exposure on healthcare and indirect costs (Snowden, Rose et al. 2011, Vansteelandt and Keiding 2011). Specifically for this project, the coefficients of the regression model were used to predict healthcare costs for each individual using the observed smoking or alcohol classes (i.e. the observed exposure status as reported in HIS). The same coefficients of the regression model were used to predict healthcare costs for each individual in a scenario where no one uses alcohol or tobacco, keeping all other characteristics observed (including the use of other substances).

Predict(Alcohol class[classes]) – Predict(Alcohol class[no alcohol]) = Attributable cost of alcohol

Predict(Tobacco class[classes]) – Predict(Tobacco class[no tobacco]) = Attributable cost of tobacco

Thereafter, individual incremental cost for alcohol or tobacco use were calculated as the difference between an individual’s predicted cost in the two above-described scenarios.

To calculate indirect costs, the following formula was used:

Cost of absenteeism = yearly days absent from work * average labour cost per day

The cost of absenteeism was estimated based on the questions available in the HIS. The productivity loss was calculated using the human capital approach, assuming that each day of absence corresponds to the average gross daily wage (Van den Hout 2010). The number of days absent from work were then be multiplied by the national yearly average labour cost per hour multiplied by an average of 7.6 hours (38 hours per week) per working day. Only the working population was included in this calculation (respondents who stated having a paid job at the moment of the study).

The total costs was computed by multiplying the population-weighted average cost for exposure by the prevalence of the exposure in the general Belgian population for the direct costs and in the working Belgian population for the indirect costs.

3 RESULTS

3.1 Tobacco

3.1.1 Appraisal

BOD and the CRA methodology rely on consistency in definition, units of the exposure data, and the exposure-response functions to calculate the PAF (Plass et al., 2022). These indicators are essential as they provide information on the degree to which the exposure (e.g. tobacco or alcohol use) increases the risk of developing a certain disease in that population. The indicators are different depending on data availability and study settings (Plass et al., 2022). Different approaches from BOD studies in other countries are described and compared below and in Table 1.

Table 2. Overview of tobacco use indicators found in other burden of disease studies

Indicator	Definition	Burden of Disease Study
Current and former smoking	Current smokers as individuals who currently use any smoked tobacco product on a daily or occasional basis Individuals who quit using all smoked tobacco products (Australian Institute of Health and Welfare, 2019a).	Australian Burden of Disease Study 2015
Second-hand smoke	Involuntary exposure involving inhaling carcinogens and toxic components present in tobacco smoke at home, at work, or in other public places (Australian Institute of Health and Welfare, 2019a).	Australian Burden of Disease Study 2015 Global Burden of Disease Study 2019
Pack-years	A measure of smoking that includes intensity and time smoked. It is calculated by multiplying the number of packs of cigarettes smoked per day by the number of years the person has smoked (National Cancer Institute, 2011)	Global Burden of Disease Study 2019
Number of cigarettes per day	Cigarette-equivalents per day smoked by a daily smoker	Global Burden of Disease Study 2019
Number of years since quitting	Number of years since quitting for former smokers	Global Burden of Disease Study 2019
5-year lagged daily smoking	Smoking prevalence lagged by 5 years from the current rate, used to represent the exposure-lag response of smoking prevalence on disease (Smith et al., 2021)	Global Burden of Disease Study 2019

3.1.1.1 Tobacco use data

We identified four sources that met the inclusion criteria for tobacco use:

- The Belgian Health Interview Survey (HIS)
- The Foundation Against Cancer Survey (FCC)
- The Eurobarometer survey on public opinions in the European Union (EB)
- The Health Behavior in School-aged Children International Study (HBSC)

Belgian Health Interview Survey

The HIS is a household cross-sectional population-based survey of the whole of Belgium including all age groups. It provides a broad picture of the population health in Belgium by identifying the main health problems, as well as the social and behavioral factors that have an impact on them (Demarest et al., 2018). The survey uses a stratified multi-stage, clustered sampling with proportional representation and replacement by region of Belgium. The HIS started in 1997 and is conducted every four or five years with a new sample (Demarest et al., 2018). Data are self-reported with a small sub-sample (around 10%) completing an examination survey that includes objective measures including urine cotinine, relevant for assessing tobacco use (Nguyen et al., 2020).

The HIS assesses a broad range of indicators for tobacco use including smoking habits and history, intensity of smoking, duration of tobacco use, age at initiation, and attempts to quit. The measures are all self-reported but the portion of the survey where these data are collected is self-administered to reduce the risk of interviewer bias (Demarest et al., 2018). Data on tobacco use are only collected for people ≥ 15 years, thus adolescent tobacco use is not included. Some data on second-hand smoke exposure are also collected.

Appraisal

The HIS stands out as a consistent and nationally representative survey of self-reported health, covering more than two decades. However, it has limitations in terms of monitoring tobacco use. The tobacco-related data in the survey provide snapshots and do not perfectly or annually reflect the tobacco consumption situation in Belgium. Since the HIS employs a random sample, there is always an inherent 'uncertainty' associated with these prevalence figures, as indicated by the 95% confidence intervals (CI). For instance, if the same surveys were conducted infinitely many times with the same sample size in the same population, 95% of all these prevalence estimates would fall between 18% and 22%. While the HIS primarily focuses on tracking changes in the population's health rather than exact prevalence estimates, understanding long-term trends might require a costly cohort study, which is susceptible to loss of follow-up.

The primary strength of the HIS lies in its consistent and representative methodology spanning from 1997 to 2018. It utilizes a weighted sample from the national registry as a sampling frame, providing a robust overview of tobacco use in Belgium for individuals aged 15 years and above. Although participants differ across survey waves, they are considered representative of the population due to the sampling methods, including regional and age stratification, standardization of age and sex, as well as systematic multi-stage survey and clustering. Moreover, the survey employs a representative sample of the Belgian population, not just a simple random sample, ensuring high-quality results that reflect the entire population (Demarest et al., 2018). The adherence to international recommendations further enables comparability with European data. Additionally, the HIS survey includes all necessary indicators for evaluating tobacco exposure when calculating the attributable burden.

Foundation Against Cancer Survey

The Foundation Against Cancer (FCC) has conducted an annual survey of tobacco consumption in Belgium since 2012 with the help of IPSOS, a marketing firm (Gisle, 2008). The aim was to estimate tobacco consumption in the Belgian population using phone calls and then online surveys based on an (online) panel. This panel consists of a large group of people who are willing to participate in surveys and are also paid for doing so. This is a multi-purpose panel, which can be used for a wide range of surveys. Based on the composition of the population (in terms of age, gender, level of education, etc.), strata are determined (combination of age, gender, etc.) and it is known what percentage of the population each stratum comprises (Fondation contre le cancer, 2021).

Appraisal

The annual cross-sectional survey conducted by Fondation contre le cancer (FCC) uses a predetermined sample size with the number of participants per category calculated as quotas. Panel members are invited to participate until these quotas are met; initially conducted via phone, the survey transitioned to an online format in 2018. Any refusals are replaced with similar individuals. However, the FCC approach lacks detailed information on the sampling frame, hampering a comprehensive evaluation of sample quality. There is a potential risk of selection bias in the sampling frame but without more details, this can be difficult to assess. For instance, participants are invited by telephone which would exclude those without a registered phone number.

Eurobarometer

The Eurobarometer (EB) survey on public opinions in the European Union is also a good source of information on tobacco use. The survey was conducted for tobacco use from 2002 to 2016 and is defined as a cross-sectional survey (Nissen, 2014). During each wave, the same sample design is applied in all Member States and several sampling points are drawn with a probability proportional to population size, to aim for a total coverage of the country, to have a sample of 1000 participants within each European country (Bogdanovica et al., 2011; Nissen, 2014). The national samples were weighted. They used face-to-face interviews in each country's national language and data were collected via CAPI in the countries where face-to-face interviews were not applicable.

Appraisal

The methodological limits of the Eurobarometer survey are described by Nissen (2014). Specifically, the comparison between different years of the EB survey is limited since it can be due to a change of phrasing of the questions asked and not necessarily due to a real change in behaviors. In addition, when assessing behaviors between countries, it is important to take into account that for cultural reasons some respondents might underreport their consumption (European Union, 2010, 2014). Finally, only self-reported prevalence rates for tobacco use were available on a national level with no stratification for age, sex, and region. The only comparisons that can be made are at a country level and within the countries of the EU. Those limitations make it hard to assess the real impact of tobacco use in Belgium.

Health Behavior in School-aged Children study

By incorporating the international Health Behavior in School-aged Children (HBSC) study, we aim to obtain a comprehensive overview of tobacco use in Belgium across various sociodemographic variables. Taking place in Flanders and French-speaking community for the past twenty years, with the supervision of the regional office of the World Health Organization , the study aims to describe the health behaviors, health status, and well-being of teenagers and bring to light demographical, school-related, and social disparities (Moreau et al., 2017).

The study is a school-based survey, where the questionnaires were administered in class. Three questionnaires were launched to take into account level disparities. The methodology is consistent over time and is decided on an international level (Moreau et al., 2017; Roberts et al., 2009) and uses cluster sampling and a large sample with proportional stratification by school population by province and school network. Two steps were used to create the sample: first, a random selection of schools within each province based on the list from FWB and FL per province and by the network were made then they randomly selected class in the fifth primary grade to the sixth secondary grade to have all ages available in the sample. Those steps were us to obtain a representative sample of pupils that are enrolled full-time in Belgium (Roberts et al., 2009).

Appraisal

The HBSC surveys are part of an international collaboration and have a well-documented methodology. The sample is limited to school-aged children enrolled in schools, thus excluding those who are not enrolled. This presents a selection bias which means the validity of the results can only be interpreted as representing children in school. They cover age groups that are not captured by surveys on adults and thus provide a useful window into the ages at which most adolescents begin experimenting with tobacco. They are conducted by language community in Belgium (Dutch and French) and the two surveys are not combined, nor do they have perfectly overlapping reporting of their results or questions. This limits the utility of the surveys to create a national picture. The limited age groups exclude this survey from being considered for a wider assessment of tobacco use nationally. In terms of attributable burden of disease, the risk of disease from tobacco use begins to accumulate from around age 30, which is well beyond the age of this survey. Therefore, while it provides important information on the early adoption and use of tobacco in Belgium, it cannot be extended in any consideration of the burden of disease.

3.1.1.2 Other data sources

In addition, the following sources were found but as they are using data that are gathered from other data sources, they were not included in the mapping of the sources as they did not meet our quality criteria. Nevertheless, we still found it relevant to present them briefly.

- **Preventiebarometer**: Sciensano has conducted the Prevention Barometer survey in the Flemish Region, targeting residents aged 18 and above, regardless of nationality or existing health behaviours. A random sample is drawn from the national register, and participants are invited via mail to complete the questionnaire online. The survey aims to gather insights into health behaviours, including tobacco consumption frequency and intentions to change behaviours, with a goal of at least 3,000 participants (Sciensano, s. d.).
- **The European Social Survey**: The survey is an international research initiative carried out every two years throughout Europe since 2002. Its objective is to evaluate the attitudes, opinions, and

behaviours of populations across more than twenty countries. Within the framework of the ESS, information is gathered through in-person interviews, with a preference for employing the Computer-Assisted Personal Interview (CAPI) method, across all participating nations. Participants are individuals aged 15 and above within the population and have an identical likelihood of being selected. The sampling frame is based on the national register. Data assessing tobacco consumption in Belgium are available for the year 2014-2015 (European Social Survey, s. d.).

- **The EU-SILC**: The EU Statistics on Income and Living Conditions (EU-SILC) is a European survey that serves as a source for comprehensively understanding the various dimensions of social inclusion for households and individuals in society. It employs a multi-dimensional approach, facilitating comparisons between different Member States. Conducted in 2013, 2017, 2018, and 2022, the EU-SILC surveys approximately 6,000 households in Belgium, including a specific focus on 1,000 households in Brussels. The data provides valuable insights into income distribution, poverty, social exclusion, and various living conditions, contributing to a better understanding of the diverse factors impacting social inclusion across regions (Commission communautaire commune, s. d.). Information on tobacco consumption in Belgium by age, sex, and region is available in the latest run of the survey.

Trends in survey-derived self-reported tobacco use

Based on the main survey-derived data sources, we summarize the evidence on self-reported tobacco use over time.

Table 4 highlights the availability of the indicators that we have found in the five data sources that met our inclusions and quality criteria by year. Indicators were available depending on the data sources' frequency and regarding those frequencies in each data source or only captured in one data source (e.g., second-hand smoking).

Figure 1 shows the distribution of smoking from Belgian surveys. There is overall a downward trend in daily smoking (Figure 1 A) and a concomitant rise in people reporting never smoking (Figure 1 C). Former smokers and occasional smokers have a more stable pattern with some heterogeneity across surveys.

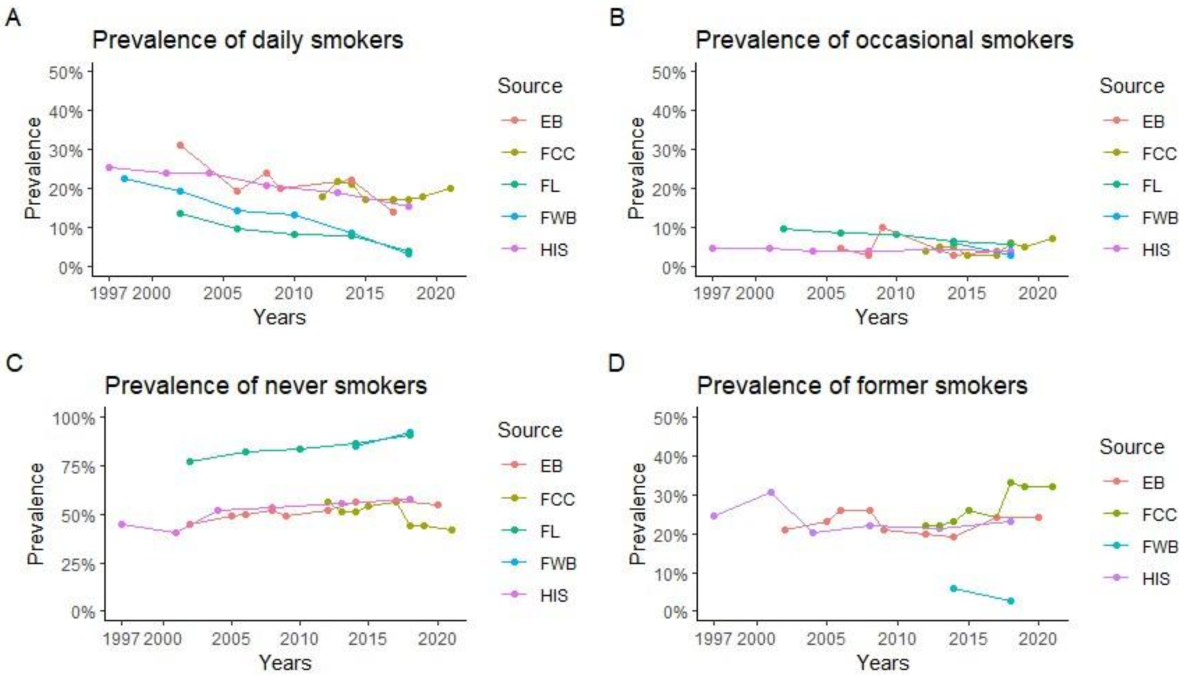

Figure 1. Prevalence of daily smokers, occasional smokers, ex-smokers, and never smokers from 1997 to 2021 according to different sources. Abbreviations: EB: Eurobarometer; FCC: Fondation contre le cancer; FL: HBSC/Flanders; FWB: HBSC/Fédération Wallonie-Bruxelles; HBSC: Health behaviour in school-aged children study; HIS: health interview survey

Second-hand or passive smoking was only assessed in the HIS by looking at the proportion of households with daily exposure to smoking indoors, and shows a similar downward trend. This is consistent with the decrease in daily smoking seen across the surveys.

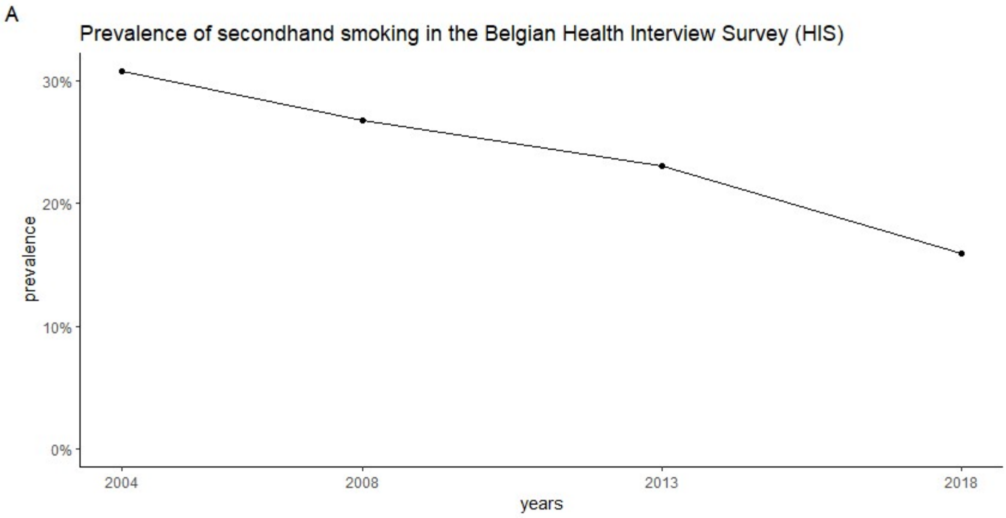

Figure 2. Prevalence of secondhand smoking in Belgium from 2004 to 2018 according to the Belgian health interview survey

Discussion of different survey-derived data sources

Mapping existing sources gave us insights into the availability of data for most of the past 20 years in Belgium for tobacco consumption in Belgium. We found that those sources use different methodologies, and have different findings regarding the same variables with sometimes different prevalence estimates for the same year. This difference can in part be explained in the paper of Bogdanovica et al. (2011) stating that national surveys use a larger sample size, different phrasing in the questions, frequency, and methodological differences when studying the population health and smoking status.

Another example was found between the HIS and FCC survey is the prevalence of daily smoking is increasing in the FCC survey but decreasing in the HIS for the year 2018.

Which figures then provide an accurate representation of the smoking behavior situation? It is important to note that the percentages reported by the FCC approach differ significantly from those obtained by the HIS and the alleged evolution of smoking behavior also shows discrepancies (HIS: decrease, FCC: stable).

This difference may have something to do with the sampling strategies for each survey. While the approach is similar at the point of sampling, the sampling frame (or where the sample is drawn from) is not explained by the FCC and may be inadvertently biased, potentially selecting from people who smoke and are therefore more likely to engage in a survey about tobacco. Without more detail on this strategy, it is not clear what may lead to the differences.

Similarly, the Eurobarometer data is higher and follows more closely that of the FCC sample. This, again, may be a result of the sampling frame which we know comes from the NUTS categories in the population, but for which we do not have further details. Despite these differences, there is general agreement in the overall trends across the surveys, showing a downward trajectory for daily smoking across Belgium.

3.1.1.3 Tobacco sales data

Indirect methods, such as monitoring sales, packaging, tax signs, and discarded cigarette butts, can contribute to enhancing our comprehension of tobacco usage among the population in Belgium. These alternative data sources can also offer insights into the number of people using tobacco products. We identified one data source based on expert opinion and one data source based on an internet search:

- FPS Finance data on tobacco sales and labelling
- The Center for Consumer Research and Information (CRIOC)

Tobacco sales data sources

FPS Finance sales data

Sales data collected by the FPS Finance includes the following indicators:

- Government tax revenues from manufactured tobacco products (cigarettes, cigars, and manufactured tobacco) from 1980 to 2021.
- Excise duties on manufactured tobacco products (cigarettes, cigars, and manufactured tobacco) from 1980 to 2021, represented in millions of euros.
- Government tax signs from manufactured tobacco products (cigarettes, cigars, and manufactured tobacco) in Belgium from 1980 to 2021.
- The evolution of tobacco product sales (cigarettes, cigars, and manufactured tobacco) in Belgium from 1980 to 2021.

These data points were available annually and covered the country at a national level. Data were collected by motoring and tracking imports and exports from customs.

Monitoring of tobacco consumption using sales data has been ongoing in Belgium since 2019 as part of the track and trace.

Appraisal

Data from the FPS Finance are nationally representative and a useful complement to survey-derived tobacco use data. The findings reinforce the trends seen in the self-reported data. The data are also collected on an annual basis which makes it possible to see fluctuations in sales and track more closely the impact of policies in the short term. This is currently not possible with survey-derived data sources. However, the data include a lot of variability which makes it difficult to connect to individual behaviour of people on tobacco use. It is thus not useful for the estimation of disease burden but can help to describe the supply side of tobacco over time.

Although the data offer insights into tobacco product sales in Belgium, it lacks breakdowns by age, region, or sex. Additionally, the FPS Finance data does not take into account illicit or cross-border purchases of tobacco products and underage purchases which can lead to an underestimation of the sales (Reid & Robinson, 2017).

The Center for Consumer Research and Information (CRIOC)

The Center for Consumer Research and Information (CRIOC) was a public interest foundation established to safeguard consumer interests and provide vital consumer protection information related to various forms of consumption (Centre de recherche et d'information des organisations de consommateurs (CRIOC), 2011). The report compiled by CRIOC includes valuable insights into various aspects of tobacco sales in Belgium, comprising the following:

- The number of regular smokers in Belgium, both nationally and regionally, from 1980 to 2009.
- Government tax revenues generated from tobacco products in Belgium from 1980 to 2009.
- Evolution of tobacco product sales in Belgium from 1980 to 2009 using SPF Finance data

However, it is important to note that data on tobacco use, which was derived from surveys conducted by the former institute, were not displayed in our report due to the lack of information on the sampling methodology in those surveys. While CRIOC data was not critically assessed, the information gathered in the report helps to validate trends in tobacco use and supply.

Trends in tobacco sales

Figure 3 highlights the trend in the yearly count of tobacco tax signs and government tax revenues from 1980 to 2021. Over this period, as the number of tobacco tax signs declines, annual government tax revenues rise steadily, reaching their peak in 2021. The declining tax signs reflect an overall decrease in tobacco use seen in the survey-derived data sources. Tobacco tax signs can then be an indirect method to have an understanding of the consumption in Belgium using sales data. They are interesting as they indicate that taxes have been paid on tobacco products for a certain period (Cour des comptes, 2015). Overall, sales data follow the same decreasing trend as consumption data. The increases in tax revenues can reflect increases in the cost-per-package applied to tobacco products.

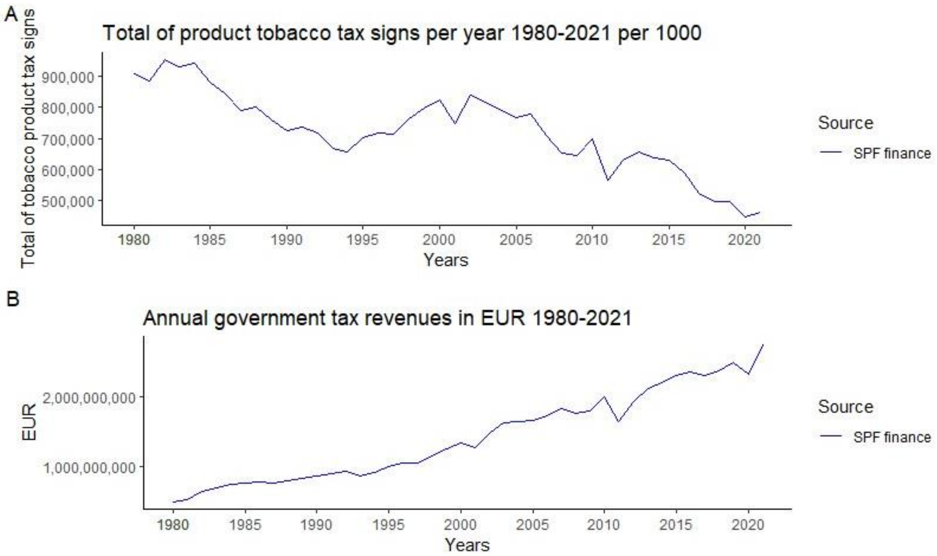

Figure 3. Total of tobacco tax signs and annual government tax revenues in EUR from 1980 to 2021

Figure 4 illustrates the sales trends of tobacco products in Belgium spanning four decades, from 1980 to 2021. The graph offers insights into the fluctuations in sales figures for different tobacco products over time, with each product depicted in a specific color and labeled in the legend. Changes in sales could be linked to regulation actions, shifts in consumer behavior, or economic influences. The variations in the lines indicate periods of growth, decline, or stability in the sales of specific tobacco products. Growth can be explained by cross-border purchases as the price of cigarettes and rolled tobacco in Belgium was low compared to other countries at the beginning of the year 2000 (Centre de recherche et d'information des organisations de consommateurs (CRIOC), 2010).

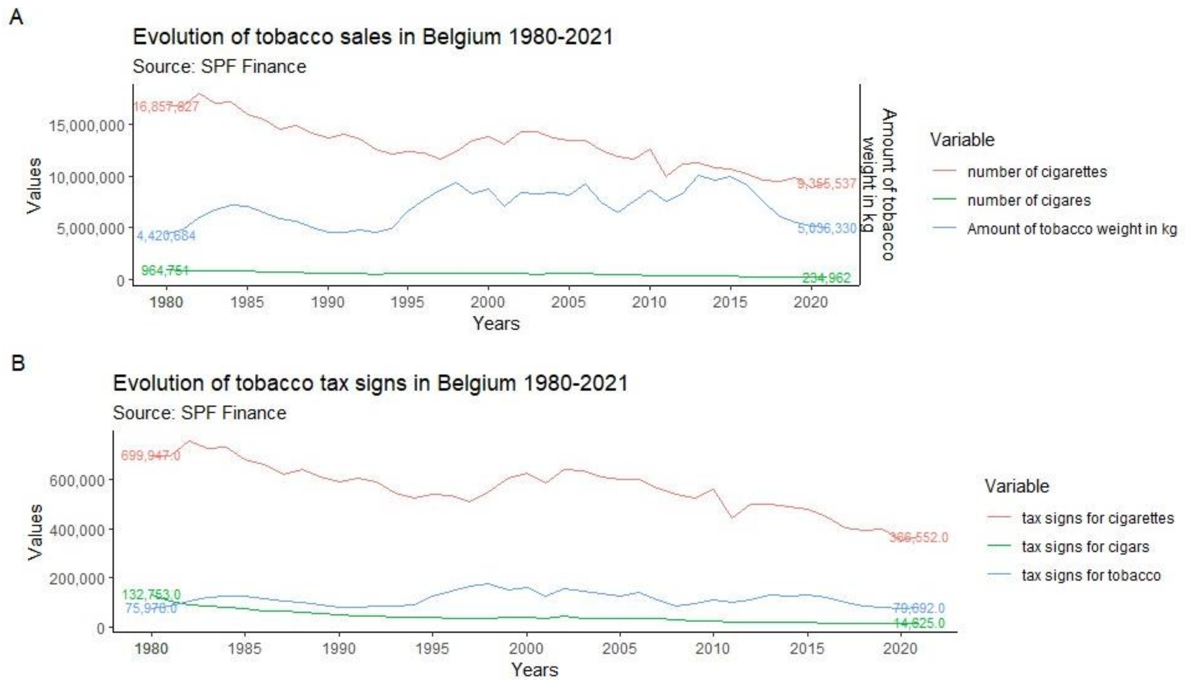

Figure 4. Total of tobacco tax signs and annual government tax revenues in EUR from 1980 to 2021

The decrease in cigarettes sold over time can be attributed to several policy interventions: smoking banned in restaurants, café and hotels (2007), price increase for packs of cigarettes and roll-your-own tobacco, smoking banned in the car with a minor present in the car (2014), increasing the minimum age of purchasing tobacco products (2016), standardize packaging (2017) (Cellule Général de Politique de Drogues, 2022).

The global financial crisis of 2008 might have impacted consumer spending behaviours, leading some individuals to cut down on non-essential expenses, including tobacco products, and can explain the decrease that can be seen in Figure 4 (Dom et al., 2016). An increase in Roll-Your-Own Tobacco sales over time may have led to some smokers switching from cigarettes to this option due to its relatively lower cost compared to cigarettes (Centre de Recherche et d'information des organisations de consommateurs (CRIOC), 2010).

3.1.1.4 Conclusion

Several data sources exist over at least 25 years assessing the self-reported use of tobacco and for 40 years on tobacco sales data. Together, these data paint a picture of the declining use of tobacco in Belgium with some fluctuation but reflective of an effort through policy and prevention to reduce that use. These data sources each have their strengths and limitations. For the SUBOD project, we must select a data source (or data sources) that can help to provide a nationally representative sample of tobacco use including breakdowns by age, region, and sex for as many years as possible and with a high level of methodological quality and integrity. This source underpins the calculation of the attributable burden of disease which requires an estimation of the exposure in the population.

After considering the sources included in this appraisal, the SUBOD study was base its estimates on the HIS which provides the most complete and consistent assessment of tobacco use in Belgium and includes the necessary variables to support calculations (number of smokers, former smokers, and never smokers; cigarettes per day; pack-years; time since quitting for former smokers). The HIS is not without its limitations. The frequency of every five years means it lacks the detailed fluctuation of year-to-year smoking patterns that may arise from policy changes. In addition, survey data often face limitations such as low response rates and selection bias leading to underestimation of substance use (Rehm, Kilian, et al., 2021). In an ideal situation, an annual population-based nationally representative survey would capture the necessary surveillance on these trends. In addition, the HIS has the level of aggregation necessary to perform the analyses at the level of detail that would support integration into the National Belgian Burden of Disease study.

No adjustment of consumption data using sales data were made. In addition, we are exploring the attributable burden of secondhand smoke for which exposure data are available in the HIS and the potential impact of underreporting for certain populations using cotinine and hydroxycotinine in urine samples of the Health Examination Survey (a subsample of the HIS) (Nguyen et al., 2020) to get a more complete vision on tobacco use in Belgium.

3.1.2 Trends

Tobacco use encompasses a broader range of products and behaviors, including the use of cigarettes, cigars, pipes, and smokeless tobacco, such as chewing tobacco or snuff. In contrast, cigarette smoking specifically focuses on the consumption of manufactured or hand-rolled cigarettes. We followed the GBD 2019 study's approach to estimating the attributable burden of cigarette smoking. This involves calculating the PAF using key data inputs: prevalence of smoking categories (never, occasional, former, and daily smokers), cigarettes per day, smoking duration (to estimate pack-years), and time since quitting for former smokers. We will refer to cigarette smoking from now on.

The first step to burden calculation is to construct a time series of cigarette smoking exposure data in Belgium from 2013 to the most recent available mortality data (2021 at the time of writing), using the BeBOD methodology to select the "best-fitted" model described above.

The covariates for the model for smoking categories (current, never, and former smokers) and continuous variables (mean cigarettes per day, pack-years, and time since quitting) include those we need for our output, namely: age, sex, region, and year, as described in Table 3.

Table 3. Description of exposure indicators in the HIS

Exposure variable	Definition	Variables in the HIS	Years Available
Smoking status			
Daily smoker	People who report smoking every day	TA06_1	All years
Occasional smoker	People who report smoking but not every day	TA06_1	All years
Former smoker	People who report having smoked but have quit for any time	TA06_1	All years
Never smoker	People who report never having smoked	TA06_1	All years
Measures of frequency and intensity			
Cigarettes per day	Number of cigarettes per day was recorded only for those who reported daily smoking	TA07_1	2004, 2008, 2013, 2018

Duration of smoking	The number of years a person has smoked; and is estimated for daily smokers by subtracting the age at initiation from the age at the time of the survey. Age at initiation is not captured for former smokers, so a variable for the recalled duration of smoking is used.	Daily smokers: TA04_1, AGE; former smokers: TA05_1	2004, 2008, 2013, 2018
Pack-years	Calculated by multiplying duration times cigarettes per day/20 (one pack)		2008, 2013, 2018
Time since quitting	To calculate the time since quitting smoking (QUIT_TIME), we estimate the number of years that have passed since a former smoker stopped smoking. This is derived using the individual's current age, their age at smoking initiation, and the total years they smoked.	TA04_1 = is age start of daily smoking, TA05_1 = TA05_1 = number of years of daily smoking, AGE	2008, 2013, 2018

We first estimate the mean proportion of smoking categories including the survey weighting built into the HIS using the svyby function in R.

Table 4. Model selection for categorical exposure variables

Exposure	Best-Fitted Model	WAIC Value
Current Smokers	*Current_cases* ~ 1 + YEAR * AGEGR * REGION * SEX	3683
Never Smokers	*Never_cases* ~ 1 + YEAR * AGEGR * REGION * SEX	4509
Former Smokers	*Former_cases* ~ 1 + YEAR * AGEGR + YEAR * REGION + YEAR * SEX + AGEGR * REGION + AGEGR * SEX + SEX * REGION	4247

In addition to smoking prevalence, measures of intensity of smoking must be included to calculate the PAF. The measures are selected based on the inputs used by the GBD in their calculations of attributable burden. These include cigarettes per day, pack-years (which includes duration of smoking), and the time since quitting in former smokers. Data on intensity measures was available for 2004, 2008, 2013, and 2018. The model was fitted from 1997 to 2018. As with smoking categories, a mean measure of intensity for each age, region, and sex category for each year of the HIS is computed using a svyby() function in R.

The models predicting trends in continuous variables are different from smoking prevalence in that the outcome is not a binomial. We fitted a quasi-Poisson INLA model.

Table 5. Model selection for continuous exposure variables

Exposure	Best-Fitted Model	WAIC Value
Cigarettes/Day	*CIG_DAY* ~ 1 + YEAR + SEX + AGEGR + REGION	927
Time Since Quitting	*TIME_QUIT* ~ 1 + YEAR + SEX + AGEGR + REGION	638
Pack-Years	*PACK_YEARS* ~ 1 + YEAR * AGEGR * REGION + YEAR * REGION * SEX + YEAR * SEX * AGEGR	1041

The modelled smoking prevalence categories are computed individually using binomial models. In order to create a single estimate of smoking prevalence categories we combine these three models and normalize them. In practical terms, their sum should equal to one. Thus, current smoking prevalence is calculated to equal daily smoking prevalence divided by the sum of the current, former, and never smoking prevalence. We do a similar calculation for never smoking. Former smoking is then one minus the prevalence of daily smoking plus never smoking.

3.1.2.1 Projecting daily smoking trends

In 2022, Belgium adopted the **Inter-federal Strategy 2022-2028 for a Tobacco-free Generation** aimed at reducing smoking among the general population and young people aged 15-24 years. The vision of the plan is to achieve a generation that is tobacco-free and drastically reduce the prevalence of tobacco use in the general population (Cellule Général de Politique de Drogues, 2022).

The plan set ambitious targets for reductions in daily smoking as follows:

- Reduce the prevalence of daily smokers of tobacco to 10% by 2028 and 5% by 2040 among those 15+ years;
- Reduce, by 2040, the prevalence of people initiating tobacco use to 0% or nearly 0%;
- By 2028, reduce the number of daily smokers among the population 15-24 years to 6%.

To reach these targets, various policy measures have been implemented, including fiscal policies, regulations on tobacco product composition and labeling, initiatives to improve health literacy and public awareness, restrictions on sales to minors, and enhanced cooperation in monitoring and surveillance of tobacco use. Using modeled time series projections, we assess whether these targets are likely to be met if current trends persist without significant policy changes.

Based on these projections, Belgium is not on track to achieve the national targets of reducing daily smoking prevalence to 10% among those aged 15+ by 2028 and 5% by 2040 under current trajectories. Without additional policy interventions, the prevalence of daily smoking is unlikely to fall below 10% before 2040, as shown in Figure 5.

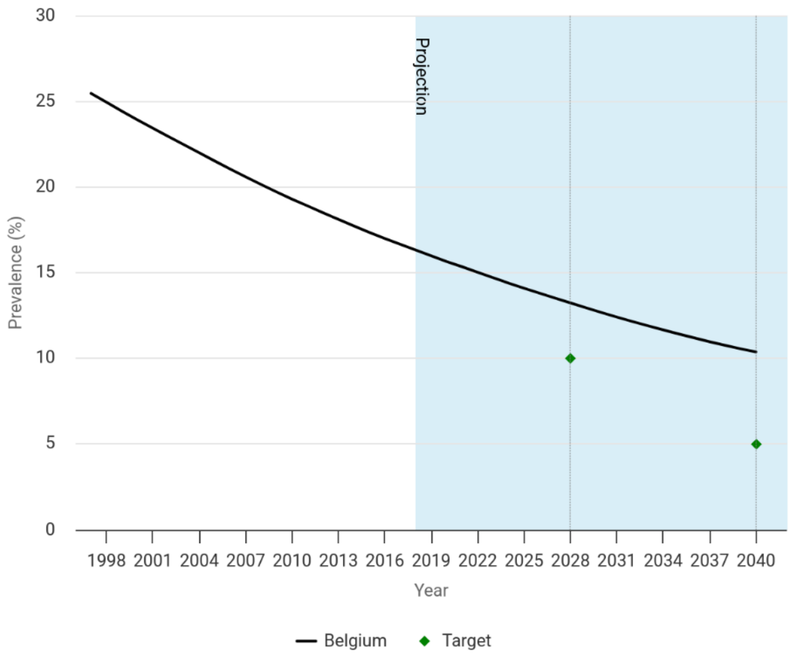

Figure 5: Trends in prevalence (%) of daily smoking among adults 15 + years, Belgium, 1997-2040.

The prevalence of daily smoking is expected to decline in all regions, yet it will remain highest in the Walloon Region and lowest in the Flemish Region as illustrated in Figure 6 . However, no region is on track to meet the targets of 10% daily smoking by 2028 or 5% by 2040.

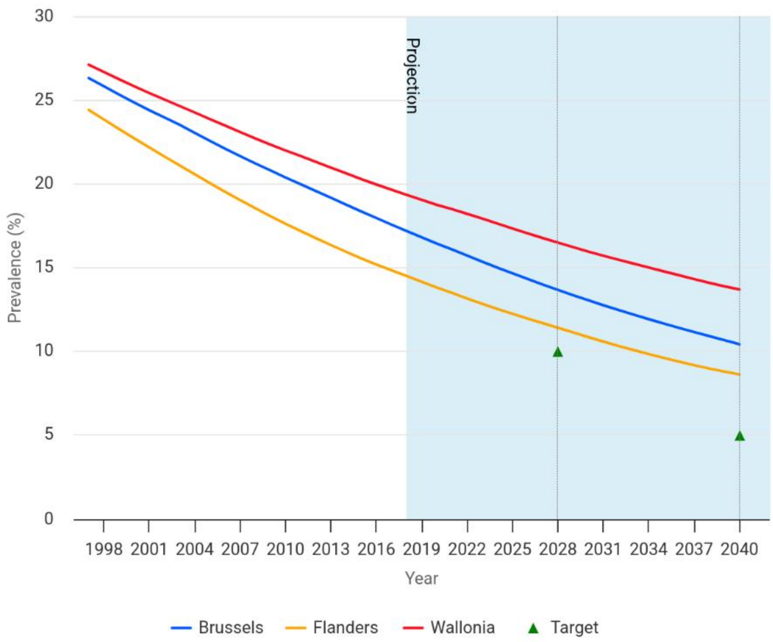

Figure 6: Trends in prevalence (%) of daily smoking among adults 15 + years, by region, Belgium, 1997-2040.

A significant disparity exists in the prevalence of daily smoking across different levels of educational attainment. As a measure based on the number of years of formal schooling completed, education serves as a proxy for overall socioeconomic status, given its strong correlation with factors such as household income, deprivation levels, and employment status. These social determinants of health are closely linked to inequalities in risk behaviors, placing the most vulnerable populations at a heightened risk of disease

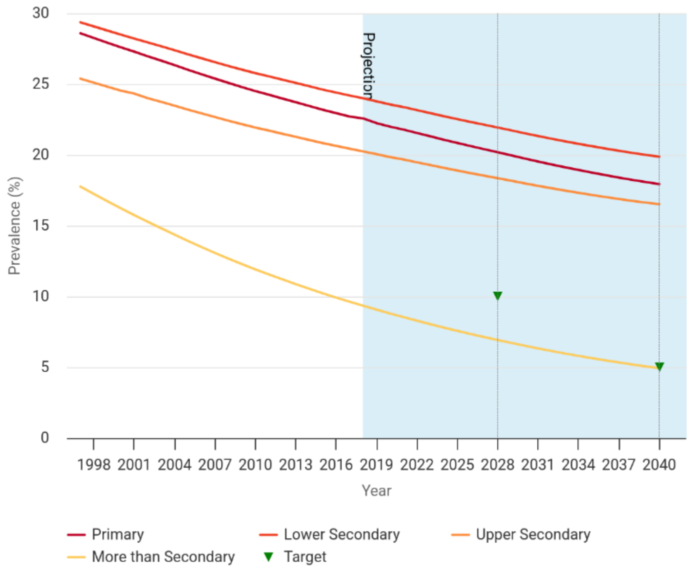

Figure 7: Trends in prevalence (%) of daily smoking by educational attainment, Belgium, 1997-2040

When examining tobacco use, a persistent gap in smoking rates exists between individuals with higher education levels (beyond secondary school) and those with lower educational attainment. This disparity has remained over time and is projected to continue and be seen in Figure 7, with smoking rates declining more rapidly among those with more years of education. On the current trajectory, only this higher-educated group in Belgium is expected to meet both targets set by the Inter-Federal Strategy. To achieve these goals across the entire population, targeted interventions that address social inequalities and the vulnerabilities of different community groups will be essential.

3.1.3 Disease-specific deaths

After the critical appraisal and defining exposure, we needed to identify and quantify the risk-outcome pairs related to cigarette smoking to calculate the AB. We identify two potential sources: the GBD study, and national initiatives, such as Public Health England (PHE). Those comprehensive studies have provided valuable insights into the diseases attributable to cigarette smoking and the methodologies used to estimate their burden. The two datasets were appraised based on the sets of evaluation criteria mentioned in the method section.

The GBD study relies on a variety of data sources to calculate the burden attributable to tobacco use, including epidemiological studies, national health surveys, cause-of-death registries, and hospital and clinical records: Data on admissions and outpatient visits associated with tobacco-related illnesses (GBD 2019 Risk Factors Collaborators, 2020).

At a national level, PHE has developed smoking-attributable burden estimates to inform policy and interventions in the United Kingdom. PHE's work focuses on reducing health inequalities and providing evidence-based recommendations to government bodies, local authorities, and the public. Smoking-attributable calculations were made by using hospital admissions (2019/20) and deaths (2019), focusing on individuals aged 35 and older. Data on hospital admissions come from Hospital Episode Statistics (HES), based on primary diagnoses, while mortality data are sourced from the Office for

National Statistics (ONS). By analyzing and sharing this data, PHE supports targeted interventions to reduce smoking-related harm and improve public health (Public Health England, 2020b).

Table 6. Cigarette smoking outcomes included in evaluated risk-outcome pair sets

	Global Burden of Disease Study	Public Health England
Tuberculosis	X	
Lower respiratory infections	X	
Esophageal cancer	X	X
Stomach cancer	X	X
Bladder cancer	X	X
Liver cancer	X	
Larynx cancer	X	X
Tracheal, bronchus, and lung cancer	X	X
Upper respiratory sites cancer		X
Breast cancer	X	
Cervical cancer	X	X
Colon and rectum cancer	X	
Lip and oral cavity cancer	X	
Nasopharynx cancer	X	
Other pharynx cancer	X	
Pancreatic cancer	X	X
Kidney cancer	X	X
Leukemia	X	X (myeoloid)
Unspecified site cancer		X
Ischaemic heart disease	X	X
Stroke (includes all types of stroke)	X	X
Atrial fibrillation and flutter	X	Included in 'other heart disease category
Other heart disease		X
Other arterial disease		X
Aortic aneurysm	X	X
Atherosclerosis		X
Lower extremity peripheral arterial disease	X	
Chronic obstructive pulmonary disease	X	X
Other chronic respiratory diseases	X	

Chronic airway obstruction		X
Pneumonia, Influenza		X
Asthma	X	
Peptic ulcer disease	X	Included in ‘stomach / duodenal ulcer’ category
Stomach / duodenal ulcer		X
Crohn’s disease		X
Periodontal disease / Periodontitis		X
Gallbladder and biliary diseases	X	
Alzheimer's disease and other dementias	X	
Parkinson's disease	X	
Multiple sclerosis	X	
Diabetes mellitus	X	
Rheumatoid arthritis	X	
Low back pain	X	
Cataract	X	X (age related)
Age-related macular degeneration	X	
Fracture	(NOT in 2021)	X (hip fracture)
Spontaneous abortion		X

Table 7. Evaluation grid for tobacco risk-outcome pair sets

	Global Burden of Disease Study	Public Health England
Accessibility	Available for download from Burden of Proof tool	Available via Appendix in 2020 report together with comparison to old RR estimates
Transparency	The methodology is described in the Appendix. Run to DisMod to get non-parametric splines. Not reproducible without their help.	Easy to reproduce. Equations and citations for each relationship.
Reliability	Evaluate risk of publication bias and quantify within and between-study heterogeneity. Uncertainty limits included.	Mainly systematic review and meta-analysis. Possible bias in selecting studies for RR curves. No uncertainty estimates. No uniform method for estimation.
Evidence	730 studies between 1970 and 2022 included, from 55 countries	Studies from 2013 onwards from selected countries
Relevance	Similar definitions for outcome and exposure. Global estimates but similar exposure ranges	Geography is limited to UK Europe, Canada, Australia, and New Zealand.

Discussion

The Global Burden of Proof 2021 dataset offers extensive coverage of 36 risk-outcome pairs, including fractures, and provides relative risk dose-response curves for smoking and disease outcomes. Each dose-response relationship is derived from systematic reviews of 730 studies, ensuring robust evidence (Dai et al., 2022) The methodology includes testing and adjusting for biases such as variation in study characteristics (e.g., population selection and study design biases) and quantifying remaining between-study heterogeneity.

Key features include bias evaluation in which publication and reporting bias are addressed using Egger's regression, as well as their outcome presentation. Results are reported using the Burden of Proof Risk Function (BPRF) alongside a score and star rating to assess the strength of evidence for each association. The GBD dataset is uniquely comprehensive due to its extensive input data, advanced bias correction methods, and quality measures. Few research institutes possess the resources to achieve this scale of analysis.

While GBD is a powerful resource, it has certain limitations such as representation issues, timeframe, biological plausibility, and evidence strength. Data spans 55 countries but does not account for subpopulations within countries, and all information is summarized into a single global estimate. The dataset uses sources from 1970 to 2021, which may smooth out recent trends. Some findings, like the reported protective effect of smoking on Parkinson's disease, raise questions about biological reasoning. Of the 36 risk-outcome pairs, only 8 showed strong-to-very-strong evidence of association with smoking, 21 showed weak-to-moderate evidence, and 7 had no evidence of association. To address these limitations, we considered supplementing GBD with regional datasets (e.g., European or Western-European studies) to enhance the relevance of estimates for Belgian research. A rigorous assessment of data quality and reliability remains critical for ensuring suitability to our research context (Brauer et al., 2024).

The PHE 2020 dataset also uses a systematic literature search to analyze predetermined outcomes. It reports risk factors, disease outcomes, and measures such as RR, hazard ratio (HR), or odds ratio (OR). Meta-analysis is performed to generate dose-response curves, similar to GBD (Public Health England, 2020b). Some key differences compared to GBD are the geographic scope, study design selection, and methodological transparency. PHE focuses on Western countries (UK, Europe, Canada, Australia, and New Zealand) and includes studies published after 2013. They prioritize systematic reviews and meta-analyses, whereas GBD includes broader study designs. PHE selects the most suitable study for each purpose and provides equations and citations for reproducibility, though it lacks uncertainty limits included in GBD. PHE offers age- and sex-specific dose-response curves for some diseases (mostly 35+ years old), along with estimates for more specific causes than GBD. It excludes controversial findings, such as smoking's purported protective effect on Parkinson's disease. The PHE dataset provides only RRs for current smokers, regardless of smoking intensity (e.g., pack years or cigarettes/day), though it includes estimates for former smokers. The PHE platform lacks uncertainty measures such as those present in GBD (Public Health England, 2020b).

After evaluating both datasets, we chose to use the GBD 2021 estimates for the following reasons:

- **Uniformity**: GBD's standardized framework is crucial for comparing results with other studies.

- **User-Friendly Tool**: The Burden of Proof framework enhances the transparency and transportability of GBD's methodology.
- **Comprehensive Bias Correction**: GBD's advanced methods for addressing biases and heterogeneity make it a more reliable option overall.

While GBD has its limitations, its global scope, bias-adjusted estimates, and robust quality measures make it the preferred choice for our study.

3.1.3.1 Calculation of the attributable burden to risk factors

Theoretical minimum risk exposure level (TMREL)

The theoretical minimum-risk exposure level is 0 (no tobacco use).

Population-attributable fraction

As illustrated in Figure 1, we need to calculate the PAF to have attributable burden calculation. For smoking, the PAF equation was based on the GBD study 2019 methods for calculating smoking-attributable burden (Murray et al., 2020) using the following formula:

$$\text{PAF} = \frac{(P_{never} + P_{former} * RR_{former} + P_{current} * RR) - 1}{P_{never} + P_{former} * RR_{reduce} + P_{current} * RR}$$

Where

P_{never} = prevalence of never-smokers

P_{former} = prevalence of former smokers

$P_{current}$ = prevalence of current smokers

RR = the relative risk of getting the disease depending on the smoking intensity

RR_{former} = reduction in the relative risk among former smokers compared with current smokers.

For former smokers, the relative risk is adjusted to account for the reduction in risk over time after quitting. This is done by applying a percentage reduction ($RRreduce$) to the RR for current smokers. The RRreduce is provided as a percentage in the GBD 2021 study. The percentage is multiplied by RR for current smokers to obtain the RR for former smokers (RR_{former}).

The formula for this adjustment is:

$RR_{former} = 1 + ((RR - 1) \times RRreduce)$

This reflects a decrease in the relative risk for former smokers compared to current smokers, depending on how long it has been since they quit.

3.1.3.2 Results of the attributable burden calculation related to cigarette smoking in Belgium

In 2021, cigarette smoking was responsible for 9,362 deaths, accounting for 8.3% of all deaths in Belgium. This resulted in 201,965 years of life lost due to premature death, which can be linked to tobacco use.

Smoking is causally linked to the burden of 35 diseases including 16 types of cancer, 5 cardiovascular diseases, chronic obstructive pulmonary disease (COPD), and asthma. Lung cancer, COPD, and ischemic heart disease are the main causes of tobacco-related mortality, linked to 3630, 1381, and 1317 deaths, respectively.

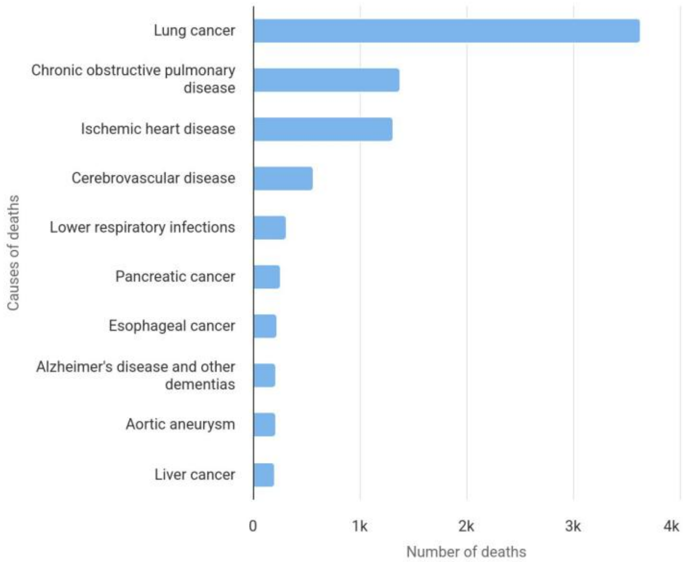

Figure 8 leading causes attributed to smoking, in number of deaths, both sexes, all ages combined, Belgium, 2021

Overall, the ten main causes of tobacco-related mortality are similar across genders and regions. In the Flemish and Brussels-Capital regions, Alzheimer's and other dementias ranked eighth among smoking-related deaths. In the Walloon region, they ranked eleventh. Women's rankings differed due to breast and cervical cancer, related to 55 and 60 deaths, respectively. For men, the ranking included aortic aneurysm, bladder, and liver cancer.

Most of the smoking-related deaths occurred in people aged between 65 and 84. Most of these deaths were due to cancer (neoplasms, 53%), heart disease (cardiovascular diseases, 20%), and lung disease (chronic respiratory diseases, 16%). The disease burden related to smoking was higher in men than in women, regardless of their age.

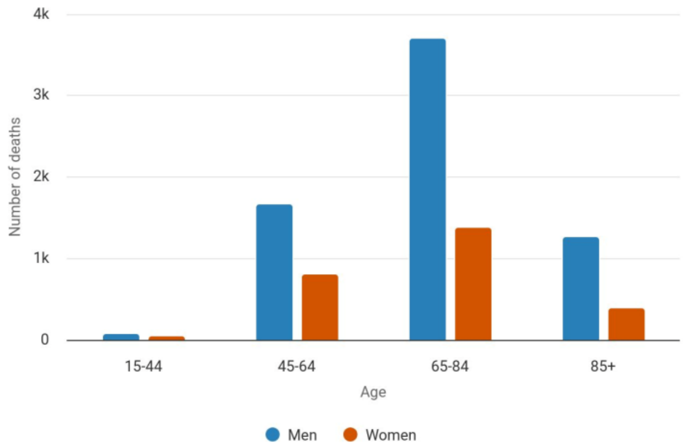

Figure 9: Distribution of smoking-related deaths, by age and sex, Belgium, 2021

There has been an overall declining trend in the smoking-associated death rate by region since 2013. Despite a decrease, regional differences persist. The rate of smoking-related deaths was the highest in the Walloon Region (108.80 per 100,000), followed by the Brussels Capital Region (91.43 per 100,000), both of which are around 50% higher compared to the Flemish Region (66.22 per 100,000).

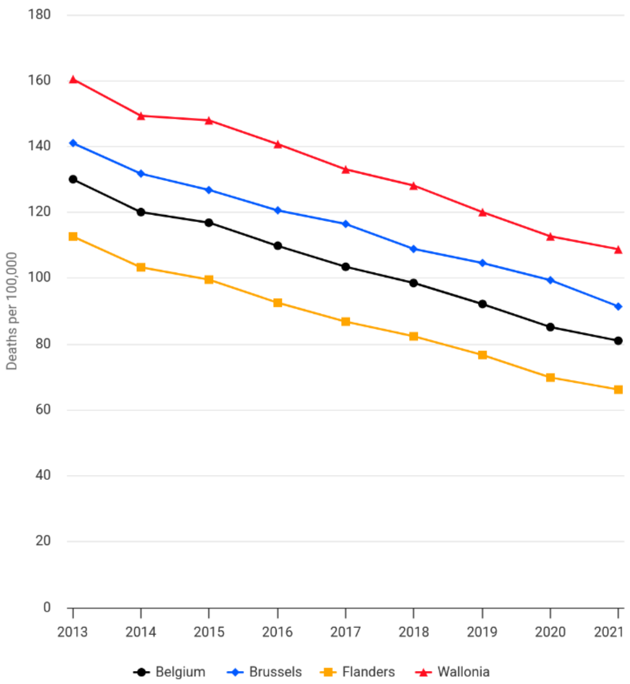

Figure 9: Distribution of age-adjusted smoking-attributed deaths per 100,000 people by region, for both sexes, 2013-2021

3.1.4 Global cost

The mean total healthcare cost was estimated at €2320 (4940) per capita (mean (SD)). The ambulatory costs (78%) were responsible for the largest share of the total costs, followed by hospital costs (19%). Stratified per smoking category, our results indicated that the highest costs were found for former smokers and daily smokers (€3239 and €2279 per capita per year, respectively).

When looking at the average incremental cost per individual, a higher cost was found for daily (21%; $P = 0.02$) and former smokers (26%; $P < 0.001$) compared with never-smokers. The adjusted mean attributable cost for daily smokers and former smokers was estimated at €311.38 and €500.61, respectively. Taking into account that 15% of the Belgian population were daily smokers in 2018, the national cost for daily smokers equates to €533.861.010.

	RR°	Standard error	P-value	95% CI	Attributable cost
Model 1					
Never smoked (reference)	1	—	—	—	—
Daily smoker	1.24	0.08	0.006	1.06-1.44	444.43
Occasional smoker	1.17	0.13	0.26	0.90-1.52	275.73
Former smoker	1.21	0.06	0.004	1.06-1.38	529.91
Model 2					

Never smoked (reference)	1	—	—	—	—
Daily smoker	1.18	0.08	0.03	1.01-1.38	364.18
Occasional smoker	1.19	0.13	0.18	0.92-1.52	305.54
Former smoker	1.20	0.06	0.002	1.07-1.37	517.82
Model 3					
Never smoked (reference)	1	—	—	—	—
Daily smoker	1.20	0.08	0.03	1.02-1.41	393.50
Occasional smoker	1.27	0.13	0.07	0.98-1.63	412.85
Former smoker	1.27	0.06	<0.001	1.13-1.43	647.73

**Daily, occasional or former smoker*
°Rate ratio; expected value of the coefficient with never smoked as reference
Model 1: Adjusted for age and gender
Model 2: Adjusted for age, gender, educational level, and preferential reimbursement
Model 3: Adjusted for age, gender, educational level, region, preferential reimbursement, and alcohol use

No significant differences ($P > 0.05$) were observed for the cost of absenteeism for the smoking population compared with never smokers However, the adjusted analyses indicated a borderline significant result (i.e. Model 3) in disfavour of former smokers compared with never-smokers (39%, $P = 0.07$). This equates to an adjusted incremental cost of absenteeism of €1198.58 per capita.

	RR°	Standard error	P-value	95% CI	Attributable cost*
Model 1					
Never smoked (reference)	1	—	—	—	—
Daily smoker	1.41	0.18	0.06	0.99-2.01	1219.93
Occasional smoker	1.12	0.23	0.61	0.72-1.75	320.89
Former smoker	1.27	0.17	0.17	0.90-1.79	932.46
Model 2					
Never smoked (reference)	1	—	—	—	—
Daily smoker	1.33	0.17	0.11	0.94-1.87	1032.02
Occasional smoker	1.04	0.23	0.87	0.67-1.62	84.58
Former smoker	1.26	0.17	0.18	0.90-1.77	912.25
Model 3					
Never smoked (reference)	1	—	—	—	—
Daily smoker	1.35	0.18	0.10	0.95-1.92	1092.09
Occasional smoker	1.14	0.23	0.57	0.73-1.77	354.12
Former smoker	1.37	0.18	0.07	0.97-1.93	1198.58

*Based on days of work missed due to illness
°Rate ratio; expected value of the coefficient with never smoked as reference
Model 1: Adjusted for age and gender
Model 2: Adjusted for age, gender, educational level, and preferential reimbursement

Model 3: Adjusted for age, gender, educational level, preferential reimbursement, region, and alcohol use

3.2 Alcohol use

3.2.1 Appraisal

Data on alcohol use in Belgium were extracted from different national, and international surveys that use various and heterogeneous methodologies. Identified sources were chosen for their potential relevance to the SUBOD project. It is almost certain some have been missed, but this review provides an overview of those deemed most applicable.

Estimating population consumption has traditionally relied on standardized self-reported measures from surveys (Gartner et al., 2010; Reid & Robinson, 2017). However, to gain a comprehensive overview of alcohol consumption, data sources comprising non-survey data such as sales data can be used (Reid & Robinson, 2017). These additional sources can help to overcome limitations and biases often associated with survey data, as underestimation can arise and can help give a more comprehensive understanding of alcohol consumption(Gartner et al., 2010; Rehm, Kehoe, et al., 2010; Reid & Robinson, 2017). This under-reporting is illustrated in Figure 10 (Devaux & Sassi, 2015, p19) and can be explained by survey methodology, sampling bias, and self-reported bias (Devaux & Sassi, 2015; Kilian et al., 2020; Rehm, Kilian, et al., 2021). Survey data typically cover only 20% to 70% of alcohol consumption when compared to sales data (Kilian et al., 2020; World Health Organization, 2000). Triangulation methods between consumption and sales data can help account for and adjust for under-reporting (Jackson et al., 2019; Rehm et al., 2007; Rehm, Kehoe, et al., 2010). We therefore additionally searched for data on alcohol sales from any source in Belgium to be able to produce a triangulation of survey data. The data on alcohol sales were found in discussions with experts on the subject and from national data sources

Table 8. Overview of alcohol use indicators found in other burden of disease studies

Indicator	Definition	Burden of Disease Study
Current drinkers	Proportion of individuals who have consumed at least one alcoholic beverage (or some approximation) in 12 months.	Global Burden of Disease Study 2016, 2019 Australian Burden of Disease Study 2011, 2015 Scotland Burden of Disease Study 2018 Public Health England 2020
Lifetime abstainers	Proportion of individuals who have never consumed an alcoholic beverage.	Global Burden of Disease Study 2016 Public Health England 2020 Australian Burden of Disease Study 2011 Scotland Burden of Disease Study 2018
Former drinkers	Person who is not a current drinker but who has drunk alcohol in the past.	Public Health England 2020 Australian Burden of Disease Study 2015 Scotland Burden of Disease Study 2018

Binge drinkers	Drinking more than eight units for men and more than six units for women on a single drinking occasion	Public Health England 2020
Alcohol consumption (in grams per day)	Grams of alcohol consumed by current drinkers, per day, over 12 months.	Global Burden of Disease Study 2016, 2019 Public Health England 2020 Australian Burden of Disease Study 2011, 2015 Scotland Burden of Disease 2018
Alcohol litres per capita	Defined in litres per capita of pure alcohol, over a 12-month period.	Global Burden of Disease Study 2016 Scotland Burden of Disease Study 2018 Public Health England 2020

To overcome the limitations of individual surveys and sales data, different initiatives seek to integrate available information and estimate total alcohol per capity (APC). Data on total APC were found in discussions with experts on the subject, from international data sources and grey literature such as the InterMAHP (The International Model of Alcohol Harms and Policies) where total APC is presented as an accurate estimate produced by the WHO, incorporating both recorded and unrecorded alcohol consumption, accounting for spillage and adjusting for tourism-related consumption in WHO member countries (Sherk & Dorocicz, s. d.)

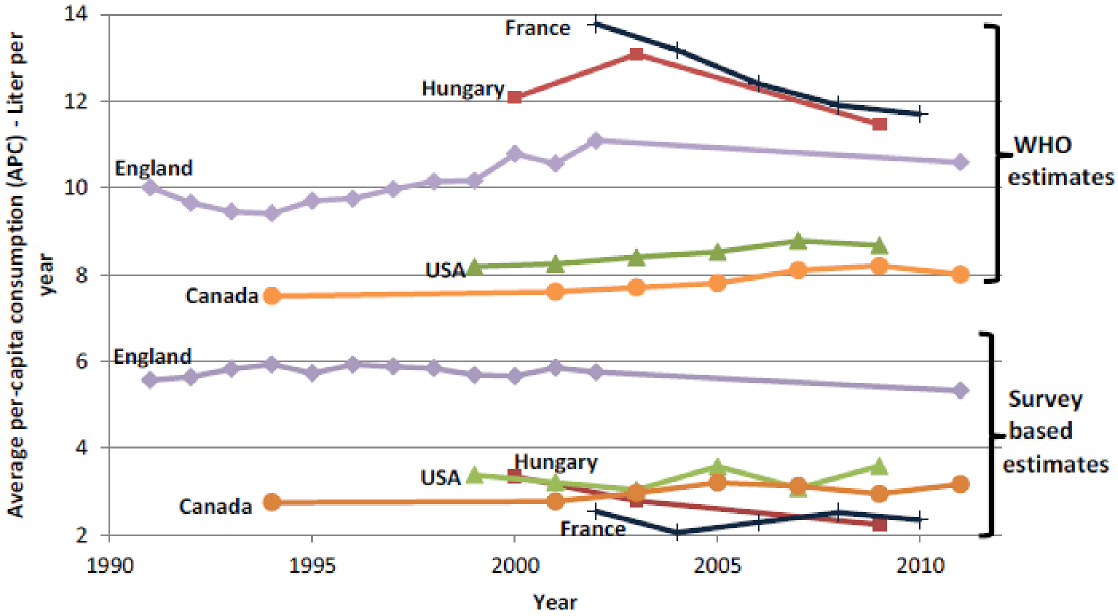

Figure 10. Comparison of WHO sales data and survey-based estimates by Devaux and Sassi (2015).

Available datasets to monitor alcohol use in the past 20 years in Belgium were identified and critically assessed to identify a representative estimate with a minimum of bias. We identified sources using an unstructured literature review (e.g., web search) and expert consultations. We applied broad inclusion criteria for a variety of estimates to provide a complete picture of alcohol use in Belgium. Data sources were assessed that provided information on alcohol use at a national level and had more than one year of data.

3.2.1.1 Alcohol use data

We identified four sources that met the inclusion criteria for tobacco use:

- The Belgian Health Interview Survey (HIS)
- The Eurobarometer survey on public opinions in the European Union (EB)
- The Health Behavior in School-aged Children International Study (HBSC)

Belgian Health Interview Survey

The **Belgian Health Interview Survey** (HIS) is a household cross-sectional population-based survey of the whole of Belgium including all age groups. It provides a broad picture of the population health in Belgium by identifying the main health problems, as well as the social and behavioural factors that have an impact on them (Demarest et al., 2018). The survey uses a stratified multi-stage, clustered sampling with proportional representation and replacement by region of Belgium. The HIS started in 1997 and is conducted every four years with a new sample.

The HIS assesses a broad range of indicators for alcohol use including drinking patterns and history, intensity and volume of drinking, but also age at initiation. The measures are all self-reported but the portion of the survey where these data are collected is self-administered to reduce the risk of interviewer bias. Data on alcohol use are only collected for people ≥ 15 years, thus adolescent alcohol use is not included.

Appraisal

The HIS stands out as a consistent and nationally representative survey of self-reported health, covering more than two decades. However, it has limitations in terms of monitoring alcohol use. The HIS is a repeated cross-sectional survey with a sampling strategy that is consistent from one wave to the next. Some questions within the survey may change, but overall monitoring of alcohol use has remained consistent since its inception. Because the HIS has a broad focus on many aspects of health, there is no special attention paid to minimizing non-response to alcohol-related questions. This leads to some strata of the survey having more missing values than others (particularly older age groups), which may affect the validity of those estimates and lead to wide confidence intervals around point estimates. The collection of details on grams per day of alcohol consumption has changed since the beginning of the HIS and a new set of questions was included in 2008. Furthermore, data on former drinkers is only available since 2018 and no data on the amount of drinking for this group exists.

The primary strength of the HIS lies in its consistent and representative methodology spanning from 1997 to 2018. It utilizes a weighted sample from the national registry as a sampling frame, providing a robust overview of alcohol use in Belgium for individuals aged 15 years and above. Although participants differ across survey waves, they are considered representative of the population due to the sampling methods, including regional and age stratification, standardization of age and sex, as well as systematic multi-stage survey and clustering. Moreover, the survey employs a representative sample of the Belgian population, not just a simple random sample, ensuring high-quality results that reflect the entire population (Demarest et al., 2018). The adherence to international recommendations further enables comparability with global data. Additionally, the HIS survey includes all necessary indicators for evaluating alcohol exposure when calculating the attributable burden but not necessarily for all years of the HIS.

Eurobarometer

The **Eurobarometer** (EB) survey on public opinions in the European Union is also a good source of information on alcohol use. The survey was conducted for alcohol use from 2002 to 2016 and is defined as a cross-sectional survey (Nissen, 2014). During each wave, the same sample design is applied in all Member States and several sampling points are drawn with a probability proportional to population size, to aim for a total coverage of the country, to have a sample of 1000 participants within each European country (Bogdanovica et al., 2011; Nissen, 2014). The national samples were weighted. They used face-to-face interviews in each country's national language and data were collected via computer-assisted personal interviewing (CAPI) in the countries where face-to-face interviews were not applicable.

Appraisal

The methodological limits of the **Eurobarometer survey** are described by Nissen (2014). Specifically, between different years of the Eurobarometer survey is limited since it can be due to a change of phrasing of the questions asked and not necessarily due to a real change in behaviors. In addition, when assessing behaviors between countries, it is important to take into account that for cultural reasons some respondents might underreport their consumption (European Union, 2010, 2014). Finally, only self-reported prevalence rates for alcohol use were available on a national level with no stratification for age, sex, and region. The only comparisons that can be made are at a country level and within the countries of the EU. Those limitations make it hard to assess the real impact of alcohol use in Belgium.

Health Behavior in School-aged Children study

The International **Health Behaviour in School-aged Children** (HBSC) study assesses the health of students from 5th primary to 6th secondary school. Taking place in Flanders and French-speaking community for the past twenty years, with the supervision of the regional office of the World Health Organization, the study aims to describe the health behaviours, health status, and well-being of adolescents (Moreau et al., 2017) The study is a school-based survey, where the questionnaires are administered in class. The methodology is consistent over time and is decided on an international level (Moreau et al., 2017; Roberts et al., 2009) and uses cluster sampling and a large sample with proportional stratification by school population by province and school network. Two steps were used to create the sample: first, a random selection of schools within each province based on the list from Federation Wallonie-Bruxelles (FWB) and Flanders (FL) per province, and by the network was made, then a class was randomly selected in the fifth primary grade to the sixth secondary grade to have all ages available in the sample. Those steps were used to obtain a representative sample of pupils who are enrolled full-time in Belgium (Roberts et al., 2009).

Appraisal

The HBSC surveys are part of an international collaboration and have a sound and well-documented methodology. The sample is limited to school-aged children enrolled in schools, thus excluding those who are not enrolled. This presents a selection bias which means the validity of the results can only be interpreted as representing children in school. They cover age groups that are not captured by surveys on adults and thus provide a useful window into the ages at which most adolescents begin experimenting with alcohol. They are conducted by the language community in Belgium (Dutch and

French) and the two surveys are not combined, nor do they have perfectly overlapping reporting of their results or questions. This limits the utility of the surveys to create a national picture. The limited age groups exclude this survey from being considered for a wider assessment of alcohol use nationally. In terms of the attributable burden of disease, the risk for disease for many conditions from alcohol use begins to accumulate from around age 15, which is well beyond the age of this survey. Therefore, while it provides important information on the early adoption and use of alcohol in Belgium, it cannot be extended in any consideration of the burden of disease.

3.2.1.2 Other data sources

In addition, the following sources were found but as they are using data that are gathered from other data sources, they were not included in the mapping of the sources as they did not meet our quality criteria. Nevertheless, we still found it relevant to present them briefly.

- The **EUROTOX** reports reporting tool that collects data and describes trends on substance use in Wallonia in Brussels. While the main focus is the use of illicit drugs, the report presents regular estimates and trends of alcohol use in Brussels and Wallonia using the HBSC study and the HIS survey (EUROTOX, s. d.).
- **The VAD** (Flemish Center of Expertise on alcohol, illegal drugs, psychoactive medication, gambling, and gaming) reports and factsheets combine information on substance use from various sources e.g.: surveys, a national database such as Statbel or National Bank of Belgium database) (VAD, 2021b). They provide an annual update or insight into the evolutions and trends of substance use in Flanders and Belgium presenting results regarding different subgroups: age groups, school-aged children, adults, university students, pregnant women, and workers,… to look at the comparison of how substance use consumption patterns evolves over time (VAD, 2021a, 2021b).
- **The European School Survey Project on Alcohol and Other Drugs (ESPAD)** survey collects data on Flemish teenagers aged 15-16 years old using a representative sampling design of the Flemish secondary schools to assess and monitor substance use among that specific age category (VAD, s. d.).
- **EUROSTAT** gathers information on alcohol consumption in the European Union through the **European Health Interview Survey** (EHIS). The survey occurs on average every 5 years. The results come from national surveys (HIS) as questions from the E-HIS are implemented in the national surveys (EUROSTAT, 2018). For Belgium, data on alcohol consumption is coming from the HIS (EUROSTAT, 2018). Note that the upcoming wave of the EHIS will be conducted in 2025, independently of national surveys (EUROSTAT, s. d.).
- **Preventiebarometer:** Sciensano has conducted the Prevention Barometer survey in the Flemish Region, targeting residents aged 18 and above, regardless of nationality or existing health behaviours. A random sample is drawn from the national register, and participants are invited via mail to complete the questionnaire online. The survey aims to gather insights into health behaviours, including alcohol consumption frequency and intentions to change behaviours, with a goal of at least 3,000 participants (Sciensano, s. d.).

- **The European Social Survey**: The survey is an international research initiative carried out every two years throughout Europe since 2002. Its objective is to evaluate the attitudes, opinions, and behaviours of populations across more than twenty countries. Within the framework of the ESS, information is gathered through in-person interviews, with a preference for employing the Computer-Assisted Personal Interview (CAPI) method, across all participating nations. Participants are individuals aged 15 and above within the population and have an identical likelihood of being selected. The sampling frame is based on the national register. Data assessing alcohol consumption in Belgium are available for the years 2014-2015 (European Social Survey, s. d.).

- **The EU-SILC**: The EU Statistics on Income and Living Conditions (EU-SILC) is a European survey that serves as a source for comprehensively understanding the various dimensions of social inclusion for households and individuals in society. It employs a multi-dimensional approach, facilitating comparisons between different Member States. Conducted in 2013, 2017, 2018, and 2022, the EU-SILC surveys approximately 6,000 households in Belgium, including a specific focus on 1,000 households in Brussels. The data provides valuable insights into income distribution, poverty, social exclusion, and various living conditions, contributing to a better understanding of the diverse factors impacting social inclusion across regions (Commission communautaire commune, s. d.).Information on alcohol consumption in Belgium by age, sex, and region is available in the latest run of the survey.

Trends in survey-derived self-reported alcohol use

Based on the main survey-derived data sources, we summarize the evidence on self-reported alcohol use over time.

Table 4 highlights the availability of the indicators that we have found in the five data sources that met our inclusions and quality criteria by year.

Figure 11 presents a comparison of the point estimates on self-reported alcohol use from the three different surveys. The surveys have broad agreement on the level of current drinking but only the HIS has a long enough time span to assess trends. Broadly, self-reported alcohol use has not changed in the last 25 years. Data on former drinkers and abstainers is less available. Daily drinkers also remain a smaller but persistent proportion of alcohol users.

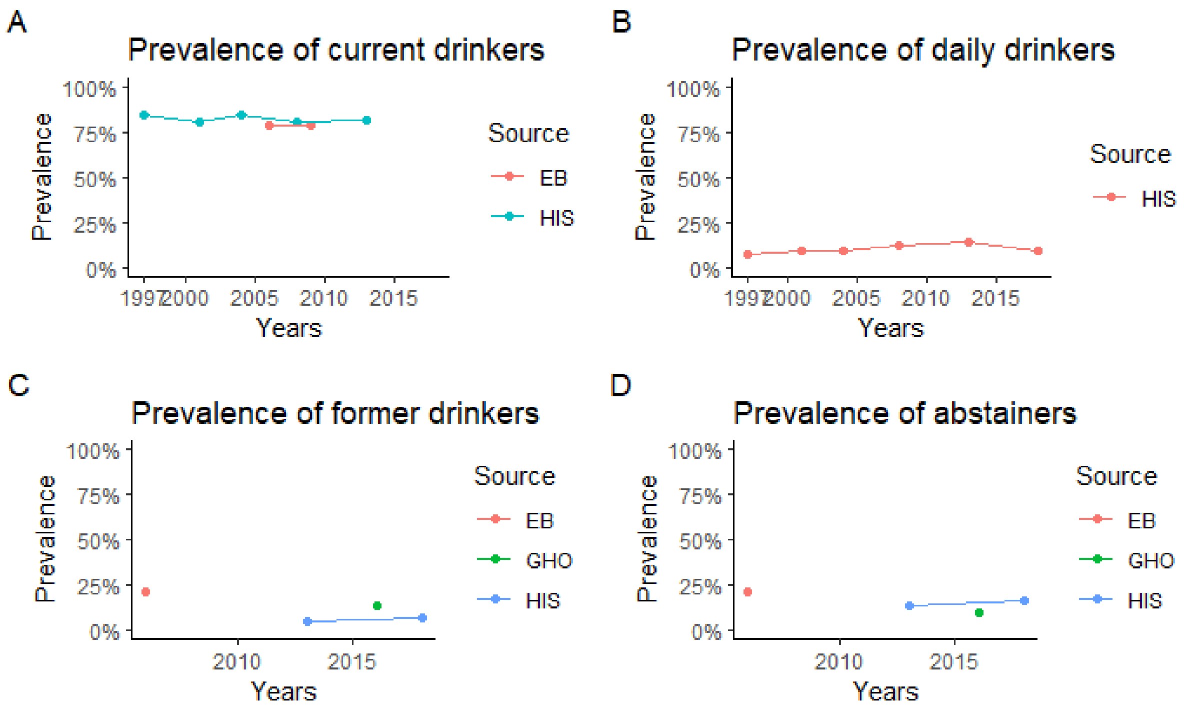

Figure 11: Prevalence of current drinkers, daily drinkers, former drinkers, and abstainers from 1997 to 2020 by sources. Abbreviations: EB: Eurobarometer; GHO: Global Heath Observatory; HIS: health interview survey

Discussion of different survey-derived data sources

Mapping existing sources gave us insights into the availability of data for most of the past 20 years in Belgium for alcohol use. We found that those sources use different methodologies, and have different findings regarding the same variables with sometimes different prevalence estimates for the same year. Most notably, apart from the HIS, most data sources had very few years of data collection, making overall trends and differences difficult to assess. Patterns from the HIS seem to suggest a steady level of current drinking that has not changed in the last decades.

3.2.1.3 *Alcohol sales data*

Indirect methods, such as monitoring sales, packaging, tax signs, and discarded cigarette butts, can contribute to enhancing our comprehension of tobacco usage among the population in Belgium. These alternative data sources can also offer insights into the number of people using tobacco products. We identified one data source based on expert opinion and one data source based on an internet search:

FPS Finance sales data

Data collected by FPS Finance includes the following indicator:

- The volume of pure alcohol (litres) sold in a year

These data points were available from 2008 to 2012 and 2016 to 2019 and covered the country at a national level. Data were collected by motoring and tracking imports and exports from customs.

Appraisal

Data from the FPS Finance are nationally representative and a useful complement to survey-derived alcohol use data. The data are also collected on an annual basis which allows us to observe fluctuations in sales and track more closely the impact of policies in the short term. This is currently not possible with survey-derived data sources.

Government statistics capture the volume of pure alcohol in litres in a given year. These data are based on sales and production records and are derived from data sources such as production, import, export, sales, or taxation records. Import and export data primarily originate from customs departments. (Rehm et al., 2007). Per capita alcohol consumption or recorded alcohol consumption can be then calculated by summing beverage-specific pure alcohol consumption (beer, wine, spirits, other) expressed in litres of pure alcohol and then divided by the population aged 15 years and above to have per capita consumption (Devaux & Sassi, 2015; Rehm et al., 2007; World Health Organization, s. d.-b).

The accuracy of government data relies heavily on the precision of sales data concerning alcoholic beverages. Relying on production data presents a limitation: it requires obtaining precise export and import figures. Inaccuracies in these numbers can lead to production figures that do not accurately present the actual situation—potentially being either underestimated or overestimated (Rehm et al., 2007; World Health Organization, 2000). Furthermore, these data might not accurately reflect consumption, as beverages bought in a specific year might not be consumed during that same year. This is especially applicable to premium products like quality wines and aged spirits, although they typically make up only a minor fraction of overall consumption. Additionally, establishments selling alcohol might accumulate stock in anticipation of a tax increase, thereby artificially skewing the data (Kling, 1991). Furthermore, these statistics may underestimate alcohol sales by not accounting for unrecorded consumption, such as homemade production, cross-border smuggling, illegal sales, and other untaxed forms of production and consumption (Manthey et al., 2023; Rehm et al., 2007; World Health Organization, 2000). Additionally, tourist statistics are overlooked, potentially leading to an underestimation of alcohol consumption in Belgium annually. Regarding demographics, sales data do not provide information by age and sex.

Trends in alcohol data

FPS data are presented in Figure 12 and display an overall decline in the volume of pure alcohol sold in Belgium over time spanning from 2008 to 2012 and 2016 to 2018. The graph offers insights into the fluctuations in the volume of pure alcohol sold over time. Changes in sales could be linked to policy regulation, shifts in consumer behavior, or economic influences.

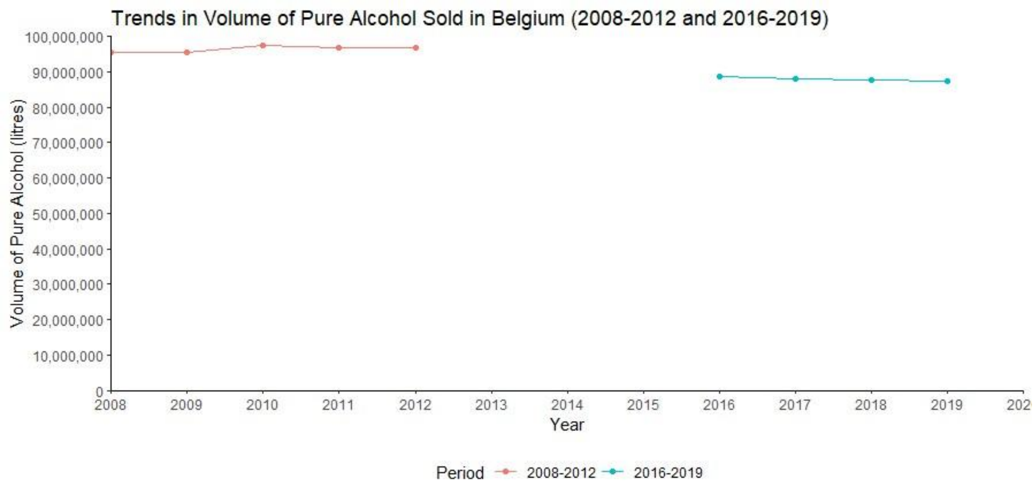

Figure 12: Trends of the volume of pure alcohol (litres) sold in Belgium (2008-2019)

Total APC

Information regarding this estimate was found in :
Global Health Observatory (GHO) dashboard.

The Global Health Observatory

The GHO serves as a repository and provides a global picture of several indicators useful for understanding the extent of alcohol consumption and sales in each country. Data on alcohol use are coming from national entities and are gathered in the observatory. Several indicators can be found: patterns of consumption, level of consumption (Recorded alcohol per capita consumption in litres per capita and by types of alcohol, unrecorded per capita consumption, tourist consumption), and economic indicators such as government tax revenue and excise revenue from alcohol use (World Health Organization, s. d.-a). Note that the frequency of the data depends on the indicator, not all indicators are available for more than one time point (World Health Organization, s. d.-a). Calculations are derived from national data when available. The WHO Secretariat ensures the validity of the data by compiling country profiles with all the relevant data for key indicators and validates them with countries. The data are then uploaded to the WHO GISAH (Global Information System on Alcohol and Health) and GHO (Poznyak et al., 2014).

The observatory is part of a global initiative to establish a comprehensive monitoring system on alcohol and health. This initiative aims to strengthen the connection between monitoring activities and policy development and evaluation, supporting the strategy to reduce the harmful use of alcohol (Poznyak et al., 2014).

In the dashboard, WHO presents the total APC as a variable that provides a comprehensive measure of alcohol consumed by adults (aged 15 and above) within a calendar year, expressed in liters of pure alcohol per country. This indicator integrates:

- recorded alcohol consumption data,
- unrecorded alcohol consumption,
- tourist consumption (adjusted for)

(Kilian et al., 2020; World Health Organization, n.d.-d).

- **Recorded alcohol consumption** comes from official statistics derived from data sources such as production, import, export, sales, or taxation records and is calculated by summing beverage-specific pure alcohol consumption (beer, wine, spirits, other) from various sources such as Government statistics as the primary source. Other sources capturing those data exist namely the Food and Agriculture Organization of the United Nations (FAO), and data from the alcohol industry (Poznyak et al., 2014; Rehm et al., 2007). To convert volumes into pure alcohol litres, percentages are applied: Beer (5%), Wine (grape wine 12%, must of grape 9%, vermouth 16%), Spirits (distilled spirits 40%, spirit-like 30%), and Other (varied percentages based on beverage type) (World Health Organization, s. d.-b). To ensure a more stable country estimate, recorded data are presented as averages of previous years, (e.g. estimate for 2019 is calculated as the average of the data from 2017, 2018, and 2019) (Rehm et al., 2007; World Health Organization, s. d.-b).

- **Unrecorded alcohol consumption**, looks at alcohol that is not captured by taxation and falls outside the official governmental system (Manthey et al., 2023). The estimation of unrecorded alcohol consumption in litres of pure alcohol among individuals aged 15 and above, provided by WHO, involves determining its proportion within the total alcohol per capita consumption. This calculation is performed through a regression analysis at the country level to find the percentage of total alcohol consumption attributed to unrecorded alcohol. The analysis also incorporates various factors such as urbanization, migration rates, malnutrition, sanitation, education levels, and per capita gross domestic product adjusted for purchasing power parity (World Health Organization, s. d.-c). This approach is detailed in several studies (Manthey et al., 2023; Probst et al., s. d.).
- **Tourist consumption** considers both tourists visiting a particular country and residents of that country traveling abroad. Data for tourist consumption is obtained from United Nations tourist statistics (Kilian et al., 2020; World Health Organization, s. d.-f).

The total APC is calculated by summing these recorded and unrecorded consumption, adjusted by tourist consumption to provide a comprehensive view of alcohol consumption trends in a respective country (World Health Organization, s. d.-f).
For Belgium, total APC is calculated using the following data sources: for recorded consumption, data is sourced from World Drink Trend (WDT) for the years 1963-1999, Food and Agriculture Organization of the UN (FAO) for 2000-2007, and WHO Global Survey on Alcohol and Health for 2008-2015, along with Belgium Customs and Excise Department for 2016-2019; for unrecorded consumption, data is sourced from the WHO survey of experts; and for tourist consumption, data is sourced from UN tourist statistics for all countries. Data for Belgium are available from 2000 to 2019 by 5 years breaks.

Appraisal

Data on total APC from national entities are gathered in the observatory and are available for almost all countries. Estimates are calculated as a population-weighted average of national data. The recorded alcohol per capita consumption only takes into account the consumption that is recorded from production, import, export, and sales data often derived from taxation (Poznyak et al., 2014; Rehm et al., 2007; World Health Organization, s. d.-a). However, note that the recorded figures presented reflect multi-year averages, and the prevalence of unrecorded alcohol consumption remains inadequately understood (Manthey et al., 2023). Finally, the total APC figures provided are modeled estimates coming from various data sources, offering a synthesized perspective on alcohol consumption in Belgium. The total APC is often seen as a more accurate measure of consumption but lacks regional and demographic breakdowns (Poznyak et al., 2014).

Trends in total APC

When separating by sex (Figure 13), the total APC (in litres of pure alcohol) starts notably higher at 18.1 in 2000, experiences a gradual decline, and then shows a more significant drop to 16.2 in 2019 in men. This decrease highlights a noteworthy reduction in male alcohol consumption, although it remains considerably higher than the overall and female APC. Female APC, starting at 5.2 in 2000, remained relatively stable until 2019 when it experienced a slight decrease to 4.7. Females consistently exhibit lower APC compared to males and the overall population, with a minimal decline noted in 2019.

In summary, the data reflect a slight decrease in total and male APC over the years, with a more substantial decline in male consumption leading up to 2019. Female APC remained relatively constant over the period, showing a slight reduction in 2019.

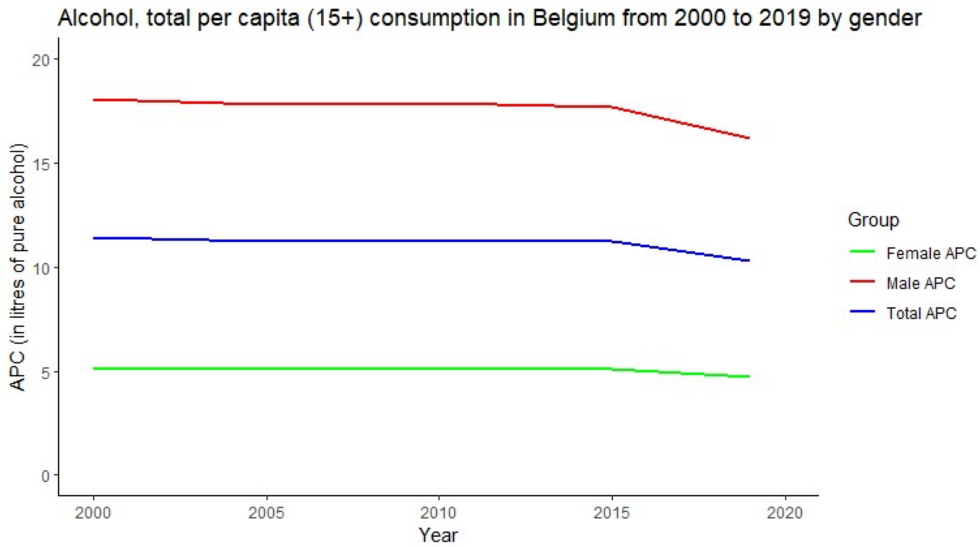

Figure 13. Alcohol, total per capita (15+) consumption (APC) (in litres of pure alcohol per year) in Belgium from 2000 to 2018 by sex (World Health Organization, s. d.-a)**.**

3.2.1.4 Conclusion

In order to establish a consistent time series of exposure data, having representative and transparent estimates of the burden attributable to alcohol use is crucial, especially when analyzing different demographic factors such as sex, age, and region. To achieve this, various data sources were selected in Belgium, considering their specificity and sensitivity. After critically evaluating these sources, we have identified the HIS (for drinking category prevalences) and total APC (for alcohol consumption among current drinkers) as the most suitable data sources and estimates for our project.

However, it is important to note the limitations of the chosen dataset and estimate. The HIS is conducted every five years, and some indicators are not available for every HIS wave (e.g. former drinkers) which might impact the frequency of our analysis. Additionally, survey data often face challenges such as low response rates and selection bias, the tendency for late or non-responses toward heavier drinkers (non-response bias), the methodology used by the survey to assess drinking behavior, potential non-recall bias (omission of episodes of heavy drinking), and individuals' tendency to portray themselves as moderate drinkers (Kilian et al., 2020). Knowing this, relying only on survey data would likely underestimate the burden of alcohol use. Underreporting of alcohol consumption levels in surveys is well-documented and is estimated to represent only 30-40% of actual sales (Stockwell et al., 2018). Total APC however lacks detailed breakdowns by age, sex, and region, and may underestimate actual consumption due to unaccounted illicit and cross-border purchases (Rehm et al., 2007; Rehm, Kehoe, et al., 2010). Addressing these limitations is essential to ensure the accuracy of the estimation of alcohol use and its associated burden of disease.

To address these issues, we integrated APC with HIS data, by allocating survey distribution data (region, sex, age categories, and year) with total APC to have an adjusted consumption of alcohol. This combined approach aims to provide a comprehensive understanding of alcohol consumption burdens across various levels and is based on the work of Rehm et al. (2007).

3.1.1 Trends

We followed the GBD 2016 study's approach to estimating the AB of alcohol use. This involves calculating the PAF using key data inputs: prevalence of drinking categories (former, current, and lifetime abstainers) and mean consumption in grams/day among current drinkers.

All potential data sources for estimating exposure (published or unpublished) were evaluated based on a set of quality criteria such as comparability, relevance, representativeness, currency, accuracy, validation, credibility, and accessibility in a critical appraisal published elsewhere (Nayani et al., 2024). The best-selected data source for drinking status was the HIS. Self-reported alcohol use data are available by sex, region, 5-year age group, and year from 1997 to 2018. Note that for former drinkers and lifetime abstainers, data were only available for 2 time points: 2013 and 2018 and the mean consumption of drinks per day was available from 2008-2018, as defined in table 5.

The first step to burden calculation is to construct a time series of alcohol use exposure data in Belgium from 2013 to the most recent available mortality data (2021 at the time of writing), using the BeBOD methodology to select the "best-fitted" model described above. The covariates for the model for smoking categories (current, never, and former smokers) and continuous variables (mean cigarettes per day, pack-years, and time since quitting) include those we need for our output, namely: age, sex, region, and year, as described in Table 3.

Table 9. Description of exposure indicators in the HIS

Exposure variable	Definition	Variables in the HIS	Years available
Current drinkers	Proportion of individuals who have consumed at least one alcoholic beverage (or some approximation) in 12 months.	AL01_1	All years
Former smoker	People who report having smoked but have quit for any time	AL01	2013, 2018
Lifetime abstainers	Proportion of individuals who have never consumed an alcoholic beverage	AL01	2013,2018
Measures of intensity			
Average number of drinks per day among weekly drinkers	Number of drinks per day recorded only for those who report weekly drinking	AL_7	2008, 2013, 2018

The covariates for the model for drinking categories and continuous variables include those we need for our output, namely: age, sex, region, and year.

We first estimate the mean proportion of drinking categories including the survey weighting built into the HIS using the svyby function in R.

Table 10. Model selection for categorical exposure variables

Exposure	Best-Fitted Model	WAIC Value
Current Drinkers	Current_cases ~ 1 + YEAR * AGEGR * REGION + YEAR * REGION * SEX + YEAR * SEX * AGEGR	1041
Former Drinkers	Former_cases ~ 1 + YEAR * AGEGR * REGION * SEX	272
Lifetime Abstainers	Abstainers_cases ~ 1 + YEAR * AGEGR * REGION + YEAR * REGION * SEX + YEAR * SEX * AGEGR	276

The models predicting trends in continuous variables are different from drinking prevalence in as the outcome is not a binomial. We applied a gamma INLA model instead. Indeed, a gamma distribution is often used in the literature to present the continuous distribution of alcohol consumption the best based on its flexibility. This model is usually used to model alcohol consumption for its flexibility and ability to take into account heavy drinkers, as the tail of the distribution is long (Kehoe et al., 2012; Rehm, Kehoe, et al., 2010).

Table 11. Model selection for continuous exposure variables

Exposure	Best-Fitted Model	WAIC Value
Mean Consumption (grams/day)	up_g_day ~ 1 + YEAR * AGEGR * REGION + YEAR * REGION * SEX + YEAR * SEX * AGEGR	276

3.1.1.1 Projecting Consumption Trends

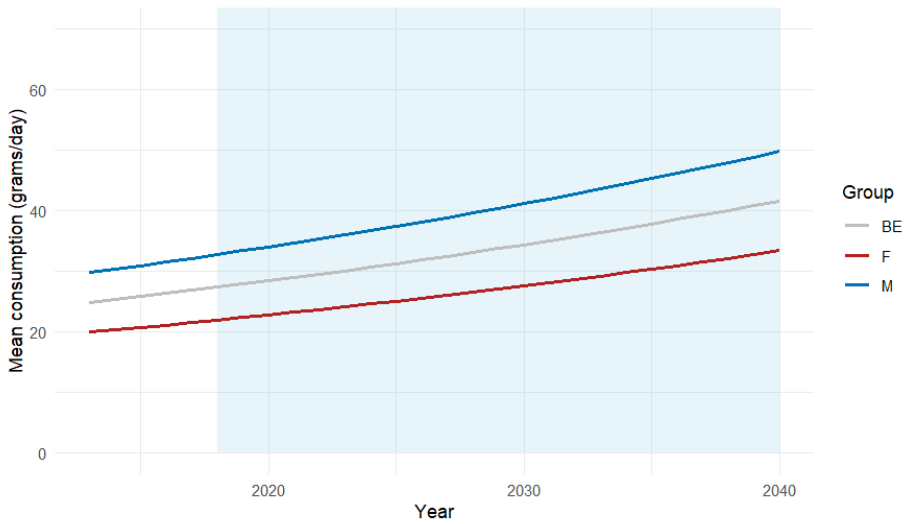

Figure 14: Projected trends in mean alcohol consumption (grams/day) in Belgium, 2013-2040

The graph illustrates trends in average alcohol consumption (grams per day) in Belgium from 2013 to 2040, showing the overall trend (BE) and trends by sex (M and F). The overall consumption trend (BE) shows a gradual increase over time, positioned between the values for men and women, reflecting the national average. Men consistently exhibit higher alcohol consumption than women, with a stable gap throughout the observed period. All three trends indicate a steady rise in alcohol consumption up to 2040, with no signs of stabilization or decline. The blue-shaded area highlights the projection period starting from 2018.

3.1.2 Disease-specific deaths

After the critical appraisal and defining exposure, we needed to identify and quantify the risk-outcome pairs related to alcohol consumption to calculate the AB. We identified four possible datasets: the GBD study 2016, PHE, the World Health Organization (WHO) study, and the Australian Burden of Disease Study (AUS).

The GBD study is the most comprehensive effort to link risk factors to health outcomes, employing a detailed exploration of causality through the Bradford Hill criteria to identify diseases attributable to alcohol use. It also incorporates a meta-analysis to estimate relative risks associated with exposure. Additionally, the study provides insights into the burden of alcohol use across 204 countries with the latest iteration being published in 2024 (Brauer et al., 2024).

At the national level, PHE works to protect and improve population health while reducing inequalities, and providing evidence-based support to government, local authorities, and the public. Public Health England has been calculating Alcohol Attributable Fraction (AAF) since 2008. The latest report was published in 2020.

The WHO plays a pivotal role in assessing the global health impact of alcohol use and guiding evidence-based interventions to mitigate its burden. Alcohol consumption is a significant public health concern, contributing to a range of health outcomes, including injuries, chronic diseases, and premature mortality. The WHO's efforts to quantify this burden are rooted in rigorous methodologies that draw on global and country-specific data to estimate the attributable harm of alcohol use. This study highlighting the burden of alcohol use across 204 countries and territories, employed comprehensive approaches, including the GBD methodology, to evaluate the relationship between alcohol consumption and health outcomes (Shield et al., 2020)

The Australian Burden of Disease Study is a comprehensive effort to measure the impact of various risk factors, including alcohol use, on health outcomes in Australia. It aims to provide insights that inform public health policies and priorities. The 2011 assessment of the burden of alcohol use in Australia was published in 2018, using a combination of self-reported and corrected data to provide a more accurate picture of alcohol consumption and its effects (Australian Institute of Health and Welfare, 2019a; Gao & Ogeil, 2018; Rehm, Baliunas, et al., 2010).

Table 12. Alcohol outcomes included in evaluated risk-outcome pair sets

	Global Burden of Disease Study	Public Health England	World Health Organization	Australian Burden of Disease Study
HIV/AIDS			X	
Tuberculosis	X	X		X
Lower respiratory infections	X	X (Pneumonia)	X	X
Lip and oral cavity cancer	X	X (lip, oral, and pharynx cancer)		X
Pharynx and nasopharynx cancer	X	X	X (other pharynx cancer)	X
Esophageal cancer	X	X	X	X
Colon and rectum cancer	X	X	X	X
Liver cancer	X (Liver cancer due to alcohol use)	X	X	X
Larynx cancer	X	X	X	X
Breast cancer	X	X	X	X
Diabetes mellitus	X	X		X
Alcohol use disorders			X	
Epilepsy	X	X (Epilepsy and Status epilepticus)	X	X
Hypertensive heart disease	X	X	X	X
Ischaemic heart disease	X	X	X	X
Cardiomyopathy, myocarditis, endocarditis			X	
Atrial fibrillation and flutter	X	X (Cardiac arythmias)		X
Heart failure		X		
Ischaemic stroke	X	X	X	X
Hemorragic stroke	X	X	X	X
Oesophageal varices		X		
Gastro-oesophageal		X		

laceration haemorrhage syndrome				
Unspecified liver disease		X		
Cholelithiasis (gall stones)		X		
Cirrhosis and other chronic liver diseases	X	X	X (Cirrhosis of the liver)	X
Pancreatitis	X	X (acute and chronic)	X	X
Psoriasis		X		
Spontaneous abortion		X		
Low birth weight		X		
Unintentional injuries	X	X (Road/pedestrian traffic accidents, Poisoning, Fall injuries, Fire injuries, Drowning, other unintentional injuries)	X (Road/pedestrian traffic accidents, Poisoning, Fall injuries, Fire, heat and hot substance injuries, Drowning, Exposure to mechanical forces, other unintentional injuries)	X
Transport injuries	X	X		X
Tuberculosis	X	X		X
Cirrhosis and other chronic liver diseases	X	Included in 'other heart disease category		X
Interpersonal violence	X		X	X
Self-harm	X	X		X
Assault		X		
Event of undetermined intent		X		

Table 13. Evaluation grid for alcohol risk-outcome pair sets

	Global Burden of Disease Study	Public Health England	World Health Organization	Australian Burden of Disease Study
Accessibility	Available to download from GBD healthdata, supplementary materials GBD appendix from the Lancet publications	Available via NHS/ PHE website Appendix for RR search strategy in 2020	Appendix available via the lancet publication supplementary materials	Appendix available via the Australian Institute for Welfare and Health (AIWH) for multiple iterations. The study also relies on the National Drug Strategy Household Survey (NDSHS) and alcohol sales data, with adjustments outlined in publicly available reports.
Transparency	Methodology described in Appendix. Requires running DisMod to obtain non-parametric splines, and these splines cannot be reproduced without access to the GBD team's expertise. Specific adjustments for country-specific contexts (e.g., Belgium) may not be fully transparent or easily replicated.	Detailed method, easy to reproduce. Transparent with the approach and choices they made (e.g. search strings and inclusion/exclusion criteria)	The methodology, detailed in the Appendix, relies on literature reviews, self-reports, and comparisons to GBD data. It acknowledges GBD 2017 limitations, such as excluding heavy episodic drinking and risks for former drinkers. WHO's Technical Advisory Group selected relative risk estimates based on meta-analyses of alcohol-cancer dose-response relationships, adjusted for confounders and country-specific contexts.	The methodology is detailed in AIHW publications, including how self-reported survey data were adjusted using alcohol sales data and methods adapted from GBD 2013. Transparent in describing assumptions, limitations, and adjustments for the Australian context.
Reliability	The GBD model integrates data from national surveys, global reports, and studies across 190+ countries, using uncertainty analysis for confidence	Mainly systematic review and meta-analysis, from 2013 onwards. Possible bias in selecting studies for RR curves. Latest evidence linking alcohol consumption to	WHO's alcohol-attributable burden estimates were improved by addressing gaps in GBD 2017. The study suggests that alcohol-attributable burdens might be	Combines data from the NDSHS, epidemiological studies, and alcohol sales. Adjustments ensure better alignment between self-reported and

	intervals. However, it relies on assumptions about data quality, availability, and region-specific models.	diseases based on new available data. Uncertainty estimates allowing for the computation of Confidence Intervals. Uniform method for estimation, same method over time but update of evidence when necessary	greater than previously thought, especially in sub-Saharan Africa and Eastern Europe regions.	observed data, but reliability depends on the quality of input data and assumptions used in corrections.
Evidence	The GBD model combines extensive data from national surveys, global health reports, and studies across 190+ countries, covering decades of trends. However, variations in the quality and availability of country-level data can limit the comparability of estimates.	Studies from 2013 onwards from selected countries.	WHO reviewed publications on alcohol-related disease burden (2000–2019) from its Global Health Observatory and the IHME database. It used data from alcohol sales, drinking prevalence, self-reports, and relative risk functions. The study addresses GBD 2017 gaps and highlights a higher burden in regions like sub-Saharan Africa and Eastern Europe, though some methodological limitations persist.	Uses self-reported survey data from NDSHS (2016) adjusted with sales data and historical trends from Australian records. Relies on relative risk functions from GBD and international meta-analyses.
Relevance	The GBD model uses individual-level data for more precise estimates and provides global, standardized estimates for various risk factors. However, assumptions about certain factors may not always align with regional contexts like Belgium.	The model focuses on data from the UK, Scotland, Europe, Canada, Australia, and New Zealand. It uses individual-level data for alcohol consumption, providing detailed estimates. The burden of alcohol-related acute and chronic diseases is calculated using two separate equations, offering a	The WHO approach is global, focusing on the alcohol-attributable burden of disease across regions with varying alcohol-related health impacts. It highlights alcohol's role in both communicable and non-communicable diseases, stressing the need for regional alcohol	Combines data from the NDSHS, epidemiological studies, and alcohol sales. Adjustments ensure better alignment between self-reported and observed data, but reliability is tailored to the Australian context and depends on the quality of input data and the

		comprehensive overview.	policies. Using individual-level data allows for more precise and representative estimates.	assumptions used in corrections.

Discussion

The latest GBD study estimating the attributable burden of alcohol use was published in 2024. Data on alcohol use were gathered from self-reported surveys from 63 countries. The self-reported data were corrected for underestimation using estimates of sales of alcohol in liter per capita (Brauer et al., 2024).

For GBD 2016, a systematic review was conducted to include cohort and case-control studies reporting relative risks, hazard ratios, or odds ratios for alcohol-related outcomes. Studies had to report alcohol consumption dose and uncertainty measures, with a representative population. Dose-response curves were estimated using DisMod ODE, which models non-linear relationships and handles categorical dose data, estimating relative risks for doses between 0 and 100 g/day, assuming consistent risk across ages and sexes (Brauer et al., 2024).

The GBD dataset is uniquely comprehensive due to its extensive input data, advanced bias correction methods, and quality measures. Few research institutes possess the resources to achieve this scale of analysis. Indeed, GBD contains a broad search captured studies from 1970-2019, including cohort and case-control studies reporting alcohol use, continuous dose, effect size, and relevant study details. The Fisher Scoring correction was applied for data-sparse situations, and a method for detecting publication bias was added, though the bias is not yet corrected (Brauer et al., 2024).

The RRs in GBD 2016 are readily accessible and are presented by cause and consumption levels, with breaks at 12 to 72 grams per day. These levels are the same across all age groups, though they are sometimes specified by sex (GBD 2016 Risk Factors Collaborators, 2017). The exposure indicators included are drinking category (current, abstainers), alcohol consumption in grams/day, alcohol litres per capita stock, number of tourists within a location, unrecorded alcohol stock, tourists' duration of stay. Note that the GBD study does not account for the increased risk of disease for former drinkers (Shield et al., 2020).

WHO's RR estimates for the alcohol-attributable burden of disease were selected by the WHO Technical Advisory Group on Alcohol and Drug Epidemiology. Criteria for RR selection included meta-analyses that modeled the continuous dose-response relationship, controlled for confounders, used lifetime abstainers as the reference group, and aligned with WHO-reported disease categories. For Belarus, Estonia, Latvia, Lithuania, Moldova, Russia, and Ukraine, RRs from a Russian cohort study were used to account for regional drinking patterns and risk factors (Shield et al., 2020).

Dose-response functions are provided as mathematical expressions for current drinkers, stratified by consumption level, sex, and for some diseases, by age group. For former drinkers, only a single data point is available, which does not vary by consumption level but is stratified by sex for certain diseases (Shield et al., 2020).

Public Health England has been calculating Alcohol Attributable Fractions (AAFs) since 2008, with the most recent report released in 2020. The methodology uses exposure estimates from the 2016 Health Survey for England, adjusted for underreporting through sales data (Jaccard et al., 2020). RRs) are derived from Jones & Bellis, (2017) which synthesized data from 20 meta-analyses examining the links between alcohol use, chronic conditions, and injury risks. For the latest update, Jaccard et al. (2020) expanded on this foundation by conducting a new systematic review to identify additional sources, including studies published since 2013. To ensure transparency and replicability, the research strings, inclusion/exclusion criteria, and detailed methodology are publicly accessible. Furthermore, the dataset includes relative risks (RRs) with uncertainty intervals and the source of the dose-response function offering a robust measure of reliability and transparency. These RRs are available for current drinkers, categorized by consumption levels (light, moderate, and heavy) but sometimes specific levels of consumption (continuous) as well as for former drinkers, stratified by sex (Jaccard et al., 2020) Estimates are not age-specific (Public Health England, 2020a).

The Australian Burden of Study assessed the impact of alcohol use on the burden of disease in Australia in 2011. The report was published in 2018 using exposure data of alcohol consumption in Australia from their national health survey NDSHS 2016 and covers burden estimates for 26 diseases. The self-reported data of the survey were inflated with the data of alcohol sales using the method of GBD 2013 since the amount of self-reported data does not reflect the true extent of the consumption (Australian Institute of Health and Welfare, 2019b; Gao & Ogeil, 2018; Rehm, Baliunas, et al., 2010). The RR comes from the GBD 2015 and comprises 26 diseases linked with the risk factor (Gao & Ogeil, 2018). Current drinkers, lifetime abstainers, and former drinkers were used as exposure indicators for alcohol use.

Based on this appraisal, we have chosen to use the GBD 2016 RR estimates for current drinkers for the calculation of the attributable:

- **Uniformity**: GBD’s standardized framework is crucial for comparing results with other studies.
- **Comprehensive Bias Correction**: GBD’s advanced methods for addressing biases and heterogeneity make it a more reliable option overall.
- **Accessibility**: The GBD 2016 RR are readily available and widely documented, facilitating their use in our analysis.
- **Evidence Quality**: The estimates are underpinned by rigorous evidence, with contributing studies evaluated using established bias assessment tools to ensure reliability and validity.
- **Detailed Stratification**: These RR offer dose-response functions that are:
    - stratified by consumption levels (0,12,24,36,48,60,72)
    - categorized by sex for some diseases, but not age-groups specific
- **Global Alignment**: The GBD methodology is internationally recognized, providing a robust and standardized framework for assessing alcohol-attributable risks.

Because we acknowledge that former drinkers account for excess risk, we used the WHO relative risk estimates for former drinkers due to:

- **Data Availability**: WHO RR are easily retrievable, ensuring easy integration into our analysis.
- **Appropriate Risk Representation**: These estimates effectively capture the excess health risks that former drinkers face compared to lifetime abstainers, recognizing the lingering impacts of past alcohol consumption.
- **Sex-Specific Details**: While the WHO RR for former drinkers are based on a single data point, they are stratified by sex for some diseases, allowing for a more nuanced reflection of risk.

This approach ensures that both current and former drinkers are represented in our analysis, using the most accessible data sources available to calculate the attributable burden due to alcohol use.

3.1.1.1 Calculation of the attributable burden to risk factors

Theoretical minimum risk exposure level (TMREL)

The theoretical minimum-risk exposure level is 0 (no alcohol use).

Population-attributable fraction

As illustrated in Figure 1, we need to calculate the PAF to have attributable burden calculation. For smoking, the PAF equation was based on the GBD study 2019 method.

$$PAF = \frac{(P_{abstainers} + P_{former} * RR_{former} + P_{current} * RR_{current}) - 1}{P_{abstainers} + P_{former} * RR_{former} + P_{current} * RR_{current}}$$

Where

$P_{abstainers}$ = prevalence of lifetime abstainers

P_{former} = prevalence of former drinkers

RR_{former} = relative risk (RR) for former drinkers

$P_{current}$ = prevalence of current drinkers who consume an average daily amount (x) of alcohol

$RR_{current}$ = average daily amount of alcohol consumed by current drinkers

3.1.1.1 Results of the attributable burden calculation related to cigarette smoking in Belgium

In 2021, alcohol consumption was responsible for 4,022 deaths, accounting for 3.6% of all deaths in Belgium. This represents 101,368 years of life lost related to alcohol use. 71% of all alcohol-attributable deaths were in men (2,842 deaths). The majority of deaths occurred in persons aged 65-84 years, who accounted for 42% of all alcohol-attributable deaths (1674 deaths), followed by persons aged 45-65 years, who accounted for 34% (1,376 deaths).

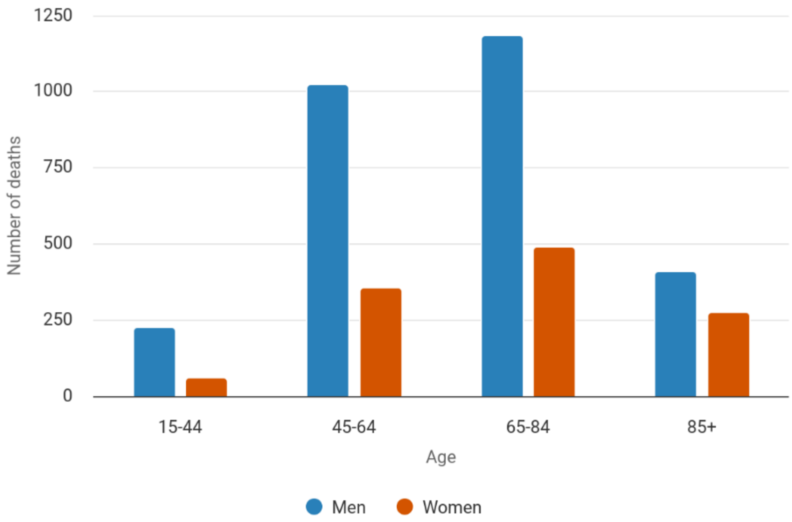

Figure 14 : Distribution of alcohol-attributable deaths, by age and sex, Belgium, 2021

Alcohol use was found to be related to more than 200 diseases or health conditions. From the 34 health conditions included in this study, cirrhosis of the liver, alcohol use disorders and colorectal cancer are the main causes of alcohol-attributable mortality, responsible for 1011, 541 and 495 deaths respectively.

There are significant differences between men and women in the specific causes of alcohol-attributable deaths. Among women, breast cancer is the leading cause, accounting for 339 deaths. In contrast, for men, cirrhosis of the liver is the leading cause, with 729 deaths. Additionally, self-harm is the fourth leading cause of alcohol-attributable deaths for men, contributing to 290 deaths. However, it ranks only eight among women, with an estimated 66 deaths.

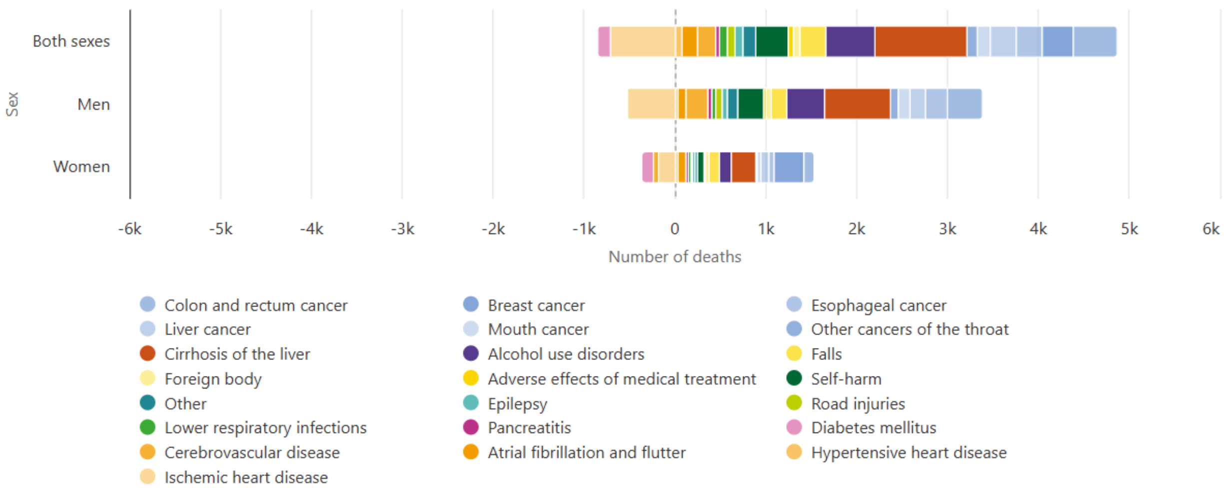

Figure 15: Distribution of alcohol-attributable deaths, by cause for each sex, Belgium, 2021

Although alcohol may appear to have a slight protective effect for certain conditions, such as ischemic heart disease and diabetes, this does not make it beneficial overall. Globally, the harmful effects of alcohol far outweigh any potential benefits. It is a major contributor to deaths from conditions like cancer, liver disease, and other cardiovascular problems. Ultimately, alcohol consumption is harmful to both individuals and society, regardless of the quantity consumed.

Since 2013, there has been an overall increasing trend in alcohol-attributable mortality rates across regions. Indeed, in 2013, the Walloon Region had the highest age-adjusted alcohol-attributable mortality rate, with 42.3 deaths per 100,000 persons attributed to alcohol. The rates in the Brussels Capital Region and the Flemish Region were lower, at 39.7 and 27.6 per 100,000 persons, respectively. Between 2013 and 2021, the Brussels Capital Region experienced the most significant increase in alcohol-attributable age-adjusted mortality rates (+14.8%). The Flemish Region also recorded a notable rise (+6.2%), while the Walloon Region saw a smaller increase (+1.5%). In 2021, the Brussels Capital Region had the highest alcohol-attributable mortality rate, at 45.6 per 100,000 deaths.

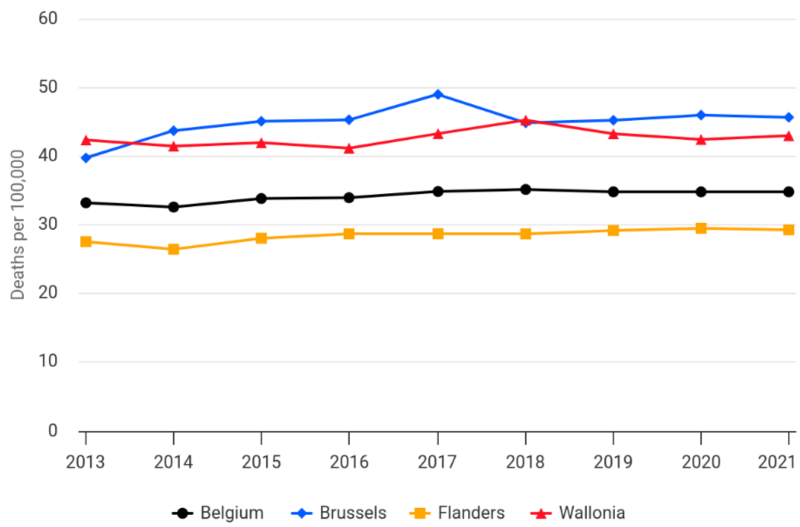

Figure 16 : Distribution of age-adjusted alcohol-attributable deaths per 100,000 people by region, for both sexes, 2013-2021

2.3.1 Global cost

The mean total healthcare cost was estimated at €2,500 per capita. Stratified for alcohol use, the results indicate that the highest costs were found for former drinkers (€4,600 per capita per year).

In the most complete model (i.e. Model 3), a lower cost was found for current drinkers (€-470; P=0.002). Despite this, a higher cost was found for former alcohol users (25%; P=0.02) compared with alcohol abstainers. The adjusted mean attributable cost for former drinkers was estimated at €889. Taking into account that 7% of the Belgian population were former drinkers in 2018, the national cost for former drinkers equates to €711,288,900.

	RR	Standard error	P-value	95% CI	Attributable cost
Model 1					
No alcohol (reference)	1	—	—	—	—
Current drinkers	0.79	0.06	<0.001	0.70-0.89	-564.26
Current drinkers - hazardous	0.80	0.10	0.03	0.66-0.98	-521.89
Current drinkers – non hazardous	0.78	0.06	<0.001	0.69-0.88	-568.50
Former drinkers	1.36	0.10	0.002	1.12-1.65	1232.61
Model 2					
No alcohol (reference)	1	—	—	—	—
Current drinkers	0.86	0.07	0.02	0.75-0.97	-350.52
Current drinkers - hazardous	0.89	0.11	0.27	0.72-1.10	-269.87
Current drinkers – non hazardous	0.85	0.07	0.01	0.75-0.96	-369.25
Former drinkers	1.29	0.09	0.005	1.08-1.54	1007.82
Model 3					
No alcohol (reference)	1	—	—	—	—
Current drinkers	0.81	0.07	0.002	0.72-0.83	-469.78
Current drinkers – hazardous	0.81	0.12	0.06	0.64-1.01	-511.28
Current drinkers – non hazardous	0.81	0.07	0.002	0.71-0.93	-467.75
Former drinkers	1.25	0.09	0.02	1.04-1.49	888.46

°Risk ratio; expected value of the coefficient with never smoked as reference
Model 1: Adjusted for age and gender
Model 2: Adjusted for age, gender, educational level, and preferential reimbursement
Model 3: Adjusted for age, gender, educational level, region, preferential reimbursement, and tobacco use

When looking at indirect costs – cost of absenteeism in function of alcohol consumption, no significant differences (P>0.05) were found for the cost of absenteeism for current drinkers and former drinkers compared with abstainers from alcohol.

4 DISCUSSION

4.1 Key outcomes

The SUBOD project represents a significant advancement in our understanding of the disease burden and economic impact from cigarette smoking and alcohol use in Belgium. For the first time, it provides consistent estimates of past, present, and future trends, disaggregated by sub-national regions, age, and sex. The enhanced monitoring mechanism furthermore allows identifying attributable deaths and costs, which are essential policy indicators. The approach used by SUBOD is based on large, nationally representative datasets, ensuring consistent and reliable estimates that are continuously updated. As a result, the findings serve as a critical tool for public policy planning and health strategy development. The project also provides a stepping stone towards assessing the overall burden of disease due to substance use in Belgium.

The SUBOD project has successfully carried out the necessary methodological developments and their implementation for the systematic monitoring of the societal impact of tobacco and alcohol use in Belgium. The study has provided key insights into current trends and future projections, and quantified attributable deaths and direct economic costs, contributing valuable data to inform public health strategies. Specifically, SUBOD estimated that, in the year 2021, there were 9,362 smoking-related deaths and 4,022 alcohol-related deaths, corresponding to 8.3% and 3.6% of all deaths that year, respectively. The population health impact of cigarette smoking shows a steady decline, while that of alcohol use remains constant or even tends to increase. The direct medical costs of daily cigarette smoking were estimated at €533.861.010 on an annual basis, and former alcohol use amounted to €711.288.900 on an annual basis. These are, however conservative estimates of the economic cost of both risk factors, as they do not take into account the, the costs incurred by prevention services (in health, crime and traffic), nor the costs incurred by victims of these substances (e.g., passive smoking, or road traffic accidents).

In addition to performing the necessary methodological developments, the SUBOD project also ensured integration within the BeBOD and the Belgian Health Status Report. These steps are necessary for enhancing its utility for long-term health monitoring. Today, the study's outputs are accessible through a series of interactive dashboards and reports, ensuring that stakeholders and policymakers can easily access and utilize the findings for decision-making and public health planning:

- BeBOD dashboard: https://burden.sciensano.be/shiny/risk
- Health Status Report chapter: https://www.healthybelgium.be/en/health-status/burden-of-disease/risk-factor-attributable-burden/
- Factsheets assessing tobacco trends and national targets set: https://www.healthybelgium.be/en/health-status/factsheets/tobacco-control-policies-are-needed-to-change-smoking-trends

4.2 Comparisons with other studies

The SUBOD project is complementary to a series of other, high-level estimation efforts, most notably the SOCOST study and the Global Burden of Disease study.

The **Social Cost of Legal and Illegal Drugs in Belgium (SOCOST) study** was a cost-of-illness study that estimated the social costs of substance use in Belgium, focusing on alcohol, tobacco, illegal drugs, and psychoactive medications. Conducted for the reference year 2012, SOCOST provided a comprehensive assessment of the financial and societal burden of substance use, estimating total social costs to exceed €4.5 billion. This figure encompassed the direct costs (such as healthcare expenditures, law enforcement and judicial system costs, and costs associated with traffic accidents), and indirect costs (such as productivity losses due to disability, premature death, and incarceration). In addition, more than 515,000 healthy years were lost due to substance misuse, representing €515 billion in intangible costs, which were calculated by monetizing DALYs. SUBOD complements the SOCOST approach by adopting a BoD perspective rather than a cost-of-illness approach. While SOCOST quantified the broader economic consequences of substance use, our study focuses on the disease burden attributable to cigarette smoking and alcohol use in Belgium, and provided insights into long-term trends and future projections. Additionally, our study introduces sub-national, age, and sex disaggregation, allowing for a more detailed analysis of smoking and alcohol related health outcomes across different population groups. Together, these two approaches offer a more comprehensive understanding of the impact of substance use in Belgium, SOCOST highlighting the economic burden, while SUBOD emphasizes the population health consequences. The findings from both studies can be used in tandem to inform policymakers on the dual challenge of addressing substance use-related health outcomes and mitigating the associated economic costs.

The **Global Burden of Disease (GBD) study** is an international research initiative led by the Institute for Health Metrics and Evaluation (IHME) that quantifies health loss from diseases, injuries, and risk factors worldwide. It provides comparable estimates of mortality, morbidity, and risk-attributable disease burden across countries and over time, using a standardized methodology that integrates multiple data sources. While there are discrepancies between the estimates generated by SUBOD and those reported by the GBD study for Belgium, both studies reveal similar overall magnitude and trends in attributable burden. Discrepancies likely stem from differences in data sources and methodological approaches, which are, however difficult to assess given the complexity and limited transparency of GBD's methodological framework at the national level. Ultimately, however, both studies provide valuable insights, with GBD offering a comparative global perspective and SUBOD delivering more locally relevant estimates for Belgium. These complementary approaches help inform national health policies while situating Belgium's disease burden within a broader international context.

4.3 Strengths and limitations

The SUBOD project represents the first comprehensive assessment of the disease burden attributable to cigarette smoking and alcohol use in Belgium based on local data and methods. By using nationally representative datasets and a transparent modeling approach, it provides detailed estimates at the sub-national level, disaggregated by age and sex. The successful implementation of the overall methodological framework as initially envisioned demonstrates the feasibility of this approach for ongoing monitoring. Furthermore, the integration of results into broader burden of disease frameworks, such as BeBOD, will further enhance its policy relevance.

Despite these strengths, several limitations should be acknowledged. These limitations are both linked to the overall methodological framework as to the data sources used by SUBOD.

4.3.1 Methodological constraints

Comparative Risk Assessment. The Comparative Risk Assessment (CRA) framework, while well-suited for estimating overall burden and enabling cross-risk comparisons, has inherent limitations. It follows a cross-sectional approach, which does not fully capture the dynamic, temporal relationships between policy changes, smoking exposure, and health outcomes. Alternative modeling approaches, such as (discrete) Markov models, system dynamics modeling (SDM), or agent-based models (ABM), allow for more detailed longitudinal analyses that could provide deeper insights into the impact of tobacco control measures over time. Additionally, the CRA framework does not integrate multiple risk factors to assess the "overall" burden from combined exposures, which could be a relevant extension for future research.

Cost Perspective. SUBOD primarily focused on direct medical costs associated with smoking- and alcohol-related diseases, excluding broader economic impacts such as productivity losses due to disability and premature mortality. Additionally, the estimates center on the users themselves, without fully accounting for the financial and social burden on victims of second-hand smoke exposure, alcohol-related traffic accidents, and alcohol-induced violence. These indirect costs—including healthcare expenses, legal system strain, and lost productivity among victims—represent a significant yet often overlooked component of substance-related harm. Expanding future analyses to incorporate these broader consequences would provide a more comprehensive assessment of the economic impact of smoking and alcohol use on society.

Projections. The projections in this study are based on statistical extrapolations of past trends, assuming that the current pace of policy implementation and its effects remain consistent over time. This approach provides useful insights into potential future disease burden but does not account for the introduction of new tobacco control measures or significant shifts in smoking behaviours, such as the sudden increase in the use of e-cigarettes. Future updates could enhance predictive accuracy by incorporating scenario analyses that model the potential impact of policy changes and behavioural trends.

4.3.2 Data constraints

Disease-Specific Burden and Costs. While SUBOD aimed to quantify the disease-specific burden and costs attributable to tobacco and alcohol use, this objective was only partially achieved due to data limitations. Tobacco and alcohol use are causally linked to 35 different diseases. Although mortality estimates for these diseases are readily available from the BeBOD study, morbidity estimates are not. SUBOD contributed to the expansion of BeBOD by developing morbidity models for 15 additional diseases. This process is ongoing, with the goal of providing a comprehensive assessment of both fatal and non-fatal disease burden from tobacco and alcohol use in future iterations.

Regarding direct medical costs, calculating disease-specific incremental costs requires linking databases containing disease diagnoses with the healthcare reimbursement database from the Intermutualistic Agency (IMA). These linkages are in place for all but one diagnostic data source—the Intego Sentinel network of General Practitioners. A request has been submitted to the Information Security Committee to establish this linkage, which would enable more accurate cost calculations for diseases where Intego is the most reliable source. Future iterations will integrate these new insights, ultimately providing the first complete picture of the disease-specific costs of tobacco and alcohol use.

Self-Reported Data. The estimates in this study rely on self-reported smoking and alcohol use prevalence, which are subject to well-documented biases such as underreporting due to social desirability, recall inaccuracies, selection effects, and differences in survey methodologies. Although correction factors were applied for alcohol consumption, similar adjustments for tobacco use were not available. In some European countries, underreporting of smoking has been increasing, making this a potential source of bias. While sales data provide an objective proxy for actual tobacco consumption, they were not available for Belgium within the timeframe of this study. Alternatively, the use of hydroxycotinin as a proxy for tobacco was explored, but did not prove to be a better alternative. The reliance on self-reported data will therefore remain a necessity, and increasing our understanding of the potential underreporting will become increasingly important.

Scope of Tobacco Use Data. Certain tobacco-related factors are not fully captured in this study. The analysis focuses on conventional cigarette smoking but does not separately assess the burden attributable to vaping, smokeless tobacco, or second-hand smoke exposure. Additionally, no information is available on the frequency of smoking in former smokers, which limits insights into the long-term effects of different smoking patterns.

Underreporting of Alcohol Use Data. For alcohol-related burden estimates, the approach used to correct for underestimation follows the methodology applied by WHO/GHO, which has its own inherent limitations. Alternative approaches or supplementary data sources could enhance the robustness of alcohol-related burden estimates in future studies.

5 RECOMMENDATIONS

Based on the findings from the SUBOD project, we outline a series of policy recommendations. These recommendations were shaped through discussions with our follow-up committee, representing Belgium's public health sector. For each theme, we summarize the supporting key findings and their relevance to the study. The recommendations are categorized into five key themes:

1. **SUSTAIN**: Maintain and strengthen the developed monitoring framework
2. **IMPROVE**: Address current data gaps in the monitoring of substance use
3. **EXPAND**: Extend monitoring framework beyond alcohol and tobacco use
4. **ACT**: Strengthen and improve existing policies, regulation, and health literacy while limiting industry interference
5. **IMPACT**: Set up mechanisms to go from estimates to policy

5.1 SUSTAIN — Maintain and strengthen the developed monitoring framework

Maintaining and strengthening the substance use monitoring framework in Belgium is essential to support effective, data-driven public health policies. Accurate, consistent, and timely data, particularly on tobacco and alcohol use, are critical for tracking trends, evaluating past interventions, and guiding resource allocation. The existing time series from 2013–2021, based primarily on the HIS, already serves as a valuable baseline for monitoring tobacco- and alcohol-related mortality. However, improvements are needed to ensure the system remains responsive to changing consumption patterns and emerging public health challenges. Indeed, currently, the HIS is conducted every 4–5 years (Demarest et al., 2018). While this long-standing consistency allows for robust trend analysis, transitioning to more frequent data collection, potentially on an annual basis, could allow to have more timely tracking of substance use behaviors. For example, inviting participants each year to report on selected indicators may provide quicker insights and more timely and accurate data to support policy evaluation and trend assessment.

Improving the monitoring framework also involves enhancing its ability to detect emerging risks, such as shifts in use among young people or the rise of dual use (e.g., smoking and vaping), and addressing persistent socioeconomic inequalities in substance use and its consequences. Regular assessments of the effectiveness of prevention and cessation programs, particularly among vulnerable groups, should be integrated into routine monitoring efforts.

Integration of the monitoring framework within the BeBOD study offers a sustainable path forward, embedding substance use monitoring into Belgium's broader national health data strategy. This integration reinforces the role of monitoring as a foundational tool for evidence-based action and long-term health planning. Moreover, using data from global initiatives, such as the Global Burden of Disease Study, can offer valuable insights into the broader impact of tobacco and alcohol on health. The monitoring framework should also investigate the consumption of alternative tobacco products, such as e-cigarettes and nicotine pouches, and incorporate previous binge drinking behaviours. Understanding the timing of substance use, when individuals begin, the duration of intensive use, and the timing of cessation efforts, will deepen the analysis.

To further improve the framework, greater attention should be paid to socioeconomic disparities and emerging patterns of substance use, such as dual use of tobacco and vaping. These enhancements will support more comprehensive, data-driven public health responses that are equitable and responsive to population needs.

5.2 IMPROVE — Address current data gaps in the monitoring of the burden of tobacco and alcohol use

Accurate and timely data are essential for shaping effective public health policies, particularly concerning tobacco and alcohol use. By assessing the burden of tobacco and alcohol use in Belgium, the SUBOD project has identified some gaps and limitations in the data inputs required for the calculations. Indeed, one major challenge with the method we are using is the reliance on mortality data, which often suffers from delays in determining the causes of death. In addition, there is underexposure to indirect mortality caused by alcohol, such as cancers, chronic diseases, and accidents, deaths that are often underestimated due to the reliance on relative risk estimates or incomplete observed data (Rehm, Rovira, et al., 2021; Rehm & Shield, 2014). This statistical lag can obscure the real-time impact of tobacco and alcohol on public health. Furthermore, there is a notable lack of comprehensive exposure data for youth under the age of 15, leaving a significant gap in our understanding of substance use patterns in this vulnerable population. To address these challenges, the implementation of electronic death certificates (e-death certificates) is vital. This approach has shown promise in countries like France and Norway, where faster data processing has led to more accurate and timely reporting of causes of death (Eng et al., 2024; Lefeuvre et al., 2014).

Furthermore, there is a call for incorporating additional data into our monitoring, such as statistics on using proxies such as alcohol intoxication from the (IMA-AIM), to further enhance our understanding of alcohol-related harms. Updating the BHIS to include comprehensive data on alcohol use and its determinants is essential. Collaboration among health agencies (HIS-link) will also play a critical role in enhancing data sharing and integration, leading to more informed public health strategies.

Overall, a comprehensive overview of healthcare interactions related to alcohol problems, encompassing general practitioners, early intervention programs, and emergency services, will be instrumental in developing targeted interventions. Strengthening monitoring and data collection will support ongoing assessments of alcohol use. Also, about the use of classic and newer tobacco products, better registration in patient records, for example, could be very helpful for setting up better care and better follow-up care. Both smoking status and smoking cessation status, with e.g. information on previous smoking cessation attempts, could improve the quality of care, informing policy decisions and ensuring a responsive approach to public health challenges. Lastly, collecting representative exposure data related to tobacco or alcohol consumption will be critical for establishing a clearer picture of tobacco and alcohol use trends, allowing policymakers to make informed decisions that effectively address these public health challenges. Those findings help us understand limitations regarding the data use and how addressing those challenges can help improve the monitoring of substance use. By launching this first national effort to improve monitoring as part of the SUBOD project, Belgium can better understand the impacts of these substances on public health and implement effective strategies to mitigate their harm.

5.3 EXPAND — Extend the monitoring framework to other risk factors

The SUBOD project focused initially on tobacco and alcohol use as a first step towards integrating risk factors into the BEBOD study. other addictive behaviors, are also important to consider in the context of the ACD.

The CRA framework is a robust methodology that can be effectively applied to a variety of risk factors (Plass et al., 2022). While each risk factor possesses unique characteristics that necessitate tailored approaches, the overarching principles of the CRA framework allow for a consistent evaluation strategy. By expanding our monitoring to include additional risk factors, we can gain a more comprehensive understanding of public health dynamics in Belgium. As part of the SOCOST2 project, the health and cost implications of **gambling** in Belgium, acknowledging its rising profile as a public health concern will be assessed. This application will contribute to the broader Belgian National Burden of Disease Study.

There is also a pressing call to expand our focus to include **illicit drug use** such as cannabis, cocaine and ketamine use, which presents a critical area of concern for public health. By integrating data on substance use beyond just alcohol and tobacco, we can better understand the new emerging risks affecting the population and formulate targeted interventions.

Another important aspect to consider is the trade-off between different risk factors. For instance, when individuals decide to quit drinking alcohol, there may be a tendency to compensate by increasing food intake, potentially leading to overeating and subsequent weight gain, or live a healthier lifestyle. Understanding these behavioural interactions is crucial for developing effective public health strategies that address multiple risk factors simultaneously, rather than in isolation, which is currently a limitation of the CRA framework.

Moreover, the role of social norms and cultural factors in shaping health is not to be overlooked. Understanding how societal attitudes influence individual choices is essential for designing interventions that resonate with the community. By addressing these social determinants of health, we can foster environments that encourage healthier lifestyles. For now, the project assesses the burden of tobacco and alcohol use by age, sex, region, and education status as a proxy for socio-economic status. Expanding to other variables driving health inequity can help reduce the widening gap among individuals. This will be further explored in the proposed SOCOST2 project, which is currently under review.

In addition, evaluating the costs associated with exposure to second-hand and third-hand smoke, as well as prenatal exposure to alcohol use, will highlight the broader public health implications of tobacco use. Investigating intergenerational patterns and coping mechanisms can provide further insights into substance use dynamics in Belgium.

Looking into the future, examining disease-specific costs associated with various risk factors will provide valuable insights into the economic burden imposed on the healthcare system. This analysis will not only highlight the financial implications of poor health outcomes but also assist in prioritizing interventions and allocating resources effectively.

5.4 ACT — General recommendations based on the results

- Strengthen existing policies

Our findings indicate that tobacco and alcohol use remain major contributors to ill health and premature mortality in Belgium, and this leads to high costs for society. While guidelines such as the SAFER framework (World Health Organization, s. d.-g) and the Framework Convention on Tobacco Control (FCTC) (World Health Organization, s. d.-h) have driven significant progress in reducing alcohol and tobacco consumption, challenges persist. The FCTC emphasizes the importance of comprehensive smoke-free policies and advertising bans (among others), while the WHO SAFER framework advocates for increased alcohol taxes (among others) (World Health Organization, s.d.-d, s.d.-a). Implementing such measures has been shown to be effective (Rehm et al., 2023). Additionally, recommendations from the Superior Health Council highlight the need for continued vigilance, including measures like raising the legal age for purchasing tobacco and alcohol (Conseil Supérieur de la Santé., 2024, 2025).

Despite these advancements, our results show that although cigarette smoking has declined, it may continue to pose a public health concern, especially as inequalities widen among different regions and educational levels. Regarding alcohol use, the consumption also remains problematic, with no significant decrease in the number of current drinkers and a projected rise in average daily consumption. The cost related to alcohol and tobacco consumption in Belgium amounts to 1.2 billion euros annually, which can be avoided if no one were drinking or smoking.

For the first time ever, Belgium has adopted a national alcohol plan, an important milestone made possible through coordinated action across policy levels. However, our results highlight that past consumption patterns and existing policies have not been sufficient to reduce alcohol use. If current trends continue, alcohol consumption is expected to rise in the coming years.

To effectively address these challenges, Belgium must strengthen its ongoing initiatives and adopt more ambitious policies to reduce the health and economic burdens associated with tobacco and alcohol use. Achieving the goal of a “smoke-free generation” by 2040 and curbing harmful alcohol consumption requires a more thorough reevaluation of the Interfederal Strategy for Tobacco and Alcohol (Cellule Général de Politique de Drogues, 2022, 2023), which outlines key objectives and proposed actions. However, it is important to note that not all measures included in these strategies are (or will be) currently implemented.

To support these objectives, both tobacco and alcohol strategies should be fully implemented and prioritized measures such as increasing prices, marketing ban, implementing clear warning labels, restricting product availability, and raising the minimum purchase age (Conseil Supérieur de la Santé., 2024; World Health Organization, 2024). Success in these measures relies on collaboration among various stakeholders, including federal, regional, and local governments, non-governmental organizations, educational institutions, and the healthcare sector (World Health Organization, 2024). Public engagement is also needed, as fostering broad societal support is essential for achieving the ambitious goals of a smoke-free generation and reducing alcohol consumption.

Moreover, improving screening and brief interventions for alcohol use within healthcare settings, workplace, and productivity initiatives where companies can actively promote a smoke-free and alcohol-responsible culture, could benefit from incentives that encourage employee well-being, alongside integrating smoking cessation support into the health system, can significantly improve intervention effectiveness. Campaigns like *Tournée Minérale* should continue to promote awareness and encourage alcohol-free lifestyles, ensuring that preventive efforts resonate with the public and contribute to a healthier society. Similar initiatives regarding tobacco use, such as campaigns like *Mois sans Tabac* in France or *Stoptober* in the UK and the Netherlands, have also been proven effective and cost-effective. The evaluation of *Mois sans Tabac* by Santé Publique France and the OECD found that every € 1 invested saves € 7 in health care costs (Santé Publique France, 2023).

Regarding the cost, our results highlight that economic and social considerations must be considered when developing public health policies. The economic impact of alcohol and tobacco on healthcare budgets and national productivity requires careful evaluation to ensure cost-effective interventions. It is also important to address socioeconomic disparities, as lower-educated individuals tend to have higher rates of smoking and, although they are less likely to be current drinkers, they often consume larger quantities of alcohol when they do drink. Tailored prevention and intervention strategies for these populations can help reduce health inequalities and economic strain.

To achieve a meaningful reduction in alcohol consumption and its related harms, more ambitious and effective measures are needed, and were suggested by stakeholders, such as:

- Raising the minimum age for alcohol sales and introducing stricter controls on availability, such as banning alcohol sales in hospitals, gas stations, highway service areas, and night shops.
- Implementing a comprehensive ban on alcohol advertising and sponsorship, particularly in sports, to reduce exposure and influence on public behavior.
- Increasing alcohol prices through taxation and introducing a minimum unit price are both proven effective measures to reduce consumption.
- Reducing the density of alcohol shops and ensuring greater availability of non-alcoholic alternatives in public spaces.
- Developing a long-term national strategy that addresses overall alcohol use, not just harmful consumption, with clear objectives and accountability mechanisms.
- Protecting alcohol policy development from industry interference, as has been done successfully in tobacco control.

In parallel, tobacco control efforts must also be reinforced by:

- Expanding smoke-free environments to include more public spaces (f.i, beaches or terraces of bars and restaurants)
- Increase tobacco taxation, the best measure in tobacco control, going hand in hand with better help for smokers to quit the nicotine addiction
- Strengthening regulations on e-cigarettes and other tobacco-related products is essential to prevent uptake among youth and ensure consistent public health protection. At the same time, for adults who already smoke, the temporary use of e-cigarettes, as an effective cessation aid or a less harmful nicotine source, can support smoking cessation and offer health benefits, particularly for those unable or unwilling to quit immediately, in line with the advice

of the Superior Health Council. For smoking cessation aid, special attention is needed to better serve the most disadvantaged groups in society, including individuals with lower socio-economic status, people with mental health conditions, and those in prison settings.

- Continue reducing the number of points of sale for tobacco and nicotine products, and introduce a licensing system for retailers to strengthen oversight, limit access, especially for youth, and align sales practices with public health goals.

Indeed, such policies have been proven effective in the reduction of hospitalizations and fully attributable deaths in Scotland (Wyper et al., 2023) and are recommended in several international but also national reports from the High Council for health (Conseil Supérieur de la Santé., 2024) and some are already stated in the Inter federal strategy for a smoke-free generation (Cellule Général de Politique de Drogues, 2022). Australia has implemented similar strategies, but with a more stringent and ambitious focus on improving population health through a tobacco-free approach (Greenhalgh et al., 2024).

- Limit industry interference and strengthen regulation

While our findings focus on the burden of disease and related costs associated with tobacco and alcohol use in Belgium, they point to the continued need for stronger public health action. Indeed, to support meaningful reductions in consumption, it is essential to limit the influence of the alcohol and tobacco industries on policy development. This influence can also help understand stagnating consumption trends, especially regarding alcohol use.

Although our study does not assess the impact of specific policy measures, evidence from the wider literature increasingly highlights how industry lobbying delay, weaken, or obstructs effective public health policies (Garde et al., 2025; Gilmore et al., 2023). For instance, strategies used by the food industry on sugar-sweetened beverages and ultra-processed foods, such as reframing public health issues or opposing fiscal measures, mirror those historically used by the tobacco and alcohol industries (Lauber et al., 2022; Serodio et al., s.d.; VAD, 2022).

Safeguarding the independence of public health policies from industry interests remains crucial. Frameworks like the Commercial Determinants of Health (CDOH) provide useful guidance in this regard (Gilmore et al., 2023). National efforts, such as stricter regulation of advertising, particularly in sports and cultural settings, and enhanced control of emerging products like electronic smoking devices, may contribute to reducing exposure and use.

Ongoing projects at Sciensano, including analyses of **corporate political activity** and participation in the **Global Tobacco Industry Interference Index**, aim to provide a better understanding of how industry strategies may influence policymaking in Belgium. This index evaluates countries based on their efforts to counter industry influence, with a lower score indicating less interference from the tobacco industry. However, it is essential to note that the index relies solely on official data, and therefore captures only part of the actual influence exerted by the industry. These efforts are especially relevant when considering policies that affect vulnerable groups, such as youth, pregnant women, and those from lower socioeconomic backgrounds.

- Improve public awareness and health literacy

Our findings highlight the continued health burden associated with tobacco and alcohol use, underlining the need for a comprehensive and sustained prevention approach when addressing both risk factors. This means investing across the entire **prevention continuum**: from primary prevention (stopping problems before they start), through early intervention and assistance, to harm reduction and social reintegration. Addressing all levels of this continuum is crucial not only to reduce the future burden of disease but also to tackle **persistent health inequalities** by addressing the social determinants of health and promoting **equity** across populations.

Public understanding of the risks associated with alcohol and tobacco use remains limited. Even low levels of alcohol consumption can increase health risks, yet awareness of these dangers is low (World Health Organization, 2024). This lack of understanding can be attributed to insufficient information about the harms of alcohol and can be translated into the stagnation of the prevalence of current drinkers in Belgium. Strengthening alcohol health literacy through effective labeling, pictograms, and clear messaging is one element to better inform consumers, as suggested by WHO's Best Buy and international recommendations (World Health Organization, 2024).

Similarly, for tobacco use, targeted campaigns should emphasize that quitting smoking at any age significantly reduces disease risk. Most tobacco-attributable deaths occur among current smokers, while those who quit, especially at younger ages, can gain up to 10 years of life expectancy and, in some cases, approach the longevity of never-smokers (Gruer et al., 2009; Jha et al., 2013; Pirie et al., 2013; Reitsma et al., 2021). This message is particularly important for older smokers (aged 55 and over), who not only have the highest rates of cigarette consumption but also bear a disproportionate burden of premature mortality, as shown in the findings of the SUBOD project.

5.5 IMPACT — Set up mechanisms to go from estimates to policy

- Future Directions

By systematically tracking trends, we can assess the current state and evaluate how policies influence these trends through ex-post evaluations, helping us understand the effectiveness of past interventions. However, current data alone cannot continuously evaluate the impact of policies on the population, highlighting the need for a more comprehensive approach that integrates both evaluation and monitoring stages to enhance policy development and effectiveness.

Looking ahead, the framework should expand to include **Health Impact Assessments (HIA).** The HIA framework offers a promising approach to linking estimates with policy decision-making. It evaluates the potential health effects of policies across various sectors, such as transportation, housing, and taxation, considering both direct and indirect impacts (World Health Organization, s. d.-e). By providing evidence-based insights, HIA helps policymakers identify risks and benefits, supporting informed decision-making. Beyond assessing health outcomes, HIA fosters cross-sector collaboration, engaging stakeholders and emphasizing the connections between health, environmental, social, and economic factors. It also raises awareness among decision-makers about the broader health implications of their actions (World Health Organization, s. d.-e). Although not used in this project, HIA is a valuable tool for integrating health considerations into policy, strengthening the evidence base, and ensuring more effective public health strategies (World Health Organization, s.d.-b).

To improve the monitoring of indicators and evaluate the implementation and impact of national plans, Sciensano, through the IMPACT project (proposed project currently under review), aims to use HIA to provide actionable recommendations for decision-makers and stakeholders. These recommendations will guide data-driven decisions regarding alternative and enhanced public health interventions. Furthermore, incorporating HIA into our framework will enable us to conduct ex-ante evaluations, modeling the potential impacts of future policies before they are implemented, ensuring decisions are based on robust evidence and better anticipating their outcomes.

- Navigating the political landscape in Belgium

Navigating the political complexity of Belgium presents significant challenges in implementing effective public health policies, particularly when addressing substance use. The country's federal structure, divided into regional and community governments, often leads to fragmented approaches to public health issues. Each region has its own priorities and governance, which complicates the creation of cohesive, nationwide policies and, in the long run, can create disparities within and between regions (Levy & Annemans, 2023), as highlighted in the results of the project.

Another layer of complexity is that alcohol and tobacco regulations also come from the EU level, where industry interests can influence decisions, further complicating Belgium's ability to implement robust national policies (Kluge et al., 2025). The strong influence of tobacco and alcohol industries at the EU level, through lobbying efforts and campaigns, often aims to soften regulations or delay stronger policy measures (Gilmore et al., 2023; The Lancet, 2023; Willemsen et al., 2022). These industries frequently push back against stricter regulations or higher taxes, citing economic impacts and questioning the effectiveness of public health measures (Gilmore et al., 2023). This, coupled with ongoing EU-level debates, can delay the implementation of effective public health measures in Belgium. The combination of political fragmentation at the national level and industry influence at both the EU and national levels creates significant barriers to achieving comprehensive public health policies (Duncan, 2002). As a result, EU policies on tobacco and alcohol use directly impact Belgium's political landscape, contributing to further delays in enacting effective measures (McCambridge et al., 2019).

A key moment in Belgium's policy development came with the introduction of the first national plan specifically addressing alcohol use in 2023. This initiative marked a significant step forward by recognizing the need to tackle alcohol-related harm at a national level. However, the plan primarily focused on harmful alcohol use without considering the broader context of overall consumption patterns or preventive measures that could reduce alcohol use at all levels. This limited scope may have been influenced by political and economic pressures from the alcohol industry, which has historically resisted policies that could harm its profits.

Another pivotal moment was the adoption of the 2022–2028 Inter-federal Strategy for a Smoke-Free Generation. For the first time, Belgium has a relatively comprehensive anti-tobacco plan, jointly endorsed by federal and regional governments. The major challenge now lies in fully implementing the agreed strategies and operational targets. However, to truly achieve a smoke-free generation by 2040, several key policy levers are still missing.

In times of budget constraints, innovative funding mechanisms may be necessary. One option is to require the tobacco industry to contribute financially to prevention and cessation efforts, as recently implemented in Canada. There, tobacco companies will reimburse the government based on market share, covering costs related to cessation programs, public campaigns, compliance and enforcement, research, indigenous initiatives, and international cooperation under the FCTC (Gouvernement du Canada, 2024).

There is a growing call for effective government collaboration across all layers of governance, transparent dialogue, and sustained public pressure to ensure that public health policies are both evidence-based and equitable. Moving forward, a broader, more inclusive approach to alcohol policy, addressing that all levels of consumption can lead to an increased risk for diseases and that focuses on prevention such as: prevention (preventing problems), early intervention (intervening early), assistance, harm reduction and social integration, will be essential to securing the long-term health and well-being of the population.

- Knowledge transfer and collaboration

One key solution to strengthen the impact of the monitoring framework is having a more systematic exchange of insights with stakeholders. Regular presentations at platforms such as the ACD or other policy forums can provide a space for sharing data, trends, and recommendations, ensuring that key actors are informed and engaged. Furthermore, it is essential to continue building and nurturing the relationship between Sciensano, UGent, and the FOD volksgezondheid/SPF santé publique, which was fostered during the SUBOD project. This collaboration is critical for ensuring that evidence generated from monitoring and evaluations directly informs policy decisions and contributes to effective, evidence-based public health strategies.

To effectively address the public health challenges associated with tobacco and alcohol use in Belgium, it is essential to continue implementing a comprehensive communication strategy. While maintaining existing initiatives, there is a pressing need to strengthen capacity building and collaboration with key organizations, particularly in advocacy and communication. Engaging specialists in these areas will enhance our ability to convey health messages and mobilize citizens (Street et al., 2014).

Dissemination and knowledge transfer were also part of the core of the SUBOD project. A well-designed communication strategy, led by specialists, can draw attention to the costs and cost savings associated with interventions, helping decision-makers. Strengthening the link between estimates and policy can be achieved by incorporating foresight exercises into the decision-making process. These exercises help anticipate future trends, identify potential risks and opportunities, and establish clear priorities. By adopting a forward-looking approach, policies can become more adaptable, proactive, and better suited to addressing emerging challenges (Pagel et al., 2024).

- Focus on Economic Impact

Additionally, addressing the economic impact of substance use is critical. The issues of productivity loss and absenteeism due to alcohol and tobacco-related health problems must be highlighted. However, there is often a lack of know-how in the prevention sector regarding the estimation of the cost-effectiveness of various interventions. This gap can affect the development of evidence-based policies. Indeed, tensions between the revenue generated from tobacco taxes and the economic costs of tobacco use necessitate a careful examination. We need to explore solutions such as training and developing guidelines that can help practitioners effectively communicate these issues, especially during relevant media coverage (e.g., discussions around alcohol consumption in traffic incidents).

Another call suggested was projecting the total value of taxes against the economic costs of tobacco and alcohol use would help evaluate the feasibility of proposed interventions and the potential return on investment.

- Public Health Lobbying

A crucial component of this strategy involves public health lobbying. Identifying key actors and stakeholders who can support our initiatives. This includes forming alliances with health organizations, academic institutions, and community groups that share a common goal of reducing the burden of tobacco and alcohol consumption. By working together, we might influence policy decisions more effectively.

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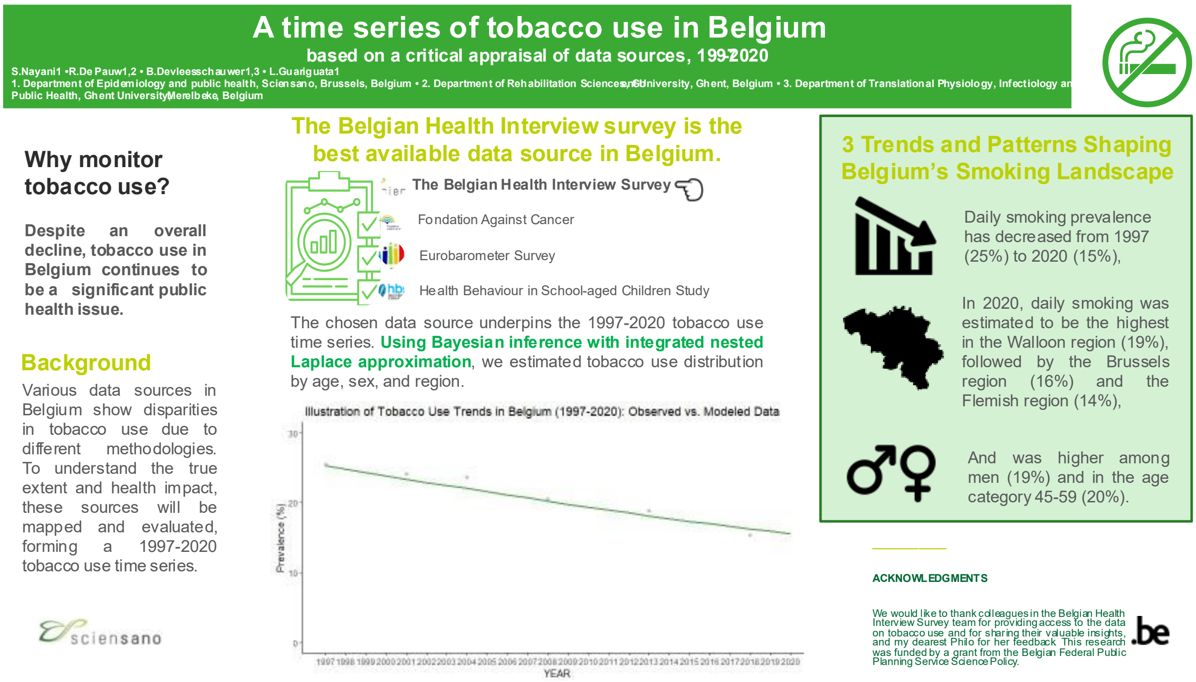
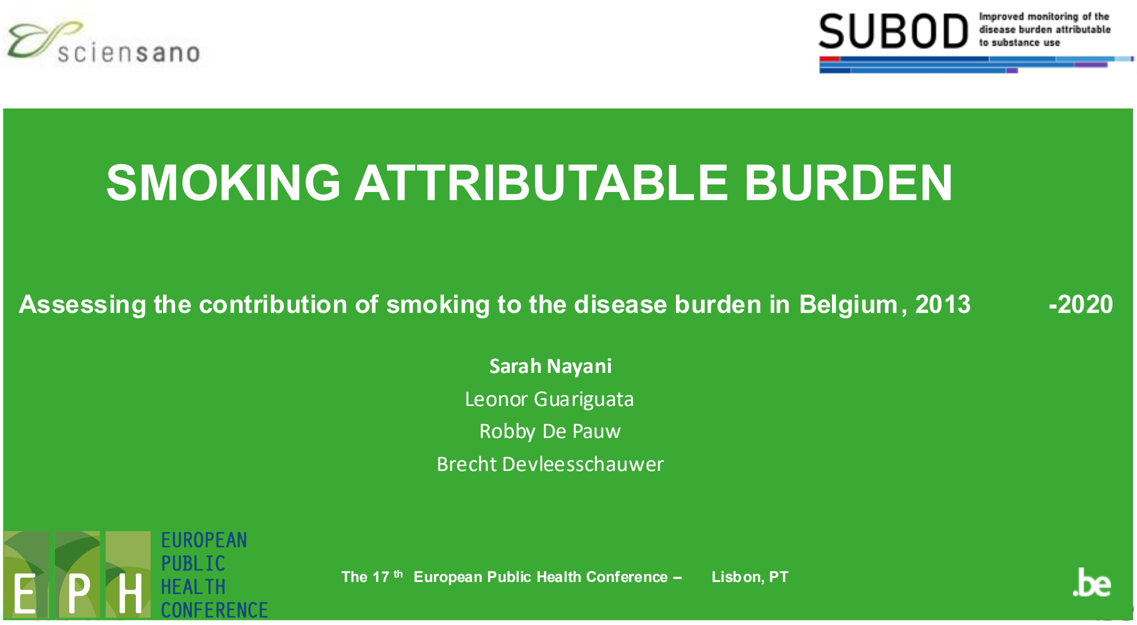
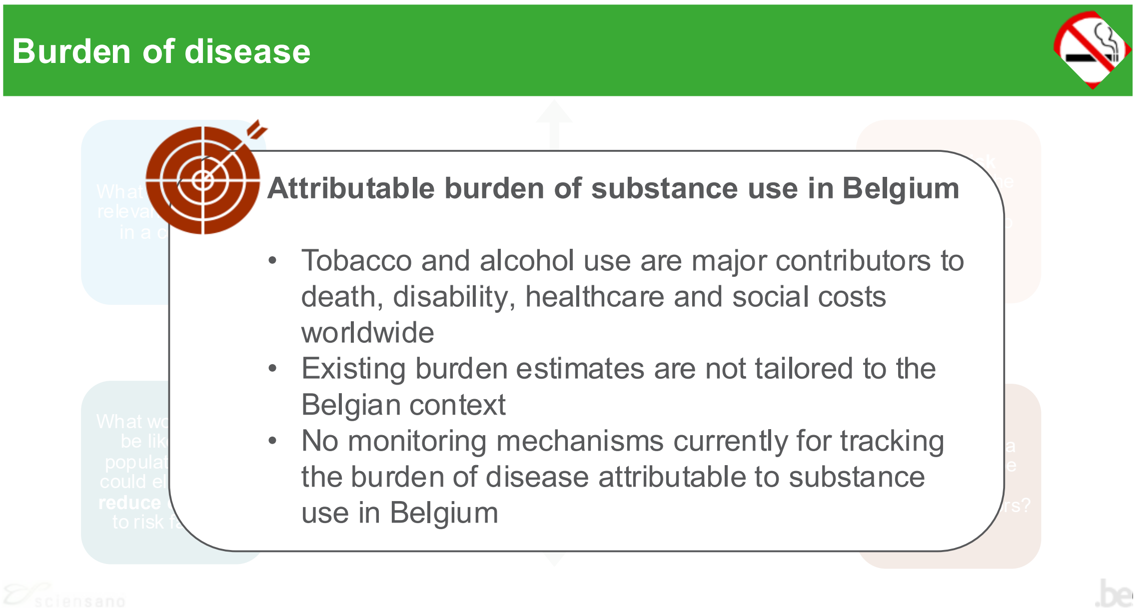
ANNEX

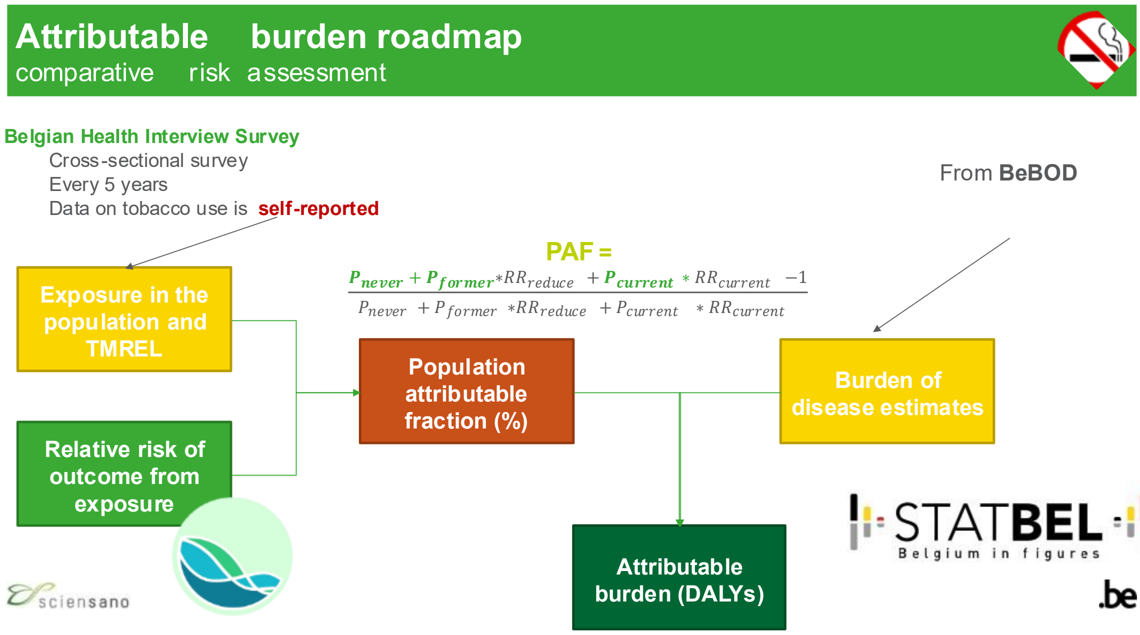
1. Poster presentation of a time series of tobacco use in Belgium, based on a critical appraisal of data sources, 1997-2020 (EPH 2023)



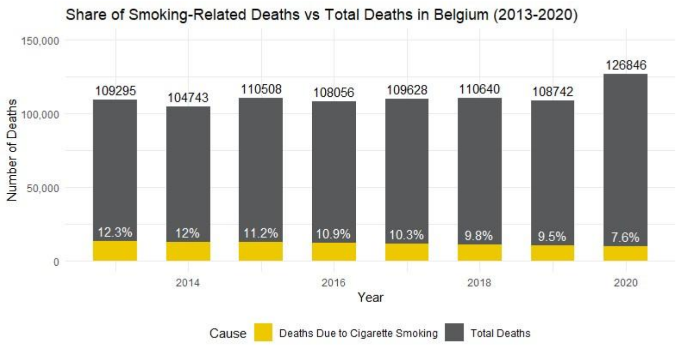
2. Presentation of the burden attributable to smoking (EPH 2024)




Burden of disease
Attributable burden of substance use in Belgium
• Tobacco and alcohol use are major contributors to death, disability, healthcare and social costs worldwide
• Existing burden estimates are not tailored to the Belgian context
• No monitoring mechanisms currently for tracking the burden of disease attributable to substance use in Belgium


Attributable burden roadmap
comparative risk assessment
Belgian Health Interview Survey
Cross-sectional survey
Every 5 years
Data on tobacco use is self-reported
From BeBOD
PAF =
$\frac{P_{never} + P_{former} * RR_{reduce} + P_{current} * RR_{current} - 1}{P_{never} + P_{former} * RR_{reduce} + P_{current} * RR_{current}}$
Exposure in the population and TMREL
Relative risk of outcome from exposure
Population attributable fraction (%)
Burden of disease estimates
Attributable burden (DALYs)

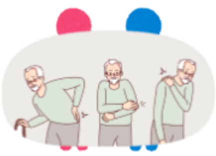
Smoking-related deaths are decreasing over time

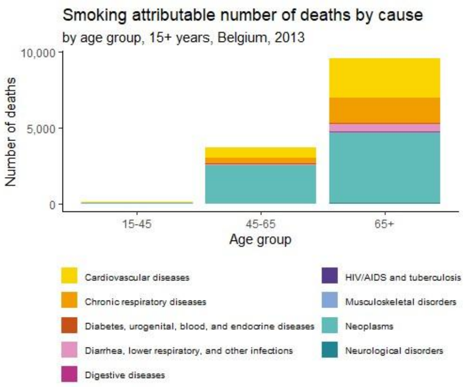


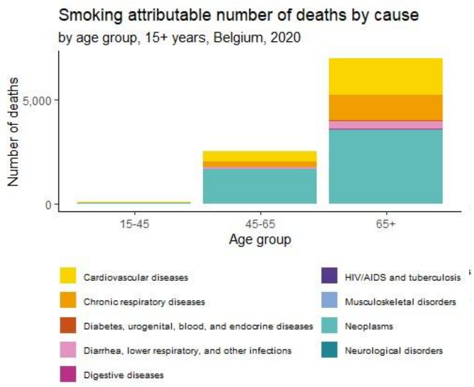
Smoking-related deaths :

- **2013**: 13,469 deaths (PAF = 12,3%)
- **2020**: 9,598 deaths (PAF = 7,6%)

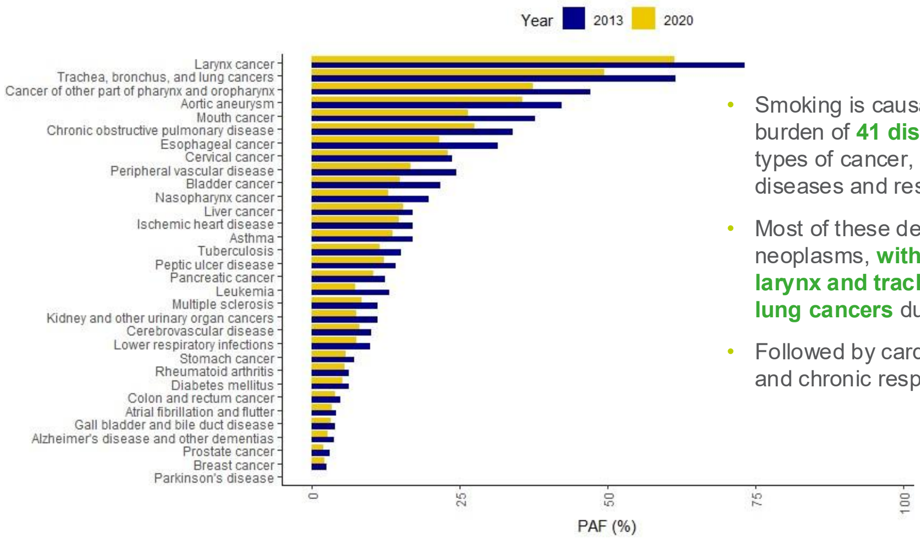
Most smoking-related deaths occur in males, and mainly in old age







Tobacco use remains a leading contributor to cancer deaths among both gender



- Smoking is causally linked to the burden of **41 diseases** including 19 types of cancer, 7 cardiovascular diseases and respiratory diseases
- Most of these deaths are due to neoplasms, **with around half of all larynx and trachea, bronchus, and lung cancers** due to tobacco use
- Followed by cardiovascular diseases and chronic respiratory diseases

Strengths and limitations

Strengths

- Robust data from a nationally representative sample
- Modelling strategy for the modelling of exposure data
- Strategy to identify and quantify sets of ROP
- Use of local data to understand the impact of smoking-related deaths in Belgium and to inform stakeholders to drive the focus:
  - Share of the deaths due to cigarette smoking (**avoidable**)
  - Ranking of smoking-related deaths

Limitations

- Exposure data are **self-reported**
- Modelled exposure data on repeat cross - sectional surveys
- RR are **not age or sex-specific** (under or over-estimation of the burden)
- Changes in tobacco products (e.g., e - cigarettes) are **not addressed**, which could affect the overall burden and trends in smoking-related diseases

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Take home message

Despite a decrease in smoking-related deaths in Belgium, tobacco use continues to be a **major public health challenge**, particularly among men. Smoking continues to impose a persistent burden on population health, with specific cancers, such as larynx and lung cancer, being major contributors. There is a critical need for **ongoing monitoring and evaluation of tobacco policies**, alongside **targeted prevention strategies** to further reduce the impact of smoking-related diseases.

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3. Oral presentation on expanding standard methodologies for correcting under-reported alcohol use survey data for the establishment of a time series in Belgium, 1997-2018 (BURDEN-EU conference 2024)

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SUBOD Improved monitoring of the disease burden attributable to substance use

ATTRIBUTABLE BURDEN OF ALCOHOL USE

Expanding standard methodologies for correcting under-reported alcohol use survey data for the establishment of a time series in Belgium, 1997-2018

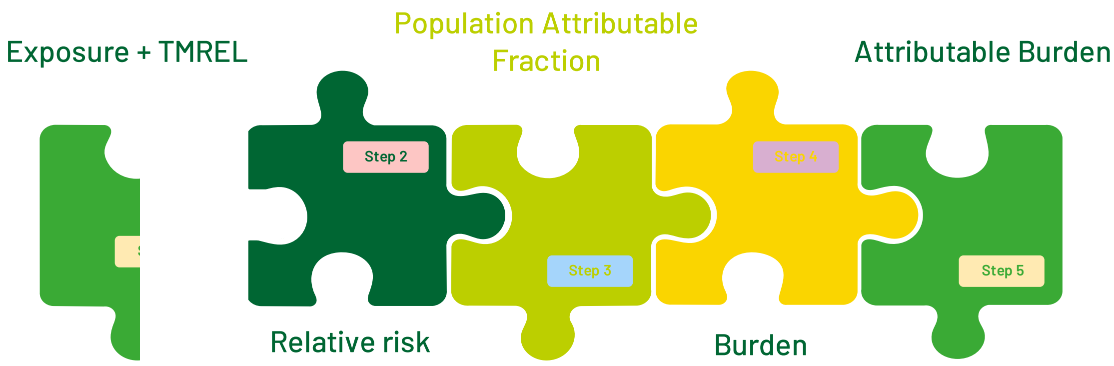
Sarah Nayani
Brecht Devleesschauwer
Leonor Guariguata

european burden-eu of disease network

2nd International Burden of Disease Conference – Trieste, IT 15 March 2024

.be

Alcohol attributable burden roadmap
comparative risk assessment



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Data availability and needs for the exposure

$$\text{PAF} = \frac{P_{abstainers} + P_{former}RR_{former} + \int_0^{150} P_{current}(x)RR_{current}(x)dx - 1}{P_{abstainers} + P_{former}RR_{former} + \int_0^{150} P_{current}(x)RR_{current}(x)dx}$$

- Data source: **Belgian Health Interview Survey**
  - Cross-sectional survey
  - Every 5 years
  - Data on alcohol use is **self-reported**
- Data needs:
  - Prevalence of drinking status: current (1997 -2018), former, and lifetime abstainers (2013 -2018)
  - Mean consumption in grams per day for current drinkers(2008 -2018)

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Survey data are under-reporting alcohol consumption

Reasons why:

- High non-response bias
- Survey methodology
- Respondents' behavior, problems in averaging consumption in standard drinks and forgetting (memory bias), or social desirability bias

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Triangulation method based on the work of Rehm et al.

Survey data

- Alcohol use trends over time
- Patterns of consumption among drinkers
- Under-reporting of consumption

Sales data

- Real consumption
- Easily available
- No breakdown by region and age groups

Combining the distribution of alcohol use (gr/day) by gender, age5y, **region** with sales figures

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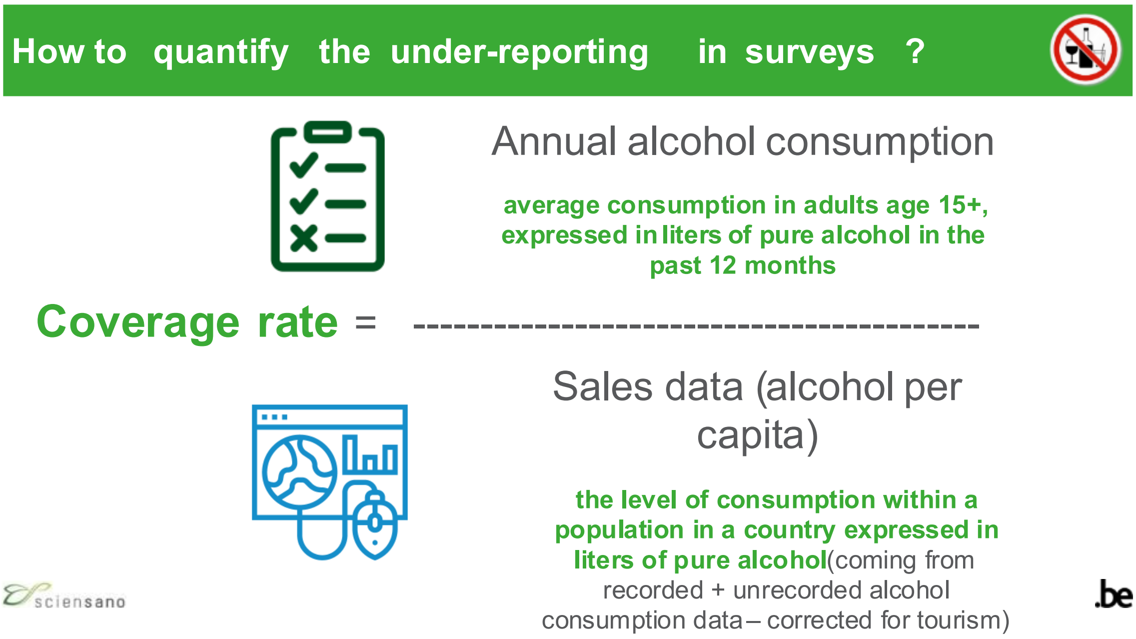
How to quantify the under-reporting in surveys ?
Annual alcohol consumption
average consumption in adults age 15+, expressed in liters of pure alcohol in the past 12 months
Coverage rate = ---
Sales data (alcohol per capita)
the level of consumption within a population in a country expressed in liters of pure alcohol (coming from recorded + unrecorded alcohol consumption data – corrected for tourism)
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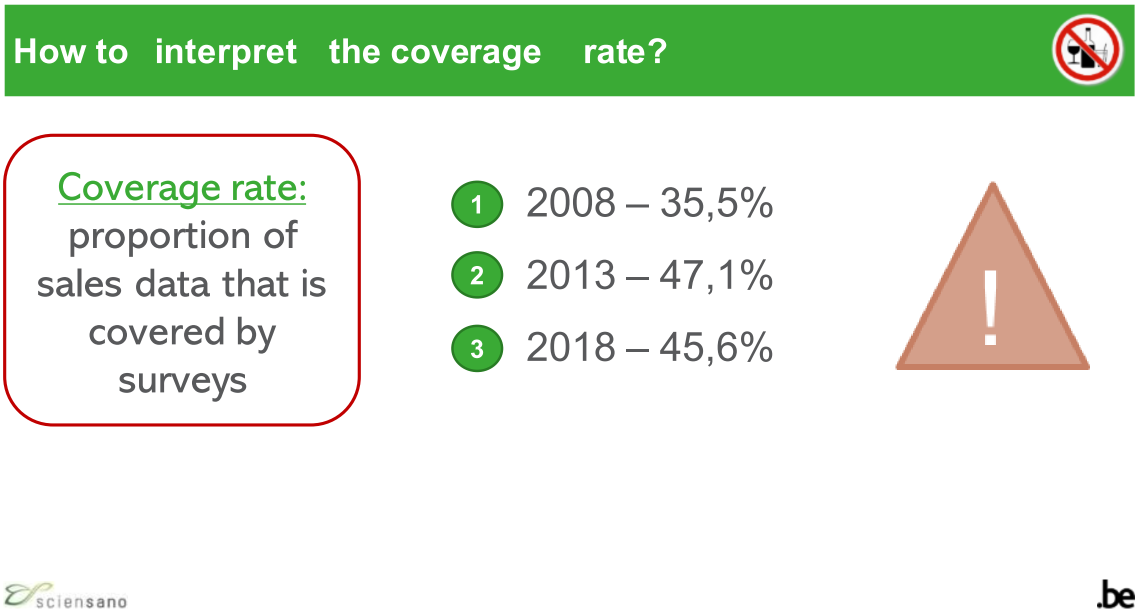
How to interpret the coverage rate?
Coverage rate: proportion of sales data that is covered by surveys
1 2008 – 35,5%
2 2013 – 47,1%
3 2018 – 45,6%
!
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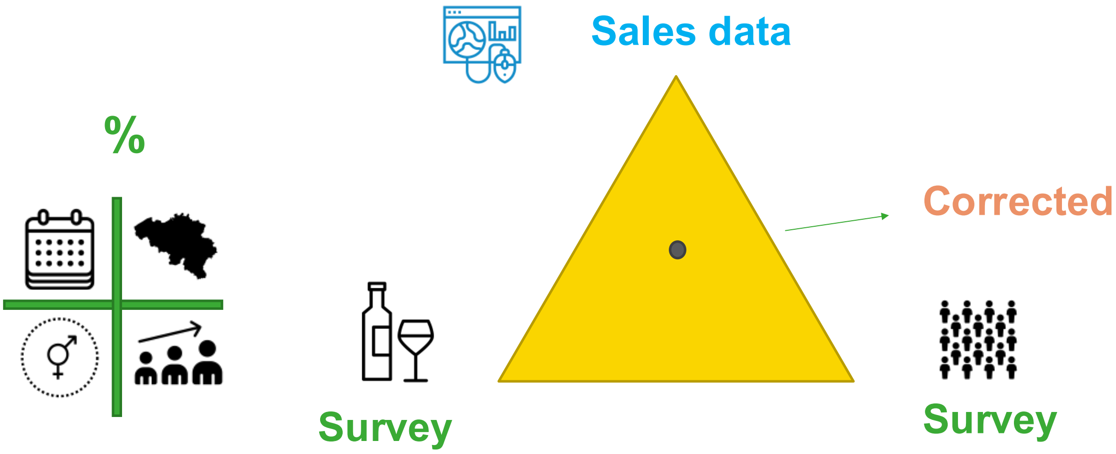
How does the triangulation work ?



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How does the triangulation work ?

Contribution of survey data

1. **Proportion of the mean consumption (gr/day)** for each age group (15+), sex, region, and year **(A)**
2. **Total contribution of the mean consumption in gr/day in the survey** **(B)**

Estimating corrected consumption with sales data

1. Sales data were converted from **liters of alcohol to grams per day.**
2. The corrected survey estimates = **A/B * sales data in gr/day**

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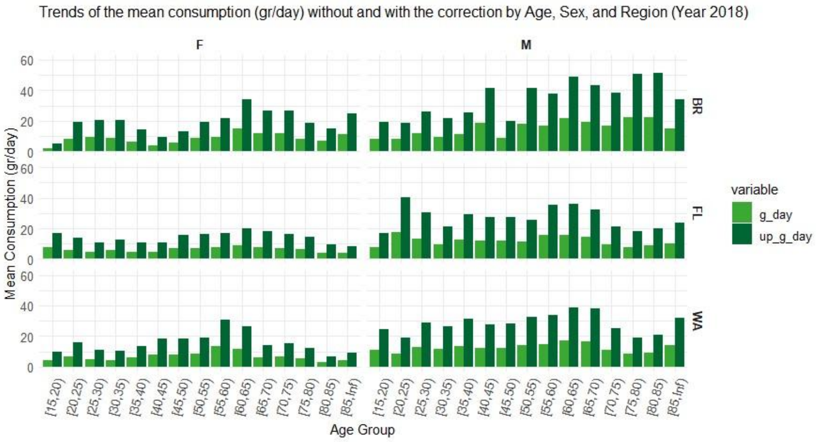
Results of the triangulation on our data



BR > WA > FL

M > F

Differences between regions and gender

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Take home message

Self-reporting surveys underestimate alcohol consumption. Correcting for this under -reporting is essential for obtaining accurate estimates of the share of alcohol (PAF) and alcohol -related burden (AB) to diseases.

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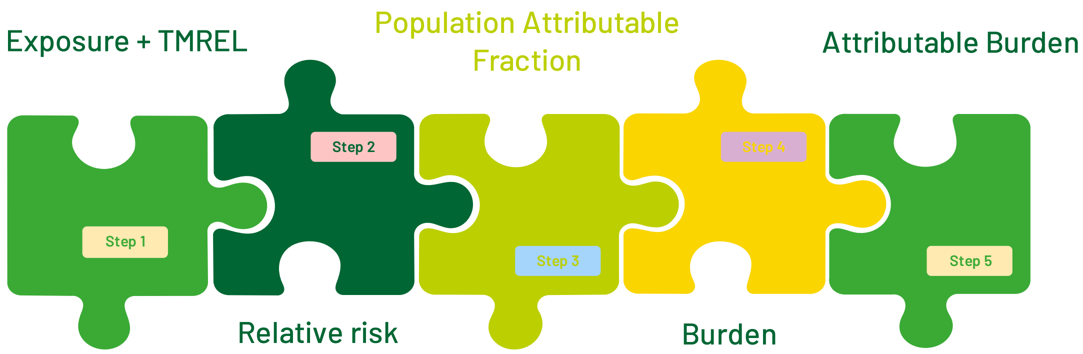
Next steps



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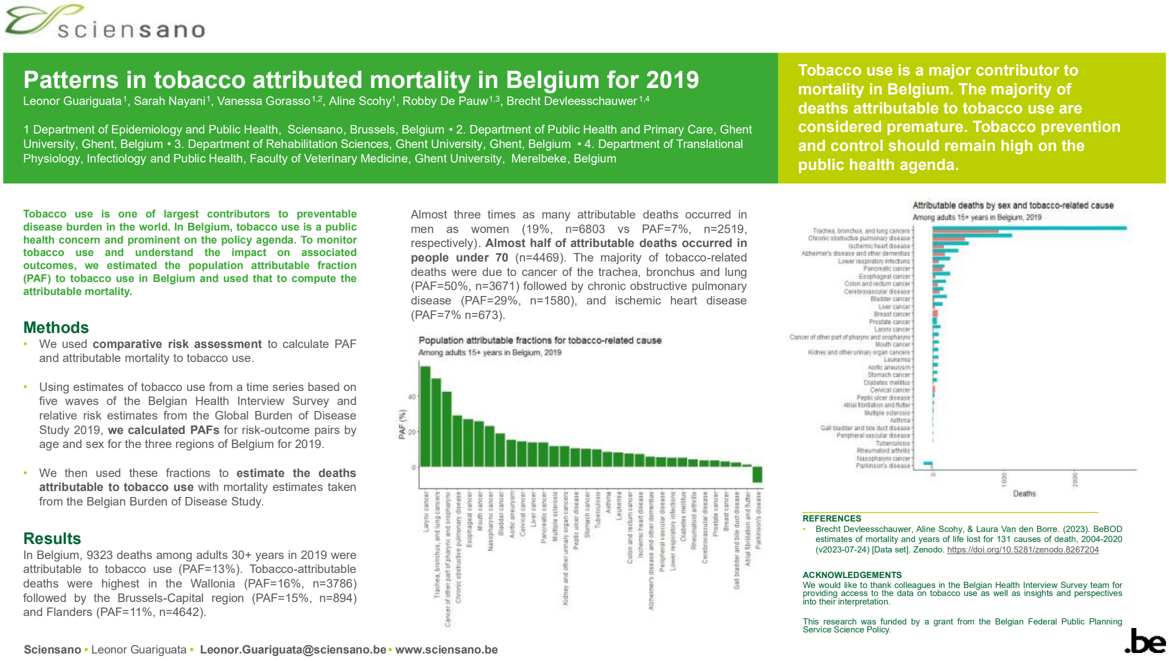
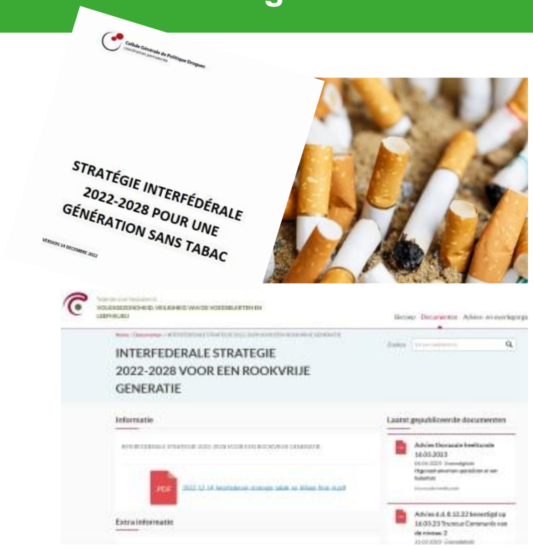
4. Attributable deaths due to smoking poster, 2019 (EPH 2023)



5. Oral presentation : Evaluating achieving tobacco control targets using modelled projections (EPH 2023)

Tobacco use is a major public health issue in Belgium

- **An estimated 15% of adults reported daily smoking in 2018**
- **Inter-federal strategy for a Tobacco-Free Generation**
  - Reduce the number of daily smokers of tobacco to 5% among those 15+ years
  - Reduce the number of people initiating tobacco use to 0% or nearly 0%
  - By 2028, reduce the number of daily smokers among the population 15+ to 10%, and among the population 15-24 years to 6%



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Objectives and Methods

- Objective: **Evaluate the feasibility and progress on targets for tobacco use set by the Inter-federal Strategy for a Generation without Tobacco**

- Data source: Belgian Health Interview Survey
  - Repeated cross-sectional survey - nationally representative, stratified multi-stage, clustered sampling
  - Waves beginning in 1997 with a wave approximately every 5 years
  - Self-reported data on tobacco use is provided by the self-administered individual questionnaire

Read the factsheet at Healthybelgium.be

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Modelling

- We used a Bayesian hierarchical logistic regression model with integrated nested Laplace approximations
  - Mixed effects models to generate annual estimates by 5 -year age group, sex, and region (Brussels, Flanders and Wallonia)
- We then used the population projections (31/1/2023 update) from the Federal Planning Bureau, by age, sex and region, to project this model forward to 2040. These projections were then compared to the targets set forth in the Inter-federal Strategy 2022-2028 for a Tobacco-free generation.
- The trajectories do not take into account any new policies and assume trends continue along their current paths.

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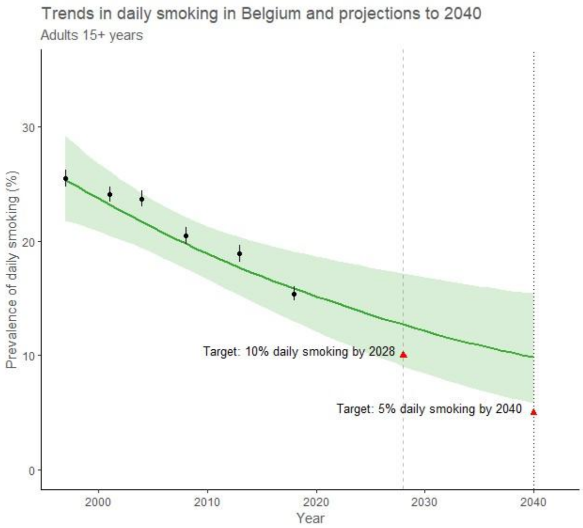
Baseline trends and projections

- Under current trajectories, the adults Belgian population will miss targets for daily smoking set for 2028 and 2040
- There is a wide but narrowing gap of smoking between men and women.

Targets
- Reduce the number of daily smokers of tobacco to 10% by 2028
- Reduce the number of daily smokers of tobacco to 5% by 2040



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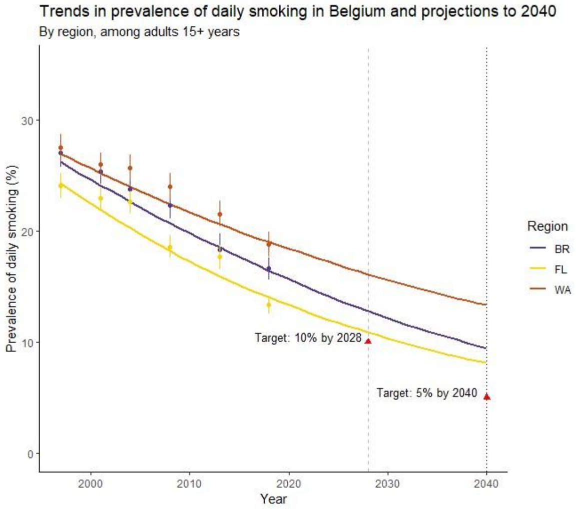
Projections by region

- Three main regions in Belgium
  - Brussels Capital Region
  - Flanders
  - Wallonia
- Diverse in terms of socioeconomic status, population demographics and social determinants
- Wallonia is the poorest and has the worst indicators for health – this is similar for tobacco
- Gaps across regions persist with Flanders on a closer track to achieving targets



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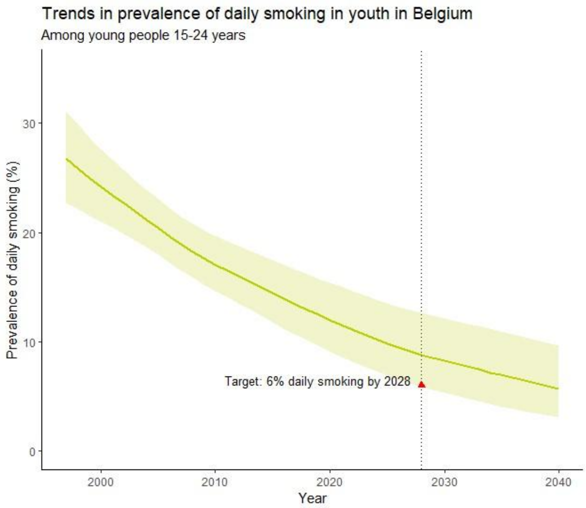
Impacts for youth 15-24 years

- Trajectories for youth 15-24 years show a slightly steeper decline than for adults
- The age of initiation of daily smoking in Belgium is between 17 and 18 years
- Current trends indicate the target will be missed for the 15-24 year olds

Target
- Reduce the number of daily smokers of tobacco in youth 15-24 years old to 6% by 2028



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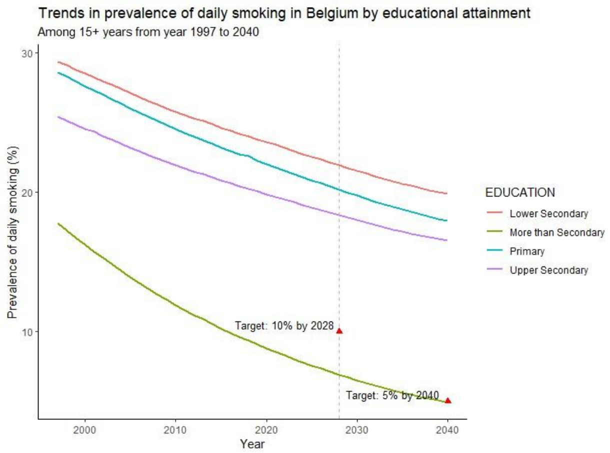
Inequalities in tobacco use are wide and persistent

- Inequalities exist in tobacco use by educational attainment
- Those with a greater than secondary education smoke at less than half the rate of those without
- Inequalities will widen over the coming years
- Policies must take this into account



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Strengths and limitations

Strengths

- Robust data from nationally representative sample
- Allows for modeling of strata of interest and diving into important details
- Flexible modeling approach

Limitations

- Modelled data on repeat cross -sectional surveys
- No current possibilities for modeling scenarios for changing trajectories
- Other stratification by social determinants is limited by missing data so may be missing a broader picture

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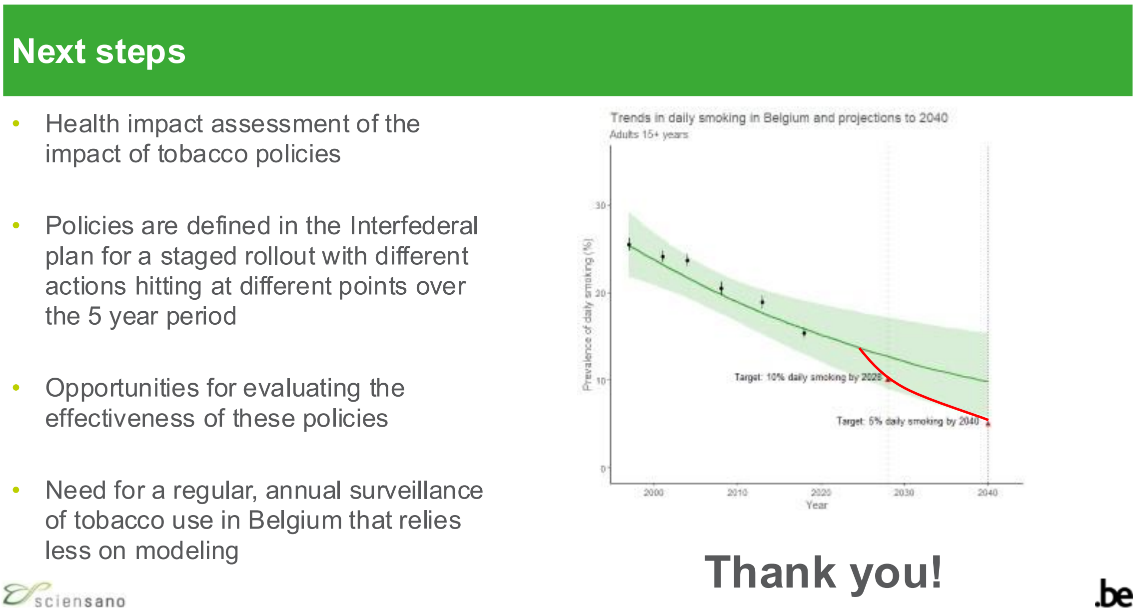

6. Factsheets

https://www.healthybelgium.be/en/health-status/factsheets/tobacco-control-policies-are-needed-to-change-smoking-trends

7. Healthy belgium pages

https://www.healthybelgium.be/en/health-status/burden-of-disease/risk-factor-attributable-burden

8. Press

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14 procent meer alcoholdoden in België in minder dan tien jaar

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Elke dag sterven in ons land elf mensen aan de gevolgen van alcoholgebruik. ©Bloomberg

OLAF VERHAEGHE

Même une faible consommation d'alcool augmente le risque de mortalité, selon Sciensano

Boire de l'alcool, même à faible dose, augmente le risque de décès. C'est ce que montre, pour la première fois, une étude réalisée en 2021 en Belgique par l'institut de santé publique, Sciensano.

Belga | Agence

Publié le 30-01-2025 à 11h48 - Mis à jour le 30-01-2025 à 13h32

Enregistrer

Même une faible consommation d'alcool augmente le risque de mortalité, selon Sciensano ©Copyright (c) 2021 cunaplus/Shutterstock. No use without permission.


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L'Echo

Alphabet s'offre la start-up de cybersécurité Wiz pour le montant record de 32 milliards de dollars

Critique de "La cocina" ou l'enfer des fourneaux

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Une génération sans tabac en 2040? Possible, mais pas sans efforts, selon Sciensano

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Aujourd'hui, 15,4% des Belges fument encore (au moins) une cigarette par jour. ©PHOTOPQR/OUEST FRANCE/MAXPPP

12 juillet 2023 11:53


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Sigaretten opnieuw duurder en uitgebreider rookverbod: zorgt anti-tabaksplan voor rookvrije generatie in 2040?

De regering verhoogt opnieuw de prijs van sigaretten. Vanaf 2025 mogen winkels ook geen tabaksproducten en vapes meer zichtbaar uitstallen. Die maatregelen maken deel uit van het plan van minister van Volksgezondheid Frank Vandenbroucke (Vooruit) om te zorgen voor een rookvrije generatie. Volgens Sciensano zijn de extra inspanningen broodnodig om die doelstelling te halen.

Cisse Michiels
di 24 okt 2023 13:05

9. Reports

- RF protocol: https://www.sciensano.be/en/biblio/belgian-national-burden-disease-study-guidelines-calculation-risk-factor-attributable-burden
- Critical appraisal of data sources for tobacco use: https://www.sciensano.be/en/biblio/belgian-national-burden-disease-study-patterns-tobacco-use-and-sales-belgium-a-critical-appraisal
- Critical appraisal of data sources for alcohol use: https://www.sciensano.be/en/biblio/belgian-national-burden-disease-study-patterns-alcohol-use-and-sales-belgium-a-critical-appraisal
- Cost calculation framework : https://www.sciensano.be/en/biblio/belgian-national-burden-disease-study-methodological-framework-cost-estimation

10. Dashboards

- https://burden.sciensano.be/shiny/risk/

11. List of publications: published/submitted/in preparation

- The economic burden of smoking in Belgium: incremental healthcare costs and lost productivity: https://academic.oup.com/eurpub/article/35/1/108/7974346 (published)

- The economic burden of alcohol in Belgium: incremental healthcare costs and lost productivity (submitted)
- Past trends and future forecasts and socio-demographic patterns of cigarette smoking in Belgium, 1997 to 2040 (in preparation)
- The attributable burden of disease to cigarette smoking in Belgium: mortality patterns and trends from 2013 to 2021 (in preparation)
- Trends in alcohol consumption and socio-demographic patterns in Belgium from 1997 to 2040 : a modelling study (in preparation)
- Trends in alcohol - attributable mortality in Belgium, 2013-2021 (in preparation)