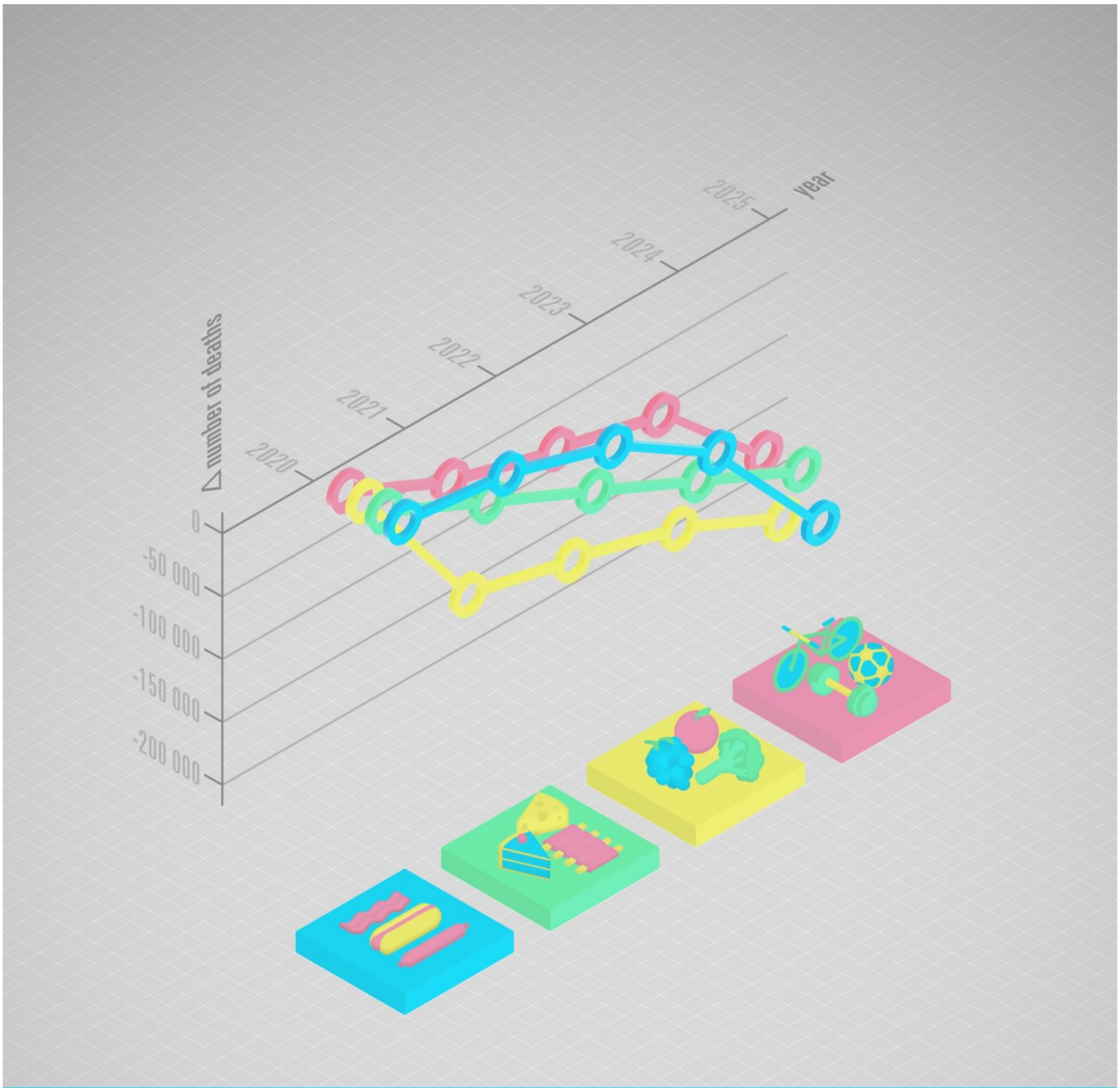

APPLYING QUANTITATIVE HEALTH IMPACT ASSESSMENT FOR EVIDENCE-BASED POLICY-MAKING IN PUBLIC HEALTH

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Applying quantitative health impact assessment for evidence-based policy-making in public health

Dissertation

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Abbreviations

BMI	Body mass index
CVDs	Cardiovascular diseases
DYNAMO-HIA	Dynamic Modeling for Health Impact Assessment
%E	Percent of total energy intake
eHealth	Electronic health
EHIS	European Health Interview Survey
GBD	Global Burden of Disease
GEDA 2012	German Health Update 2012
GEDA 2014/15-EHIS	German Health Update 2014/15-European Health Interview Survey
GfK	German consumer research association “Gesellschaft für Konsumforschung”
HIA	Health impact assessment
IHD	Ischemic heart disease
MVPA	Moderate-to-vigorous physical activity
MET	Metabolic equivalent of task
NCDs	Noncommunicable diseases
NVS II	German National Nutrition Survey II
RRs	Relative risks
VAT	Value-added tax
WHO	World Health Organization

Abstract

Background: The prevention of noncommunicable diseases (NCDs) remains a major challenge to public health. Since unhealthy diets, tobacco use, the harmful use of alcohol as well as low physical activity are the key drivers of NCDs, a range of public health interventions exist to target these lifestyle related risk factors. However, the effectiveness of these interventions depends on underlying population-specific characteristics such as the age structure, the existing risk-factor exposure, as well as the incidence-prevalence-mortality profile of the respective chronic diseases. In order to identify the best course of action among competing interventions before implementing them, prospective health impact assessments (HIAs) can be applied to quantify and compare the potential future effect of an intervention on population health. Therefore, the overall aim of this dissertation was to assess the impact public health interventions targeting lifestyle risk factors have on NCDs at the population-level in the long run, in order to contribute to evidence-based public health decision-making.

Methods: In the context of this dissertation, four HIAs of policies were conducted, which seem to be especially promising namely (i) a tax on processed meat in Germany, (ii) a tax on saturated fat in European countries, (iii) the removal of the value-added tax (VAT) and a subsidy on fruits and vegetables in Germany, and (iv) a rolling out of a digital intervention promoting physical activity among older adults at the national level in Germany while accounting for differential effectiveness across education groups. The simulations were conducted with the software tool DYNAMO-HIA, which dynamically projects deaths, ischemic heart disease (IHD), stroke, diabetes and/or colorectal cancer cases under the different policies over a projection period of 10 years.

Results: Cumulated over the 10-year projection period, a tax on processed meat would lead to 9,300 less male deaths and 4,500 less female deaths under the lowest tax of 4%, up to 76,700 less male deaths and 37,100 less female deaths under the highest tax of 33.3%. A tax on saturated fat would reduce the prevalent IHD cases in projection year 10 by a minimum of 500 among males and 300 among females in Denmark, up to a maximum of 5,600 and 4,000 among males and females in the UK. The removal of the VAT on fruits and vegetables would prevent an estimated 13,960 deaths, cumulated over the 10-year projection period, while a 20 % subsidy on fruits and vegetables would avert 54,880 deaths. Under the physical activity intervention, approximately 3,589–5,829 incident IHD, stroke and diabetes cases could be avoided among males aged ≥55 years over a 10-year projection period, as well as 4,381–7,163 disease cases among females aged ≥55 years. Strikingly, the highest reduction for males would be achieved under the intervention that is most effective for those with a high education, whereas for females, the highest reduction would be achieved under the intervention that is most effective amongst those with a low level of education.

Conclusions: Findings of the four quantitative HIAs conducted in the context of this dissertation suggest that a tax on processed meat, a tax on saturated fat, a removal of the VAT and a subsidy on fruits and vegetables as well as a digital physical activity intervention can with a varying degree contribute to the reduction of NCDs in Germany and at the European level. Especially a tax on processed meat, perhaps with a simultaneous subsidy on fruits and vegetables, may be a promising approach, as both provide comparatively large health benefits and are likely to reduce inequalities as they do not rely on individual's agency and commitment. At the same time, we identified a range of barriers in the process of conducting the HIAs and therefore formulate the following research recommendations: a) improve data availability, b) assess inequalities between population groups when conducting HIAs, and c) conduct HIAs on more complex interventions and risk factors.

Zusammenfassung

Hintergrund: Die Prävention von nichtübertragbaren Krankheiten bleibt eine große Herausforderung im Bereich Public Health. Da insbesondere ungesunde Ernährung, Tabakkonsum, schädlicher Alkoholkonsum und körperliche Inaktivität Hauptursachen für den Anstieg von nichtübertragbaren Krankheiten sind, gibt es eine Reihe von Public Health Maßnahmen, die auf diese lebensstilbedingten Risikofaktoren abzielen. Die Wirksamkeit einer bestimmten Maßnahme hängt jedoch von den zugrunde liegenden bevölkerungsspezifischen Merkmalen ab, wie der vorhandenen Risikofaktorexposition, der Inzidenz, Prävalenz und Mortalität der jeweiligen chronischen Krankheit sowie der Altersstruktur der Bevölkerung. Um noch vor der Implementierung die beste Option aus einer Reihe von konkurrierenden Interventionen zu ermitteln, können prospektive Gesundheitsfolgenabschätzungen angewendet werden, um die potenziellen zukünftigen Auswirkungen einer Intervention auf die Gesundheit der Bevölkerung zu quantifizieren und zu vergleichen. Das übergeordnete Ziel dieser Dissertation war es deswegen zu modellieren, welche Auswirkungen verschiedene Public Health Interventionen, die auf die Reduzierung von lebensstilbedingten Risikofaktoren abzielen, langfristig auf nichtübertragbare Krankheiten auf Bevölkerungsebene haben, um die evidenzbasierte Entscheidungsfindung im Bereich Public Health zu stärken.

Methoden: Im Rahmen dieser Dissertation wurden vier quantitative Gesundheitsfolgenabschätzungen von Maßnahmen durchgeführt, die als besonders vielversprechend erscheinen, nämlich (i) eine Steuer auf verarbeitetes Fleisch in Deutschland, (ii) eine Steuer auf gesättigte Fettsäuren in Europäischen Ländern, (iii) die Abschaffung der Mehrwertsteuer bzw. die Subvention von Obst und Gemüse in Deutschland sowie (iv) die Ausweitung einer digitalen Intervention zur Förderung von körperlicher Aktivität bei älteren Erwachsenen auf nationaler Ebene in Deutschland, unter Berücksichtigung der unterschiedlichen Wirksamkeit zwischen den Bildungsgruppen. Die Simulationen wurden mit dem Software-Tool DYNAMO-HIA durchgeführt, mit dem Todesfälle sowie Fälle von ischämischer Herzerkrankung (IHD), Schlaganfall, Diabetes und / oder Darmkrebs für die verschiedenen Maßnahmen über einen Zeitraum von 10 Jahren projiziert wurden.

Ergebnisse: Über den Projektionszeitraum von 10 Jahren würde eine Steuer auf verarbeitetes Fleisch in Höhe von 4% zu 9.300 weniger Todesfällen bei Männern und 4.500 weniger Todesfällen bei Frauen führen, eine Steuer in Höhe von 33,3% zu 76.700 weniger Todesfällen bei Männern und 37.100 Todesfällen bei Frauen. Unter einer Steuer auf gesättigte Fettsäuren würde die Reduzierung der im Projektionsjahr 10 anzunehmenden IHD Fälle von 500 bei Männern bzw. 300 bei Frauen in Dänemark bis zu 5.600 bzw. 4.000 bei Männern und Frauen in Großbritannien reichen. Die Abschaffung der

Mehrwertsteuer auf Obst und Gemüse würde über den 10-jährigen Projektionszeitraum 13.960 Todesfälle verhindern, während eine Subvention von 20% für Obst und Gemüse 54.880 Todesfälle verhindern würde. Die digitale Intervention zur Förderung körperlicher Aktivität könnte über einen Projektionszeitraum von 10 Jahren etwa 3.589 bis 5.829 Fälle von IHD, Schlaganfall und Diabetes bei ≥55-jährigen Männern vermindern, bei ≥55-jährigen Frauen 4.381 bis 7.163 Krankheitsfälle. Bei Männern würde die Intervention, die für Personen mit hoher Bildung am effektivsten ist, den größten Gesundheitseffekt erzielen, während bei Frauen die Intervention, die bei Personen mit niedriger Bildung am effektivsten ist, den größten Gesundheitseffekt erzielen würde.

Schlussfolgerungen: Die Ergebnisse der vier Gesundheitsfolgenabschätzungen, die im Rahmen dieser Dissertation durchgeführt wurden, legen nahe, dass eine Steuer auf verarbeitetes Fleisch, eine Steuer auf gesättigte Fettsäuren, die Abschaffung der Mehrwertsteuer bzw. eine Subvention von Obst und Gemüse sowie eine digitale Intervention zur Förderung körperlicher Aktivität mit unterschiedlichem Grad zur Reduzierung von nichtübertragbaren Krankheiten in Deutschland und auf europäischer Ebene beitragen können. Insbesondere eine Steuer auf verarbeitetes Fleisch und eine gleichzeitige Subventionierung von Obst und Gemüse scheinen ein vielversprechender Ansatz zu sein, da sie vergleichsweise große positive Gesundheitseffekte bieten. Da Lebensmittelsteuern und -subventionen unabhängig von individueller Motivation und Selbstverpflichtung sind, bieten sie außerdem das Potenzial, gesundheitliche Ungleichheiten zu verringern. Gleichzeitig konnten bei der Erstellung der vier Gesundheitsfolgenabschätzungen eine Reihe von Hindernissen identifiziert und entsprechende Forschungsempfehlungen in den folgenden Handlungsfeldern formuliert werden: a) Verbesserung der Datenverfügbarkeit, b) Berücksichtigung von Ungleichheiten bei der Erstellung von Gesundheitsfolgenabschätzungen, und c) Durchführung von Gesundheitsfolgenabschätzungen für komplexere Interventionen und Risikofaktoren.

Articles in this dissertation

The articles I to IV form the core and basis of this dissertation and can be found in the Appendix:

I. **Schönbach J-K**, Thiele S, Lhachimi SK (2019) What are the potential preventive population-health effects of a tax on processed meat? A quantitative health impact assessment for Germany. *Preventive Medicine 118*: 325-331. doi: 10.1016/j.ypmed.2018.11.011.

II. **Schönbach J-K**, Nusselder WJ and Lhachimi SK (2019) Substituting polyunsaturated fat for saturated fat: Modelling potential effects of a fat tax on ischemic heart diseases in Europe. *Plos One 14*(7): e0218464. doi: 10.1371/journal.pone.0218464.

III. **Schönbach J-K** and Lhachimi SK (2020) To what extent could cardiovascular diseases be reduced if Germany applied fiscal policies to increase fruit and vegetable consumption? A quantitative health impact assessment. *Public Health Nutrition*. doi: 10.1017/S1368980020000634.

IV. **Schönbach J-K**, Bolte G, Czwikla G, Manz K, Mensing M, Muellmann S, Voelcker-Rehage C and Lhachimi SK (2020) Equity impacts of interventions to increase physical activity among older adults: A quantitative health impact assessment. *International Journal of Behavioral Nutrition and Physical Activity, 17*(1):103*.* doi: 10.1186/s12966-020-00999-4.

The articles V to VII contribute to the background, but do not belong to the core of the dissertation:

V. Brand T, Pischke CR, Steenbock B, **Schönbach J-K**, Poettgen S, Samkagne-Zeeb F and Zeeb H (2014) What works in community-based interventions promoting physical activity and healthy eating? A review of reviews. *International Journal of Environmental Research and Public Health 11*(6): 5866-5888. doi: 10.3390/ijerph110605866

VI. Steenbock B., Pischke CR, **Schönbach J-K,** Poettgen S and Brand T (2015) [The effectiveness of primary prevention interventions promoting physical activity and healthy eating in preschool children: A review of reviews]. *Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz 58(6)*: 609-619. doi: 10.1007/s00103-014-2100-7.

VII. **Schönbach J-K**, Pfinder M, Börnhorst C, Zeeb H and Brand T (2017) Changes in Sports Participation across Transition to Retirement: Modification by Migration Background and Acculturation Status. *International Journal of Environmental Research and Public Health 14*(11): 1356. doi: 10.3390/ijerph14111356.

Presentations

The findings of the included studies have also been presented at a number of national and international conferences as listed below:

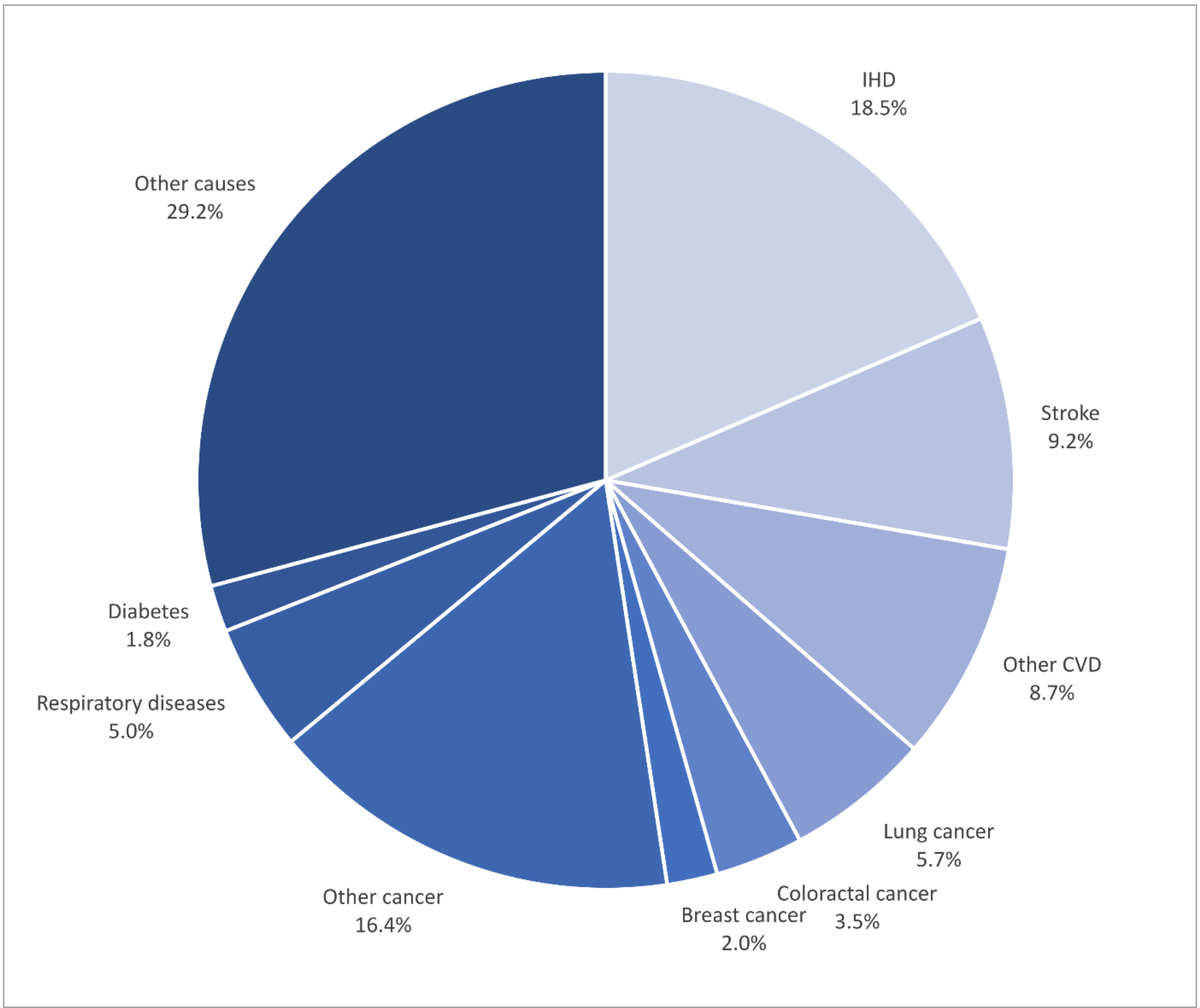
- **Schönbach J-K**, Brand T and Zeeb H (2014) Migration background, acculturation status and physical activity. A longitudinal analysis using data from the German Socio-Economic Panel Survey. *9th annual conference of the German Society for Epidemiology*, 17th-20th September 2014, Ulm, Germany [oral].
- **Schönbach J-K**, Lhachimi SK and Thiele S (2015) Modelling effects of nutrition improvements on health outcomes. Proposed outline of analysis. *Workshop Dynamo-HIA: International experiences, results & further perspectives*, 27th-28th May 2015, Bielefeld, Germany [oral].
- **Schönbach J-K**, Lhachimi SK and Thiele S (2016) Modelling potential health effects following a hypothetical 10% price increase of processed meat in Germany. *24th Annual Population Postgraduate Conference*, 4th-06th July 2016, Manchester, UK [oral].
- **Schönbach J-K**, Pfinder M, Börnhorst C, Zeeb H and Brand T (2017) Changes in leisure-time physical activity across transition to retirement: modification by migration background and acculturation status. *Public Health Conference: Key Issues in current health research: Ageing - Health – Equity,* 29th-30th June 2017, Bremen, Germany [oral].
- **Schönbach J-K**, Lhachimi SK and Thiele S (2017) Potential health impacts of processed meat taxation: a quantification study from Germany. *10th European Public Health Conference*, 1st-4th November 2017, Stockholm, Sweden [oral].
- **Schönbach J-K**, Bolte G, Czwikla G, Manz K, Mensing M, Muellmann S, Voelcker-Rehage C and Lhachimi SK (2020) Equity impacts of interventions to increase physical activity: A health impact assessment. *16th World Congress on Public Health 2020*, 12th-16th October 2020, Rome, Italy [poster].

1 Introduction

1.1 The burden of disease from the main types of noncommunicable diseases

Cardiovascular diseases (CVDs) are the leading cause of deaths in the European Union. According to the Global Burden of Disease (GBD) Study 2017, they accounted for 1.9 million deaths, corresponding to 36.4% of all deaths. Half of these (963,800) were due to ischemic heart disease (IHD) and a quarter (476,900) to stroke. The second leading cause was cancer with 1.4 million deaths, corresponding to 27.6% of all deaths. Among these, 298,000 were due to lung cancer, 181,000 to colorectal cancer and 103,700 to breast cancer. This was followed by respiratory diseases with 260,800 deaths, corresponding to 5.0% of all deaths, mainly from chronic obstructive pulmonary disease. Diabetes accounted for another 95,700 deaths, corresponding to 1.8% of all deaths, with 78,900 deaths from diabetes mellitus type II (GBD Collaborative Network, 2018a) (see Figure 1).

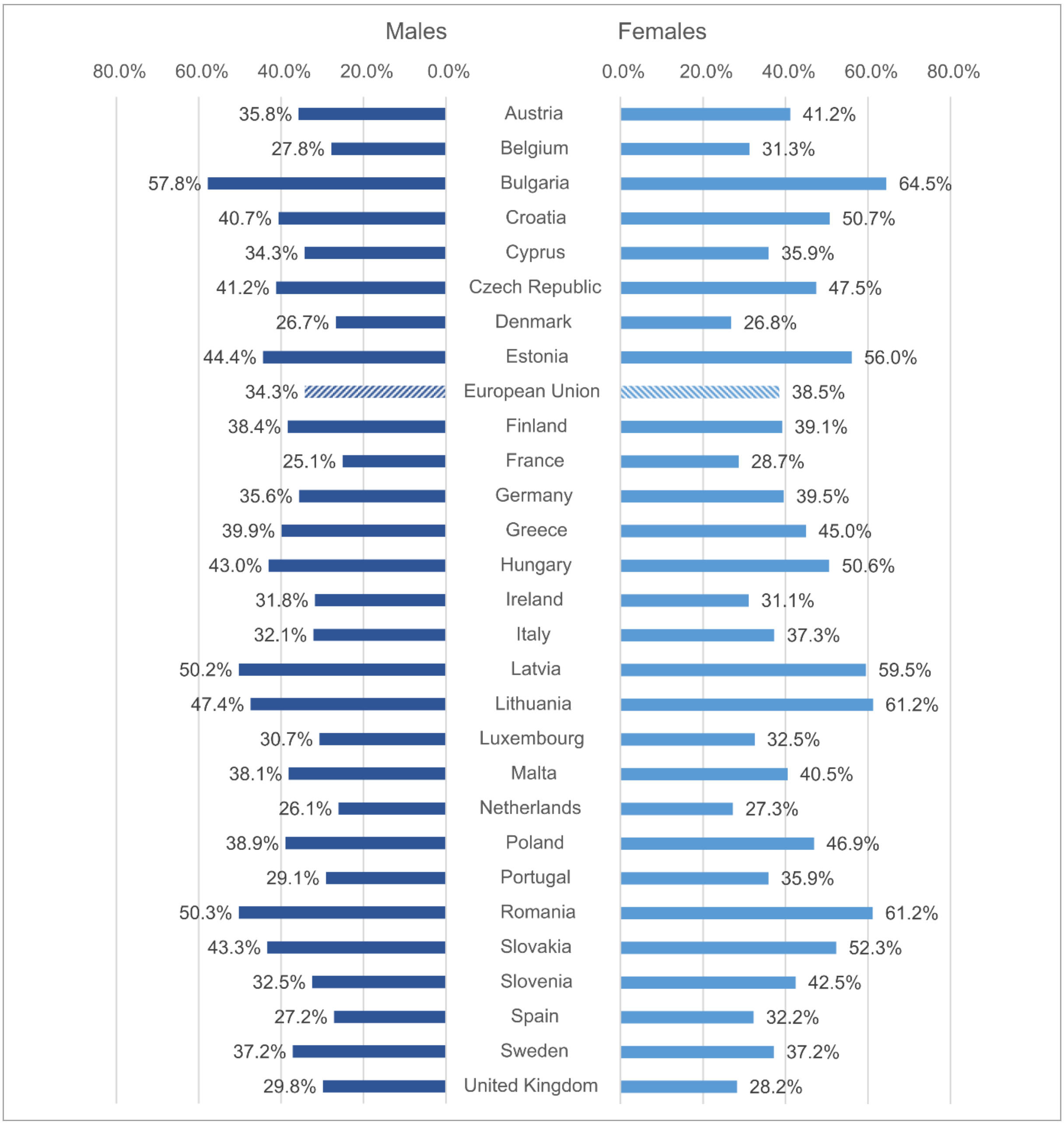
Figure 1: Deaths by cause in the European Union, 2017



Own work based on GBD Collaborative Network (2018a); IHD= Ischemic heart disease; CVD= Cardiovascular disease

Differences exist across countries and gender: In the European Union as a whole, CVDs account for 34.3% of deaths among men, ranging from 25.1% in France to 57.8% in Bulgaria. Among women they account for 38.5%, ranging from 26.8% in Denmark to 64.5% in Bulgaria (GBD Collaborative Network, 2018b) (see Figure 2).

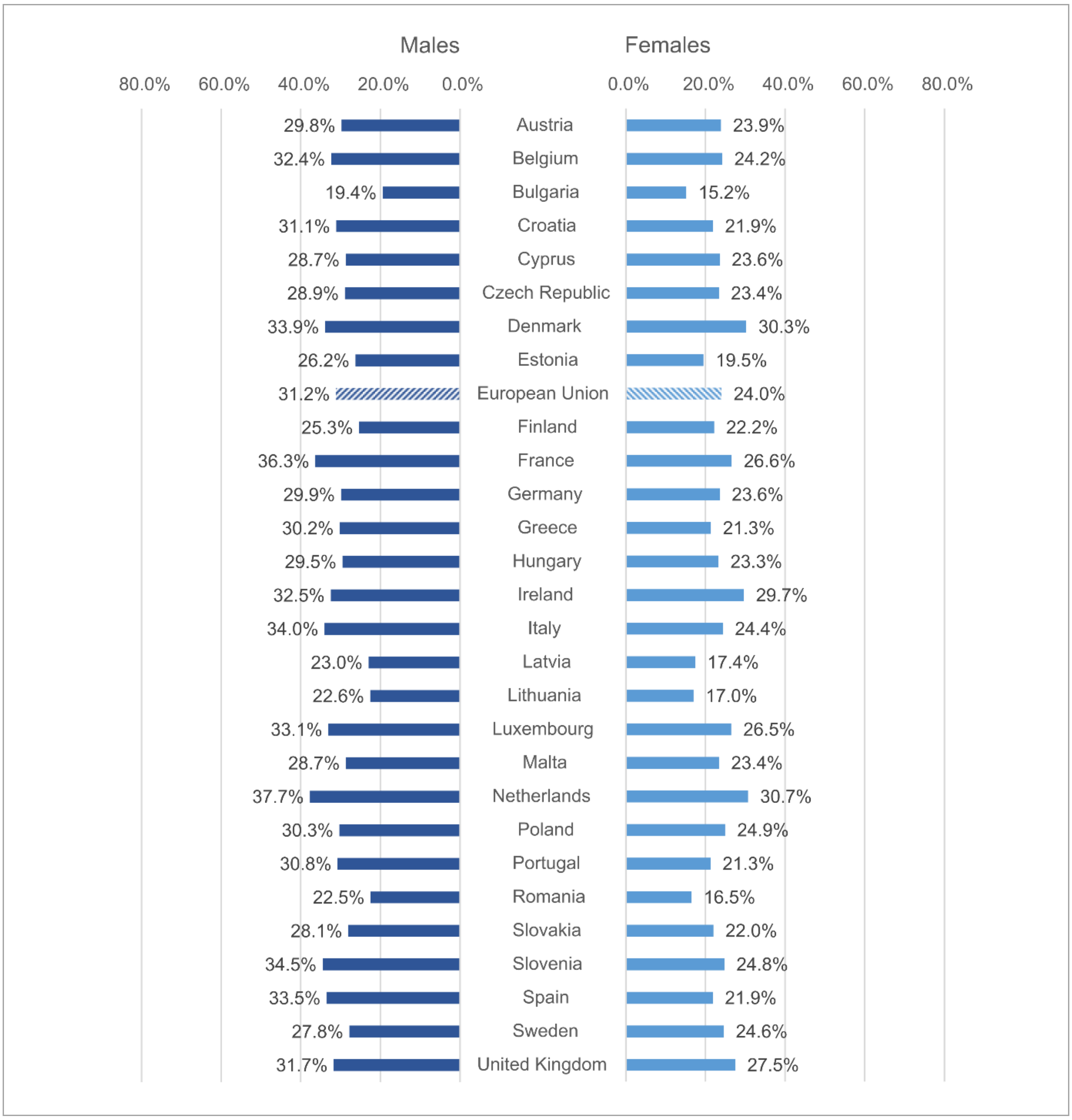
Figure 2: Cardiovascular disease deaths in the European Union, 2017



Own work based on GBD Collaborative Network (2018b)

Similarly, cancer accounts for 31.2% of deaths in men in the European Union, ranging from 19.4% in Bulgaria to 37.7% in the Netherlands. In women, it accounts for 24.0%, ranging from 15.2% in Bulgaria to 30.7% in the Netherlands (GBD Collaborative Network, 2018b) (see Figure 3).

Figure 3: Cancer deaths in the European Union, 2017



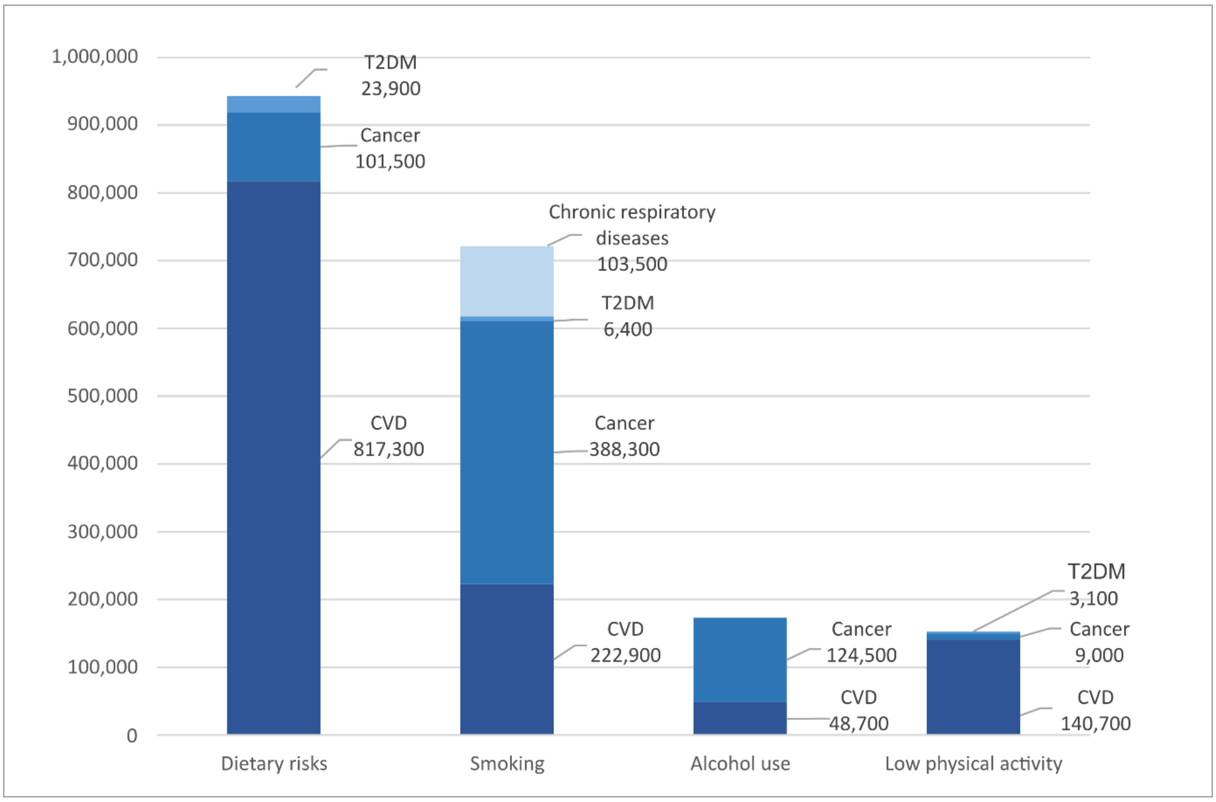
Own work based on GBD Collaborative Network (2018b)

Differences however not only exist between countries, but also within countries by socioeconomic characteristics such as education, occupation or income. For instance, there is an educational gradient in health, where a range of noncommunicable diseases (NCDs) have a higher prevalence among the medium and low educated group in comparison to the high educated group. These inequalities can be observed everywhere across Europe, but their extent differs. For instance, educational inequalities in heart disease were found to be larger in northern European countries in comparison to southern European countries (Dalstra et al., 2005; McNamara et al., 2017). Furthermore, pooled analyses suggest a greater number of educational health inequalities (McNamara et al., 2017) as well as larger educational health inequalities among women than among men (Dalstra et al., 2005).

1.2 Risk factors for the main types of noncommunicable diseases

Unhealthy diet, tobacco use, the harmful use of alcohol and lack of physical activity are four key risk factors, which impact NCDs directly or through conditions such as raised blood pressure, raised blood glucose, raised cholesterol as well as overweight and obesity (Peters et al., 2019). According to the GBD Study 2017 (GBD Collaborative Network, 2018c), these four key risk factors largely contributed to the number of deaths from CVD, cancer, respiratory disease and diabetes in the European Union described in chapter 1.1 (see Figure 4).

Figure 4: Number of deaths in the European Union attributable to dietary risks, smoking, alcohol and low physical activity, 2017



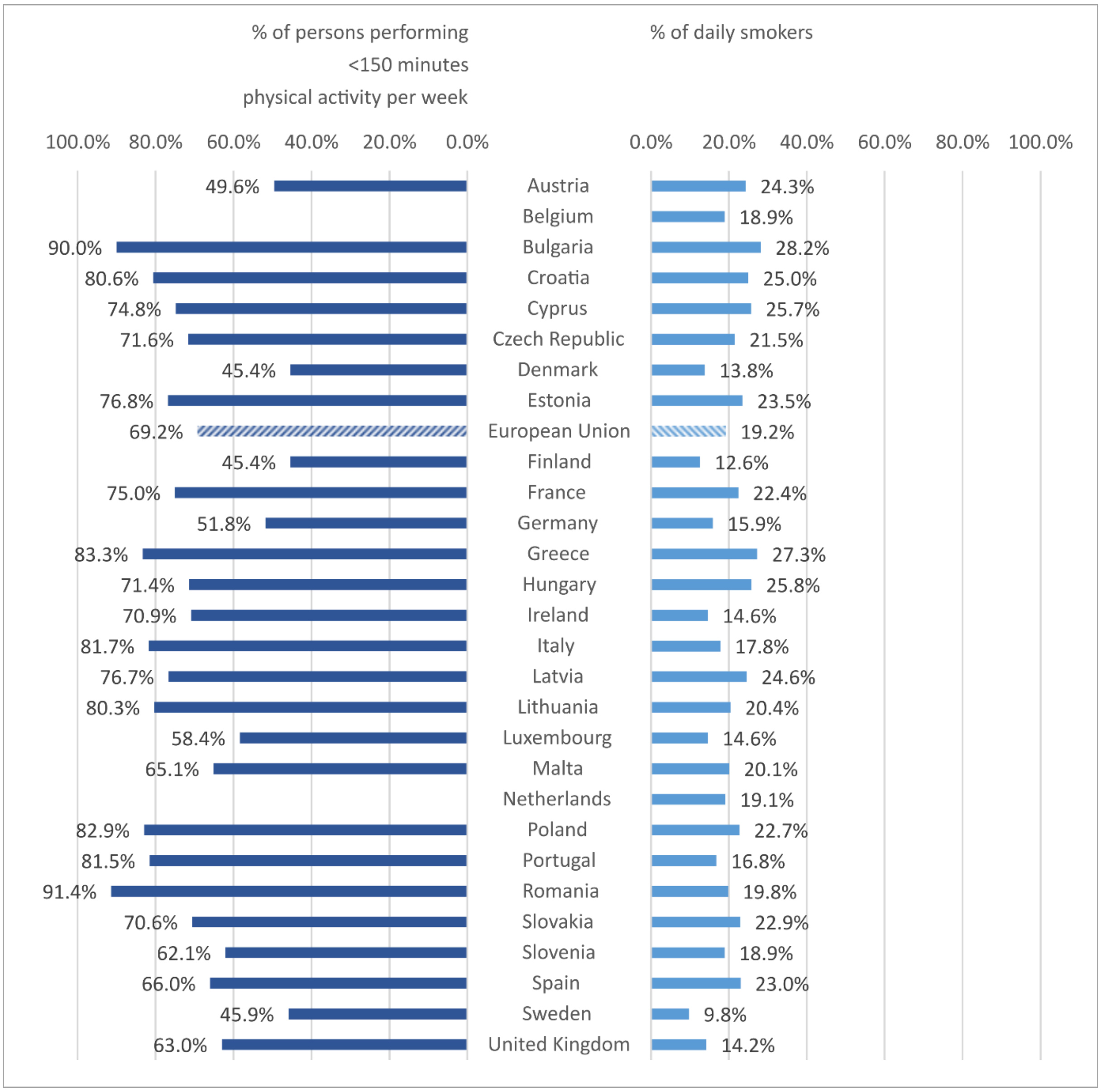
Own work based on GBD Collaborative Network (2018c); CVD= Cardiovascular disease, T2DM= Diabetes mellitus type II

For instance, dietary risk factors played a role in approximately 817,300 (43.2%) of the 1.9 million mentioned CVD deaths, 101,500 (7.1%) of the 1.4 million cancer deaths, and 23,900 (30.3%) of the 78,900 diabetes mellitus type II deaths. In descending relevance, dietary risk factors consist of diets low in whole grains, high in sodium, low in nuts and seeds, low in fruits, low in seafood omega-3, low in vegetables, low in fibre, low in legumes, low in polyunsaturated fat, low in calcium, high in processed meat, high in sugar-sweetened beverages, low in milk, high in trans-fat, and high in red meat. At the same time, smoking was associated with 222,900 (11.8%) CVD deaths, 388,300 (27.1%) cancer deaths and 103,500 (39.7%) of the 260,800 mentioned chronic respiratory disease deaths. Alcohol (more than 0–10 g of pure alcohol per day) contributed to 48,700 (2.6%) CVD deaths and 124,500 (8.7%) cancer deaths. Low physical activity (less than 3,000–4,500 metabolic equivalent of task (MET) minutes per week) was related to 140,700 (7.4%) CVD deaths and 3,100 (3.9%) diabetes mellitus type II deaths (GBD Collaborative Network, 2018c).

As unhealthy diet, tobacco use, harmful use of alcohol and lack of physical activity are major determinants of NCDs, unfavourable levels in these risk factors can, to some extent, explain the health differences between countries, between men and women, as well as between educational groups that were described in chapter 1.1.

For instance, the proportion of persons performing less than the recommended 150 minutes of physical activity per week ranges from 45.4% in Denmark to 91.4% in Romania (European Union and Eurostat, 2014a). Similarly, the proportion of daily smokers ranges from 9.8% in Sweden to 28.2% in Bulgaria (European Union and Eurostat, 2014b) (see Figure 5).

Figure 5: Prevalence of physical inactivity and smoking in the European Union, 2014

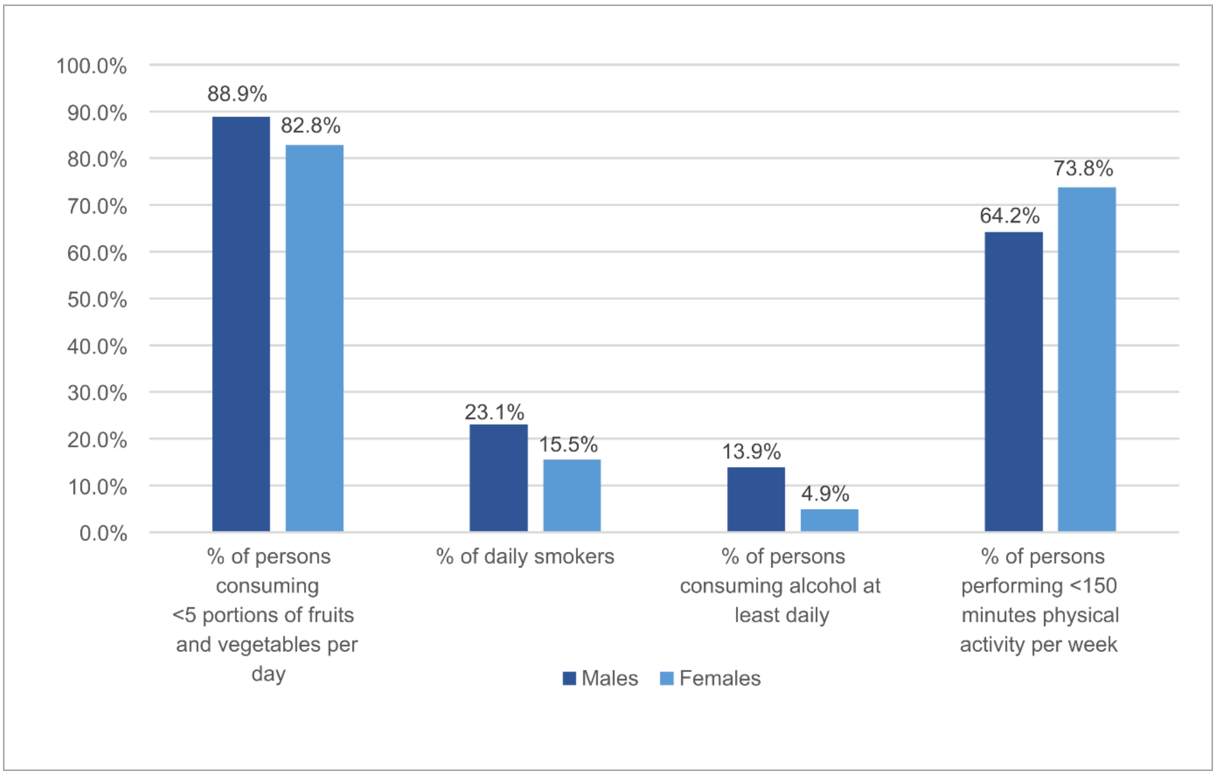


Own work based on European Union and Eurostat (2014a) and European Union and Eurostat (2014b)

In line with this, Mackenbach et al. (2013) hypothesize that favourable mortality trends in Western Europe are not only due to economic growth and better health care, but also due to successful health policies (for example on tobacco control), while less favourable mortality trends in eastern Europe reflect a failure to implement effective health policies in many areas.

At the same time, the prevalence of risk factors differs between men and women (see Figure 6). In 2014, 64.2% of men and 73.8% of women in the European Union were less than 150 minutes physically active per week (European Union and Eurostat, 2014a). Further, 23.1% of men and 15.5% of women smoked on a daily basis (European Union and Eurostat, 2014b), 88.9% of men and 82.8% of women did not consume at least five portions of fruits and vegetables a day (European Union and Eurostat, 2014c) and 13.9% of men and 4.9% of women consumed alcohol every day (European Union and Eurostat, 2014d). Thus, differences in risk factor behaviour regarding smoking, physical activity, diet and alcohol consumption, which are shaped by gender norms and roles, may, in addition to biological aspects, explain health differences between men and women (WHO, 2019).

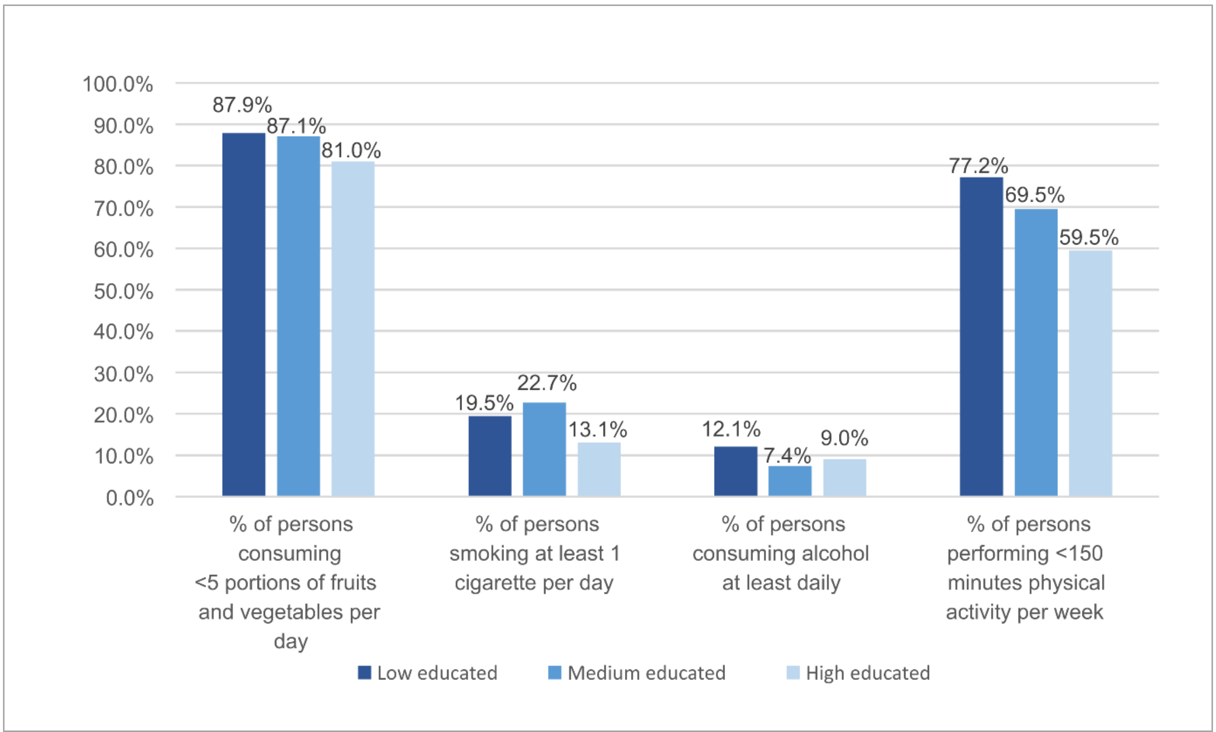
Figure 6: Prevalence of unfavourable fruit and vegetable intake, smoking behaviour, alcohol consumption and physical inactivity among men and women in the European Union, 2014



Own work based on European Union and Eurostat (2014a), European Union and Eurostat (2014b), European Union and Eurostat (2014c) and European Union and Eurostat (2014d)

Likewise, the prevalence of risk factors differs between education groups in the European Union (see Figure 7). For fruit and vegetable intake as well as physical activity, there is a gradient where the proportion of unfavourable behaviour decreases with education (European Union and Eurostat, 2014a; European Union and Eurostat, 2014c). In addition to that, a higher percentage of the low educated smoke and drink on a daily basis compared to the high educated (European Union and Eurostat, 2014b; European Union and Eurostat, 2014d).

Figure 7: Prevalence of unfavourable fruit and vegetable intake, smoking behaviour, alcohol consumption and physical inactivity among education groups in the European Union, 2014



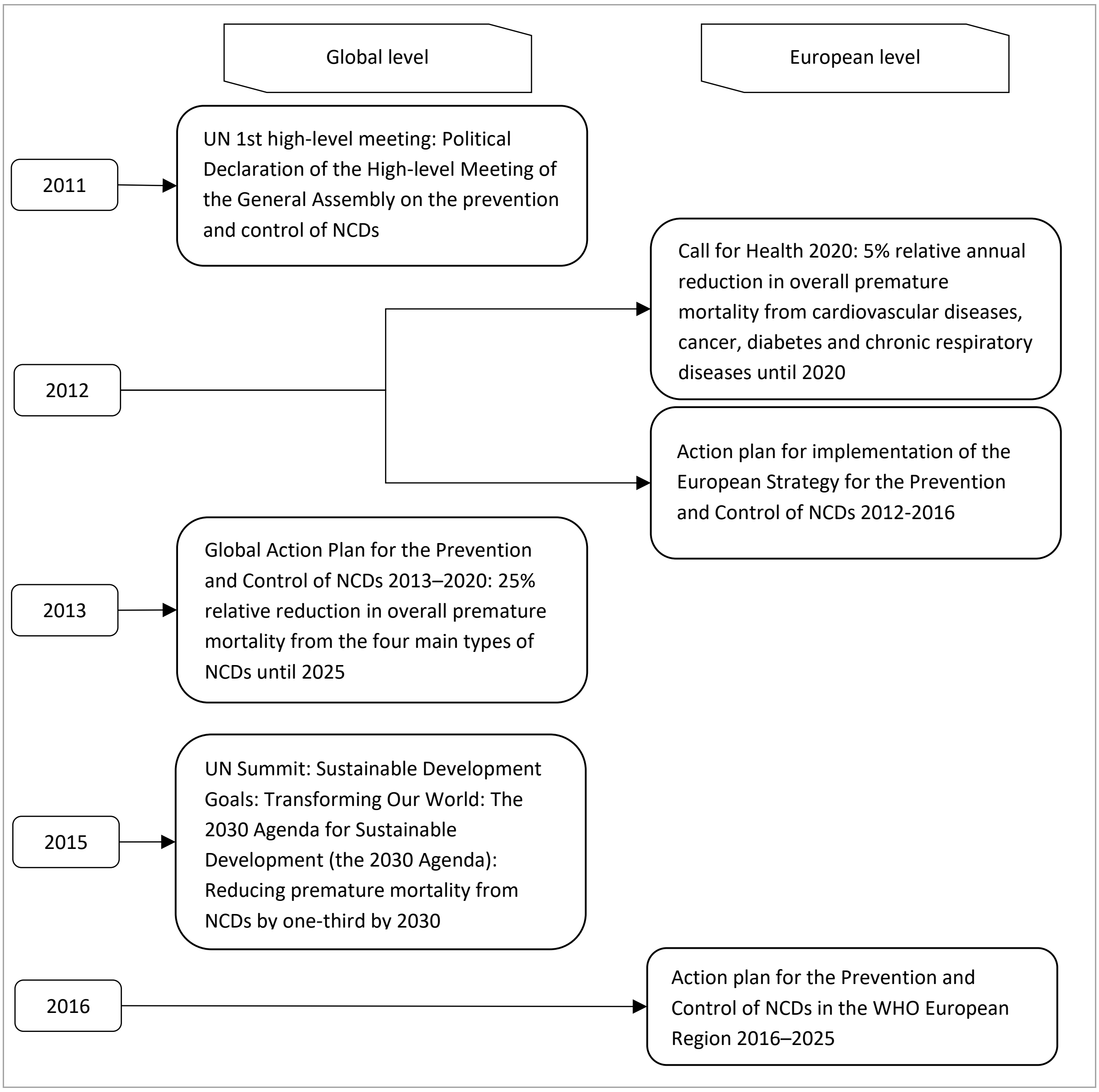
Own work based on European Union and Eurostat (2014a), European Union and Eurostat (2014b), European Union and Eurostat (2014c) and European Union and Eurostat (2014d)

Education is relevant in this context, because it is a widely recognised indicator of socioeconomic position (Galobardes et al., 2006a). Besides material resources, education provides psychological resources for a healthy lifestyle (Mirowsky and Ross, 2003). Education is associated with knowledge and cognitive skills, which may lead to less risk behaviours and healthier decisions over the life course (Galobardes et al., 2006b; Glymour et al., 2014; Shaw et al., 2007). Notably, Petrovic et al. (2018) found that diet contributed to 24% of educational differences in cardiovascular disorders, smoking to 17% and alcohol and physical activity to 6% each. Nevertheless, while accounting for the effect of the most common lifestyle risk factors eliminated the observed educational health inequalities to some extent, other factors such as occupation and associated exposure to toxicants may also play a role (Gallo et al., 2012). Hence, Mackenbach et al. (2008) argues that improving educational opportunities, income distribution, access to health care, as well as health-related behavior might reduce the educational inequalities in health.

1.3 Global and European goals for the reduction of noncommunicable diseases

There have been a range of declarations and action plans at the global and European level during the last years that aim to reduce NCDs (see Figure 8).

Figure 8: Global and European response to address noncommunicable diseases



Own work; NCDs= Noncommunicable diseases; ; WHO= World health organisation

For instance, in September of 2011, heads of state and government officials assembled at the United Nations High-Level Meeting on NCDs. In their "Political Declaration of the High-level Meeting of the General Assembly on the prevention and control of Noncommunicable Diseases" they committed to increase efforts to prevent and control NCDs (United Nations, 2012). In order to operationalize these commitments, the World Health Organization (WHO) endorsed the "Global Action Plan for the Prevention and Control of NCDs 2013–2020". The action plan suggested a range of policy options to attain nine voluntary global targets. The first and overarching target was to achieve a 25% relative reduction in overall premature mortality from the four main types of NCDs until 2025. Further targets were related to the reduction of alcohol, insufficient physical activity, intake of salt/sodium, tobacco use and raised blood pressure. Alongside, the action plan provided a comprehensive Global Monitoring Framework with indicators to assess progress (WHO, 2013b).

In September 2015, the United Nations General Assembly set up the “2030 Agenda for Sustainable Development”, consisting of 17 sustainable development goals. Reducing premature mortality from NCDs by one-third by 2030 was included as a target of the third sustainable development goal on ensuring healthy lives and promoting well-being for all at all ages (Collins et al., 2018; Mendis, 2017; United Nations, 2015; WHO, 2015a).

Meanwhile, in 2012, member states of the WHO European Region agreed on “Health 2020”, a health policy framework with six targets. One core indicator was to achieve a 1.5% relative annual reduction in overall premature mortality from cardiovascular diseases, cancer, diabetes and chronic respiratory diseases until 2020, compared to the baseline of 2010 (WHO, 2013a; WHO, 2014). Further, the “Action Plan for implementation of the European Strategy for the Prevention and Control of Noncommunicable Diseases 2012–2016” was developed (WHO, 2012). It identified priority interventions, such as fiscal and marketing policies to promote healthy consumption, salt reduction, replacement of trans fats in food with polyunsaturated fats, as well as promoting active mobility. The plan was updated by the “Action Plan for the Prevention and Control of Noncommunicable Diseases in the WHO European Region 2016–2025” in 2016 (WHO, 2016a).

2 Population-level public health approaches targeting behavioural risk factors

2.1 Classification of public health strategies

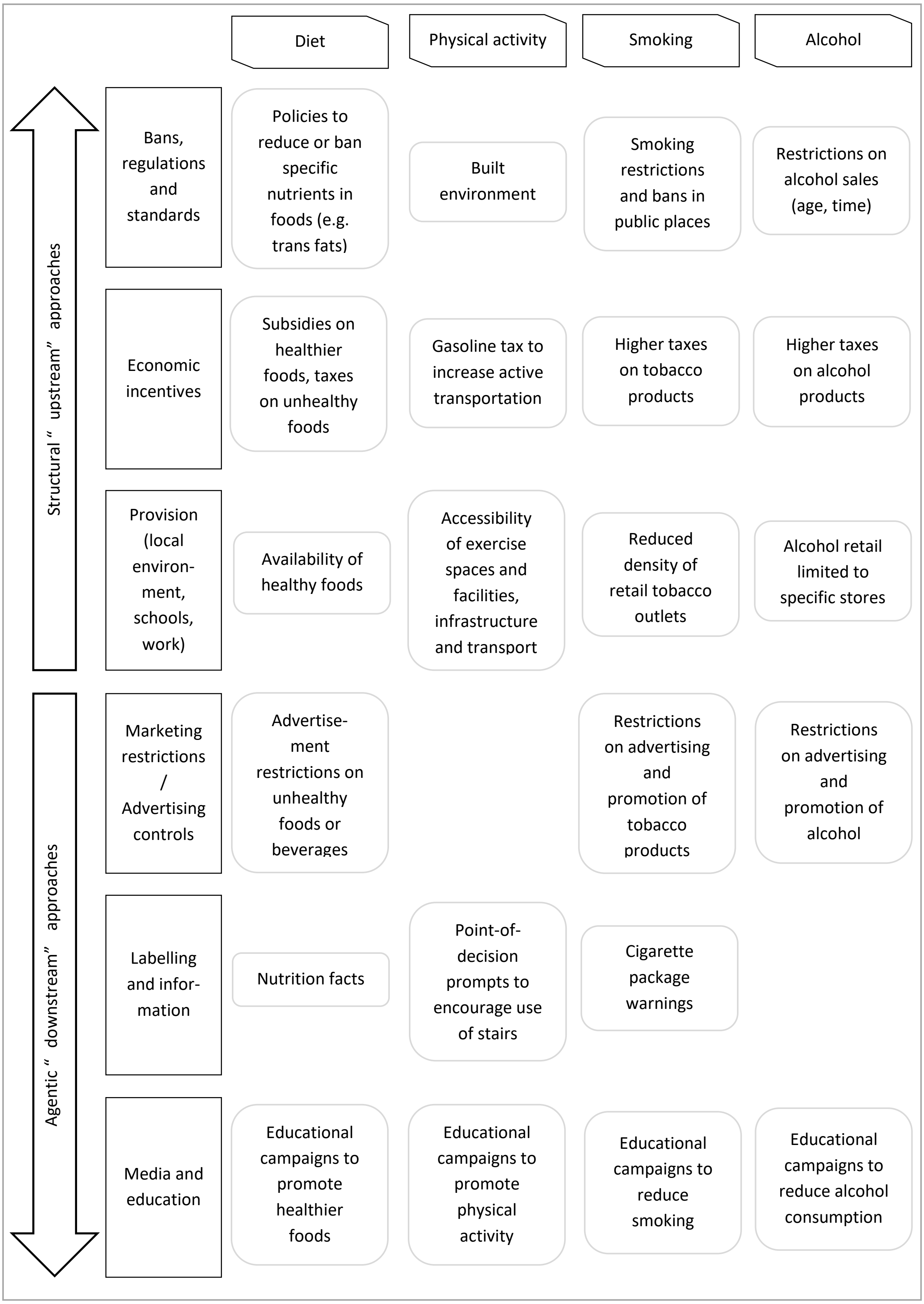
Prevention strategies may be differentiated according to whether they are universal, i.e. focusing on the whole population regardless of individuals' risk status, or targeted, i.e. focusing on high- risk groups or individuals (Gordon, 1983). Interestingly, universal approaches may have a greater health benefit at the overall population-level than approaches focusing on high-risk groups or individuals, as shown by Geoffrey Rose in 1985. Rose stated that the majority of disease cases are not made up by the small number of people who are considered to be at a high risk, but the large number of people who are considered to be at small or medium risk. This is because the risk exposure within a population is usually normally distributed, with most people being at small or medium risk, and only a few at high risk. Conversely, a universal approach, which shifts the whole risk exposure curve to a more favourable direction, might therefore prevent more cases than a targeted approach, which identifies particularly susceptible persons on the basis of their risk and thereby truncates the risk factor curve (Rose, 1985).

Whereas the targeted approach has been criticized for stigmatizing persons, the universal approach has been criticized for potentially increasing health inequalities. That is, a universal intervention might widen inequalities in health, if it shifts the risk exposure curves for population groups unequally. This seems to be particularly the case for agentic "downstream" approaches, in contrast to structural "upstream" approaches. While structural "upstream" approaches aim to provide conditions and environments that facilitate healthy behaviour, agentic "downstream" approaches aim to achieve behaviour change by enhancing knowledge and informed choice (McLaren et al., 2009). The former may be less likely to increase inequalities than the latter, which has impressively been illustrated in an article by Adams et al. (2016). In the article, the authors show how downstream interventions, such as advice, guidance, and encouragement, require individuals' understanding, ability and motivation at several points, in order to provide benefit from the intervention. In contrast to that, upstream interventions require less, if any, personal resources.

2.2 Public health strategies targeting behavioural risk factors of noncommunicable diseases

In Figure 9, a range of exemplarily approaches and interventions to target diet, physical activity, smoking and alcohol consumption are summarized and arranged on the continuum of structure and agency.

Figure 9: Examples of universal upstream and downstream approaches to improve diet and physical activity



Own work based on Capewell and Capewell (2018); Mozaffarian et al. (2012); Brambila-Macias et al. (2011); Capacci et al. (2012); Hawkes et al. (2013); WHO (2013b)

The European Union has implemented some of these measures to promote healthier lifestyles. On the agentic side, it has previously passed information disclosure requirements, which are supposed to provide consumers with some key information in order to make informed decisions, for instance health warnings on tobacco products or nutrition declarations on food products (Alemanno and Garde, 2013). These are agentic approaches, since they need people to process this information. Further, the European Union has passed some marketing restrictions, so that information on food or tobacco may not be misleading. In the case of tobacco, it banned advertising that crosses national borders (such as press, radio or internet advertising), whereas it did not ban advertising within member states (e.g. on billboards). On the structural side, the European Union has adopted fiscal measures, such as minimum rates of excise duties on cigarettes and alcoholic beverages (Alemanno and Garde, 2013).

In general, governments tend to implement approaches that require a high level of agency (Adams et al., 2016), even though structural approaches that require individuals to use a low level of agency seem not only to be more effective, but also more equitable. Structural upstream interventions are politically more challenging than agentic downstream approaches, because opponents claim that structural upstream interventions restrict free choice (Adams et al., 2016; Capewell and Capewell, 2018). It could however be argued that current risk factor behaviour is far from being the result of free choice but the result of past and current policies. Current policies influence norms, which in turn impact risk factor behaviour. As evidenced by the seatbelt legislation or smoke-free environments regulation, in particular younger cohorts inherit the new "social norms" and public support actually increases with time (Adams et al., 2016; Capewell and Capewell, 2018).

Sassi et al. (2009: 6) summarized that "Governments have implemented a wide range of interventions at the national and local levels, particularly during the past 5 years. They have been taking action in accordance with calls by international organisations and pressure by the media and the public health community, but without a strong body of evidence on the effectiveness of interventions, and virtually no evidence of their efficiency and distributional impact".

A similar trend can be observed on the local level. A review of reviews (study V) assessing the effectiveness of community-based interventions to promote physical activity and healthy eating aimed at the general adult population identified mainly agentic downstream interventions such as the provision of information material, individual or group counselling, and devices for self-monitoring. All in all, the evidence for these interventions was rather inconclusive (Brand et al., 2014). Similarly, a review of reviews (study VI) examining the effectiveness of interventions promoting healthy eating and physical activity in childcare settings also identified mainly agentic downstream interventions such as imparting skills and competencies as well as strengthening self-efficacy. Again, evidence for effective interventions was rather weak (Steenbock et al., 2015).

2.3 Fiscal policies targeting diet

Price interventions, such as “health taxes” or “sin taxes”, have previously been widely used to discourage the purchase of unhealthy products such as tobacco and alcohol. Likewise, price interventions as a universal upstream approach seem to be a particularly effective approach to promote healthy diets (Hyseni et al., 2017). In fact, they do not require individual agency or resources for uptake (Adams et al., 2016). Thus, the WHO recommends Member States to use targeted subsidies and taxes on foods to promote healthier diets (WHO, 2015b; WHO, 2015c; WHO, 2016b). These economic tools are supposed to provide an incentive for consumers, encouraging the purchase of healthy foods and discouraging the purchase of unhealthy foods.

In economic theory, price elasticities represent the impact that respective price changes have on demand. Own-price elasticities express how the demand for a quantity of a good changes in response to the price of the good. For instance, a price elasticity of -1.12 means that when the price of a product increases by 1%, the quantity demand for this product decreases by 1.12%. Cross-price elasticities express how the demand for a product changes in the response to the price of another product: if, for instance, the price of product A increases by 1% while the demand for product B increases by 0.3%, this translates to a cross-price elasticity of 0.3 (Nghiem et al., 2013).

Correspondingly, a meta-analysis of interventional or prospective observational studies found that each 10% price increase on sugar-sweetened beverages would reduce the consumption of sugar-sweetened beverage by 7%, each 10% increase on fast products would reduce the consumption of fast foods by 3%, and each 10% price decrease of fruits and vegetables would increase the consumption of fruits and vegetables by 14% (Afshin et al., 2017).

Meanwhile, food taxes are increasingly applied in European countries (see Table 1). For instance, Denmark introduced a tax on products such as meat, dairy products, animal fat, oils, margarine and butter blends with more than 2.3g of saturated fat per 100g in 2011 (Smed, 2012). However, the tax was criticized because of an expected increase in cross-border trade and harmful effects on the Danish economy, as well as administrative costs (Bødker et al., 2015). It was therefore abolished again in January 2013, before the health impact of the tax could be evaluated. Nevertheless, household scanner data indicated that the tax reduced average saturated fat intake by 4% (Smed et al., 2016).

Table 1: Examples of applied food taxes in European countries

Country	Date introduced	Products taxed	Tax rate
Hungary	2011	Food and drink high in fat, salt, sugar and caffeine	0.016€/L on soft drinks, 0.33€/kg for pre-packaged sweetened products, 0.67€/kg for salty products
Denmark	October 2011–January 2013	Products with more than 2.3% of saturated fat (e.g. meat, dairy products, animal fats, and oils)	16 DKK/kg
Finland	2014-2017	Confectionery, ice cream	0.95€/kg
Latvia	2016	Sugar-sweetened beverages	7.40€/100L
Belgium	2016	Sugar-sweetened beverages	0.068€/L
Spain	2017	Sugar-sweetened beverages	0.08€/L for drinks with 5–8 g sugar/100 mL, 0.12€ for drinks with >8 g sugar/100 mL
Portugal	2017	Sugar-sweetened beverages	0.08€/L for drinks containing <80g sugar/L, 0.16€/L for drinks containing >80g sugar/L
UK	2018	Sugar-sweetened beverages	0.18£/L for drinks containing ≥5g and <8g of sugar/100 mL; 0.24£/L for drinks containing ≥8g of sugar/100mL
Norway	2018	Chocolate, sugar products	36.92 NOK/kg
Ireland	2018	Sugar-sweetened beverages	0.20€/L for drinks containing 5–8g of sugar/100mL; 0.30€/L for drinks containing >8g sugar/100mL
France	2018	Sugar-sweetened beverages	Proportional to sugar content, e.g. 0.135€ for 10g added sugar/L

Adapted from Pfinder et al. (2020) and Villanueva (2011)

In general, opponents of food taxes argue that individuals should be self-responsible. This, on the contrary, neglects that current consumer choice is the result of marketing, advertising, food packaging, farming policy as well as national and international trade agreements (Mozaffarian et al., 2018). Further, from a societal perspective, current food prices do not fully reflect the full social costs incurred (e.g. increased health care costs). Fiscal policies may not only correct this market failure, but also generate revenues, which might compensate for these costs (Joyner and Warner, 2013; Thow et al., 2018).

Another argument against food taxes is that they fall disproportionately on the poor. However, it can be argued that if food taxes fall disproportionally on lower income households (where unhealthy behaviours such as unhealthy eating is more prevalent and who suffer disproportionally from related diseases), then lower income households might experience disproportionately greater health benefit from taxation (Joyner and Warner, 2013; Thow et al., 2018). In fact, price interventions have been shown to be most effective in groups with lower socioeconomic position, and may therefore appear likely to reduce inequalities (McGill et al., 2015). Nevertheless, taxes could be applied to non-essential foods rather than core foods and be combined with subsidies on healthy foods such as fruits and vegetables to mitigate financial consequences on lower income households (Thow et al., 2018).

2.4 Digital public health interventions targeting physical activity

Digital behaviour change interventions employ technology "[…] to promote and maintain health, through primary or secondary prevention and management of health problems. The technologies used can include not only the Internet (accessed by smartphone, PC, or tablet) but also automated healthcare and communication systems and an increasing array of mobile, wearable, and environmental sensors […]" (Yardley et al., 2016: 814).

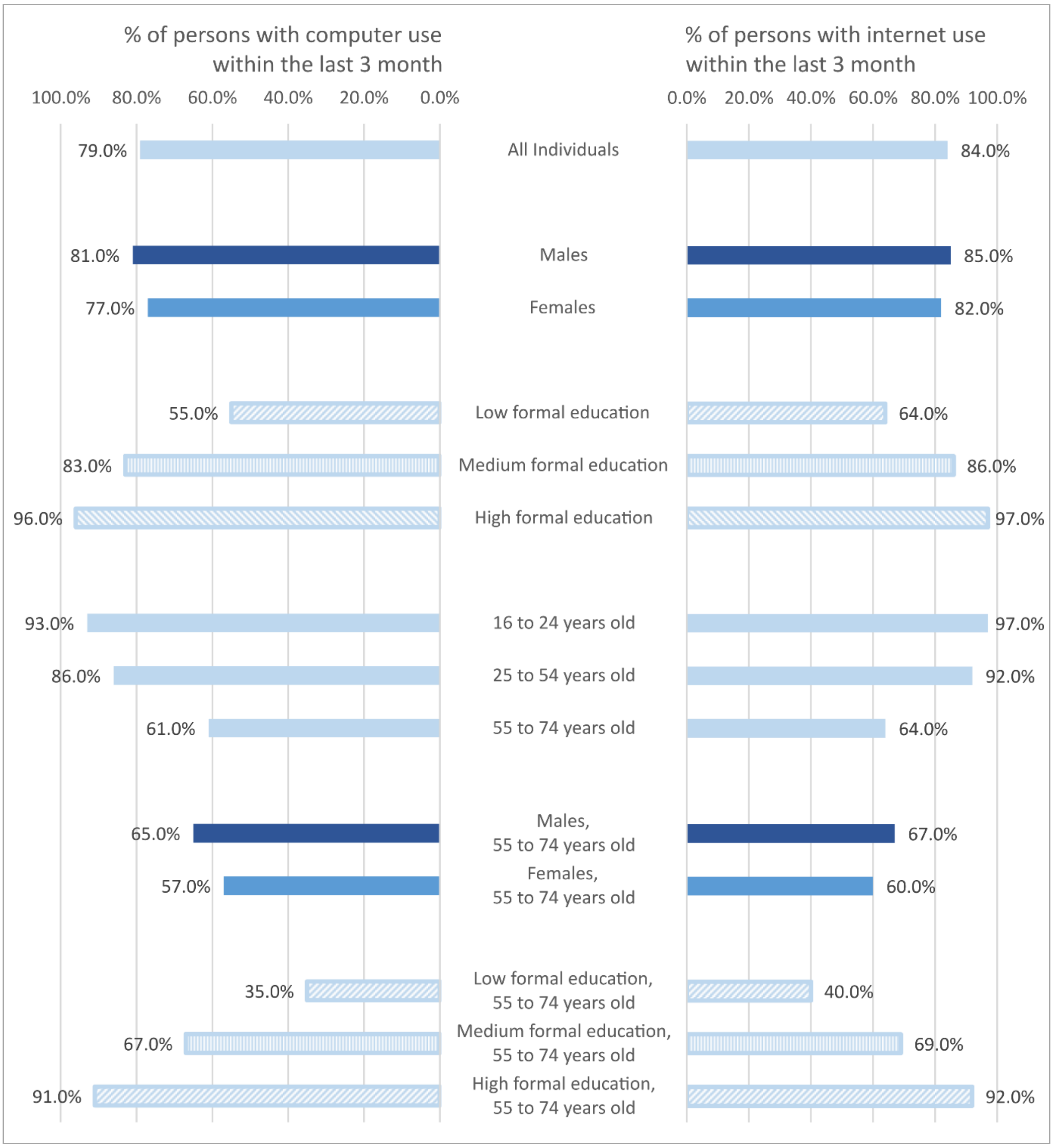
These electronic health (eHealth) approaches, which have a focus on prevention and health promotion rather than clinical aspects, are also known as digital public health (Zeeb et al., 2020). A rapidly growing field of research deals with eHealth interventions targeting physical activity and diet (Müller et al., 2018). Nevertheless, the evidence on effectiveness is mixed so far. For instance, only half of the examined studies in a review found eHealth interventions targeting physical activity and dietary behaviour to be more effective than the control condition (Norman et al., 2007). In another systematic review, health and fitness apps improved physical activity in 14 of 21 studies, diet in seven of 13 studies and decreased sedentary behaviour in two of five studies (Schoeppe et al., 2016).

Using digital approaches for public health interventions promises a range of advantages. They provide the opportunity to reach many people at low cost, while still providing personalized and individually tailored interventions (Oldenburg et al., 2015).

On the other hand, concerns have been raised that digital approaches may inadvertently generate or widen health inequalities. This is the case if digital interventions are more accessible, more frequently adopted, or more effective in already advantaged groups (Veinot et al., 2018).

In fact, in 2017, 79.0% of persons in the European Union had used a computer and 84.0% had used the internet within the last three months (see Figure 10). However, the percentage of those using a computer decreased with age: from 93.0% among the 16 to 24 years old, to 61.0% among the 55 to 74 years old. Further, there was a gradient by age and education among those aged 55 to 74: More males (65.0%) than females (57.0%) and more persons with high formal education (91.0%) than medium formal education (67.0%) or low formal education (35.0%) had used a computer within the last three months (European Union and Eurostat, 2020a). A similar trend was observed for internet use within the last three months (European Union and Eurostat, 2020b).

Figure 10: Prevalence of computer and internet use in the European Union, 2017



Own work based on European Union and Eurostat (2020a) and European Union and Eurostat (2020b)

Even though digital experience seems to decrease with age, the retirement age is likely to present an exceptional opportunity to modify health behaviours such as physical activity (Hirvensalo and Lintunen, 2011). In fact, sports and leisure-time physical activity have shown to increase after transition to retirement (Barnett et al., 2012). Notwithstanding, as study VII showed, sports participation increased over retirement to a lesser extent in persons with a migrant background compared to non-migrant persons (Schönbach et al., 2017). Thus, it seems to be reasonable to focus interventions on disadvantaged groups, for example persons with a migrant background or persons with low socioeconomic position.

3 Health impact assessment

3.1 Challenges in evidence based public health

Public health interventions are ideally supposed to be based on the best available scientific evidence, not only to avoid unintended harmful outcomes, but also to allocate scarce resources in the best way possible (Brownson et al., 2009; Gerhardus et al., 2008). Thus, the concept of evidence-based public health aims to make decisions based on the best available research evidence, with the consideration of specific contexts, i.e. of population characteristics, needs, values and preferences as well as resources (Brownson et al., 2009).

In the case of clinical interventions, randomized controlled trials are the gold standard to provide evidence as they have strong internal validity for certain contexts and study populations. However, their application to public health interventions is limited. Firstly, because they are often logistically or ethically impossible for large-scale public health interventions; and secondly, because the generalizability and the transferability of their results to other contexts and populations is uncertain (Victora et al., 2004).

Countries differ with regard to their risk-factor profile, their population-specific age structure, as well as their disease incidence-prevalence-mortality profile. These factors may influence the effect that an intervention has on population health. In fact, the effect on population health for the same intervention might vary from country to country.

Health impact assessment (HIA) therefore aims to (i) upscale intervention effects from examined groups to the population level while (ii) taking contextual factors into account that could influence the effect of an intervention.

3.2 Prospective health impact assessment evidence synthesis

HIA is defined as "[…] a combination of procedures, methods and tools by which a policy, program or project may be judged as to its potential effects on the health of a population, and the distribution of those effects within the population" (WHO, 1999: 4). An HIA systematically predicts the future health consequences of a proposal, even before implementing it. HIAs thereby aim to provide information that enables decision-makers to take impacts on health outcomes into account when choosing which courses of options to implement (Kemm, 2013c).

HIAs belong to the family of (prospective) impact assessments, which systematically anticipate the societal impact of human activities (Fehr et al., 2014). However, in contrast to other assessments such as environmental impact assessment or strategic environmental assessment, a legal basis for HIA at the European or national level is lacking. Nevertheless, HIAs are relevant for decisions inside and outside the health sector. After all, health and its determinants, such as diet and physical activity, may be influenced by policies of sectors other than health. HIAs thereby support the Health in All Policies approach, which was adopted as a main theme under the Finish European Union presidency in 2006. The Health in All Policies approach advocates the consideration of health aspects in policies across all sectors (Sihto et al., 2006).

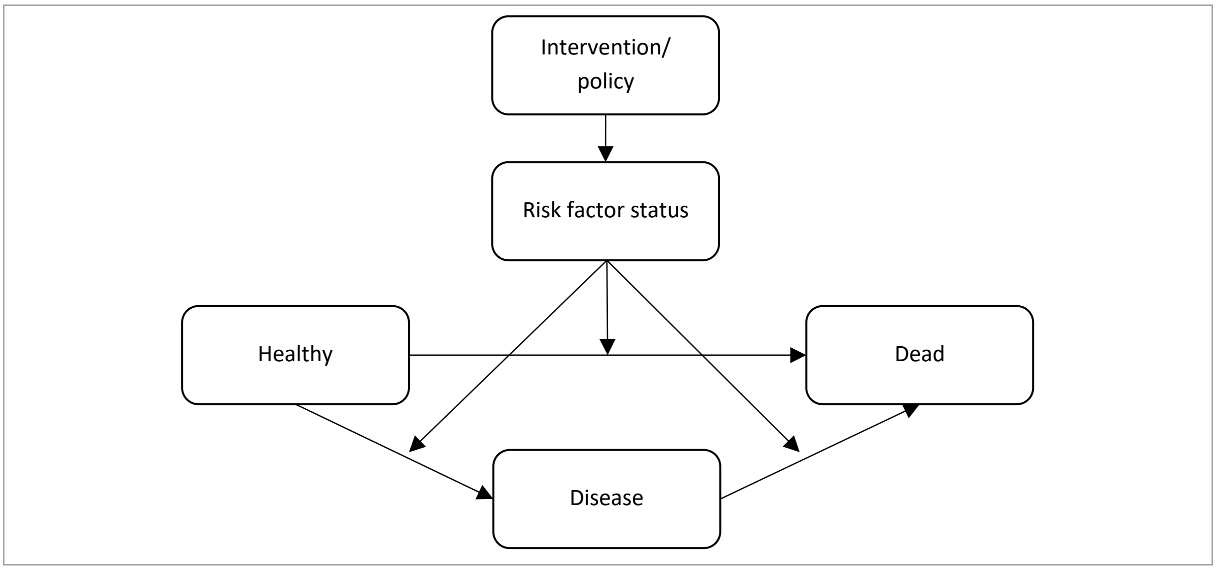
An HIA consists of the following steps (Kemm, 2008; Kemm, 2013c): 1. Screening (deciding whether a proposal needs an HIA); 2. Scoping (planning how to conduct an HIA); 3. Risk assessment/Effect analysis (the core of the HIA, which assesses possible health impacts qualitatively or quantitatively); 4. Recommendations and reporting to decision-makers (whereby it is not agreed on whether the HIA should or should not advocate for certain options); 5. Implementation, monitoring and evaluation (after a decision has been made). Whereas the main stage, the effect analysis, may be qualitative or quantitative, Kemm (2013a) argues that quantified outcomes are more likely to help decision-makers when comparing different options.

A range of surveys on HIAs and their current practice and future challenges have been published (Bhatia and Seto, 2011; Dannenberg et al., 2008; Fehr et al., 2012; Haigh et al., 2013; O'Connell and Hurley, 2009; Veerman et al., 2005). These have identified certain areas that have been neglected so far and that future HIAs would benefit from. For instance, Veerman et al. (2005) observed a lack of numeric quantification, with only 16 out of 98 HIAs included in their survey reporting numeric estimates of change in health outcome. In other surveys, the assessment and reporting of differential impacts on subgroups and impacts on health inequalities was found to be neglected (Bhatia and Seto, 2011; Fehr et al., 2012; Haigh et al., 2013). A lack in the assessment of uncertainties was also observed (Fehr et al., 2012). Further, the majority of HIAs were related to projects, and not (national) policies (Kemm, 2013b).

3.3 DYNAMO-HIA: A tool for quantitative health impact assessment

There are a range of tools that exist for quantitative HIA (Fehr et al., 2012; Fehr et al., 2016; Lhachimi et al., 2010). One of them is DYNAMO-HIA (DYNAmic MOdeling for Health Impact Assessment). In DYNAMO-HIA, a range of “what-if” scenarios with an intervention-induced risk factor change can be specified. DYNAMO-HIA then simulates the effect of these risk factor changes on the health outcomes for a whole population over a projection period defined by the user (Lhachimi et al., 2012a) (see Figure 11).

Figure 11: General concept of a model for health impact assessment



Adapted from Boshuizen et al. (2012)

The DYNAMO-HIA project started in 2007 and was funded by the European Commission's Directorate General for Health and Consumers, with co-financing from a range of institutes such as the Erasmus Medical Center in Rotterdam and the National Institute of Public Health and the Environment in the Netherlands. Its aim was to quantify the health impact of policies.

DYNAMO-HIA consists of

1. a generic software, which is able to quantify the effect of a policy-induced risk factor change on the health outcomes of interest, given necessary data on the risk factor, diseases and the population,
2. a database, which provides a range of reference data. For 27 European countries, data is available on risk factors such as alcohol intake, smoking and body mass index (BMI); on diseases such as IHD, stroke, diabetes, chronic obstructive pulmonary disease, lung cancer, colorectal cancer, oral cancer, breast cancer and oesophageal cancer; as well as on populations (population size, projected births and mortality)

Both the software and the database are freely available from the website (https://www.dynamo-hia.eu/).

At its core, the generic DYNAMO-HIA software is a partial micro simulation based on a Markov model. It consists of (i) a stochastic micro-simulation of risk factor exposure and (ii) a deterministic macro-simulation of diseases and deaths. In the beginning, a baseline population of individuals by age and gender is generated, based on the risk factor exposure data that the user has to provide to the model. In the micro-simulation, a representative sample of individuals is selected from this baseline population. For each individual, DYNAMO-HIA generates a risk factor biography over the life-course using pre-defined transition probabilities between risk-factor states. In the macro-simulation, DYNAMO-HIA constructs disease life tables for every risk factor biography. Then, it calculates the probability of disease incidence and mortality over time for every risk-factor biography. In the end, biography-specific life tables are calculated for every birth cohort and can be aggregated (Boshuizen et al., 2012; Lhachimi et al., 2008; Lhachimi et al., 2012a).

Since the tool was released in 2010, a range of HIAs have been conducted using DYNAMO-HIA (see Table 2).

Table 2: Health impact assessments conducted using DYNAMO-HIA

Author	Risk factor	Country/City	Time horizon	Outcome
Kulik et al. (2012)	Smoking	Netherlands	2010–2060	Lung cancer, COPD and IHD prevalence, deaths
Lhachimi et al. (2012b)	Alcohol consumption	11 countries of the European Union	10 years	Stroke, diabetes, IHD and cancer prevalence, deaths
Lhachimi et al. (2013)	BMI	UK	Cohort	Colorectal cancer, diabetes, stroke and IHD prevalence, cohort life expectancy, disease-free life expectancy
Holm et al. (2014)	Smoking	Copenhagen	Until 2040	Lung cancer, IHD, stroke and COPD prevalence, excess mortality rate, cohort life expectancy
Hendriksen et al. (2015)	Salt intake	9 countries of the European Union	20 years	Stroke and IHD prevalence, deaths, life expectancy
Mansfield and MacDonald Gibson (2015)	Walking (for transportation)	3 communities in North Carolina	40 years	Hypertension, diabetes, IHD and stroke prevalence, deaths
Erkoyun et al. (2016)	Salt intake	Turkey	2013–2025	IHD and cerebrovascular prevalence and incidence
Fischer and Kraemer (2016)	Second-hand-smoke	Germany	2014–2040	IHD, COPD and stroke prevalence
Lhachimi et al. (2016)	Alcohol consumption, BMI, Smoking	11 countries of the European Union	10 years	IHD, stroke, diabetes, COPD and cancer prevalence, deaths, life expectancy
Kang (2017)	Smoking	Korea	2017–2027	IHD, COPD, diabetes, stroke and cancer prevalence and incidence, deaths
Brønnum-Hansen et al. (2018)	Air pollution	Copenhagen	Until 2040	Diabetes, IHD, stroke, COPD, asthma and lung cancer prevalence and incidence, life expectancy, disease-free life expectancy
Otavova et al. (2019)	Smoking	Belgium	Until 2048	Life expectancy, healthy life years, unhealthy live years
Leão et al. (2020)	Smoking	7 countries of the European Union	Cohort	Healthy life years
Broeks et al. (2020)	Meat, fruit and vegetable intake	Netherlands	2018–2048	Colorectal cancer, IHD, diabetes, lung cancer, stroke prevalence
Bender et al. (2020)	Obesity	Copenhagen	2014–2040	IHD, stroke and diabetes prevalence and incidence, life expectancy

Own work; BMI= Body mass index; IHD= Ischemic heart disease; COPD= Chronic obstructive pulmonary disease

So far, most of the HIAs were run on the risk factors smoking and alcohol intake. Only one HIA has been conducted on physical activity, namely on walking for transportation (Mansfield and MacDonald

Gibson, 2015), and until recently, salt intake (Erkoyun et al., 2016; Hendriksen et al., 2015) was the only dietary risk factor that had been modelled. However, DYNAMO-HIA is a generic software that can handle any risk factor, as long as the user provides data for it. These risk factors can consist of up to 12 categories per simulation.

DYNAMO-HIA provides some additional flexibility to the user. For instance, DYNAMO-HIA relies, by default, on age- and gender-specific model parameters. Nonetheless, differentiation by other characteristics such as socioeconomic position is possible by portioning the risk factor accordingly.

Further, even though DYNAMO-HIA does not provide a default option to consider and account for the uncertainty of model parameters, it is nevertheless possible to carry out a probabilistic sensitivity analysis. In order to do so, sufficiently repeated replications of the model have to be run, each with a new set of input parameters that have previously been drawn randomly from specified distributions.

4 Research objectives

The overall aim of this dissertation was to quantify the long-term population health impact of public health interventions targeting lifestyle risk factors, thereby supporting evidence-based policy-making. To this end, we conducted four prospective quantitative HIAs, each of which addressed a population-wide intervention targeting nutrition or physical activity behaviour. A special focus was to overcome current challenges in HIA by a) using realistic policy scenarios instead of artificial counterfactual scenarios, b) not only estimating an intervention's impact on risk behaviour change, but to extend the analysis by quantifying actual health outcomes, c) adding new risk factors to DYNAMO-HIA and d) assessing the differential distribution of health impacts by socioeconomic characteristics such as education (as an explorative extension).

The following questions were addressed in this dissertation:

I. To what extent can a tax on processed meat potentially improve population health in Germany?

   → Study I (processed meat)

   In order to answer this question, we modelled three environmental taxes (4%, 18.5%, 33.3%) as well as a value-added tax (VAT) increase on processed meat from 7% to 19%.

   Methodologically, the focus was to model – for the first time – the health impact of a realistic tax on processed meat for a European country, using price elasticities from the German context. Processed meat had just shortly before been classified to be carcinogenic by the International Agency of Research on Cancer (Bouvard et al., 2015; IARC Working Group on the Evaluation of Carcinogenic Risk to Humans, 2018).

   Furthermore, this was the first time that a partial probabilistic sensitivity analysis was conducted in DYNAMO-HIA in order to account for uncertainty.

II. What are the health gains of a European fat tax?

   → Study II (saturated fat)

   In order to answer this question, we applied the saturated fat intake reduction and simultaneous polyunsaturated fat intake increase that has been observed under the Danish fat tax to six other European countries.

   This was the first approach to apply the actual intake change that has been observed under the fat tax in Denmark as a real-life setting to a range of other European counties.

III. What are the health impacts of a VAT removal or a subsidy on fruits and vegetables in Germany?

   → Study III (fruits and vegetables)

In order to answer this question, we modelled a VAT reduction on fruits and vegetables from the current 7% to 0%, as well as the implementation of a 20% subsidy on fruits and vegetables. Methodologically, the focus was to use price elasticities from the German context.

IV. What are the potential impacts of a large-scale physical activity intervention for older adults in Germany on long-term health and health inequalities?

→ Study IV (physical activity)

In order to answer this question, we used the physical activity change that was observed in the project “PROMOTE – Tailoring physical activity interventions to promote healthy ageing” as a case study, as well as a range of hypothetical intervention scenarios with the effect size of PROMOTE but with different effectiveness across education groups. While the PROMOTE intervention consisted of two web-based interventions (for self-tracking physical activity behaviour) and a delayed intervention control group, conducted among 589 adults aged 65 to 79 years in five German communities (Muellmann et al., 2019), it was scaled up from community to national level in the simulation.

The methodological challenge was to model health impacts following behavioural risk factor changes by education as an indicator of socioeconomic position using DYNAMO-HIA, which had not been done before.

Studies I–III were conducted within the Research group for Evidence-based public health, founded by the Leibniz Institute for Epidemiology and Prevention Research – BIPS and the Institute for Public Health and Nursing Research at the University Bremen.

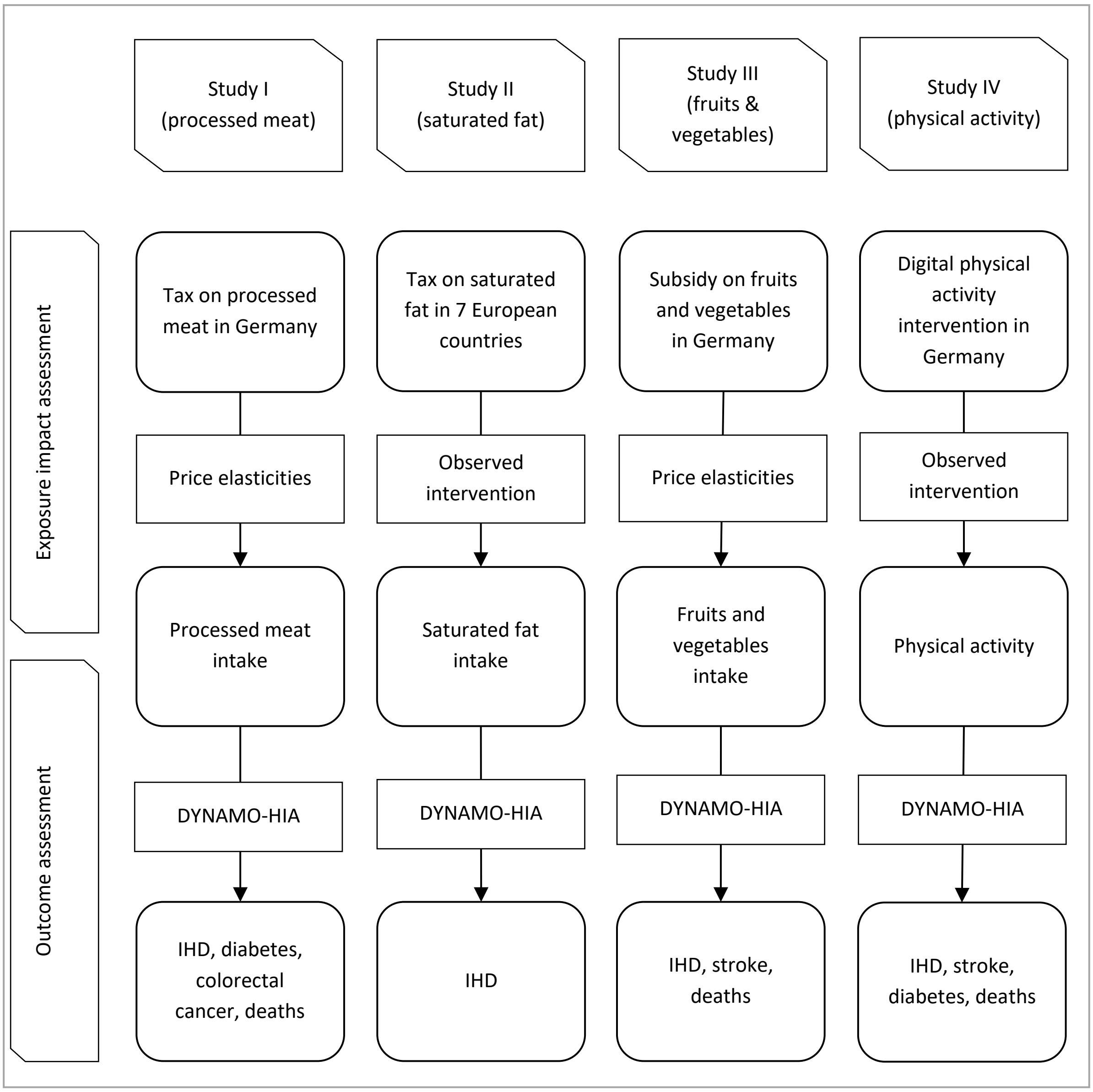
Study IV was conducted within the project “EQUAL – Equity impacts of interventions to increase physical activity” (Lehne et al., 2019), which is a subproject of the research network “AEQUIPA – Physical activity and health equity: primary prevention for healthy ageing” (Forberger et al., 2017).

5 Data and methods

5.1 Conceptual pathway

The conceptual pathway of the HIAs conducted in studies I–IV comprises two steps, as suggested by Veerman et al. (2005): 1. Exposure impact assessment, which is representing the effect of a policy on the risk factor or health determinant, and 2. Outcome assessment, which is representing the impact of the change in a risk factor on health (see Figure 12).

Figure 12: Conceptual pathway of the health impact assessments conducted in studies I-IV



Own work; IHD= Ischemic heart disease

5.2 Exposure impact assessment: from policy to risk factor

In order to estimate what impact the policy of interest has on the respective risk factor (processed meat intake, saturated fat intake, fruits and vegetables intake or physical activity), we used the following data and assumptions (see Table 3):

Table 3: Overview of data sources for the exposure impact assessment

	Study I (processed meat)	Study II (saturated fat)	Study III (fruits & vegetables)	Study IV (physical activity)
Policy	Environmental tax on processed meat (4%, 18.5%, 33.3%), VAT increase for processed meat (11.2%)	Tax on saturated fat (€2.15 per kg of saturated fat in products with more than 2.3g of saturated fat per 100g)	VAT decrease for fruits and vegetables (6.54%), subsidy on fruits and vegetables (20%)	Digital intervention promoting physical activity at population-level (with PROMOTE as case study)
Intervention effect	Own calculated price elasticities derived from consumer panel dataset by the GfK	Observed intake change following Denmark's fat tax, derived from Smed et al. (2016)	Price elasticities derived from Thiele (2008)	Observed physical activity change following PROMOTE intervention, derived from re-analysis (Czwikla et al., 2019)
Risk factor/ health determinant in the reference scenario	Processed meat intake from the NVS II (Max Rubner-Institut, 2009)	Saturated fat intake from European Nutrition and health report (Elmadfa et al., 2009)	Fruits and vegetables intake from GEDA 2012 (Robert Koch Institute, 2014)	Physical activity from GEDA 2014/15-EHIS (Robert Koch Institute, 2018)

Own work; GEDA 2012= German Health Update 2012; GEDA 2014/15-EHIS= German Health Update 2014/15- European Health Interview Survey; GfK= German consumer research association "Gesellschaft für Konsumforschung"; NVSII= German National Nutrition Survey II; VAT=Value-added tax

<u>Policy</u>

Study I (processed meat) hypothesized three environmental taxes on processed meat (4%, 18.5%, 33.3%), as well as a VAT increase for processed meat from 7% to 19% (translating to a price increase of 11.2%). Study II (saturated fat) adapted the Danish fat tax to six other countries. Study III (fruits and vegetables) hypothesized a VAT reduction from the current 7% to 0% (translating into a price decrease of 6.54%), as well as a 20% subsidy. Study IV (physical activity) assumed a digital intervention promoting physical activity among older adults, by rolling out PROMOTE as a case study from community to national level.

These policies built the "intervention scenarios" of the HIA. For comparison purposes, in each study we additionally simulated a "reference scenario", also known as "business-as-usual" scenario, where the age- and gender-specific risk factor exposure (processed meat intake, saturated fat intake, fruit and vegetable intake or physical activity) remained unchanged. Further, we simulated a special intervention scenario, a so-called “guideline scenario” or “minimum-risk-exposure-scenario” where the risk factor was assumed to be shifted to a level that is recommended by guidelines and/or assumed to reduce harm to a minimum (i.e. <15g/day of processed meat, ≤10 percent of total energy intake (%E)/day from saturated fat, >4.5 portions/day of fruits and vegetables as well as physical activity of ≥22.5 MET-hours/week). Thus, the guideline scenario functions – by presenting the number of deaths and disease cases that could maximally be prevented by a risk factor modification – as a benchmark.

<u>Intervention effect</u>

For study I (processed meat) and study III (fruits & vegetables), we used price elasticities to predict the impact respective price changes would have on processed meat and fruit and vegetable intake, respectively. For study I (processed meat), own-and cross-price elasticities were calculated by one of the co-authors, based on a consumer panel dataset collected from January to December 2011 by the German consumer research association “Gesellschaft für Konsumforschung” (GfK) (Thiele et al., 2017). The GfK-data cover all food purchases of 13,125 representative German households. According to these elasticities, a 4%, 11.2%, 18.5% and 33.3% price increase of processed meat results in a drop of demand by 2.8%, 7.8%, 12.9% and 23.3%, respectively. For study III (fruits & vegetables), we used own-price elasticities derived from Thiele (2008), which were based on the Income and Expenditure Survey of the Federal Statistical Office of Germany from 2003 with 12,000 households. According to these price elasticities, removing the VAT on fruits and vegetables and its associated price reduction of 6.54% would increase fruit intake by 5.2% and vegetable intake by 3.6%. Correspondingly, the 20% subsidy scenario with its 20% price decrease would lead to an increase in fruit intake by 16% and an increase in vegetable intake by 11%.

For study II (saturated fat) and study IV (physical activity), we used observed data from previously conducted interventions. In the case of study II (saturated fat), we assumed the tax would have the same effect on saturated fat intake that it had in Denmark. In order to do so, we derived the age- and gender-specific saturated fat intake change that was observed in Denmark after the introduction of a fat tax from the literature. The observed saturated fat intake reduction ranged from 0.48%E to 0.68%E for males and from 0.43%E to 0.58%E for females (Smed et al., 2016). In the case of study IV (physical activity), the intervention effect estimates were derived from the project PROMOTE (Muellmann et al., 2019), which were re-analysed within the EQUAL project (Czwikla et al., 2019). The re-analysis suggested that in persons with low education, the weekly moderate-to-vigorous physical activity (MVPA) was 19.7 minutes higher in the intervention groups than in the control group 12 weeks after baseline. In persons with medium education it was 5.8 MVPA minutes higher, and in persons with high education 9.53 MVPA minutes higher.

<u>Risk factor/ health determinant (in the reference and intervention scenarios)</u>

The intervention effects were applied to current risk factor exposure (i.e. the exposure under the reference scenario) to estimate the risk factor exposure under the intervention scenarios.

For study I, current processed meat intake was derived from the German National Nutrition Survey II (NVSII) public use file (Max Rubner-Institut, 2009). The NVSII is a nationwide representative food consumption survey, which was conducted between November 2005 and January 2007. In the survey, 15,371 persons completed the diet history interviews and reported the foods and beverages they had consumed over the preceding 4 weeks (Heuer et al., 2015). For study II, current saturated fat intake was derived from the European Nutrition and Health Report (Elmadfa et al., 2009). For study III, current fruits and vegetables intake was derived from the German Health Update 2012 (GEDA 2012) public use file (Robert Koch Institute, 2014). GEDA 2012 was carried out by the Robert Koch Institute between March 2012 and March 2013 (Lange et al., 2015) and comprises 19,189 persons with complete fruit and vegetable information. For study IV, current physical activity was derived from the German Health Update 2014/2015-European Health Interview Survey (GEDA 2014/2015-EHIS) dataset (Robert Koch Institute, 2018). The GEDA 2014/2015-EHIS study was conducted by the Robert Koch Institute from November 2014 to July 2015. It collected data from 24,016 adults (Finger et al., 2017; Lange et al., 2015; Saß et al., 2017).

5.3 Outcome assessment: from risk factor to health outcome using DYNAMO-HIA

In order to estimate the impact that the change in risk factor exposure (processed meat intake, saturated fat intake, fruits and vegetables intake and physical activity) has on health, we used the DYNAMO-HIA software. As stated in chapter 3.3, DYNAMO-HIA is a software tool, which dynamically projects a real-life population through risk factor exposure and a range of associated diseases. In the simulation, it projects the health outcomes of one or more scenarios, and compares the health outcomes of intervention scenarios, in which a change in the risk factor exposure is presumed, to a reference scenario, in which the risk factor exposure remains unchanged (Lhachimi et al., 2012a).

For the simulation, we used the following input data that are summarized in Table 4:

Table 4: Overview of data sources and configuration for the outcome assessment using DYNAMO-HIA

		Study I (Processed meat)	Study II (Saturated fat)	Study III (Fruits & vegetables)	Study IV (Physical activity)
Data sources	Risk factor prevalence for each scenario	Ten intake categories, by age and gender	Ten intake categories, by age and gender	Six intake categories, by age and gender	Three categories, by age, gender and education
	Transition probabilities	Net transitions	Net transitions	Net transitions	Zero transitions
	Relative risks for death	Per 50g/day, taken from Rohrmann et al. (2013)	-	Per 200g/day, taken from Aune et al. (2017)	For seven categories of MET-hours/week, taken from Arem et al. (2015)
	Relative risks for diseases	Per 50g/day, taken from GBD 2016 Risk Factor Collaborators (2017)	For each 5%E of lowered polyunsaturated fat intake, being replaced with saturated fat, taken from GBD 2016 Risk Factor Collaborators (2017)	Per 200g/day, taken from Aune et al. (2017)	Per 11.25 MET-hours/week, taken from Wahid et al. (2016)
	Incidence, prevalence, excess mortality of diseases	DYNAMO-HIA database	DYNAMO-HIA database	DYNAMO-HIA database	DYNAMO-HIA database
	Relative risks from other diseases	DYNAMO-HIA database	DYNAMO-HIA database	DYNAMO-HIA database	DYNAMO-HIA database
	Population size, newborns, mortality, (DALY weights)	Germany, derived from DYNAMO-HIA database	Denmark, Italy, Poland, Spain, Sweden, the Netherlands, United Kingdom, derived from DYNAMO-HIA database	Germany, derived from DYNAMO-HIA database	Germany, derived from DYNAMO-HIA database
Configuration	Start year	2018	2019	2019	2019
	Projection period	10 years (end: 2028)	10 years (end: 2029)	10 years (end: 2029)	10 years (end: 2029)
	Outcomes	Prevalence of IHD, diabetes and colorectal cancer, deaths	Prevalence of IHD	Incidence + prevalence of IHD and stroke, deaths	Incidence of IHD, stroke and diabetes, deaths

Own work; IHD= Ischemic heart disease; MET= metabolic equivalent, %E= percent of total energy intake

Risk factor prevalence (for each scenario)

For study I (processed meat), we obtained the proportion of persons for each of the following ten intake categories, by age and gender: 0 to <15 g/day, 15 to <30 g/day, 30 to <45 g/day, 45 to <60 g/day, 60 to <75 g/day, 75 to <90 g/day, 90 to <105 g/day, 105 to <120 g/day, 120 to <135 g/day and ≥135 g/day. For study II (saturated fat), we obtained the proportion of persons for the following ten intake categories, by age and gender: ≤10%E, >10 to ≤12%E, >12 to ≤14%E, >14 to ≤16%E, >16 to ≤18%E, >18 to ≤20%E, >20 to ≤22%E, >22 to ≤24%E, >24 to ≤26%E and >26%E. For study III (fruits and vegetables), the intake was classified into six categories, by age and gender: ≤0.5 portions, >0.5 to ≤1.5 portions, >1.5 to ≤2.5 portions, >2.5 to ≤3.5 portions, >3.5 to ≤4.5 portions and >4.5 portions. For study IV (physical activity), the intake was classified into three categories: <11.25 MET-hours/week, ≥11.25 to <22.5 MET-hours/week and ≥22.5 MET-hours/week, by age, gender and education.

In order to avoid the occurrence of unsteadiness, the risk factor was smoothed over age.

Transition probabilities

For studies I–III, we used net transitions, i.e. we assumed that gender- and age-specific risk factor prevalence would remain constant over the whole projection period. For study IV, we used zero transitions, i.e. we assumed that persons keep their risk factor exposure throughout the whole projection period.

Relative risks for diseases and death

For study I (processed meat), we used relative risks (RRs) on IHD, diabetes and colorectal cancer for 50 g increments from the GBD study 2016 (GBD 2016 Risk Factor Collaborators, 2017), and RRs on death for 50 g increments per day from a publication based on the German European Prospective Investigation into Cancer and Nutrition cohort (Rohrmann et al., 2013). For study II (saturated fat), we used RRs on IHD from the GBD study 2016 (GBD 2016 Risk Factor Collaborators, 2017), for each 5%E of lowered polyunsaturated fat intake per day with simultaneous increase in saturated fat. For study III (fruits and vegetables), we used RRs on IHD, stroke and deaths per 200 g of fruits and vegetables per day from a meta-analysis (Aune et al., 2017). For study IV (physical activity), we used RRs on IHD, stroke, diabetes for an increase of 11.25 MET-hours per week from a meta-analysis (Wahid et al., 2016), and RRs on death for seven categories of MET-hours per week from a pooled analysis (Arem et al., 2015).

Disease data

For all studies, we used the DYNAMO-HIA database, which incorporates incidence, prevalence, and excess mortality for a range of diseases such as ischemic heart disease, stroke, diabetes and cancer for nearly all European countries.

Population data

For all studies, we used population size, newborns and mortality (in the case of studies I–III for Germany; in the case of study III for Denmark, Italy, Poland, Spain, Sweden, the Netherlands, United Kingdom) from the DYNAMO-HIA database.

Configuration

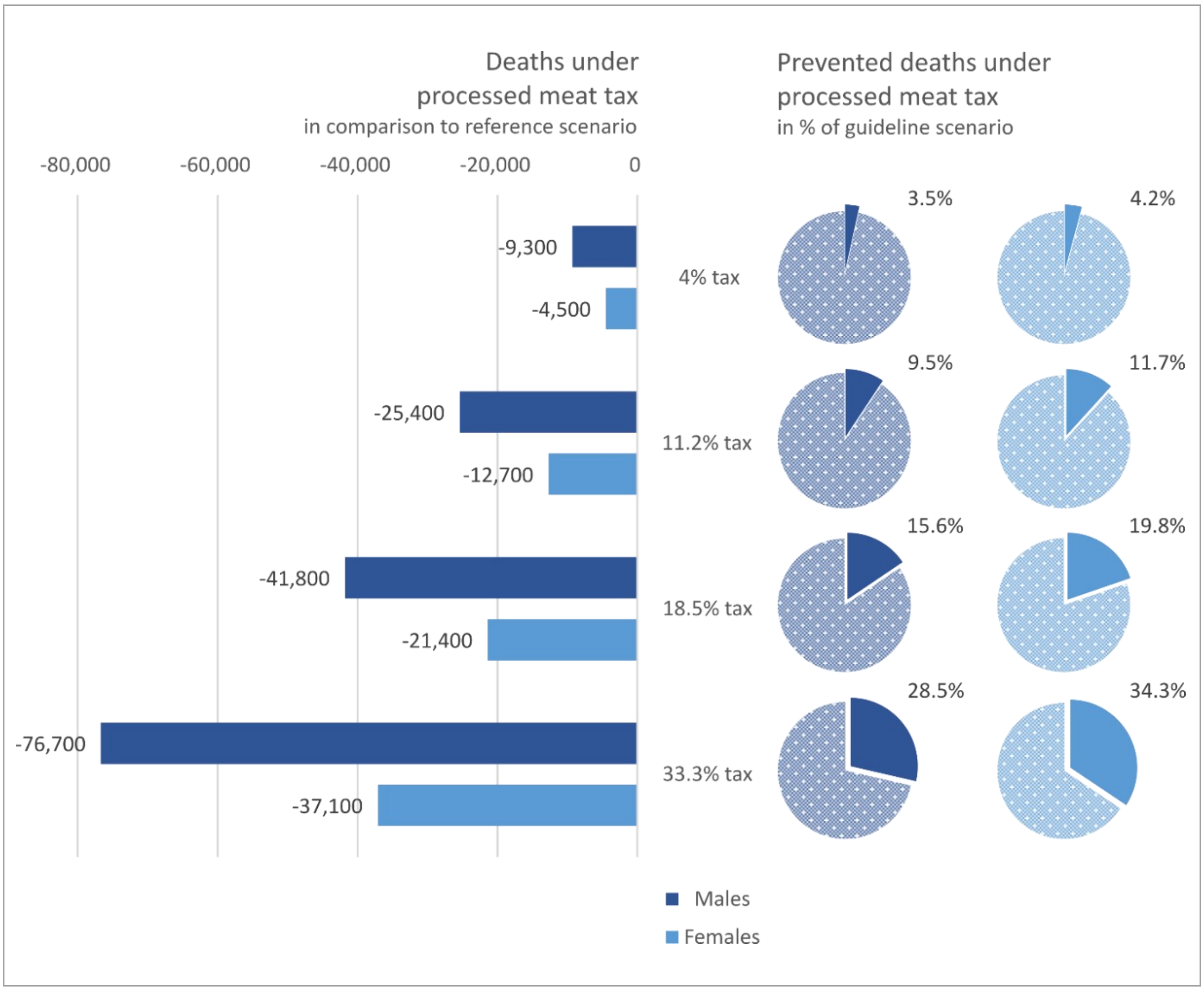
The simulations were run for a projection period of ten years in all studies.

6 Results

6.1 To what extent can a tax on processed meat potentially improve population health in Germany? (Study I)

Over the 10-year projection period, there would be 9,300 less male deaths and 4,500 less female deaths under the lowest tax of 4%, compared to the reference scenario. At the same time, the highest tax of 33.3% would prevent 76,700 male and 37,100 female deaths. Thereby, the lowest tax of 4% reaches 3.5% of the maximal number of preventable deaths as presented in the guideline scenario in males and 4.2% in females, while the highest tax of 33.3% reaches 28.5% and 34.3% of the maximal number of preventable deaths in males and females, respectively (see Figure 13).

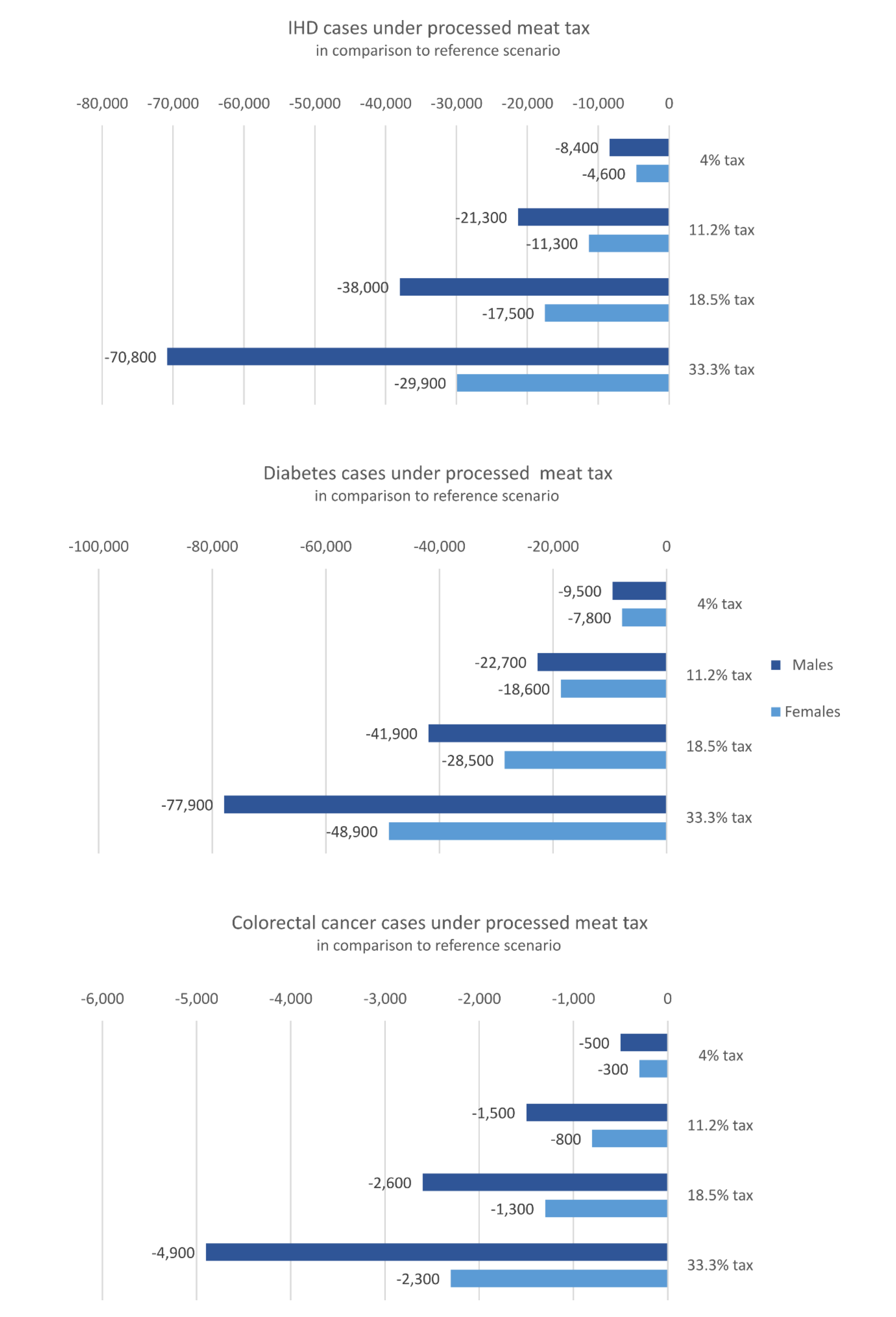
Figure 13: Deaths under processed meat tax, cumulated over the 10-year projection period



Own work

In projection year 10, prevalent IHD, diabetes and colorectal cancer cases under the lowest tax of 4% would be 8,400, 9,500 and 500 lower in males, respectively, and there would be 4,600, 7,800 and 300 less cases in females. Under the highest tax of 33.3%, prevalent IHD, diabetes and colorectal cancer cases would be 70,800, 77,900 and 4,900 lower in males and 29,900, 48,900 and 2,300 lower in females (see Figure 14).

Figure 14: Prevalent ischemic heart disease, stroke and colorectal cancer cases under processed meat tax in projection year 10

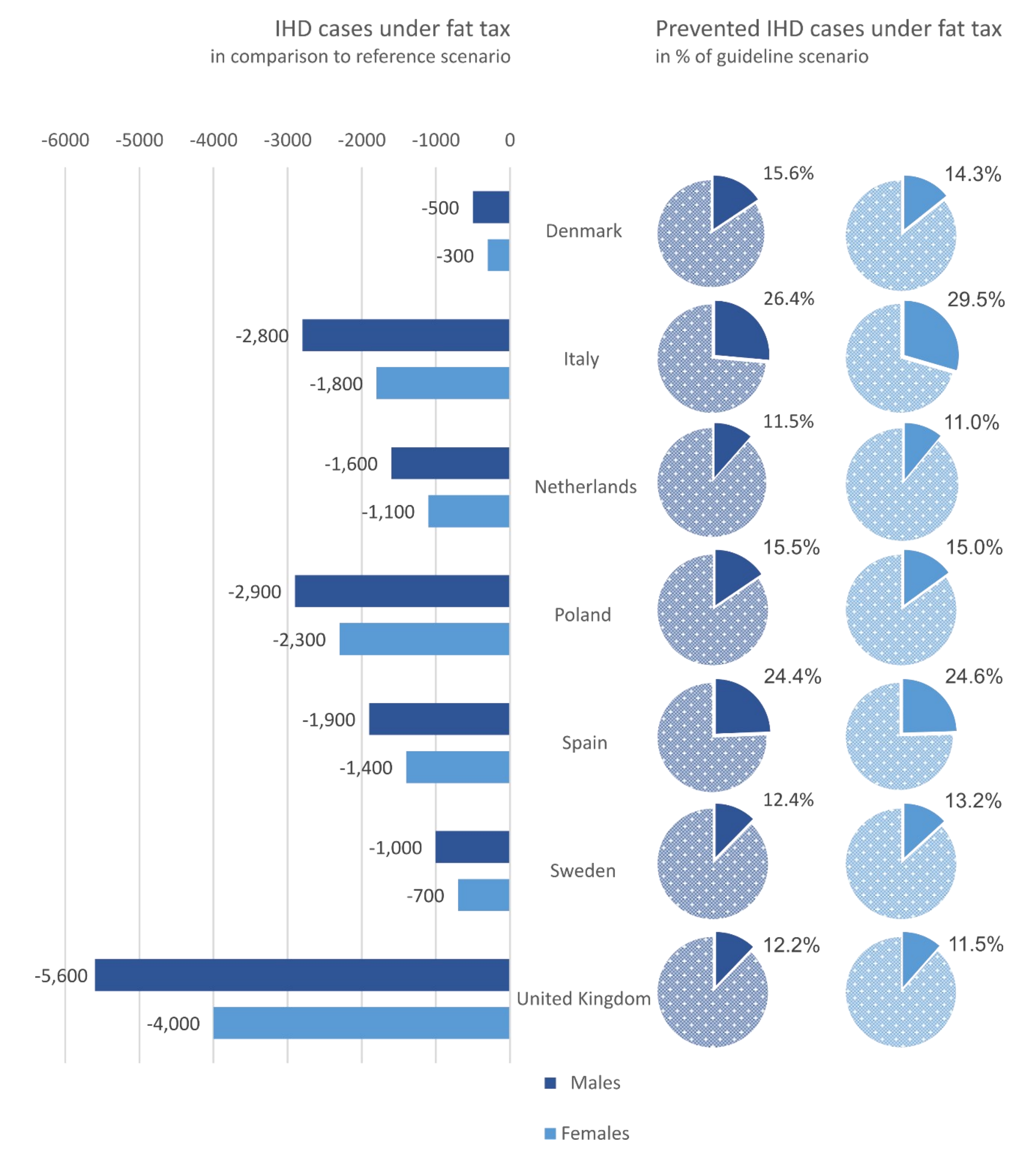


Own work; IHD= Ischemic heart disease

6.2 What are the health gains of a European fat tax? (Study II)

Compared to the reference scenario, a fat tax would reduce the prevalent IHD cases in projection year 10 by a minimum of 500 among males and 300 among females in Denmark, up to a maximum of 5,600 among males and 4,000 among females in the UK. Measured against the guideline scenario, the prevented IHD cases under the fat tax scenario would correspond to between 11.0% (in females in the Netherlands) and 29.5% (in females in Italy) (see Figure 15).

Figure 15: Prevalent ischemic heart disease cases under fat tax in projection year 10

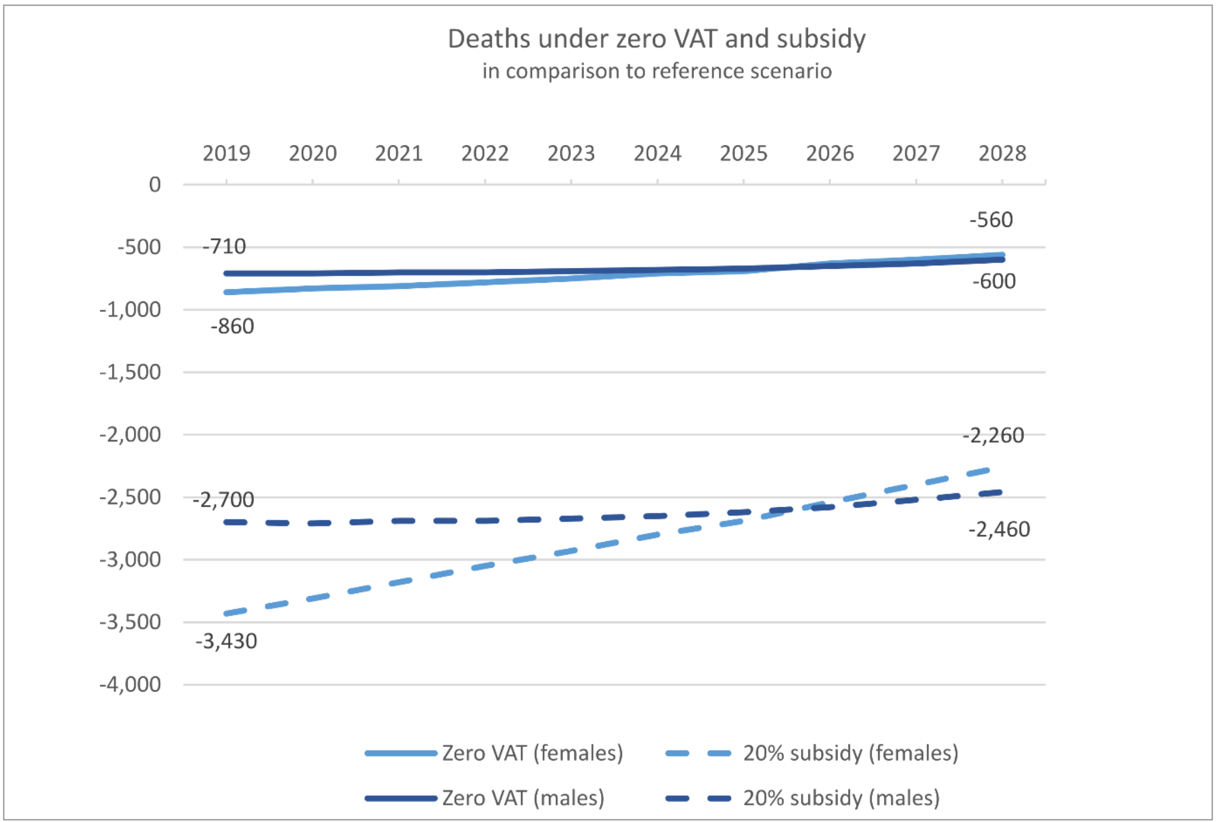


Own work; IHD= Ischemic heart disease

6.3 What are the health impacts of a value-added tax removal or a subsidy on fruits and vegetables in Germany? (Study III)

After the first year of projection, the removal of the VAT on fruits and vegetables would prevent 1,570 deaths, 510 IHD cases and 730 stroke cases in comparison to the reference scenario. At the same time, the 20% subsidy would prevent 6,130 deaths, 2,010 incident IHD cases, as well as 2,830 stroke cases (see Figure 16 for deaths, results for diseases not shown).

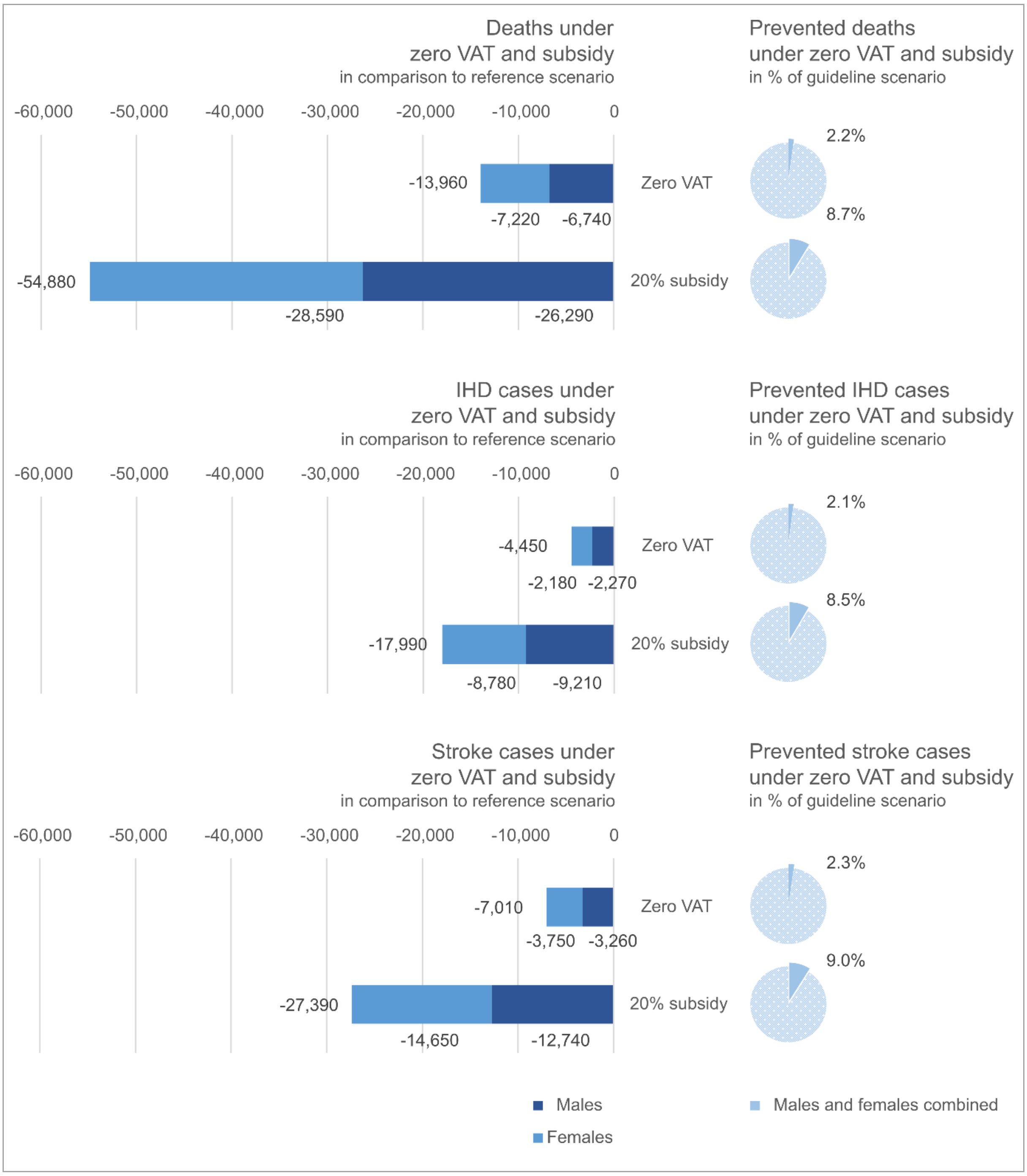
Figure 16: Deaths under value-added tax removal and subsidy on fruits and vegetables over the 10-year projection period



Own work; VAT= Value-added tax

Cumulated over the 10-year projection period, an estimated 13,960 deaths, 4,450 incident IHD cases and 7,010 stroke cases would be prevented after removing the VAT on fruits and vegetables. After implementing a 20% subsidy, 54,880 deaths, 17,990 incident IHD cases and 27,390 stroke cases would be averted. Although this corresponds to only a fraction of the incidents that would occur under the reference scenario, the averted cases translate to approximately 2% (for the zero VAT scenario) and 9% (for the 20% subsidy scenario) of deaths as well as IHD and stroke cases that would be prevented under the guideline scenario, i.e. if the whole population consumed the recommended five portions of fruits and vegetables per day (see Figure 17).

Figure 17: Deaths, incident ischemic heart disease and stroke cases under value-added tax removal and subsidy on fruits and vegetables, cumulated over the 10-year projection period

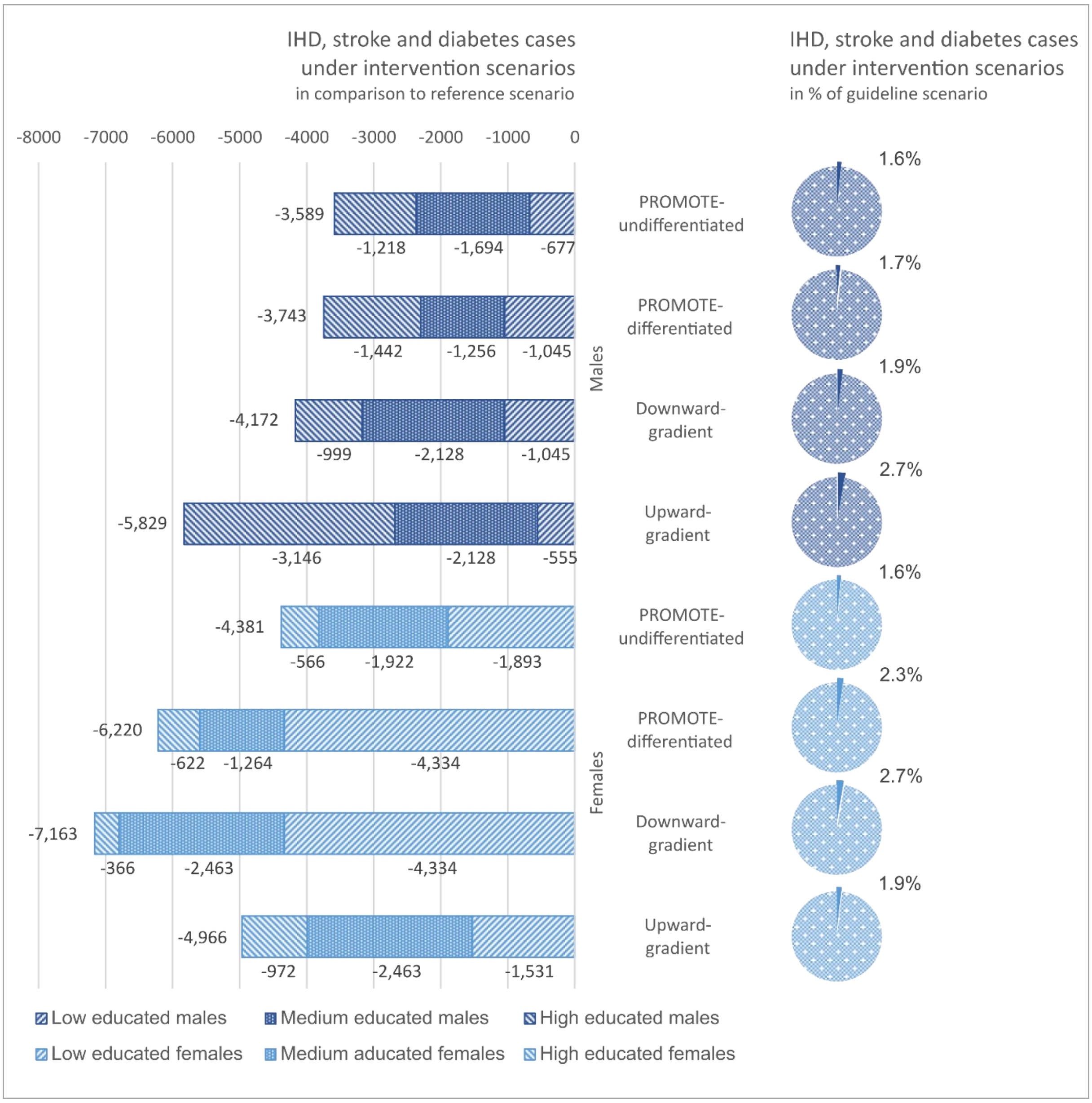


Own work; IHD= Ischemic heart disease, VAT= Value-added tax

6.4 What are the potential impacts of a large-scale physical activity intervention for older adults in Germany on long-term health and health inequalities? (Study IV)

Under the four interventions promoting physical activity among people aged 55 and over, there would be approximately 3,589–5,829 less incident disease cases among males aged ≥55 years compared to the reference scenario, as well as 4,381–7,163 less disease cases among females aged ≥55 years, over the 10-year projection period (see Figure 18).

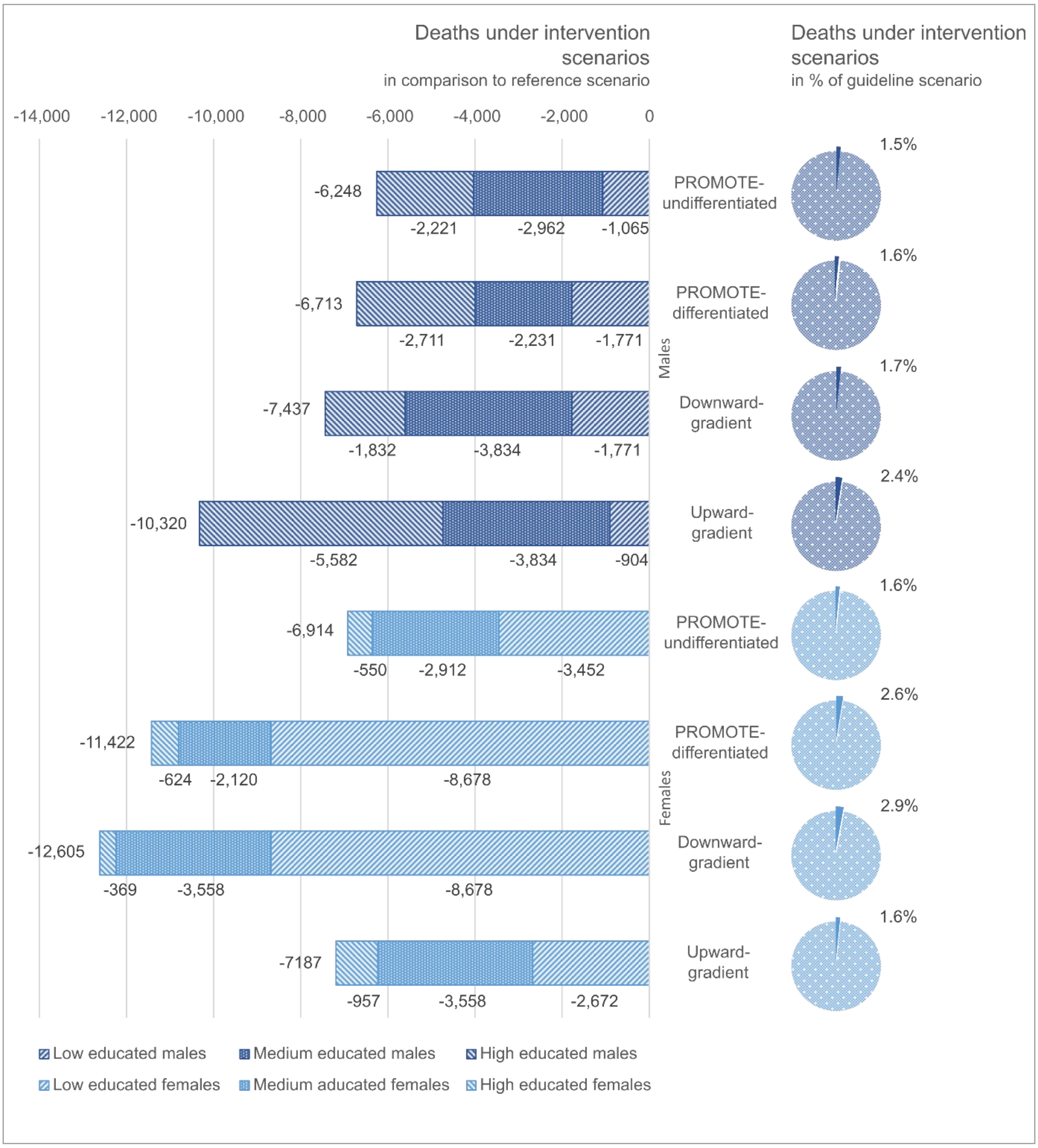
Figure 18: Incident ischemic heart disease, stroke and diabetes cases under physical activity intervention, cumulated over the 10-year projection period



Own work; IHD= Ischemic heart disease

The highest reduction for males would be achieved under the upward gradient scenario, under which the intervention is most effective for those with a high education level. This upward-gradient scenario realizes 2.7% of the prevented disease cases observed under the guideline scenario, while increasing inequalities between education groups. In females, the highest reduction would be achieved under the downward-gradient scenario, under which the intervention is most effective amongst those with low levels of education. This scenario realizes 2.7% of the prevented disease cases under the guideline scenario, while decreasing inequalities between education groups. A similar pattern can be observed for deaths (see Figure 19).

Figure 19: Deaths under physical activity intervention, cumulated over the 10-year projection period



Own work

Under the assumption that all persons with low or medium education adapted the physical activity profile of those with high education, approximately 31,687 incident disease cases and 59,068 deaths could be prevented among males over a 10-year projection period, as well as 59,173 incident disease cases and 121,689 deaths among females. Among males, this translates to 14.4% of the prevented disease cases and 13.7% of the prevented deaths observed under the guideline scenario. Among females, this translates to 22.2% and 27.7% of the prevented disease cases and deaths observed under the guideline scenario (results not shown).

7 Discussion

7.1 Main findings

We conducted four HIAs of policies and interventions that were assumed to i) increase the prices of processed meat, ii) decrease the price for fruits and vegetables, iii) decrease saturated fat intake and iv) increase physical activity over a projection period of 10 years.

After the implementation of a tax on processed meat, the reduction of deaths over the 10-year projection period would range from 9,300 in males and 4,500 in females under the lowest tax of 4%, up to 76,700 in males and 37,100 in females under the highest tax of 33.3%. A fat tax would reduce the prevalent IHD cases in projection year 10 by a minimum of 500 and 300 among males and females in Denmark, respectively, up to a maximum of 5,600 and 4,000 among males and females in the UK. When removing the VAT on fruits and vegetables, an estimated 13,960 deaths would be prevented over the 10-year projection period. At the same time, a 20% subsidy on fruits and vegetables would avert 54,880 deaths. Under the four physical activity interventions, approximately 3,589–5,829 incident disease cases could be avoided among males aged ≥55 years over a 10-year projection period, as well as 4,381–7,163 disease cases among females aged ≥55 years. The highest reduction for males would however be achieved under the intervention that is most effective for those with a high education level, thereby increasing inequalities between education groups. In females, the highest reduction would be achieved under the intervention that is most effective amongst those with a low level of education, thereby decreasing inequalities between education groups.

These are non-negligible health benefits, compared to other preventive interventions. For instance, Mackenbach et al. (2012) estimated that the vaccination for influenza avoids 500 deaths annually in the Netherlands, population-based screening for breast cancer 700 deaths and tobacco control measures 6,900 deaths.

As another illustration, the VAT increase for processed meat by 11.2% would avoid approximately 38,100 deaths (25,400 in males and 12,700 in females) over a period of 10 years, corresponding to approximately 3,810 deaths per year. This is slightly more than the 3,046 traffic deaths that occurred in Germany in 2019 (Statistisches Bundesamt, 2020). This is a finding of particular interest, because processed meat had been classified as carcinogenic just shortly before the HIA was conducted (Bouvard et al., 2015; IARC Working Group on the Evaluation of Carcinogenic Risk to Humans, 2018).

Thus, our results show that a tax on processed meat, a tax on saturated fat and a subsidy on fruits and vegetables as well as a digital intervention promoting physical activity can contribute to the reduction of NCDs in Germany and at the European level. We thereby illustrated how HIAs can be applied to strengthen evidence-based public health decision-making.

7.2 Strengths and limitations

The four HIAs conducted within the context of this dissertation could – in a relatively short period of time and with few resources – quantify the health-related implications of certain policies for a specific population's age structure, disease profile and risk factor exposure. For decision-makers, these provide valuable information where otherwise long-term studies would need to be conducted at the population-level in order to evaluate the impacts of public health interventions.

DYNAMO-HIA is a well-established model for quantitative HIA and has been used for similar HIAs of population-level policies and risk factors, e.g. taxation of alcohol (Lhachimi et al., 2012b), smoking and second-hand-smoking (Fischer and Kraemer, 2016; Holm et al., 2014; Kulik et al., 2012; Lhachimi et al., 2012a), obesity (Lhachimi et al., 2013), and salt intake (Erkoyun et al., 2016; Hendriksen et al., 2015). Since the model relies on the accuracy of input data and underlying assumptions, these are therefore discussed hereafter.

To begin with, we aimed to use recent and nationally representative data. However, these are not always easily available. For instance, in the case of processed meat intake (study I) and saturated fat intake (study III), the NVSII public use file (Max Rubner-Institut, 2009) and the European Nutrition and Health Report (Elmadfa et al., 2009) seem to be outdated, but were the most recent source we could identify.

The fact that the DYNAMO-HIA tool does not generically allow the simulation of several risk factors at the same time is another limitation. Thus, in studies I-III it was not possible to estimate the impact of cross-price effects and compensatory buying, i.e. whether consumers are substituting taxed products with desired healthier products or whether they are switching to unhealthier products (Cornelsen et al., 2014). Similarly, study IV could not estimate the extent to which sport injuries would influence health outcomes.

A further limitation is that dose-response curves are not yet fully understood in many cases. For instance, it is not clear whether risk increases linearly or exponentially, or whether there is a certain threshold (Kemm, 2013a). Our model assumes that risk will grow exponentially with intake in the case of processed meat and saturated fat (study I and II), and will decrease exponentially in the case of fruits and vegetables. In the case of physical activity and related diseases, we assumed that the relationship followed a 0.25 power transformation. If, in contrast, there is a threshold effect above a certain level, we may have overestimated the positive health effects in higher risk factor categories.

Finally, DYNAMO-HIA needs age- and gender-specific input data and also provides the results of a simulation by age and gender by default. However, there is no default option to include further distinctions, for instance by education or other indicators of socioeconomic position. These can only be incorporated as a second dimension of the risk factor. For a risk factor exposure with originally three categories (low, medium and high) and a socioeconomic position with three categories (low, medium and high), this translates to a total of nine risk factor categories (e.g. low education and low risk factor exposure, low education and medium risk factor exposure, low education and high risk factor exposure, medium education and low risk exposure,…). Since a maximum of 12 risk factor categories can be used in DYNAMO-HIA, incorporating socioeconomic position as a second dimension requires that the categories of the original risk factor be widened. This, however, means that possibly people in the simulation experience a change in the risk factor exposure without switching to a different risk factor category and there will be no change in health outcomes. This shortcoming, in addition to lack of respective data, was the reason we incorporated the differentiation by education as an explorative extension in study IV, but not in studies I–III.

7.3 Research implications and recommendations

<u>Improve data availability</u>

The quality of HIAs relies on the accuracy of input data and underlying assumptions. Nonetheless, lessons learned from conducting the four quantitative HIAs in the context of this dissertation were that the data sources still need to be improved. For instance, in study I we used processed meat data from the NVSII collected between November 2005 and January 2007 and for study II we used saturated fat data from the European Nutrition and Health Report based on surveys conducted around the year 2000. To our knowledge, these were the most recent data sources for processed meat and saturated fat intake, even though they seem rather outdated. For study III, it was originally planned to conduct an analysis for the whole European Union. For this to be done, the data on fruit and vegetable intake was supposed to be derived from the European Comprehensive Database (https://www.efsa.europa.eu/en/microstrategy/foodex2-level-1), which was set up by the European Food Safety Authority (European Food Safety Authority, 2011). The database provides intake on food groups (mean, standard deviation, and six percentiles) for infants, children, adolescents, adults, and the elderly, in 23 countries. Unfortunately, the data were – until recently – not provided for males and females separately and therefore could not be used for our analysis.

Meanwhile, member states of the European Union have to mandatory implement the European Health Interview Survey (EHIS), which aims to provide harmonized and comparable data on health determinants, health status, health care use and socioeconomic background variables (Fehr et al., 2017). In Germany, this is conducted by the Robert Koch Institute in form of the German Health Update (GEDA) (Lange et al., 2015). In fact, the GEDA 2014/2015-EHIS dataset was used for study IV (Saß et al., 2017). Eurostat, the statistical office of the European Union, provides a range of these EHIS health determinants such as BMI, physical activity, intake of fruits and vegetables, tobacco consumption and alcohol consumption in a publicly available database (https://ec.europa.eu/eurostat/data/database). It contains data for the 27 countries of the European Union, plus the United Kingdom, Norway, Iceland and Turkey, by age, gender and education. Fruit and vegetable intake, however, is only one of the 12 dietary risk factors suggested by the GBD study (GBD 2017 Risk Factor Collaborators, 2018). So far, the Eurostat database does not provide data on the remaining dietary risk factors, such as whole grains, sodium, nuts and seeds, seafood omega-3, fibre, legumes, polyunsaturated fat, calcium, processed meat, sugar-sweetened beverages, milk, trans-fats, or red meat.

In addition to this, dose-response curves need to be further examined. Kemm (2013a: 31f.) summarizes that "In many cases the dose-response curve is not fully understood. For many substances it is clear that higher exposures are very harmful to health, but are small exposures slightly harmful? Is there a threshold below which there is no increase in risk? Does the risk increase linearly with exposure or exponentially? Frequently, the data needed to answer these questions are not available". At the same time, Hendriksen et al. (2017) found that the effect sizes in the risk factor to health association resulted in the largest change in health impact estimates.

<u>Assess inequalities between population groups when conducting HIAs</u>

Study IV highlights the importance of assessing the distribution of health impacts both overall and within a population, as interventions with the greatest population health gain might be accompanied by an increase in health inequalities.

In general, most HIAs so far do not assess the distribution of health impacts between different population groups, be it those conducted with DYNAMO-HIA (Brønnum-Hansen et al., 2018; Erkoyun et al., 2016; Fischer and Kraemer, 2016; Hendriksen et al., 2015; Holm et al., 2014; Kang, 2017; Kulik et al., 2012; Lhachimi et al., 2012b; Lhachimi et al., 2013; Lhachimi et al., 2016; Mansfield and MacDonald Gibson, 2015; Otavova et al., 2019) or other tools (Briggs et al., 2016; Briggs et al., 2017; Collins et al., 2015; Manyema et al., 2016; Ni Mhurchu et al., 2015; Sanchez-Romero et al., 2016; Scarborough et al., 2012; Soerjomataram et al., 2010; Veerman et al., 2016).

Recently, terms such as "equity-focused HIA" or "health inequalities impact assessment" or "health equity impact assessment" have emerged as a distinction from the standard (non-inequality-considering) HIAs. However, it can be argued that this is not only superfluous but also a wrong approach, because it ignores the fact that the standard HIA incorporates the consideration of equity by default. After all, according to the definition of the Gothenburg consensus conference, a HIA judges not only the overall potential effects on the health of a population (on an aggregate level), but also "[…] the distribution of those effects within the population" (WHO, 1999: 4). In fact, a separate health inequality impact assessment "[…] would do no more than a properly conducted HIA" (Sihto et al., 2006: 197).

Instead, it would be more important to work on tools and data that facilitate the incorporation of inequalities in standard HIAs. For instance, in DYNAMO-HIA, there is no default option to assess the distribution of health impacts between different population groups. There is a workaround by incorporating the socioeconomic position as a second dimension of risk factor, which was done in study IV, but this comes at the expense of the reduction of available exposure categories in the first risk factor. Further, to be able to consider inequalities in HIAs, data on risk factors, relative risks and disease data by for instance gender, age, ethnic background, and socioeconomic status are needed.

Conduct HIAs on more complex interventions and risk factors

Apart from the HIAs conducted within the context of this dissertation, we could identify HIAs for Germany that assessed the reduction of sugar-sweetened beverage intake (Schwendicke and Stolpe, 2017), alcohol intake (Lhachimi et al., 2012b), BMI and smoking (Lhachimi et al., 2016). Future HIAs could be conducted on interventions such as food advertising controls, labelling, mass media campaigns and school-based interventions. For other countries and contexts, HIAs have for instance already assessed the impact of a total ban on TV food advertising on children in the US (Veerman et al., 2009), traffic-light nutrition labelling in Australia (Sacks et al., 2011), mass media campaigns in the US (Pearson-Stuttard et al., 2017a), the elimination of industrial trans fats in England (Pearson-Stuttard et al., 2017b), mandatory reduction of sodium levels in foods, a media campaign and food labelling in New Zealand (Nghiem et al., 2015), public transport fare increases in the US (James et al., 2014) and fuel price increase in Australia (Brown et al., 2017).

In addition to that, in times of climate change, HIAs can be used to estimate the health impacts from climate friendly diets (Aston et al., 2012), environmentally sustainable diets (Scarborough et al., 2012), or the taxation of all food and drink groups with certain greenhouse gas emissions (Briggs et al., 2016). In fact, HIAs have already been used in other topics of interest, such as Brexit (Seferidi et al., 2019) and the COVID-19 pandemic (Douglas et al., 2020).

Results from these HIAs cannot simply be transferred to other countries, since the health effect of an intervention may vary from context to context due to differing risk-factor profiles, age structures, as well as disease incidence-prevalence-mortality profile of populations. Instead, each country has to conduct its own context- or country-specific HIA.

Not all of the previous HIAs could be conducted with DYNAMO-HIA, though, since the DYNAMO-HIA tool does not allow the simulation of several risk factors at the same time. Particularly when it comes to diet, more than one risk factor might be needed to incorporate the impact of cross-price effects and compensatory buying.

7.4 Policy implications and recommendations

In 2015, the United Nations General Assembly proposed in its 2030 Agenda for Sustainable Development that measures to reduce premature mortality from NCDs by one-third by 2030 be taken (United Nations, 2015). Our four studies provide evidence on how a tax on processed meat, a tax on saturated fat, a removal of the VAT and a subsidy on fruits and vegetables as well as a digital physical activity intervention can contribute to this goal of reducing NCDs in Germany and at the European level.

Especially the tax on processed meat with a simultaneous subsidy on fruits and vegetables may be a promising approach, as both provide comparatively large health benefits. Further, a combination of both could mitigate financial consequences on lower income households. Both price interventions do not rely on individual’s agency and commitment and are therefore relatively easy to implement. Decision-makers could now prompt a broader investigation in the political and technical feasibility of such a policy, as well as the expected costs and revenues.

7.5 Conclusion and perspective

In a relatively short period of time and with few resources, we were able to quantify the health-related implications of a tax on processed meat, a tax on saturated fat, a removal of the VAT and a subsidy on fruits and vegetables as well as a digital intervention promoting physical activity. The underlying age structure, the disease profile and the risk factor exposure of the respective population of interest were taken into account. The HIAs conducted within the context of this dissertation indicate the extent to which these policies could contribute to the reduction of NCDs in Germany and at the European level. These estimates could help decision makers not only weigh between different interventions and policy options (e.g. a tax on processed meat versus a tax on saturated fat), but also between different scenarios for a particular type of intervention (i.e. different tax rates). In a next step, an investigation in the political and technical feasibility of such policies is needed.

Notably, we identified a range of barriers while conducting the HIAs and therefore formulate the following research recommendations: a) Improve data availability. A HIA relies on a range of input data. Nonetheless, while conducting the four quantitative HIAs in the context of this dissertation, it became clear that data sources still need to be improved. b) Assess inequalities between population groups when conducting an HIA. Most HIAs lack to assess the distribution of health impacts between different population groups so far. However, one HIA conducted in the context of this dissertation suggested that interventions with the greatest population health gain might be accompanied by an unintended increase in health inequalities. Therefore, both the assessment of health impacts overall as well as within a population is relevant for decision-makers. c) Conduct HIAs on more complex interventions and risk factors. HIAs have to be carried out context- and country-specific, because the health effect of an intervention may vary from context to context due to different risk-factor profiles, age structures, as well as disease incidence-prevalence-mortality profiles. Even though a range of HIAs already exists, results from these HIAs cannot be simply transferred to other contexts or countries.

8 References

Adams J, Mytton O, White M and Monsivais P (2016) Why Are Some Population Interventions for Diet and Obesity More Equitable and Effective Than Others? The Role of Individual Agency. *PLoS Medicine 13*(4): e1001990. doi: 10.1371/journal.pmed.1001990.

Afshin A, Penalvo JL, Del Gobbo L, Silva J, Michaelson M, O'Flaherty M, Capewell S, Spiegelman D, Danaei G and Mozaffarian D (2017) The prospective impact of food pricing on improving dietary consumption: A systematic review and meta-analysis. *PloS One 12*(3): e0172277. doi: 10.1371/journal.pone.0172277.

Alemanno A and Garde A (2013) The Emergence of an EU Lifestyle Policy: The Case of Alcohol, Tobacco and Unhealthy Diets *Common Market Law Review 50*(6).

Arem H, Moore SC, Patel A, Hartge P, Berrington de Gonzalez A, Visvanathan K, Campbell PT, Freedman M, Weiderpass E, Adami HO, Linet MS, Lee IM and Matthews CE (2015) Leisure time physical activity and mortality: a detailed pooled analysis of the dose-response relationship. *JAMA Internal Medicine 175*(6): 959-967. doi: 10.1001/jamainternmed.2015.0533.

Aston LM, Smith JN and Powles JW (2012) Impact of a reduced red and processed meat dietary pattern on disease risks and greenhouse gas emissions in the UK: a modelling study. *BMJ Open 2*: e001072. doi: 10.1136/bmjopen-2012-001072.

Aune D, Giovannucci E, Boffetta P, Fadnes LT, Keum N, Norat T, Greenwood DC, Riboli E, Vatten LJ and Tonstad S (2017) Fruit and vegetable intake and the risk of cardiovascular disease, total cancer and all-cause mortality – a systematic review and dose-response meta-analysis of prospective studies. *International Journal of Epidemiology 46*(3): 1029-1056. doi: 10.1093/ije/dyw319.

Barnett I, van Sluijs EM and Ogilvie D (2012) Physical activity and transitioning to retirement: a systematic review. *American Journal of Preventive Medicine 43*(3): 329-336. doi: 10.1016/j.amepre.2012.05.026.

Bender AM, Sørensen J, Holm A, Simonsen K, Diderichsen F and Brønnum-Hansen H (2020) Simulations of future cardiometabolic disease and life expectancy under counterfactual obesity reduction scenarios. *Preventive Medicine Reports 19*: 101150. doi: 10.1016/j.pmedr.2020.101150.

Bhatia R and Seto E (2011) Quantitative estimation in Health Impact Assessment: Opportunities and challenges. *Environmental Impact Assessment Review 31*(3): 301-309. doi: 10.1016/j.eiar.2010.08.003.

Bødker M, Pisinger C, Toft U and Jørgensen T (2015) The rise and fall of the world's first fat tax. *Health Policy 119*(6): 737-742. doi: 10.1016/j.healthpol.2015.03.003.

Boshuizen HC, Lhachimi SK, van Baal PH, Hoogenveen RT, Smit HA, Mackenbach JP and Nusselder WJ (2012) The DYNAMO-HIA model: an efficient implementation of a risk factor/chronic disease Markov model for use in Health Impact Assessment (HIA). *Demography 49*(4): 1259-1283. doi: 10.1007/s13524-012-0122-z.

Bouvard V, Loomis D, Guyton KZ, Grosse Y, Ghissassi FE, Benbrahim-Tallaa L, Guha N, Mattock H and Straif K (2015) Carcinogenicity of consumption of red and processed meat. *Lancet Oncology 16*(16): 1599-1600. doi: 10.1016/s1470-2045(15)00444-1.

Brambila-Macias J, Shankar B, Capacci S, Mazzocchi M, Perez-Cueto FJ, Verbeke W and Traill WB (2011) Policy interventions to promote healthy eating: a review of what works, what does not, and what is promising. *Food and Nutrition Bulletin 32*(4): 365-375. doi: 10.1177/156482651103200408.

Brand T, Pischke CR, Steenbock B, Schoenbach J, Poettgen S, Samkange-Zeeb F and Zeeb H (2014) What works in community-based interventions promoting physical activity and healthy eating? A review of reviews. *International Journal of Environmental Research and Public Health 11*(6): 5866-5888. doi: 10.3390/ijerph110605866.

Briggs ADM, Kehlbacher A, Tiffin R and Scarborough P (2016) Simulating the impact on health of internalising the cost of carbon in food prices combined with a tax on sugar-sweetened beverages. *BMC Public Health 16*: 107. doi: 10.1186/s12889-016-2723-8.

Briggs ADM, Mytton OT, Kehlbacher A, Tiffin R, Elhussein A, Rayner M, Jebb SA, Blakely T and Scarborough P (2017) Health impact assessment of the UK soft drinks industry levy: a comparative risk assessment modelling study. *Lancet Public Health 2*(1): e15-e22. doi: 10.1016/ S2468-2667(16)30037-8.

Broeks MJ, Biesbroek S, Over EAB, van Gils PF, Toxopeus I, Beukers MH and Temme EHM (2020) A social cost-benefit analysis of meat taxation and a fruit and vegetables subsidy for a healthy and sustainable food consumption in the Netherlands. *BMC Public Health 20*: 643. doi: 10.1186/s12889-020-08590-z.

Brønnum-Hansen H, Bender AM, Andersen ZJ, Sorensen J, Bonlokke JH, Boshuizen H, Becker T, Diderichsen F and Loft S (2018) Assessment of impact of traffic-related air pollution on morbidity and mortality in Copenhagen Municipality and the health gain of reduced exposure. *Environment International 121*: 973-980. doi: 10.1016/j.envint.2018.09.050.

Brown V, Moodie M, Cobiac L, Mantilla Herrera AM and Carter R (2017) Obesity-related health impacts of fuel excise taxation- an evidence review and cost-effectiveness study. *BMC Public Health 17*: 359. doi: 10.1186/s12889-017-4271-2.

Brownson RC, Fielding JE and Maylahn CM (2009) Evidence-based public health: a fundamental concept for public health practice. *Annual Review of Public Health 30*: 175-201. doi: 10.1146/annurev.publhealth.031308.100134.

Capacci S, Mazzocchi M, Shankar B, Macias JB, Verbeke W, Perez-Cueto FJ, Koziol-Kozakowska A, Piorecka B, Niedzwiedzka B, D'Addesa D, Saba A, Turrini A, Aschemann-Witzel J, Bech-Larsen T, Strand M, Smillie L, Wills J and Traill WB (2012) Policies to promote healthy eating in Europe: a structured review of policies and their effectiveness. *Nutrition Reviews 70*(3): 188-200. doi: 10.1111/j.1753-4887.2011.00442.x.

Capewell S and Capewell A (2018) An effectiveness hierarchy of preventive interventions: neglected paradigm or self-evident truth? *Journal of Public Health 40*(2): 350-358. doi: 10.1093/pubmed/fdx055.

Collins B, Capewell S, O'Flaherty M, Timpson H, Razzaq A, Cheater S, Ireland R and Bromley H (2015) Modelling the Health Impact of an English Sugary Drinks Duty at National and Local Levels. *PloS One 10*(6): e0130770. doi: 10.1371/journal.pone.0130770.

Collins T, Mikkelsen B, Adams J, Chestnov O, Evans T, Feigl A, Nugent R, Pablos-Mendez A, Srivanichakorn S and Webb D (2018) Addressing NCDs: A unifying agenda for sustainable development. *Global Public Health 13*(9): 1152-1157. doi: 10.1080/17441692.2017.1394481.

Cornelsen L, Green R, Dangour A and Smith R (2014) Why fat taxes won't make us thin. *Journal of Public Health 37*(1): 18-23. doi: 10.1093/pubmed/fdu032.

Czwikla G, Boen F, Cook DG, de Jong J, Harris T, Hilz LK, Iliffe S, Morris R, Muellmann S, Peels DA, Pischke CR, Schuz B, Stevens M, van Lenthe FJ, Vanderlinden J and Bolte G (2019) Equity-Specific Effects of Interventions to Promote Physical Activity among Middle-Aged and Older Adults: Development of a Collaborative Equity-Specific Re-Analysis Strategy. *International Journal of Environmental Research and Public Health 16*(17): 3195. doi: 10.3390/ijerph16173195.

Dalstra JAA, Kunst AE, Borrell C, Breeze E, Cambois E, Costa G, Geurts JJM, Lahelma E, Van Oyen H, Rasmussen NK, Regidor E, Spadea T and Mackenbach JP (2005) Socioeconomic differences in the prevalence of common chronic diseases: an overview of eight European countries. *International Journal of Epidemiology 34*(2): 316-326. doi: 10.1093/ije/dyh386.

Dannenberg AL, Bhatia R, Cole BL, Heaton SK, Feldman JD and Rutt CD (2008) Use of health impact assessment in the U.S.: 27 case studies, 1999-2007. *American Journal of Preventive Medicine 34*(3): 241-256. doi: 10.1016/j.amepre.2007.11.015.

Douglas M, Katikireddi SV, Taulbut M, McKee M and McCartney G (2020) Mitigating the wider health effects of covid-19 pandemic response. *BMJ 369*: m1557. doi: 10.1136/bmj.m1557.

Elmadfa I, Meyer A, Nowak V, Hasenegger V, Putz P, Verstraeten R, Remaut-DeWinter AM, Kolsteren P, Dostalova J, Dlouhy P, Trolle E, Fagt S, Biltoft-Jensen A, Mathiessen J, Velsing Groth M, Kambek L, Gluskova N, Voutilainen N, Erkkila A, Vernay M, Krems C, Strassburg A, Vasquez-Caicedo AL, Urban C, Naska A, Efstathopoulou E, Oikonomou E, Tsiotas K, Bountziouka V, Benetou V, Trichopoulou A, Zajkas G, Kovacs V, Martos E, Heavey P, Kelleher C, Kennedy J, Turrini A, Selga G, Sauka M, Petkeviciene J, Klumbiene J, Holm Totland T, Andersen LF, Halicka E, Rejman K, Kowrygo B, Rodrigues S, Pinhao S, Ferreira LS, Lopes C, Ramos E, Vaz Almeida MD, Vlad M, Simcic M, Podgrajsek K, Serra Majem L, Roman Vinas B, Ngo J, Ribas Barba L, Becker V, Fransen H, Van Rossum C, Ocke M and Margetts B (2009) *European Nutrition and Health Report 2009.* Basel: Forum of Nutrition.

Erkoyun E, Sozmen K, Bennett K, Unal B and Boshuizen HC (2016) Predicting the health impact of lowering salt consumption in Turkey using the DYNAMO health impact assessment tool. *Public Health 140*: 228-234. doi: 10.1016/j.puhe.2016.04.014.

European Food Safety Authority (2011) Use of the EFSA Comprehensive European Food Consumption Database in Exposure Assessment. *EFSA Journal 9*(3): 2097.

European Union and Eurostat (2014a) *Time spent on health-enhancing (non-work-related) aerobic physical activity by sex, age and educational attainment level*. Available at: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=hlth_ehis_pe2e&lang=en [Accessed 2020-07-23].

European Union and Eurostat (2014b) *Smoking of tobacco products by sex, age and educational attainment level*. Available at: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=hlth_ehis_sk1e&lang=en [Accessed 2020-07-23].

European Union and Eurostat (2014c) *Daily consumption of fruit and vegetables by sex, age and educational attainment level*. Available at: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=hlth_ehis_fv3e&lang=en [Accessed 2020-07-23].

European Union and Eurostat (2014d) *Frequency of alcohol consumption by sex, age and educational attainment level*. Available at: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=hlth_ehis_al1e&lang=en [Accessed 2020-07-23].

European Union and Eurostat (2020a) *Individuals - computer use*. Available at: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=isoc_ci_cfp_cu&lang=en [Accessed 2020-08-01].

European Union and Eurostat (2020b) *Individuals - internet use*. Available at: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=isoc_ci_ifp_iu&lang=en [Accessed 2020-08-01].

Fehr A, Lange C, Fuchs J, Neuhauser H and Schmitz R (2017) Gesundheitsmonitoring und Gesundheitsindikatoren in Europa. *Journal of Health Monitoring 2*(1): 3-23. doi: 10.17886/RKI-GBE-2017-004.2.

Fehr R, Hurley F, Mekel OC and Mackenbach JP (2012) Quantitative health impact assessment: taking stock and moving forward. *Journal of Epidemiology and Community Health 66*(12): 1088-1091. doi: 10.1136/jech-2011-200835.

Fehr R, Viliani F, Nowacki J and Martuzzi M (2014) *Health in Impact Assessments: Opportunities not to be missed.* Copenhagen: WHO Regional Office for Europe.

Fehr R, Mekel OCL, Fintan Hurley J and Mackenbach JP (2016) Health impact assessment – A survey on quantifying tools. *Environmental Impact Assessment Review 57*: 178-186. doi: 10.1016/j.eiar.2016.01.001.

Finger JD, Mensink G, Lange C and Manz K (2017) Health-enhancing physical activity during leisure time among adults in Germany. *J Heal Monit 2*(2): 35-42. doi: 10.17886/RKI-GBE-2017-040.

Fischer F and Kraemer A (2016) Health Impact Assessment for Second-Hand Smoke Exposure in Germany –Quantifying Estimates for Ischaemic Heart Diseases, COPD, and Stroke. *International Journal of Environmental Research and Public Health 13*(2): 198. doi: 10.3390/ijerph13020198.

Forberger S, Bammann K, Bauer J, Boll S, Bolte G, Brand T, Hein A, Koppelin F, Lippke S, Meyer J, Pischke CR, Voelcker-Rehage C and Zeeb H (2017) How to Tackle Key Challenges in the Promotion of Physical Activity among Older Adults (65+): The AEQUIPA Network Approach. *International Journal of Environmental Research and Public Health 14*(4): 379. doi: 10.3390/ijerph14040379.

Gallo V, Mackenbach JP, Ezzati M, Menvielle G, Kunst AE, Rohrmann S, Kaaks R, Teucher B, Boeing H, Bergmann MM, Tjønneland A, Dalton SO, Overvad K, Redondo M-L, Agudo A, Daponte A, Arriola L, Navarro C, Gurrea AB, Khaw K-T, Wareham N, Key T, Naska A, Trichopoulou A, Trichopoulos D, Masala G, Panico S, Contiero P, Tumino R, Bueno-de-Mesquita HB, Siersema PD, Peeters PP, Zackrisson S, Almquist M, Eriksson S, Hallmans G, Skeie G, Braaten T, Lund E, Illner A-K, Mouw T, Riboli E and Vineis P (2012) Social Inequalities and Mortality in Europe – Results from a Large Multi-National Cohort. *PloS One 7*(7): e39013. doi: 10.1371/journal.pone.0039013.

Galobardes B, Shaw M, Lawlor DA, Lynch JW and Davey Smith G (2006a) Indicators of socioeconomic position (part 1). *Journal of Epidemiology and Community Health 60*(1): 7-12. doi: 10.1136/jech.2004.023531.

Galobardes B, Shaw M, Lawlor DA, Smith GD and Lynch J (2006b) Indicators of Socioeconomic Position. In: Oakes JM and Kaufman JS (eds) *Methods in Social Epidemiology.* San Francisco: John Wiley & Sons.

GBD 2016 Risk Factor Collaborators (2017) Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990-2016: a systematic analysis for the Global Burden of Disease Study 2016. *Lancet 390*: 1345-1422. doi: 10.1016/S0140-6736(17)32366-8.

GBD 2017 Risk Factor Collaborators (2018) Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet 392*: 1923-1994. doi: 10.1016/S0140-6736(18)32225-6.

GBD Collaborative Network (2018a) *Global Burden of Disease Study 2017 Results*. Available at: http://ghdx.healthdata.org/gbd-results-tool?params=gbd-api-2017-permalink/9df6b9a15dac1b0e812e26ffcb86b537 [Accessed 2020-03-23].

GBD Collaborative Network (2018b) *Global Burden of Disease Study 2017 Results*. Available at: http://ghdx.healthdata.org/gbd-results-tool?params=gbd-api-2017-permalink/b57a5d2117e38f5456c4f688540ca2f0 [Accessed 2020-07-22].

GBD Collaborative Network (2018c) *Global Burden of Disease Study 2017 Results*. Available at: http://ghdx.healthdata.org/gbd-results-tool?params=gbd-api-2017-permalink/96311c6138f69510f3e2d7265e12313c [Accessed 2020-07-23].

Gerhardus A, Breckenkamp J and Razum O (2008) Evidence-based Public Health. Prävention und Gesundheitsförderung im Kontext von Wissenschaft, Werten und Interessen [Evidence-based public health. Prevention and health promotion in the context of science, values and (vested) interests]. *Medizinische Klinik 103*(6): 406-412. doi: 10.1007/s00063-008-1060-9.

Glymour MM, Avendano M and Kawachi I (2014) Socioeconomic Status and Health. In: Berkman LF, Kawachi I and Glymour MM (eds) *Social epidemiology.* New York: Oxford University Press.

Gordon RS (1983) An operational classification of disease prevention. *Public Health Reports 98*(2): 107-109.

Haigh F, Harris E, Chok HN, Baum F, Harris-Roxas B, Kemp L, Spickett J, Keleher H, Morgan R, Harris M, Wendel AM and Dannenberg AL (2013) Characteristics of health impact assessments reported in Australia and New Zealand 2005-2009. *Australian and New Zealand Journal of Public Health 37*(6): 534-546. doi: 10.1111/1753-6405.12102.

Hawkes C, Jewell J and Allen K (2013) A food policy package for healthy diets and the prevention of obesity and diet-related non-communicable diseases: the NOURISHING framework. *Obesity Reviews 14*: 159-168. doi: 10.1111/obr.12098.

Hendriksen MA, van Raaij JM, Geleijnse JM, Breda J and Boshuizen HC (2015) Health gain by salt reduction in europe: a modelling study. *PloS One 10*(3): e0118873. doi: 10.1371/journal.pone.0118873.

Hendriksen MAH, Geleijnse JM, van Raaij JMA, Cappuccio FP, Cobiac LC, Scarborough P, Nusselder WJ, Jaccard A and Boshuizen HC (2017) Identification of differences in health impact modelling of salt reduction. *PloS One 12*(11): e0186760. doi: 10.1371/journal.pone.0186760.

Heuer T, Krems C, Moon K, Brombach C and Hoffmann I (2015) Food consumption of adults in Germany: results of the German National Nutrition Survey II based on diet history interviews. *British Journal of Nutrition 113*(10): 1603-1614. doi: 10.1017/s0007114515000744.

Hirvensalo M and Lintunen T (2011) Life-course perspective for physical activity and sports participation. *European Review of Aging and Physical Activity 8*(1): 13-22. doi: 10.1007/s11556-010-0076-3.

Holm AL, Brønnum-Hansen H, Robinson KM and Diderichsen F (2014) Assessment of health impacts of decreased smoking prevalence in Copenhagen: Application of the DYNAMO-HIA model. *Scandinavian Journal of Public Health 42*(5): 409-416. doi: 10.1177/1403494814530048.

Hyseni L, Atkinson M, Bromley H, Orton L, Lloyd-Williams F, McGill R and Capewell S (2017) The effects of policy actions to improve population dietary patterns and prevent diet-related non-communicable diseases: scoping review. *European Journal of Clinical Nutrition 71*(6): 694-711. doi: 10.1038/ejcn.2016.234.

IARC Working Group on the Evaluation of Carcinogenic Risk to Humans (2018) *Red Meat and Processed Meat.* Lyon: International Agency for Research on Cancer.

James P, Ito K, Buonocore JJ, Levy JI and Arcaya MC (2014) A health impact assessment of proposed public transportation service cuts and fare increases in Boston, Massachusetts (U.S.A.). *International Journal of Environmental Research and Public Health 11*(8): 8010-8024. doi: 0.3390/ijerph110808010.

Joyner MJ and Warner DO (2013) The syntax of sin taxes: putting it together to improve physical, social, and fiscal health. *Mayo Clinic Proceedings 88*(6): 536-539. doi: 10.1016/j.mayocp.2013.02.008.

Kang E (2017) Assessing Health Impacts of Pictorial Health Warning Labels on Cigarette Packs in Korea Using DYNAMO-HIA. *Journal of Preventive Medicine and Public Health. Yebang Uihakhoe Chi 50*(4): 251-261. doi: 10.3961/jpmph.17.032.

Kemm J (2008) Health impact assessment: an aid to political decision-making. *Scandinavian Journal of Public Health 36*(8): 785-788. doi: 10.1177/1403494808098042.

Kemm J (2013a) Chapter 3 Quantitative assessment. In: Kemm J (ed) *Health Impact Assessment: Past Achievement, Current Understanding, and Future Progress.* Oxford: Oxford University Press.

Kemm J (2013b) Chapter 8 Health impact assessment of policy. In: Kemm J (ed) *Health Impact AssessmentPast Achievement, Current Understanding, and Future Progress.* Oxford: Oxford University Press.

Kemm J (2013c) Chapter 1 Origins and outline of health impact assessment. In: Kemm J (ed) *Health Impact Assessment: Past Achievement, Current Understanding, and Future Progress.* Oxford: Oxford University Press.

Kulik MC, Nusselder WJ, Boshuizen HC, Lhachimi SK, Fernandez E, Baili P, Bennett K, Mackenbach JP and Smit HA (2012) Comparison of tobacco control scenarios: quantifying estimates of long-term health impact using the DYNAMO-HIA modeling tool. *PloS One 7*(2): e32363. doi: 10.1371/journal.pone.0032363.

Lange C, Jentsch F, Allen J, Hoebel J, Kratz AL, von der Lippe E, Muters S, Schmich P, Thelen J, Wetzstein M, Fuchs J and Ziese T (2015) Data Resource Profile: German Health Update (GEDA) -the health interview survey for adults in Germany. *International Journal of Epidemiology 44*(2): 442-450. doi: 10.1093/ije/dyv067.

Leão T, Perelman J, Clancy L, Mlinarić M, Kinnunen JM, Nuyts PAW, Mélard N, Rimpelä A, Lorant V and Kunst AE (2020) Economic Evaluation of Five Tobacco Control Policies Across Seven European Countries. *Nicotine & tobacco research : official journal of the Society for Research on Nicotine and Tobacco 22*(7): 1202-1209. doi: 10.1093/ntr/ntz124.

Lehne G, Voelcker-Rehage C, Meyer J, Bammann K, Gansefort D, Bruchert T and Bolte G (2019) Equity Impact Assessment of Interventions to Promote Physical Activity among Older Adults: A Logic Model Framework. *International Journal of Environmental Research and Public Health 16*(3): 420. doi: 10.3390/ijerph16030420.

Lhachimi SK, Nusselder WJ, van Baal P, Boshuizen H, Mylius S and Smit J (2008) *DYNAMO-HIA. Model specification for a dynamic model for health impact assessment*. Available at: https://www.dynamo-hia.eu/sites/default/files/2018-04/o2925_Simulation%2520Brief.pdf [Accessed 2020-08-11].

Lhachimi SK, Nusselder WJ, Boshuizen HC and Mackenbach JP (2010) Standard tool for quantification in health impact assessment a review. *American Journal of Preventive Medicine 38*(1): 78-84. doi: 10.1016/j.amepre.2009.08.030.

Lhachimi SK, Nusselder WJ, Smit HA, van Baal P, Baili P, Bennett K, Fernandez E, Kulik MC, Lobstein T, Pomerleau J, Mackenbach JP and Boshuizen HC (2012a) DYNAMO-HIA – A Dynamic Modeling Tool for Generic Health Impact Assessments. *PloS One 7*(5): e33317. doi: 10.1371/journal.pone.0033317.

Lhachimi SK, Cole KJ, Nusselder WJ, Smit HA, Baili P, Bennett K, Pomerleau J, McKee M, Charlesworth K, Kulik MC, Mackenbach JP and Boshuizen H (2012b) Health impacts of increasing alcohol prices in the European Union: a dynamic projection. *Preventive Medicine 55*(3): 237-243. doi: 10.1016/j.ypmed.2012.06.006.

Lhachimi SK, Nusselder WJ, Lobstein TJ, Smit HA, Baili P, Bennett K, Kulik MC, Jackson-Leach R, Boshuizen HC and Mackenbach JP (2013) Modelling obesity outcomes: reducing obesity risk in adulthood may have greater impact than reducing obesity prevalence in childhood. *Obesity Reviews 14*(7): 523-531. doi: 10.1111/obr.12029.

Lhachimi SK, Nusselder WJ, Smit HA, Baili P, Bennett K, Fernandez E, Kulik MC, Lobstein T, Pomerleau J, Boshuizen HC and Mackenbach JP (2016) Potential health gains and health losses in eleven EU countries attainable through feasible prevalences of the life-style related risk factors alcohol, BMI, and smoking: a quantitative health impact assessment. *BMC Public Health 16*: 734. doi: 10.1186/s12889-016-3299-z.

Mackenbach JP, Stirbu I, Roskam AJ, Schaap MM, Menvielle G, Leinsalu M and Kunst AE (2008) Socioeconomic inequalities in health in 22 European countries. *New England Journal of Medicine 358*(23): 2468-2481. doi: 10.1056/NEJMsa0707519.

Mackenbach JP, Lingsma HF, van Ravesteyn NT and Kamphuis CBM (2012) The population and high-risk approaches to prevention: quantitative estimates of their contribution to population health in the Netherlands, 1970–2010. *European Journal of Public Health 23*(6): 909-915. doi: 10.1093/eurpub/cks106.

Mackenbach JP, Karanikolos M and McKee M (2013) The unequal health of Europeans: successes and failures of policies. *Lancet 381*(9872): 1125-1134. doi: 10.1016/s0140-6736(12)62082-0.

Mansfield TJ and MacDonald Gibson J (2015) Health Impacts of Increased Physical Activity from Changes in Transportation Infrastructure: Quantitative Estimates for Three Communities. *BioMed Research International 2015*: 812325. doi: 10.1155/2015/812325.

Manyema M, Veerman LJ, Tugendhaft A, Labadarios D and Hofman KJ (2016) Modelling the potential impact of a sugar-sweetened beverage tax on stroke mortality, costs and health-adjusted life years in South Africa. *BMC Public Health 16*: 405. doi: 10.1186/s12889-016-3085-y

Max Rubner-Institut (2009) *German National Nutrition Survey II (NVS II) [Scientific Use File].* Karlsruhe: Max Rubner-Institut.

McGill R, Anwar E, Orton L, Bromley H, Lloyd-Williams F, O'Flaherty M, Taylor-Robinson D, Guzman-Castillo M, Gillespie D, Moreira P, Allen K, Hyseni L, Calder N, Petticrew M, White M, Whitehead M and Capewell S (2015) Are interventions to promote healthy eating equally effective for all? Systematic review of socioeconomic inequalities in impact. *BMC Public Health 15*: 457. doi: 10.1186/s12889-015-1781-7.

McLaren L, McIntyre L and Kirkpatrick S (2009) Rose's population strategy of prevention need not increase social inequalities in health. *International Journal of Epidemiology 39*(2): 372-377. doi: 10.1093/ije/dyp315.

McNamara CL, Balaj M, Thomson KH, Eikemo TA, Solheim EF and Bambra C (2017) The socioeconomic distribution of non-communicable diseases in Europe: findings from the European Social Survey (2014) special module on the social determinants of health. *European Journal of Public Health 27*: 22-26. doi: 10.1093/eurpub/ckw222.

Mendis S (2017) Global progress in prevention of cardiovascular disease. *Cardiovascular Diagnosis and Therapy 7*: S32-S38. doi: 10.21037/cdt.2017.03.06.

Mirowsky J and Ross CE (2003) *Education, social status, and health.* New York: Aldine de Gruyter.

Mozaffarian D, Afshin A, Benowitz NL, Bittner V, Daniels SR, Franch HA, Jacobs DR, Jr., Kraus WE, Kris-Etherton PM, Krummel DA, Popkin BM, Whitsel LP and Zakai NA (2012) Population approaches to improve diet, physical activity, and smoking habits: a scientific statement from the American Heart Association. *Circulation 126*(12): 1514-1563. doi: 10.1161/CIR.0b013e318260a20b.

Mozaffarian D, Angell SY, Lang T and Rivera JA (2018) Role of government policy in nutrition-barriers to and opportunities for healthier eating. *BMJ 361*: k2426. doi: 10.1136/bmj.k2426.

Muellmann S, Buck C, Voelcker-Rehage C, Bragina I, Lippke S, Meyer J, Peters M and Pischke CR (2019) Effects of two web-based interventions promoting physical activity among older adults compared to a delayed intervention control group in Northwestern Germany: Results of the PROMOTE community-based intervention trial. *Preventive Medicine Reports 15*: 100958. doi: 10.1016/j.pmedr.2019.100958.

Müller AM, Maher CA, Vandelanotte C, Hingle M, Middelweerd A, Lopez ML, DeSmet A, Short CE, Nathan N, Hutchesson MJ, Poppe L, Woods CB, Williams SL and Wark PA (2018) Physical Activity, Sedentary Behavior, and Diet-Related eHealth and mHealth Research: Bibliometric Analysis. *Journal of Medical Internet Research 20*(4): e122. doi: 10.2196/jmir.8954.

Nghiem N, Wilson N, Genc M and Blakely T (2013) Understanding price elasticities to inform public health research and intervention studies: key issues. *American Journal of Public Health 103*(11): 1954-1961. doi: 10.2105/ajph.2013.301337.

Nghiem N, Blakely T, Cobiac LJ, Pearson AL and Wilson N (2015) Health and economic impacts of eight different dietary salt reduction interventions. *PloS One 10*(4): e0123915. doi: 10.1371/journal.pone.0123915.

Ni Mhurchu C, Eyles H, Genc M, Scarborough P, Rayner M, Mizdrak A, Nnoaham K and Blakely T (2015) Effects of Health-Related Food Taxes and Subsidies on Mortality from Diet-Related Disease in New Zealand: An Econometric-Epidemiologic Modelling Study. *PloS One 10*(7): e0128477. doi: 10.1371/journal.pone.0128477.

Norman GJ, Zabinski MF, Adams MA, Rosenberg DE, Yaroch AL and Atienza AA (2007) A review of eHealth interventions for physical activity and dietary behavior change. *American Journal of Preventive Medicine 33*(4): 336-345. doi: 10.1016/j.amepre.2007.05.007.

O'Connell E and Hurley F (2009) A review of the strengths and weaknesses of quantitative methods used in health impact assessment. *Public Health 123*(4): 306-310. doi: 10.1016/j.puhe.2009.02.008.

Oldenburg B, Taylor CB, O'Neil A, Cocker F and Cameron LD (2015) Using new technologies to improve the prevention and management of chronic conditions in populations. *Annual Review of Public Health 36*: 483-505. doi: 10.1146/annurev-publhealth-031914-122848.

Otavova M, Van Oyen H, Yokota RTC, Charafeddine R, Joossens L, Molenberghs G, Nusselder WJ, Boshuizen HC and Devleesschauwer B (2019) Potential impact of reduced tobacco use on life and health expectancies in Belgium. *International Journal of Public Health 65*(2): 129-138. doi: 10.1007/s00038-019-01315-z.

Pearson-Stuttard J, Bandosz P, Rehm CD, Afshin A, Penalvo JL, Whitsel L, Danaei G, Micha R, Gaziano T, Lloyd-Williams F, Capewell S, Mozaffarian D and O'Flaherty M (2017a) Comparing effectiveness of mass media campaigns with price reductions targeting fruit and vegetable intake on US cardiovascular disease mortality and race disparities. *American Journal of Clinical Nutrition 106*(1): 199-206. doi: 10.3945/ajcn.116.143925.

Pearson-Stuttard J, Hooton W, Critchley J, Capewell S, Collins M, Mason H, Guzman-Castillo M and O'Flaherty M (2017b) Cost-effectiveness analysis of eliminating industrial and all trans fats in England and Wales: modelling study. *Journal of Public Health 39*(3): 574-582. doi: 10.1093/pubmed/fdw095.

Peters R, Ee N, Peters J, Beckett N, Booth A, Rockwood K and Anstey KJ (2019) Common risk factors for major noncommunicable disease, a systematic overview of reviews and commentary: the implied potential for targeted risk reduction. *Therapeutic Advances in Chronic Disease 10*: 1-14. doi: 10.1177/2040622319880392.

Petrovic D, de Mestral C, Bochud M, Bartley M, Kivimaki M, Vineis P, Mackenbach J and Stringhini S (2018) The contribution of health behaviors to socioeconomic inequalities in health: A systematic review. *Preventive Medicine 113*: 15-31. doi: 10.1016/j.ypmed.2018.05.003.

Pfinder M, Heise TL, Hilton Boon M, Pega F, Fenton C, Griebler U, Gartlehner G, Sommer I, Katikireddi SV and Lhachimi SK (2020) Taxation of unprocessed sugar or sugar-added foods for reducing their consumption and preventing obesity or other adverse health outcomes. *Cochrane Database Syst Rev 4*(4): Cd012333. doi: 10.1002/14651858.CD012333.pub2.

Robert Koch Institute (2014) *German Health Update study 2012 (GEDA 2012) [Public Use File, first Version].* Berlin: Robert Koch Institute.

Robert Koch Institute (2018) *German Health Update study 2014 (GEDA 2014/2015-EHIS) [Public Use File, first Version].* Berlin: Robert Koch-Institut.

Rohrmann S, Overvad K, Bueno-de-Mesquita HB, Jakobsen MU, Egeberg R, Tjonneland A, Nailler L, Boutron-Ruault MC, Clavel-Chapelon F, Krogh V, Palli D, Panico S, Tumino R, Ricceri F, Bergmann MM, Boeing H, Li K, Kaaks R, Khaw KT, Wareham NJ, Crowe FL, Key TJ, Naska A, Trichopoulou A, Trichopoulos D, Leenders M, Peeters PH, Engeset D, Parr CL, Skeie G, Jakszyn P, Sanchez MJ, Huerta JM, Redondo ML, Barricarte A, Amiano P, Drake I, Sonestedt E, Hallmans G, Johansson I, Fedirko V, Romieux I, Ferrari P, Norat T, Vergnaud AC, Riboli E and Linseisen J (2013) Meat consumption and mortality – results from the European Prospective Investigation into Cancer and Nutrition. *BMC Medicine 11*: 63. doi: 10.1186/1741-7015-11-63.

Rose G (1985) Sick individuals and sick populations. *International Journal of Epidemiology 14*: 32–38. doi: 10.1093/ije/30.3.427.

Sacks G, Veerman JL, Moodie M and Swinburn B (2011) 'Traffic-light' nutrition labelling and 'junk-food' tax: a modelled comparison of cost-effectiveness for obesity prevention. *International Journal of Obesity 35*(7): 1001-1009. doi: 10.1038/ijo.2010.228.

Sanchez-Romero LM, Penko J, Coxson PG, Fernandez A, Mason A, Moran AE, Avila-Burgos L, Odden MA-Ohoo, Barquera S and Bibbins-Domingo K (2016) Projected Impact of Mexico's Sugar-Sweetened Beverage Tax Policy on Diabetes and Cardiovascular Disease: A Modeling Study. *PLoS Medicine 13*(11): e1002158. doi: 10.1371/journal.pmed.1002158.

Saß A-C, Lange C, Finger JD, Allen J, Born S, Hoebel J, Kuhnert R, Müters S, Thelen J, Schmich P, Varga M, von der Lippe E, Wetzstein M and Ziese T (2017) „Gesundheit in Deutschland aktuell“ – Neue Daten für Deutschland und Europa. Hintergrund und Studienmethodik von GEDA 2014/2015-EHIS ["Current Health in Germany” – New data for Germany and Europe.

Background and study methodology of GEDA 2014/2015-EHIS]. *Journal of Health Monitoring 2*(1): 83-90. doi: 10.17886/RKI-GBE-2017-012.

Sassi F, Cecchini M and Lauer J (2009) *Improving lifestyles, tackling obesity: the health and economic impact of prevention strategies.* Paris: OECD.

Scarborough P, Allender S, Clarke D, Wickramasinghe K and Rayner M (2012) Modelling the health impact of environmentally sustainable dietary scenarios in the UK. *European Journal of Clinical Nutrition 66*(6): 710-715. doi: 10.1038/ejcn.2012.34.

Schoeppe S, Alley S, Van Lippevelde W, Bray NA, Williams SL, Duncan MJ and Vandelanotte C (2016) Efficacy of interventions that use apps to improve diet, physical activity and sedentary behaviour: a systematic review. *International Journal of Behavioral Nutrition and Physical Activity 13*: 127. doi: 10.1186/s12966-016-0454-y.

Schönbach JK, Pfinder M, Börnhorst C, Zeeb H and Brand T (2017) Changes in Sports Participation across Transition to Retirement: Modification by Migration Background and Acculturation Status. *International Journal of Environmental Research and Public Health 14*(11): 1356. doi: 10.3390/ijerph14111356.

Schwendicke F and Stolpe M (2017) Taxing sugar-sweetened beverages: impact on overweight and obesity in Germany. *BMC Public Health 17*: 88. doi: 10.1186/s12889-016-3938-4.

Seferidi P, Laverty AA, Pearson-Stuttard J, Bandosz P, Collins B, Guzman-Castillo M, Capewell S, O'Flaherty M and Millett C (2019) Impacts of Brexit on fruit and vegetable intake and cardiovascular disease in England: a modelling study. *BMJ Open 9*(1): e026966. doi: 10.1136/bmjopen-2018-026966.

Shaw M, Galobardes B, Lawlor DA, Lynch J, Wheeler B and Smith GD (2007) *The handbook of inequality and socioeconomic position.* Bristol: The Policy Press.

Sihto M, Ollila E and Koivusalo M (2006) Principles and challenges of Health in All Policies. In: Ståhl T, Wismar M, Ollila E, et al. (eds) *Health in All Policies. Prospects and potentials.* Helsinki: Ministry of Social Affairs and Health.

Smed S (2012) Financial penalties on foods: the fat tax in Denmark. *Nutrition Bulletin 37*(2): 142-147. doi: 10.1111/j.1467-3010.2012.01962.x.

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

Soerjomataram I, Oomen D, Lemmens V, Oenema A, Benetou V, Trichopoulou A, Coebergh JW, Barendregt J and de Vries E (2010) Increased consumption of fruit and vegetables and future cancer incidence in selected European countries. *European Journal of Cancer 46*(14): 2563-2580. doi: 10.1016/j.ejca.2010.07.026.

Statistisches Bundesamt (2020) *Verkehrsunfälle*. Available at: https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Verkehrsunfaelle/Tabellen/getoetete-alter.html;jsessionid=8C670E003AB40108DBC559B7D2EDB3C0.internet8731 [Accessed 2020-08-12].

Steenbock B, Pischke CR, Schönbach J, Pottgen S and Brand T (2015) Wie wirksam sind ernährungs- und bewegungsbezogene primärpräventive Interventionen im Setting Kita? Ein Review von Reviews [The effectiveness of primary prevention interventions promoting physical activity and healthy eating in preschool children: A review of reviews]. *Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz 58*(6): 609-619. doi: 10.1007/s00103-014-2100-7.

Thiele S (2008) Elastizitäten der Nachfrage privater Haushalte nach Nahrungsmitteln – Schätzung eines AIDS auf Basis der Einkommens- und Verbraucherstichprobe [Food demand elasticities – an AIDS using German cross sectional date]. *Agrarwirtschaft 57*(5): 258-268. doi: 10.22004/ag.econ.97604

Thiele S, Peltner J, Richter A and Mensink GBM (2017) Food purchase patterns: empirical identification and analysis of their association with diet quality, socio-economic factors, and attitudes. *Nutrition Journal 16*: 69. doi: 10.1186/s12937-017-0292-z.

Thow AM, Downs SM, Mayes C, Trevena H, Waqanivalu T and Cawley J (2018) Fiscal policy to improve diets and prevent noncommunicable diseases: from recommendations to action. *Bulletin of the World Health Organization 96*(3): 201-210. doi: 10.2471/blt.17.195982.

United Nations (2012) *Political Declaration of the High-level Meeting of the General Assembly on the Prevention and Control of Non-communicable Diseases (A/RES/66/2).* United Nations General Assembly.

United Nations (2015) *Transforming our world: The 2030 agenda for sustainable development (A/RES/70/1).* United Nations General Assembly.

Veerman JL, Barendregt JJ and Mackenbach JP (2005) Quantitative health impact assessment: current practice and future directions. *Journal of Epidemiology and Community Health 59*(5): 361-370. doi: 10.1136/jech.2004.026039.

Veerman JL, Van Beeck EF, Barendregt JJ and Mackenbach JP (2009) By how much would limiting TV food advertising reduce childhood obesity? *European Journal of Public Health 19*(4): 365-369. doi: 10.1093/eurpub/ckp039.

Veerman JL, Sacks G, Antonopoulos N and Martin J (2016) The Impact of a Tax on Sugar-Sweetened Beverages on Health and Health Care Costs: A Modelling Study. *PloS One 11*(4): e0151460. doi: 10.1371/journal.pone.0151460.

Veinot TC, Mitchell H and Ancker JS (2018) Good intentions are not enough: how informatics interventions can worsen inequality. *Journal of the American Medical Informatics Association 25*(8): 1080-1088. doi: 10.1093/jamia/ocy052.

Victora CG, Habicht J-P and Bryce J (2004) Evidence-based public health: moving beyond randomized trials. *American Journal of Public Health 94*(3): 400-405. doi: 10.2105/ajph.94.3.400.

Villanueva T (2011) European nations launch tax attack on unhealthy foods. *Canadian Medical Association Journal 183*(17): E1229-1230. doi: 10.1503/cmaj.109-4031.

Wahid A, Manek N, Nichols M, Kelly P, Foster C, Webster P, Kaur A, Friedemann Smith C, Wilkins E, Rayner M, Roberts N and Scarborough P (2016) Quantifying the Association Between Physical Activity and Cardiovascular Disease and Diabetes: A Systematic Review and Meta-Analysis. *Journal of the American Heart Association 5*(9). doi: 10.1161/jaha.115.002495.

WHO (1999) *Health impact assessment: main concepts and suggested approach. Gothenburg consensus paper.* Copenhagen: WHO Regional Office for Europe.

WHO (2012) *Action Plan for implementation of the European Strategy for the Prevention and Control of Noncommunicable Diseases 2012-2016.* Copenhagen: WHO Regional Office for Europe.

WHO (2013a) *Health 2020. A European policy framework supporting action across government and society for health and well-being.* Copenhagen: WHO Regional Office for Europe.

WHO (2013b) *Global action plan for the prevention and control of noncommunicable diseases 2013-2020.* Geneva: World Health Organization.

WHO (2014) *Targets and indicators for Health 2020.* Copenhagen: WHO Regional Office for Europe.

WHO (2015a) *Health in 2015: from MDGs, Millennium Development Goals to SDGs, Sustainable Development Goals.* Geneva: World Health Organization.

WHO (2015b) *Using price policies to promote healthier diets.* Copenhagen: WHO Regional Office for Europe.

WHO (2015c) *European Food and Nutrition Action Plan 2015–2020.* Copenhagen: WHO Regional Office for Europe.

WHO (2016a) *Action Plan for the Prevention and Control of Noncommunicable Diseases in the WHO European Region.* Copenhagen: WHO Regional Office for Europe.

WHO (2016b) *Fiscal Policies for Diet and Prevention of Noncommunicable Diseases. Technical Meeting Report.* Geneva: World Health Organization.

WHO (2019) *Why using a gender approach can accelerate noncommunicable disease prevention and control in the WHO European region.* Copenhagen: WHO Regional Office for Europe.

Yardley L, Choudhury T, Patrick K and Michie S (2016) Current Issues and Future Directions for Research Into Digital Behavior Change Interventions. *American Journal of Preventive Medicine 51*(5): 814-815. doi: 10.1016/j.amepre.2016.07.019.

Zeeb H, Pigeot I and Schüz B (2020) Digital Public Health – ein Überblick [Digital public health – an overview]. *Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz*. doi: 10.1007/s00103-019-03078-7.

9 Appendix

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Eidesstattliche Erklärung

Hiermit versichere ich, dass ich die vorliegende Dissertation ohne unerlaubte Hilfe angefertigt habe. Es wurden keine anderen, als die angegebenen Quellen und Hilfsmittel benutzt. Alle Stellen der Arbeit, die wörtlich oder sinngemäß aus anderen Quellen übernommen wurden, sind als solche kenntlich gemacht.

Bremen, 24. August 2020

Johanna-Katharina Maria Schönbach

Article I

Schönbach J-K, Thiele S, Lhachimi SK (2019) What are the potential preventive population-health effects of a tax on processed meat? A quantitative health impact assessment for Germany. *Preventive Medicine 118*: 325-331. doi: 10.1016/j.ypmed.2018.11.011.

Full text and appendix are available at https://doi.org/10.1016/j.ypmed.2018.11.011

Article II

Schönbach J-K, Nusselder WJ and Lhachimi SK (2019) Substituting polyunsaturated fat for saturated fat: Modelling potential effects of a fat tax on ischemic heart diseases in Europe. *Plos One 14*(7): e0218464. doi: 10.1371/journal.pone.0218464.

Full text and appendix are available at https://doi.org/10.1371/journal.pone.0218464

Article III

Schönbach J-K and Lhachimi SK (2020) To what extent could cardiovascular diseases be reduced if Germany applied fiscal policies to increase fruit and vegetable consumption? A quantitative health impact assessment. *Public Health Nutrition*. doi: 10.1017/S1368980020000634.

Full text is available at https://doi.org/10.1017/S1368980020000634

Article IV

Schönbach J-K, Bolte G, Czwikla G, Manz K, Mensing M, Muellmann S, Voelcker-Rehage C and Lhachimi SK (2020) Equity impacts of interventions to increase physical activity among older adults: A quantitative health impact assessment. *International Journal of Behavioral Nutrition and Physical Activity, 17*(1):103. doi: 10.1186/s12966-020-00999-4.

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