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Abstract

Obesity is considered an important public health challenge in Europe. Largely unknown is however how obesity prevalence, and – particularly – obesity-attributable mortality will likely evolve in the long-term future.

We project obesity-attributable mortality into the long-term future using the underlying epidemic wave pattern for 30 European countries.

We used national obesity prevalence estimates, by sex and age (20-84), for the years 1975 up to 2016, from the NCD Risk Factor Collaboration Study 2017. Obesity prevalence is projected by applying the age-period Lee-Carter model to the transformed logit of prevalence, and by linearly extrapolating the speed of change from 2000 onwards (from 1980 onwards for Eastern European women). Through the application of the population-attributable fraction formula – using age- and sex-specific RRs from a meta-review - we obtained the associated past and future age- and sex-specific obesity-attributable mortality fractions (OAMF). We obtained all-age estimates of OAMF through direct standardisation.

We project that, for the 18 Western European countries, on average, age-standardised obesity-attributable mortality (20-84) will increase from 11.7% in 2016 to 15.0% in 2039 among men, and from 11.1% in 2016 to 12.5% in 2036 among women. For the 12 Eastern European countries, obesity-attributable mortality is expected to increase, on average from 12.1% in 2016 to 16.6% in 2047 among men, and from 12.4% in 2016 to 13.7% in 2040 among women. Subsequently, obesity-attributable mortality is projected to decline, and expected to reach in 2060 average levels of 12.0% (men) and 10.3% (women) in Western Europe, and 15.6% (men) and 12.3% (women) in Eastern Europe.

Thus, by applying our projection model to the NCD-RisC 2017 obesity prevalence estimates we project that, on average, around 2040 the share of mortality due to obesity will have reached its maximum at 14.3%, for the 30 European countries included in our analysis.

Key words: obesity, Europe, long-term future, prevalence, mortality, obesity-attributable mortality, time trends

Introduction

Obesity is considered an important public health challenge of the 21st century (WHO, 2018). Obese individuals, i.e. those with a body mass index (BMI) of 30 kg/m2 and over, have a higher risk compared to normal weight individuals of developing a range of non-communicable diseases including type II diabetes, several types of cancer (breast, pancreatic, colon, rectum) and cardiovascular disease (e.g. Guh et al., 2009), and – ultimately – a higher risk of dying prematurely (e.g. Fontaine et al., 2010). The severe effects of obesity on health at the individual level also pose a threat to the health of populations (NCD Risk Factor Collaboration, 2017; Dai et al., 2020), especially in light of the strong increase in obesity worldwide since the 1980s, and the – resulting - high current obesity prevalence levels (WHO, 2018). Given the above, studies that could shed light on obesity's likely future evolution are warranted (WHO, 2018).

Europe currently ranks second, after the United States of America (USA), among global regions in terms of obesity prevalence (Eurostat, 2017). In many European countries obesity prevalence has increased threefold since the 1980s (WHO, 2018), to an average self-reported obesity prevalence of about 16% in 2014 among those aged 18 and over across the EU member states (Eurostat, 2017), and an estimated measured obesity prevalence of 23% in 2016 across Europe compared to 13% globally (NCD Risk Factor Collaboration, 2017; WHO, 2020). In 2012, the share of mortality due to obesity was, on average, 10% among 26 European countries (Vidra et al., 2019). If obesity-attributable mortality was eliminated, life expectancy in the different European countries, would, on average, increase with 1.2 years among men, and 1.0 years among women (Vidra et al., 2019). Important differences, however, exist in obesity prevalence and its impact on mortality and life expectancy, across Europe. The effect of obesity on life expectancy is higher in Eastern Europe compared to Western Europe among both sexes (Vidra et al., 2019).

Given the large and unprecedented past increases in obesity prevalence and obesity-attributable mortality (Flegal, 2006), obesity is characterized by many scholars as an epidemic (Abelson & Kennedy, 2004). A distinct characteristic of epidemics is that they develop in a wave pattern (Cliff & Haggett, 2006). In its initial stages, an epidemic starts to increase slowly, followed by a more quick increase. After reaching a plateau, the epidemic declines, more intensely in the beginning and more slowly toward the end. This wave pattern has not only been observed for epidemics of contagious diseases, such as influenza (Bresee & Hayden, 2013), but also for 'epidemics' of lifestyle factors, such as for smoking (Lopez et al., 1994; Thun et al., 2012; Janssen, 2020). Very recently, this wave pattern has been proposed as well as a theoretical framework to describe the obesity epidemic and its likely evolution (Xu & Lam, 2018; Jaacks et al., 2019). Recent studies demonstrated either a levelling off or a stagnation of the increasing (severe) obesity trend in the USA (Rokholm et al., 2010; Wang et al., 2020), and among adults with a high socio-economic status in Switzerland, France, and Finland (Visscher et al., 2015), and also reported decelerating rates of increase in obesity prevalence among 18 Western European countries and the USA (Janssen et al., 2020), and a levelling or a declining obesity trend among children (Wabitsch et al., 2014; Pan et al., 2019; Lauria et al., 2019). These studies do strengthen the assumption that obesity is following the underlying wave pattern of an epidemic, and that obesity prevalence and obesity-attributable mortality will likely eventually decline.

Till recently, most previous projections of adult obesity prevalence for national populations in Europe or the USA projected ongoing increases, and considered the short-term future only (McPherson et al., 2007; Kelly et al., 2008; Wang et al., 2008; Sassi et al., 2009; Schneider et al., 2010; Wang et al., 2011; Finkelstein et al., 2012; Keaver et al., 2013; Thomas et al. 2014; OECD, 2017; Pineda et al., 2018; Foreman et al., 2018). See Janssen et al. for a more detailed overview of these previous projections. In addition, recent studies projected different future increasing trends according to socioeconomic status in selected European countries (Pérez-Ferrer et al. 2018), in the United Kingdom (UK) (Keaver et al. 2020) and according to ethnic groups and regions in the USA (Wang et al. 2020). Also the two previous projections of obesity-attributable mortality (Kelly et al., 2009; Wang et al., 2011) provided short-term projections only, and projected ongoing increases. Kelly et al. (2009) projected mortality attributable to obesity for selected diseases for England & Wales in 2015. Wang et al. 2011 projected the health and economic burden up to 2030 of a continued rise in obesity in the USA and the UK, and compared this to a hypothetical situation in which a 1% reduction in BMI across the entire adult population at baseline had occurred, and to a situation in which obesity had remained at their level in 1995.

More recently, obesity prevalence projections are increasingly taking into account the recent evidence indicating that obesity prevalence may actually be leveling off and projected a smaller increase up to 2030 (Finkelstein et al., 2012) , or a plateauing in some countries by 2030 (Schneider et al., 2010; Thomas et al., 2014, Frerichs et al., 2019). Janssen et al. 2020 comparatively projected obesity prevalence into the long-term future for 18 European countries and the USA thereby explicitly implementing the notion of a wave-shaped obesity epidemic, for the first time. However, these recent projections, focused on obesity prevalence and not obesity-attributable mortality, and mainly studied the USA or (selected) Western European countries.

In the current paper, we will project obesity-attributable mortality into the long-term future using the underlying epidemic wave pattern for 30 European countries. More specifically, we will apply the approach by Janssen et al. 2020 to project age-specific and age-standardised obesity prevalence in the long run to 18 Western and 12 Eastern European countries and the USA, and we will subsequently turn the outcomes into future age-specific and age-standardised obesity-attributable mortality up to 2100.

Data and methods

- Setting

We estimate future age-specific and age-standardised obesity attributable mortality fractions by sex for the national populations aged 20-84 in the USA, 18 Western European countries (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom) and 12 Eastern European countries (Belarus, Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Russian Federation, Slovakia, Slovenia, Ukraine).

- Approach

We estimate the future age-specific and age-standardised obesity-attributable fractions up to 2100 for the 30 European countries and the USA, by first projecting age- and sex-specific obesity prevalence up to the same year for the same countries.
In projecting age- and sex-specific obesity prevalence we applied the same approach, model and assumptions as applied in Janssen et al. (2020), but now to 30 European countries and the USA, instead of to 18 West-European countries and the USA. The novel projection approach adopted in Janssen et al. 2020, and subsequently in the current analysis, integrates the notion of a wave-shaped obesity epidemic into a conventional age-period projection applied to obesity prevalence.

- Data

Obesity prevalence data (BMI≥30kg/m2) by age (20-24, …, 85+), sex, country, and year (1975 up to 2016) were obtained from the NCD Risk Factor Collaboration (NCD-RisC) study in 2017 (NCD Risk Factor Collaboration, 2017). These data comprise the available measured height and weight data, supplemented with estimates from a Bayesian hierarchical model based on information from other years and related countries. They constitute validated data that have been used previously to study long-term time trends in obesity (Duncan & Toledo, 2018) and that are adopted by the WHO in their Global Health Observatory (WHO 2020 Global Health Observatory Data).

We converted the obesity prevalence data for five-year age groups into single-age prevalence (ages 20-84) by applying Loess smoothing (degree = 2; span = 0.75).

We estimated age-standardized obesity prevalence over the ages 20-84 using the country- and sex-specific population age structure in 2010 from the Human Mortality Database (Oct 18, 2019).

- **Projection method**

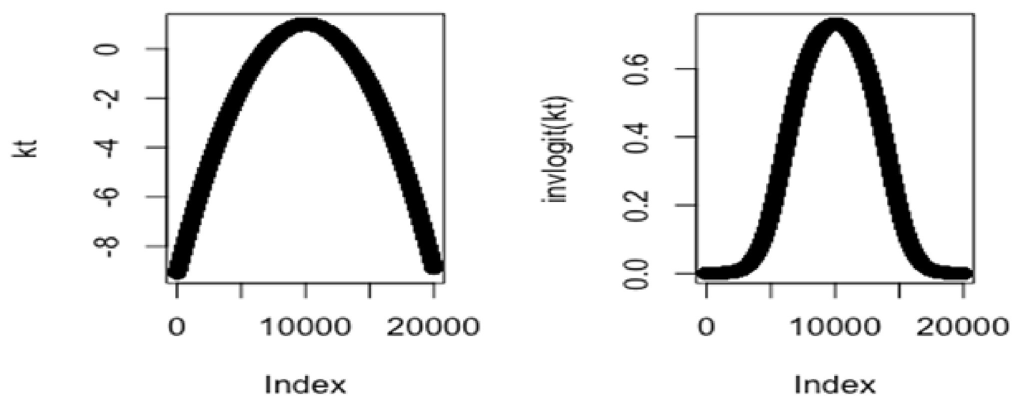
The basis of the projection method forms the Lee & Carter (1992) age-period projection methodology, which is considered the benchmark method in the field of mortality forecasting (Janssen, 2018). When applied to mortality, the method decomposes logged age-specific mortality into a time-invariant age pattern, an overall time trend across all ages, and the magnitude of the age-specific change over time; and subsequently extrapolates the overall time trend into the future (Lee & Carter, 1992).

Instead however of applying the method directly to obesity prevalence and to extrapolate the overall time trend across all ages in obesity prevalence into the future - which would generate continued increases - we apply the Lee-Carter projection methodology to the logit (= logistically transformed) obesity prevalence, and project the speed of change (and not simply the time trend) of the logit of obesity prevalence, to obtain a wave pattern.

This is because a wave pattern for prevalence can be obtained when the logit of prevalence has a quadratic shape (see Illustration I).

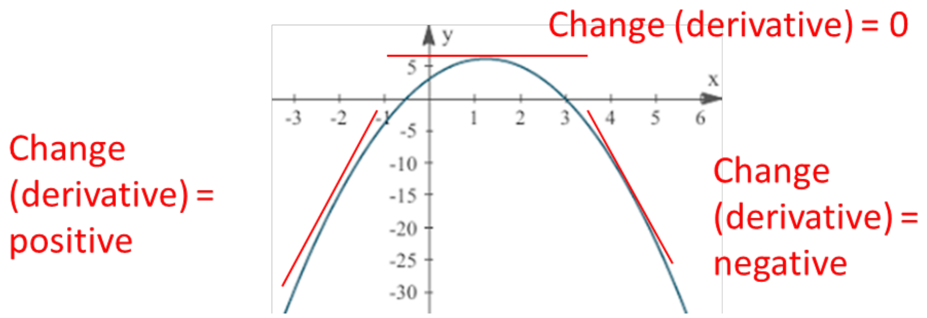
In order to obtain a quadratic shape, we focused on the first-order difference of the time trend in the logit of prevalence, which we refer to as the "speed of change". This is because a quadratic shape is obtained when the speed of change declines linearly over time, from a positive speed (increase) to a zero speed (maximum level) to a negative speed (decline) (see Illustration II). Thus, by linearly extrapolating the speed of change of the logit of obesity prevalence, we can obtain a wave-shaped pattern based on the data.

Illustration I: A quadratic shape for the logit of a measure (on the left) represents a wave pattern for the untransformed measure (on the right)



Source: Janssen et al. 2020 Supplementary methodology document.

Illustration II: A quadratic shape reflects a linear decline in the change of the curve



Source: Janssen et al. 2020 Supplementary methodology document.

- **Application of the projection method**

Thus, for the sex-specific national populations aged 20-84, we applied the Lee-Carter model to the logistically transformed obesity prevalence, logit $OP_{x,t}$, at age x and year t, by means of the formula:

$$\text{logit}\,(OP_{x,t}) = \alpha_x + \beta_x \cdot \kappa_t + \epsilon_{x,t} \qquad \text{(Equation 1)}$$

Subsequently, we linearly extrapolated the population-specific speed of change in the overall time trend of the logit of obesity (κ_t) by applying a second-order random walk with negative drift to κ_t. This linear extrapolation is applied from 2000 onwards in the majority of populations, because the decline in the speed of change was steadier during this period than before (see Janssen et al. 2020 Figure 2). However, for women in Eastern Europe, we applied the linear extrapolation from 1980 onwards, to be able to capture the decelerating trend that in these populations had already set in very early.

Because it is unlikely that obesity prevalence will reach zero in the future (Xu and Lam 2018), first however, we implemented country-, sex-, and age-specific lower limits in our projection by making use of the population-specific obesity prevalence levels in 1975 from NCD-RisC, which are the oldest available comparable data. Whereas in the majority of the populations we used the sex-specific national obesity prevalence levels in 1975, for women in Eastern Europe we, again, adopted a different strategy, because their levels were already very high in 1975 (see Figure 1). That is, for these populations, instead, we used the age-standardised national obesity prevalence levels for men, except for women in Hungary and Estonia where we still used the female age-standardised prevalence 20-84 in 1975, albeit in a different manner. See Appendix Table 1 for the age-standardised values of the implemented lower limits, and its footnote for more detailed information on how we implemented the lower bounds.

We projected the age-specific obesity prevalence levels (20-84) by sex, country, and year up to 2100; and we estimated the medians and their 95% projection intervals by performing 50,000 simulations. We obtained the projected age-standardised obesity prevalence levels and their 95% projection intervals by age-standardising over each sample path.

- **Obesity-attributable mortality fractions**

The past and future (=simulated) age- and sex-specific obesity prevalence (20-84) were converted to age- and sex-specific obesity-attributable mortality fractions (OAMFa,s) – i.e. the share of all-cause mortality due to obesity – using the population-attributable fraction formula (Rockhill et al., 1998):

$$OAMF_{a,s} = \frac{P_{a,s} \cdot (RR_{a,s} - 1)}{1 + (P_{a,s} \cdot (RR_{a,s} - 1))} \text{(Equation 2)}$$

where P is the obesity prevalence, and RR represent the relative risks of dying from obesity.

For the RRs we used the RRs by age group (<50, 50-59, 60-69 and ≥70 years) and sex from a review of studies mainly conducted in Western Europe and the USA (Lobstein et al., 2010). These age- and sex-specific RRs were close to 1.5, slightly larger for men than for women, and exhibited a small increase with age. The RRs we used were largely in line with the overall European RR of 1.64 recently estimated by the Global BMI Mortality Collaboration (Global BMI Mortality Collaboration et al., 2016). The RRs were turned into single-year RRs (20-84) using linear regression.

Subsequently, we estimated the age-standardised obesity-attributable mortality fractions, by applying to the age-specific obesity-attributable mortality fractions, the country- and sex-specific age composition of deaths in 2010 from the Human Mortality Database (Oct 18, 2019).

Results

- **Past trends**

Past trends in age-standardised (ages 20-84) obesity prevalence and obesity-attributable mortality fractions (OAMF), over the period 1975-2016, show clear increases in the 30 European countries and the USA, more so among men than among women (Figure 1). In the USA, the increases are strongest. For women in Eastern Europe, who exhibited high levels in 1975, a clear levelling off of the increase can be observed, and overall a less strong increase compared to the other populations. For women, a convergence over time between the levels in Eastern and Western Europe can be observed.

In 2016, the age-standardised OAMF was on average 11.9% among men in the 30 European countries, and slightly lower in Western Europe (11.7%) compared to Eastern Europe (12.1%) (Table 1). Among men in Western Europe, the OAMF ranged from 10.4% in Portugal to 13.5% in UK. Among men in Eastern Europe, the OAMF ranged from 10.3% in Slovenia to 14.5% in Hungary. Among men in the USA the OAMF was 16.1%.

Among women, the average age-standardised OAMF levels in 2016 (11.6%) were almost similar compared to men, although differences between the Western (11.1%) and Eastern European countries (12.4%) were slightly higher. Among women in Western Europe, the OAMF ranged from 8.9% in Switzerland to 13.4% in Spain. Among women in Eastern Europe, the OAMF ranged from 10.3% in Slovenia and 14.7% in Russia. Among women in the USA the OAMF was 15.0%.

- **Our projection**

In line with our projection methodology, and the underlying notion of the wave-shaped obesity epidemic, we project that eventually the observed increases turn into declines.

More specifically, in terms of obesity prevalence, we project for the 18 Western European countries, that, on average, the age-standardised prevalence (20-84) will increase from 25% in 2016 to an average peak of 34% in 2035 among men, and from 24% in 2016 to an average peak of 28% in 2032 among women. For the 12 Eastern European countries, obesity prevalence is expected to increase, on average from 24% in 2016 to 35% in 2044 among men, and from 28% in 2016 to 31% in 2028 among women. Subsequently, obesity prevalence is projected to decline (see Figure 2).

In terms of the age-standardised obesity-attributable mortality fractions, we project a generally similar pattern compared to the age-standardised obesity prevalence but at lower levels (Figure 2). For the 18 Western European countries, on average, age-standardised obesity-attributable mortality (20-84) is projected to increase from 11.7% in 2016 to 15.0% in 2039 among men, and from 11.1% in 2016 to 12.5% in 2036 among women. For the 12 Eastern European countries, obesity-attributable mortality is projected to increase, on average from 12.1% in 2016 to 16.6% in 2047 among men, and from 12.4% in 2016 to 13.7% in 2040 among women.

Clear differences between individual countries can be observed however (Figure 2, Table 2, Figure 3).

The USA and selected Eastern European countries are projected to reach the highest maximum levels (Table 2, Figure 3). Among men, Hungary (20.6%), Czech Republic (18.8%) and the USA (18.3) are projected to reach the highest maximum levels. Among women, this applies to the USA (16.5%), Poland (15.9%) and Russia (15.7%). Within Western Europe, the highest maximum levels are projected for UK, Ireland and Germany. The lowest maximum OAMF levels are projected among men for Italy (13.0%), the Netherlands (13.1%) and Portugal (13.3%), and among women for Denmark (10.7%).

Among men, the year in which the various countries are projected to reach the maximum level occurs earlier in Western European countries compared to Eastern European countries, with the exception of Switzerland with a late peak year (2052), and Belarus with a rather early peak year (2040) (Table 2, Figure 3). More specifically, men in the Netherlands are expected to first reach the peak (in 2030), followed by the USA (2031), UK and Portugal (2034), whereas men in Czech Republic and Lithuania (2054) and in Hungary (2052) are expected to reach the peak late. For women, this pattern is slightly more mixed, although again late peaks are observed for Eastern European countries (in particular Poland, Latvia and Estonia) and Switzerland. Next to the Netherlands, USA and Portugal, also Belarus (2028) and Lithuania (2029) are projected to reach the maximum levels early.

For men a higher peak level is projected compared to women in all countries, except for Russia where the peak levels for men and women are very close to one another (Figure 2). The peak year is also generally projected to occur later among men compared to women, with the exception of Poland, Latvia, and Switzerland, although for the latter two countries differences are small.

After these maximum levels have been reached, obesity will decline according to our projection (Figure 2). In 2060 the age-standardised OAMF is projected to be on average 13.4% among men and 11.1% among women over the 30 European countries (Table 1). For the 18 Western European countries these percentages amount to, on average, 12.0% and 10.3%, respectively. For the 12 Eastern European countries the projected average levels are higher at 15.6% and 12.3% respectively. Among men, the projected shares of all-cause mortality due to obesity in 2060 range from 6.4% (the Netherlands) to 20.2% (Hungary). Among women, these shares range from 7.4% (the Netherlands) to 15.8% (Poland).

In most countries, a clear deceleration of the decline sets in around or after 2060, although for those populations with a rather late peak (e.g. men in Czech Republic, Lithuania and in Hungary, and women in Poland, Latvia and Estonia), the decline after 2060 is projected to continue unabatedly, and will continue even after 2100.

Our projected age-specific obesity-attributable mortality levels (Appendix Figure 2; Appendix Figure 3) display an age pattern similar to the pattern observed in the past, with an inverse U-shape peaking at around the age of 50-59 years.

Discussion

We project that, for the 18 Western European countries, on average, age-standardised obesity-attributable mortality (20-84) will increase from 11.7% in 2016 to 15.0% in 2039 among men, and from 11.1% in 2016 to 12.5% in 2036 among women. For the 12 Eastern European countries, obesity-attributable mortality is projected to increase, on average from 12.1% in 2016 to 16.6% in 2047 among men, and from 12.4% in 2016 to 13.7% in 2040 among women. Subsequently, obesity-attributable mortality is projected to decline, and expected to reach in 2060 average levels of 12.0% (men) and 10.3% (women) in Western Europe, and 15.6% (men) and 12.3% (women) in Eastern Europe.

- **Evaluation of data and methods**

Our projection, like any projection, depends on the data and the model used and the underlying assumptions.

In terms of the data, we selected the longest time series of age- and sex-specific obesity prevalence data that was available. The selected data from the NCD-RisC 2017 study are based on the available population-level based information by country on measured height and weight. These data are used as input into a Bayesian hierarchical estimation model which is applied to all countries and years to obtain estimates for those countries and years for which no data was available (NCD Risk Factor Collaboration, 2017). Because the NCD-RisC 2017 study relies on measured height and weight data, their obesity prevalence levels tend to be higher compared to national obesity prevalence data that mostly rely on self-reported height and weight (see Janssen et al. 2020 online supplementary file II for a comparison). This is because people with a high BMI tend to underreport their body weight (Ezzati et al., 2006; Connor Gorber et al., 2007; Tolonen et al., 2014). Another important remark regarding the data is that the data comprise estimates and thus come with uncertainty, because national measured height and weight data, if available for a country, is often incomplete. Particularly for Eastern Europe the data is based on fewer data available compared to Western Europe, and therefore come with larger uncertainty compared to Western Europe (see Vidra et al., 2019).

To obtain past and future obesity-attributable mortality levels, we applied to the past and projected age- and sex-specific obesity prevalence levels, the relatively simple – but often applied – population-attributable fraction formula by Rockhill et al. (1998) (Vidra et al., 2019). In doing so, we used one set of age- and sex-specific RRs – obtained from a review of mainly Western European and American studies - which we applied to all countries and to all the years in our study. Although differences in the relative risks of dying from obesity between countries and over time can exist, for example because of country and/or time differences in the treatment of chronic diseases that are affected by obesity, more research is needed to establish these exact country and time differences (see as well Vidra et al. 2019).

The projection model we used has been extensively discussed before in Janssen et al. 2020. First, our use of age-period instead of age-period-cohort modelling and projecting, despite the importance of the cohort dimension in analyses of obesity prevalence and obesity-attributable mortality trends (Reither et al., 2009; Faeh & Bopp 2010; Robinson et al., 2013; Diouf et al., 2010; Masters et al., 2013; Vidra et al., 2018) is because the age-period-cohort modelling of the data resulted in unrealistically similar cohort patterns for the different countries, most likely because the data itself were estimated using an age-period model. Second, for comparative purposes we deliberately applied one model for the sex-specific populations of 30 European countries and the USA. When more closely focussing on an individual country, the inclusion of country-specific information on the determinants of (trends in) obesity prevalence may be beneficial. Third, and most important, we designed our model specifically to accommodate for the hypothesized underlying wave pattern of the obesity epidemic (Xu & Lam, 2018; Jaacks et al., 2019). In so doing, our methodology can, in contrast to the previous linear extrapolations of past trends in obesity prevalence (Wang et al., 2008; McPherson et al., 2007; Kelly et al., 2008; Foreman et al., 2018; OECD, 2017)result in plausible estimates not only for the short term future but also for the long-term future, as we regard it unlikely that obesity will continue to increase infinitely. The assumption that the obesity epidemic evolves in a wave-shaped way has, however, been debated by some scholars (Visscher et al., 2015). These scholars argue that the decelerating increases in obesity prevalence are the result of biased misinterpretation of the data, and that any stagnation that has been observed is likely to be temporary (Visscher et al., 2015). We feel strengthened in applying the wave-shaped assumption however because of the evidence that (i) recent generations of children are leaner than less recent cohorts (Wabitsch et al., 2014; Pan et al., 2019; Lauria et al., 2019), and will consequently also likely grow into more leaner adults than before; (ii) the increasing obesity trend is stagnating among populations who experienced the obesity epidemic first: the USA (Rokholm et al., 2010), and among adults with a high socio-economic status (Visscher et al., 2015), (iii) and that the increases in obesity in 18 Western European countries and the USA between 1990 and 2016 were decelerating (Janssen et al., 2020). However, at the same time, we also acknowledge that effective, ongoing public health action aimed at tackling obesity is required to ensure that these positive trends in obesity prevalence indeed leads to an eventual decline in adult obesity prevalence, and consequently obesity-attributable mortality.

Additional explicit choices and assumptions that have an effect on our projection outcomes are the start year for the extrapolation of the speed of change, and the assumed lower limits. See Janssen et al. (2020) for a more detailed discussion of these two elements. Our final choices for both these elements were based on a careful assessment of the past trends, and the available theory. For example, our assumed lower limits based on the obesity prevalence levels in 1975, proved, on average, rather close to the 10% level that Xu and Lam (2018) expected obesity to reach at the final stage of the obesity epidemic. That is, for the 18 Western European countries they were on average 7.1% for men, and 10.7% for women, and for the 12 Eastern European countries these values were 7.6%, and 9.1% respectively (see as well Appendix Table 1). Moreover, when we compared our estimates of the timing of the maximum obesity level with the estimates based on the hypothesis by Xu and Lam (2018) that a maximum will be reached about 30 years after obesity prevalence is 20%, we observed that, in general, the estimates were quite similar for Western Europe, but that for Eastern Europe, particularly for women, differences are rather large (see Appendix Table 2). That is, the assumption by Xu & Lam (2018) amounts for the 12 Eastern European countries, on average, to a peak year of 2037 among men, and 2016 among women, whereas we project for these countries, on average, a peak year of 2047 for men, and 2040 for women. That the general assumption by Xu & Lam does not work out well for women in Eastern Europe has everything to do with the already high past levels among women in Eastern Europe in 1975, and the less strong increase afterwards. These patterns were in fact the reason why we decided to employ slightly different assumptions for women in Eastern Europe compared to the other populations, in order to obtain realistic outcomes. That is, not only did we regard it unlikely that women in Eastern Europe would already reach a peak on average in 2016, we also regarded it unlikely that the peak years for men and women of the same countries would be very different, and that the peak years for women in Eastern Europe would be extremely different from the peak years for women in Western Europe.

All in all, the outcomes of our projection need to be interpreted with the underlying data, the estimation method, the applied projection model and the underlying assumptions in mind. That notwithstanding, we believe that our projection provides the society and health policy-makers with comparable and achievable estimates of age-specific and age-standardised obesity-attributable mortality for the long-term future, thereby covering a substantially longer future time horizon than previous projections did.

- **Explanation of results**

By integrating the assumed underlying wave-shaped pattern of the obesity epidemic (Xu and Lam 2018; Jaacks et al., 2019) in projecting future (age-specific) obesity prevalence and obesity-attributable mortality in 30 European countries, using the NCD-RisC 2017 obesity prevalence data, we were able to establish clear differences between Western and Eastern European countries in the expected timing and future levels of the maximum obesity-attributable mortality. That is, we project that for the 12 Eastern European countries, the age-standardised obesity-attributable mortality fractions will be approximately 1.5 percentage points higher than for the 18 Western European countries, and that the peak of the obesity epidemic will be reached, on average 8 years later among men, and 4 years later among women in Eastern Europe compared to Western Europe. These higher future peak levels are in line with the observed higher obesity-attributable mortality fractions in Eastern Europe compared to Western Europe currently and in the past (see Figure 1). Also, obesity prevalence has always been higher in Eastern Europe compared to Western Europe, at least for both sexes combined (see Figure 1). The historically higher obesity prevalence in Eastern Europe compared to Western Europe has been attributed to a higher total supply and intake of calories (Silventoinen et al., 2004). The later peak year that we project for Eastern Europe compared to Western Europe, is not merely a reflection of the current levels, but more so of the most recent trends, at least for men. Apparently for Western European men, decelerations in obesity increase after the year 2000 are slightly stronger, and combined with their slightly lower bounds, result in earlier peak years. We regard this a logical outcome, also given the theory that states that the uptake of healthy behaviours to circumvent the negative effects of obesity, either or not as a response to preventive policies, mostly occurs earlier among those with high socio-economic status, compared to those with low socio-economic status (Rogers, 1962; Robertson et al., 2007; Krokstad et al., 2013). Our outcomes and our reasoning is in line as well with the already observed stagnations of the increase in obesity prevalence among those with a high socio-economic status in Finland, France and Switzerland (Visscher et al., 2015). For Eastern European women, the projected peak years rely much more on our underlying assumptions, which were selected in such a way that the peak levels and peak years are in line with our expectations (see evaluation of data and methods). Therefore, not only for Eastern European men, but also for Eastern European women, we end up with a later peak year compared to Western Europe. The later projected peak years and higher peak levels for Eastern Europe compared to Western Europe could also be related to the later shift away from diets rich in complex carbohydrates to more Western diets rich in refined carbohydrates, in line with a later timing of the so-called super marketisation of food supplies (Knai et al., 2007).

However, within the two broader regions of Europe, important country differences exist as well. Within Western Europe, particularly the United Kingdom and Ireland stand out, with for both men and women, high and early projected peak levels (see Table 2; Figure 2). Both these countries seem to closely follow the experience of the USA in the obesity epidemic, with obesity levels rapidly approaching those in the USA (OECD, 2012) and can as such be regarded the "forerunners" of the obesity epidemic within Europe (Vidra et al., 2019). Behind their forerunner position is that these two countries share, with the USA, a widespread fast food consumption and an increasing prevalence of sedentary lifestyle, combined with a strong stigmatization of obese people (Donahue, 2018) which likely aggravates the health effects of obesity and hampers behavioral change (López-Valenciano et al. 2017; Teixeira et al. 2017).

On the other hand, for the Netherlands, Portugal, and Italy – particularly for men – we project low maximum OAMF levels that occur relatively soon, and also for women in Denmark we project rather low (future) OAMF levels (see Figure 4). These populations also exhibited the lowest levels of age-standardised obesity prevalence in 2016 (Janssen et al., 2020), and consequently – except for Dutch men – also the lowest levels of age-standardised OAMF in 2016 (see Table 1). The drivers behind their low (projected) levels are likely not exactly similar for the different populations, but all contribute to a context that is less obesogenic than in other European countries (Rabin et al., 2007). For the Netherlands and for Danish women the low obesity prevalence levels could potentially be related to their relatively high physical activity level (Rios et al., 2016), whereas for Italy and Portugal a wider availability of fruits and vegetables (Pomerlau et al., 2003) and a potentially more limited supermarketisation of food supplies, might play a role. And in addition, policies to prevent obesity might be more effective in these countries compared to elsewhere – particularly in the Netherlands and Denmark with a higher GDP per capita (Berghofer et al., 2008).

Within Eastern Europe, the populations that are performing the worst in 2016, are generally also the populations that are projected to have high maximum levels (see Table 1 and Figure 4). For men, particularly Hungary and Czech Republic stand out in this respect, with projected maximum levels even higher than the USA. For women, especially Russia and Poland stand out, albeit that their maximum levels are projected to be lower compared to the USA. For Hungary, the high obesity prevalence estimates in 2016, are very much in line with a recent large evaluation study based on anthropometric measures which reported an obesity prevalence of 32.0% among men and 31.5% among women in 2013, with increases over time being stronger among men compared to women, mainly among the youngest generations (Rurik et al., 2014). The authors observed, particularly for men, a clear shift from overweight to obesity over the past 25 years (Rurik et al., 2014), which could potentially point to a shift towards the adoption of more western diets (see before). For Russia in 2012-2014, obesity prevalence levels (based on anthropometric measurements) of 31.4% among women, and 27.5% among men were reported (Kontsevaya et al., 2019). For Russian women (not for Russian men) they observed lower obesity prevalence among those with higher educational status (Kontsevaya et al., 2019), indicating that it might be the lower socio-economic status of women in Russia that is especially driving the high obesity prevalence levels. Indeed, among Russian women with low and middle educational levels obesity prevalence levels were clearly elevated compared to the rest of the Russian population (Kontsevaya et al., 2019).

All in all, the country differences in projected obesity-attributable mortality are largely in line with country differences in projected obesity prevalence and can be related not purely to past obesity prevalence levels, but also to past increases therein, which are in themselves again determined by (changes in) contextual factors, such as economic conditions, common diet/nutrition, the obesogenic environment, and the implementation of prevention policies.

Next to important differences in projected OAMF between and within Western and Eastern Europe, we also showcase some interesting sex differences. That is, we project a lower peak level of OAMF among women than men, which women will also experience a couple of years earlier in time. These results are in line with our results for obesity prevalence (see Figure 2). Our observation could serve as an important addition to the Xu and Lam 2018 paper, as they showed their conceptual model for men and women combined, because of "the lack of substantial sex differences in the trends of obesity prevalence and the percentage of mortality attributable to obesity". Indeed, sex differences in obesity prevalence and obesity-attributable mortality are not big (see Figure 1), but still it is likely that for women the (impact of the) obesity epidemic is less than for men, because particularly higher SES women tend to be more health-conscious in general, tend to adopt healthier behaviours regarding food intake and physical activity, and are prone to follow nutritional recommendations (Fagerli et al., 1999). Also, more in general, women might experience greater social pressure than men to be thin (Psaltopoulou et al., 2017).

On average, across the 30 European countries, the age-standardised OAMF is projected to increase from on average 11.7% in 2016 to an average peak level of 14.3% in 2040, and to subsequently decline to 12.3% in 2060. It is important to note that the average projected levels in 2060 are, thus, higher compared to the average estimated levels in 2016. So although our approach might be considered optimistic (see "evaluation of data and methods"), even with such an 'optimistic' approach, the obesity prevalence levels will be higher in 2060 compared to now.

As noted already, our projections rely on the assumption of an underlying wave pattern of the obesity epidemic, and on ongoing (effective) public health action to turn the current (stagnating) increases in obesity into declines. In line with our discussion so far, and with the recent literature (Stevens et al., 2017; Paxman & Parkhurst, 2018) we believe that merely addressing individual behaviour (activity patterns, diets) through interventions regarding health and lifestyle is not sufficient, even if these interventions are context-specific (Cuschieri & Mamo, 2016). Important as well would be to tackle underlying socio-economic inequalities and addressing the negative effects of the obesogenic environment in which people live, for example by regulating the availability and accessibility of unhealthy foods, and by planning for surroundings that stimulate physical activity (Stevens et al., 2017; Paxman & Parkhurst, 2018).

Overall conclusions and implications

Integrating the underlying epidemic wave pattern in projections of (age-specific) obesity prevalence and obesity-attributable mortality for 30 European countries, we estimate that the obesity epidemic will reach its peak, on average in 2040, with obesity contributing a projected 14.3% of all deaths (compared to 11.7% in 2016), and will subsequently decline to an average level of 12.3% in 2060.

The peak is projected to occur later and at higher levels for Eastern Europe compared to Western Europe, and for men compared to women, which is in line with the observation that particularly highly educated women tend to adopt healthier food intake and physical activity patterns, either or not in response to policy actions.

Despite our approach being more optimistic compared to previous projections that mostly projected ongoing increases, still our average projected levels in 2060 are higher compared to the current levels.
All in all, we recommend strong (further) ongoing public health action to prevent obesity, to facilitate positive (behavourial) change for those with obesity, and to diminish the negative health effects of obesity. This is especially needed for the selected Eastern European populations which are currently –

and likely in the future as well - worse off, e.g. men in Hungaria and Czech Republic, and women in Russia and Poland.

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Tables and Figures

Table 1. Estimated (2016) and projected (2060) age-standardized obesity-attributable mortality fractions (%) (20-84 yrs.) and corresponding projection intervals in 2060 in the 30 European countries and the US, by sex

	Age-standardised OAMF (20-84)			
	Estimated for 2016		*Projected for 2060*	
Country	*Men*	*Women*	*Men*	*Women*
United States	16.1	15.0	12.0 (10.3; 14.4)	11.7 (10.5; 13.4)
Western Europe				
Austria	10.9	9.5	11.7 (10.0; 13.8)	9.3 (8.3; 10.5)
Belgium	12.0	11.4	12.7 (11.3; 14.3)	11.0 (10.2; 11.9)
Denmark	11.0	9.1	13.0 (11.7; 14.4)	9.6 (9.0; 10.3)
Finland	12.4	11.8	13.9 (12.0; 16.2)	11.7 (10.5; 13.1)
France	11.5	10.2	11.5 (10.2; 13.0)	9.2 (8.6; 10.0)
Germany	12.7	12.4	14.3 (12.8; 16.1)	12.8 (11.9; 13.9)
Greece	11.6	12.2	14.4 (13.5; 15.3)	12.0 (11.6; 12.4)
Iceland	11.8	10.2	12.4 (10.8; 14.5)	9.4 (8.6; 10.4)
Ireland	12.5	12.3	12.3 (10.6; 14.3)	11.0 (9.8; 12.3)
Italy	10.8	11.1	10.0 (8.9; 11.3)	10.2 (9.6; 11.0)
Luxembourg	12.1	10.4	11.8 (10.7; 13.1)	9.1 (8.6; 9.8)
Netherlands	11.0	11.8	6.4 (5.8; 7.2)	7.4 (7.0; 7.9)
Norway	11.9	11.9	10.4 (8.7; 12.5)	9.8 (8.9; 11.0)
Portugal	10.4	10.9	8.3 (7.0; 10.1)	8.2 (7.4; 9.1)
Spain	12.9	13.4	14.0 (12.9; 15.1)	13.4 (12.7; 14.1)
Sweden	11.0	9.6	11.1 (9.6; 13.1)	9.2 (8.4; 10.3)
Switzerland	10.9	8.9	16.0 (14.7; 17.4)	11.7 (10.8; 12.7)
United Kingdom	13.5	12.5	11.4 (10.3; 12.7)	10.7 (9.9; 11.6)
Eastern Europe				
Belarus	11.9	12.7	12.8 (12.0; 13.7)	10.0 (8.4; 11.9)
Bulgaria	12.6	11.6	14.8 (14.3; 15.3)	11.5 (9.3; 14.7)
Czech Republic	13.6	12.8	18.7 (18.1; 19.3)	13.2 (10.2; 17.9)
Estonia	11.2	12.0	14.2 (13.3; 15.1)	13.0 (11.0; 16.4)
Hungary	14.5	12.4	20.2 (18.0; 22.5)	11.9 (9.5; 17.4)
Latvia	11.4	12.2	15.2 (14.3; 16.2)	13.5 (11.9; 15.5)
Lithuania	12.8	14.0	17.8 (17.2; 18.5)	12.1 (10.1; 14.7)
Poland	13.1	13.2	15.1 (13.9; 16.4)	15.8 (13.9; 17.9)
Russian Federation	11.0	14.7	13.9 (13.3; 14.7)	15.2 (13.7; 17.0)
Slovakia	11.5	10.6	15.4 (14.4; 16.4)	9.3 (7.2; 12.6)
Slovenia	10.3	10.3	12.9 (11.5; 14.5)	8.9 (6.5; 13.0)
Ukraine	11.6	12.3	16.3 (15.7; 16.9)	13.1 (11.4; 15.0)

Table 2. Expected maximum levels of age-standardized obesity-attributable mortality fractions (OAMF)(20-84 yrs.) and the year these levels will be reached in the 30 European countries and the US, by sex

	Expected maximum age-standardised OAMF (%) and 95% projection intervals		Expected year that the maximum will be reached and 95% projection intervals	
Country	*Men*	*Women*	*Men*	*Women*
United States	18.3 (17.6; 19.3)	16.5 (16.1; 17.2)	2031 (2028; 2036)	2031 (2027; 2035)
Western Europe				
Austria	14.4 (13.6; 15.6)	11.2 (10.8; 11.9)	2040 (2035; 2045)	2037 (2033; 2042)
Belgium	15.0 (14.3; 15.9)	12.3 (12.0; 12.8)	2040 (2036; 2045)	2036 (2031; 2042)
Denmark	14.8 (14.2; 15.7)	10.7 (10.3; 11.1)	2042 (2039; 2046)	2041 (2037; 2045)
Finland	15.8 (14.9; 17.1)	13.3 (12.8; 13.9)	2042 (2036; 2048)	2037 (2032; 2044)
France	14.5 (13.9; 15.3)	11.3 (11.1; 11.7)	2038 (2034; 2042)	2034 (2030; 2038)
Germany	16.4 (15.6; 17.4)	14.3 (13.9; 14.9)	2041 (2037; 2046)	2039 (2035; 2044)
Greece	16.0 (15.5; 16.5)	13.4 (13.2; 13.6)	2044 (2042; 2047)	2036 (2034; 2039)
Iceland	15.1 (14.3; 16.2)	11.2 (10.9; 11.6)	2039 (2035; 2044)	2034 (2030; 2040)
Ireland	16.3 (15.5; 17.4)	14.8 (14.3; 15.4)	2037 (2034; 2042)	2035 (2032; 2039)
Italy	13.0 (12.6; 13.7)	12.1 (11.8; 12.4)	2036 (2032; 2040)	2034 (2030; 2038)
Luxembourg	15.3 (14.8; 15.9)	11.6 (11.4; 11.9)	2037 (2035; 2041)	2033 (2031; 2036)
Netherlands	13.1 (12.7; 13.5)	12.6 (12.4; 12.7)	2030 (2028; 2032)	2026 (2024; 2028)
Norway	14.7 (14.0; 15.8)	13.2 (12.8; 13.7)	2035 (2031; 2040)	2031 (2028; 2036)
Portugal	13.3 (12.6; 14.2)	12.0 (11.8; 12.4)	2034 (2031; 2038)	2030 (2027; 2034)
Spain	16.0 (15.5; 16.6)	14.5 (14.2; 14.8)	2041 (2037; 2044)	2037 (2033; 2043)
Sweden	14.2 (13.4; 15.2)	11.1 (10.7; 11.6)	2038 (2034; 2043)	2036 (2032; 2042)
Switzerland	16.3 (15.4; 17.5)	11.8 (11.2; 12.7)	2052 (2047; 2057)	2054 (2047; 2061)
United Kingdom	16.4 (15.9; 17.1)	14.3 (14.0; 14.8)	2034 (2032; 2037)	2033 (2031; 2036)
Eastern Europe				
Belarus	15.3 (14.9; 15.7)	13.2 (12.9; 13.8)	2040 (2038; 2042)	2028 (2023; 2037)
Bulgaria	16.6 (16.3; 16.9)	13.0 (12.2; 14.9)	2043 (2041; 2044)	2038 (2028; 2057)
Czech Republic	18.8 (18.4; 19.4)	14.1 (13.1; 19.0)	2054 (2052; 2057)	2041 (2025; 2086)
Estonia	15.1 (14.6; 15.8)	13.4 (12.5; 17.4)	2046 (2043; 2049)	2046 (2029; 2084)
Hungary	20.6 (19.2; 22.6)	14.0 (13.0; 17.7)	2052 (2045; 2059)	2036 (2025; 2059)
Latvia	15.9 (15.4; 16.6)	13.7 (12.8; 16.2)	2048 (2045; 2052)	2051 (2033; 2089)
Lithuania	18.0 (17.5; 18.5)	14.6 (14.2; 15.5)	2054 (2051; 2057)	2029 (2022; 2045)
Poland	17.1 (16.5; 17.8)	15.9 (14.6; 18.6)	2042 (2039; 2045)	2057 (2040; 2085)
Russian Federation	15.1 (14.7; 15.5)	15.7 (15.1; 17.1)	2046 (2044; 2048)	2043 (2029; 2070)
Slovakia	16.1 (15.5; 16.8)	11.7 (11.1; 13.3)	2048 (2045; 2052)	2033 (2025; 2049)
Slovenia	14.3 (13.5; 15.3)	11.4 (10.8; 13.6)	2044 (2040; 2049)	2033 (2024; 2052)
Ukraine	16.8 (16.4; 17.3)	13.6 (12.9; 15.0)	2050 (2048; 2052)	2043 (2031; 2065)

Figure 1. Past trends in age-standardised (ages 20-84) obesity prevalence and obesity-attributable mortality fractions (OAMF), for 30 European countries (grouped by region) and the USA, 1975-2015

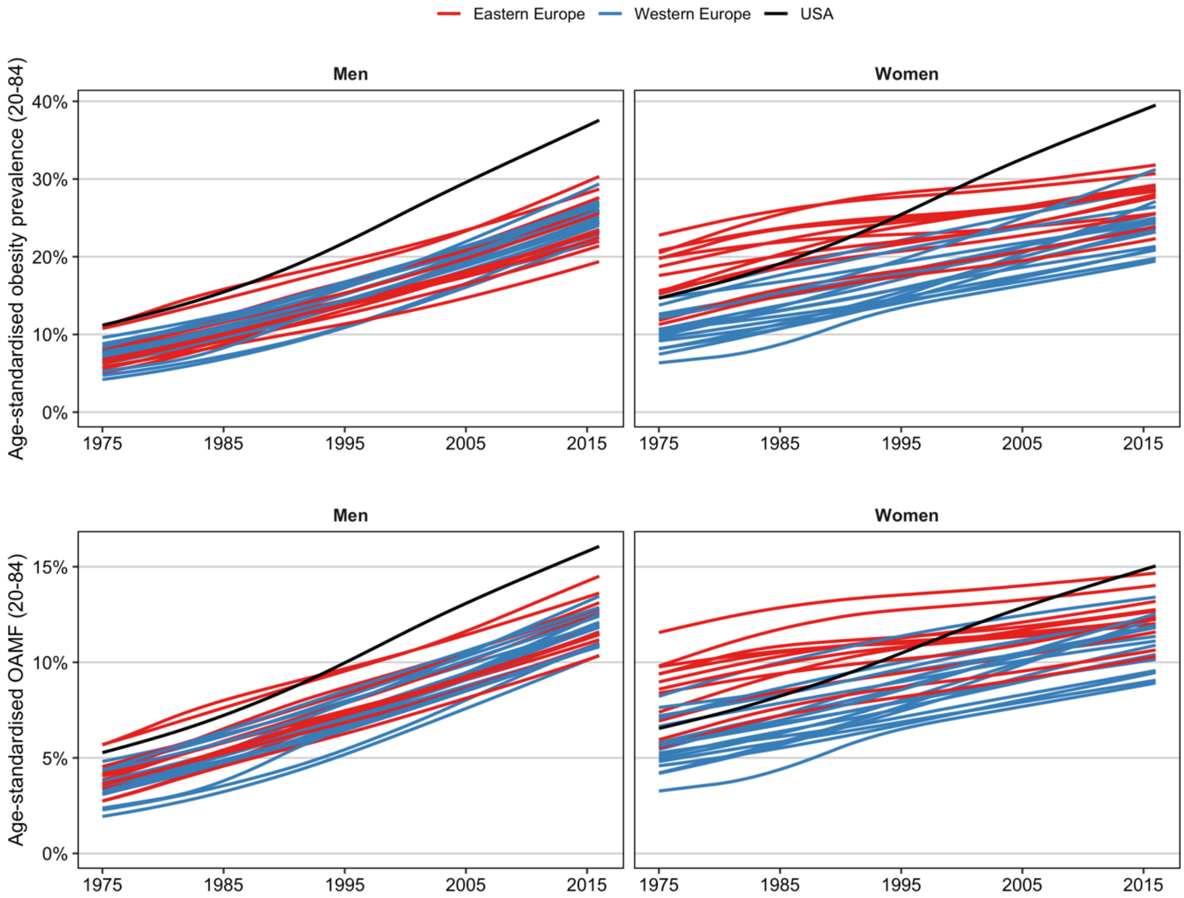


Figure 2. Past and projected age-standardised (ages 20-84) obesity prevalence and obesity-attributable mortality fractions (OAMF), for 30 European countries (grouped by region) and the USA, 1975-2100. See Appendix Figure 1 and Figure 3 for the country-specific outcomes

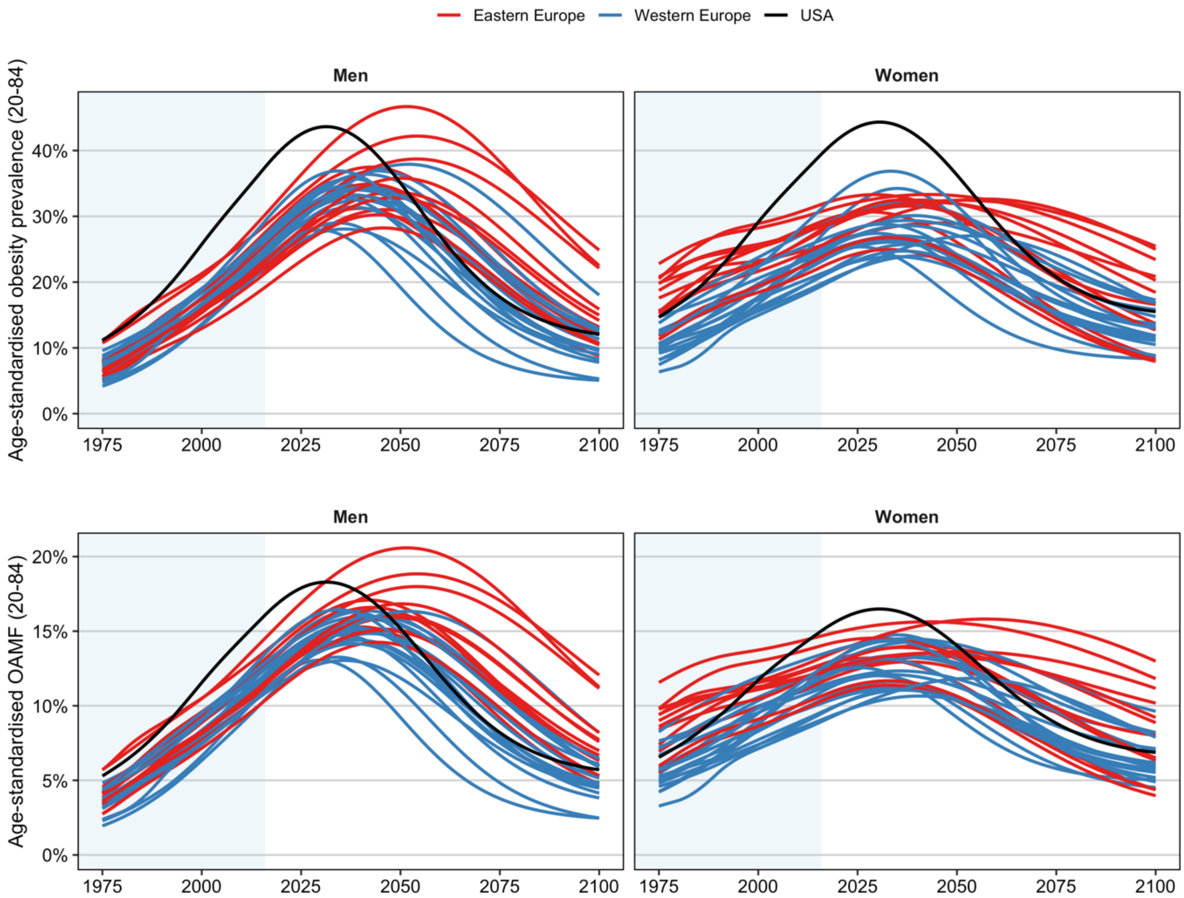


Figure 3. Past and projected age-standardized obesity-attributable mortality fractions (ages 20-84) and 95% projection intervals, 30 European countries and the USA, 1975-2100, by sex

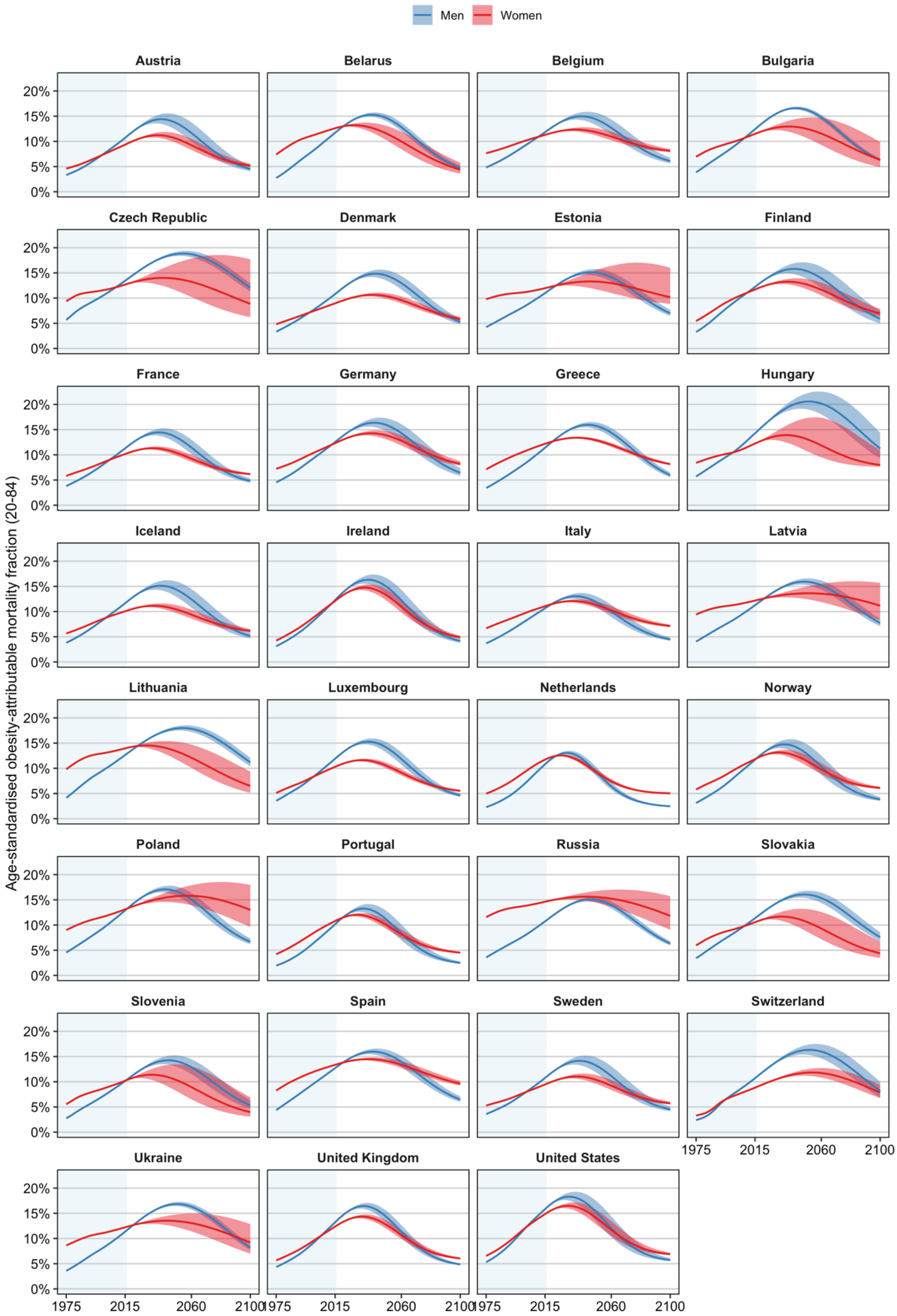
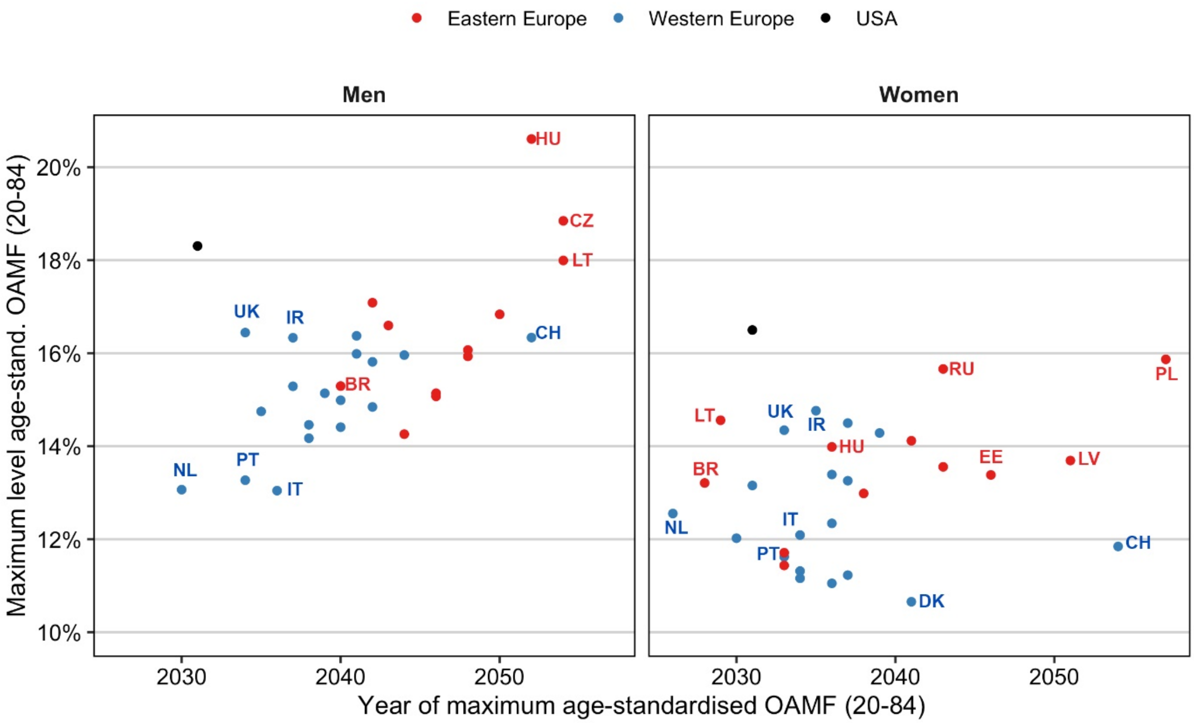


Figure 4. Future peak year and peak level age-standardised obesity-attributable mortality fraction (OAMF) (ages 20-84)



Country abbreviations used:

- For Western Europe (in bleu) => CH = Switzerland; DK = Denmark; IR = Ireland; IT = Italy; NL = the Netherlands; PT = Portugal; UK = United Kingdom;
- For Eastern Europe (in red) => BR = Belarus; CZ = Czech Republic; EE = Estonia; HU = Hungary; LT = Lithuania; LV = Latvia; PL = Poland.

Appendix Table 1. Implemented lower bounds, based on country-specific obesity prevalence levels in 1975

	*Implemented lower bounds**	
Country	*Men*	*Women*
United States	11.18	14.65
Western Europe		
Austria	7.01	9.17
Belgium	9.59	14.73
Denmark	7.11	9.51
Finland	6.55	9.80
France	7.58	12.38
Germany	8.80	12.59
Greece	7.38	14.67
Iceland	7.83	10.68
Ireland	6.24	7.45
Italy	7.38	12.62
Luxembourg	7.44	10.15
Netherlands	4.72	8.19
Norway	6.34	10.61
Portugal	4.20	8.14
Spain	8.36	13.76
Sweden	7.76	10.44
Switzerland	5.25	6.34
United Kingdom	8.71	12.11
Eastern Europe		
Belarus	5.03	5.03
Bulgaria	7.98	7.98
Czech Republic	11.06	11.06
Estonia	7.86	19.83
Hungary	10.76	17.58
Latvia	7.67	7.67
Lithuania	7.75	7.75
Poland	8.14	8.14
Russian Federation	5.83	5.83
Slovakia	6.27	6.27
Slovenia	5.57	5.57
Ukraine	6.74	6.74

* This table reports the age-standardised obesity prevalence levels (ages 20-84) in 1975. In Western Europe and among men in Eastern Europe, the lower limits are implemented in our projection of the period parameter κ_t through the following transformation: $f_t = \log(\kappa_t - \kappa_{t_{\min}})$, in which $\kappa_{t_{\min}}$ = logit $\mathrm{OP}_x^{lb} - \alpha_x$, and where OP_x^{lb} represents the population- and age-specific obesity prevalence levels in 1975 in line with the age-standardised values in the above table.

For women in Eastern Europe, however, we implemented the age-standardised obesity prevalence levels among men in 1975 in the respective countries (except for women in Hungary and Estonia where we could still use the female age-standardised prevalence in 1975), and we adopted a slightly different method to do so. That is we set the value of $\kappa_{t_{\min}}$ such that the weighted average of the inversely logit transformed (logit^{-1}) age-specific outcome of our Lee-Carter model equals the age-standardised prevalence levels for men in 1975 of the respective country (denoted as OP^{lb_men}), using the following formula: $\sum_x w_x\, logit^{-1}(\alpha_x + \beta_x \cdot \kappa_{tmin}) = OP^{lb\_men}$, where w_x denotes the proportion of the population with age x in the year 2010 (according to the HMD data).

Appendix Table 2. Year at which the maximum obesity prevalence level is expected to be reached, comparison of our projection with the application of the Xu & Lam 2018 assumption* to the data we used, for the 30 European countries and the United States (ages 20-84), by sex

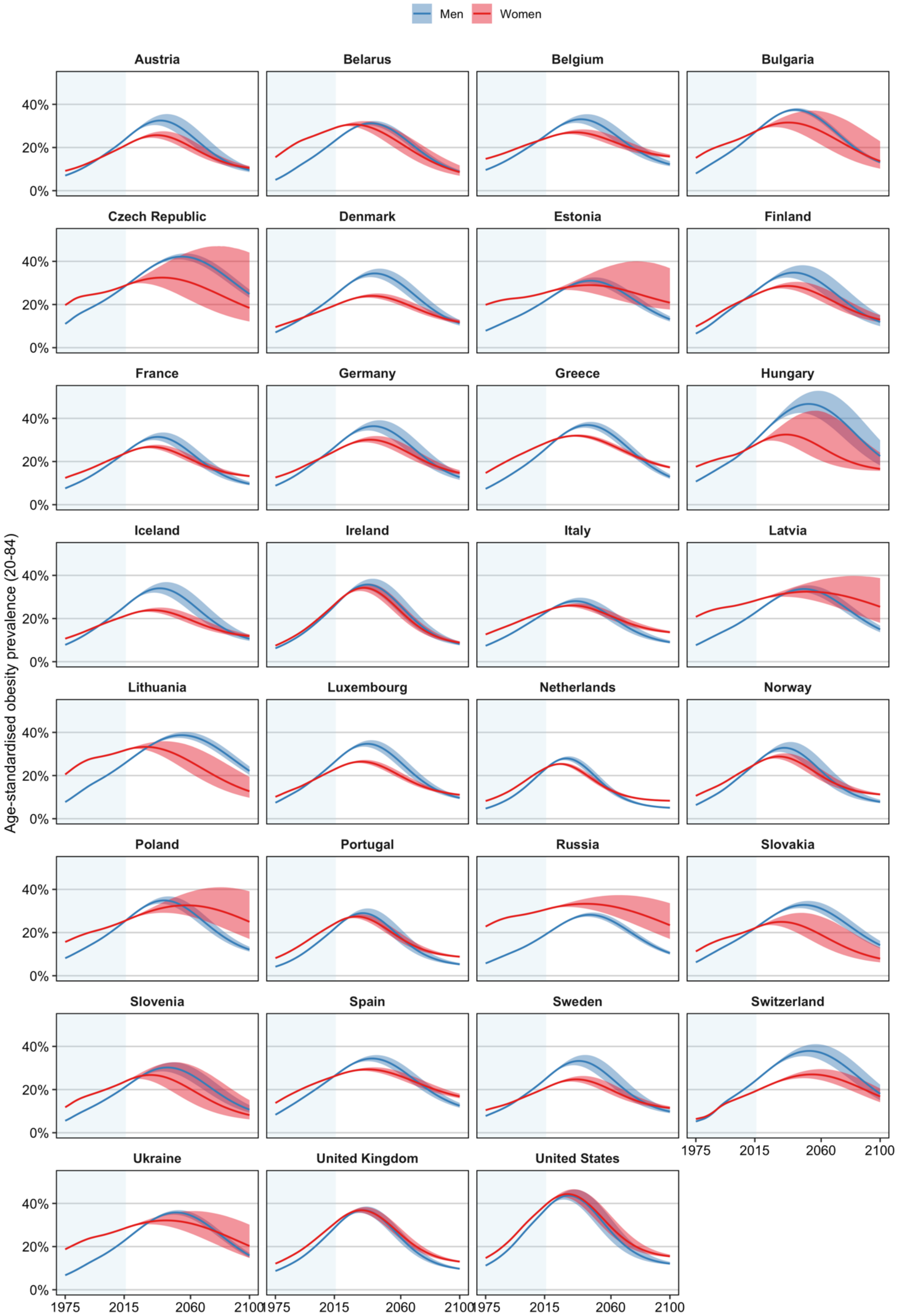
	Year at which the maximum obesity prevalence level is expected to be reached			
	Applying the Xu and Lam 2018 assumption* to the data we used		Our projection	
Country	*Men*	*Women*	*Men*	*Women*
United States	2023	2017	2031	2031
Western Europe				
Austria	2039	2044	2040	2037
Belgium	2034	2028	2040	2036
Denmark	2038	> 2046**	2042	2041
Finland	2033	2031	2042	2037
France	2038	2033	2038	2034
Germany	2033	2031	2041	2039
Greece	2036	2019	2044	2036
Iceland	2035	2041	2039	2034
Ireland	2037	2035	2037	2035
Italy	2040	2033	2036	2034
Luxembourg	2035	2037	2037	2033
Netherlands	2041	2038	2030	2026
Norway	2036	2032	2035	2031
Portugal	2042	2036	2034	2030
Spain	2033	2023	2041	2037
Sweden	2037	2044	2038	2036
Switzerland	2038	> 2046**	2052	2054
United Kingdom	2032	2026	2034	2033
Eastern Europe				
Belarus	2040	2015	2040	2028
Bulgaria	2033	2019	2043	2038
Czech Republic	2027	2006	2054	2041
Estonia	2042	2006	2046	2046
Hungary	2029	2015	2052	2036
Latvia	2040	2005	2048	2051
Lithuania	2034	2005	2054	2029
Poland	2036	2022	2042	2057
Russian Federation	> 2046**	< 2005***	2046	2043
Slovakia	2041	2038	2048	2033
Slovenia	2044	2033	2044	2033
Ukraine	2040	2009	2050	2043

* Obesity prevalence will reach its maximum 30 years after its prevalence is at 20%;

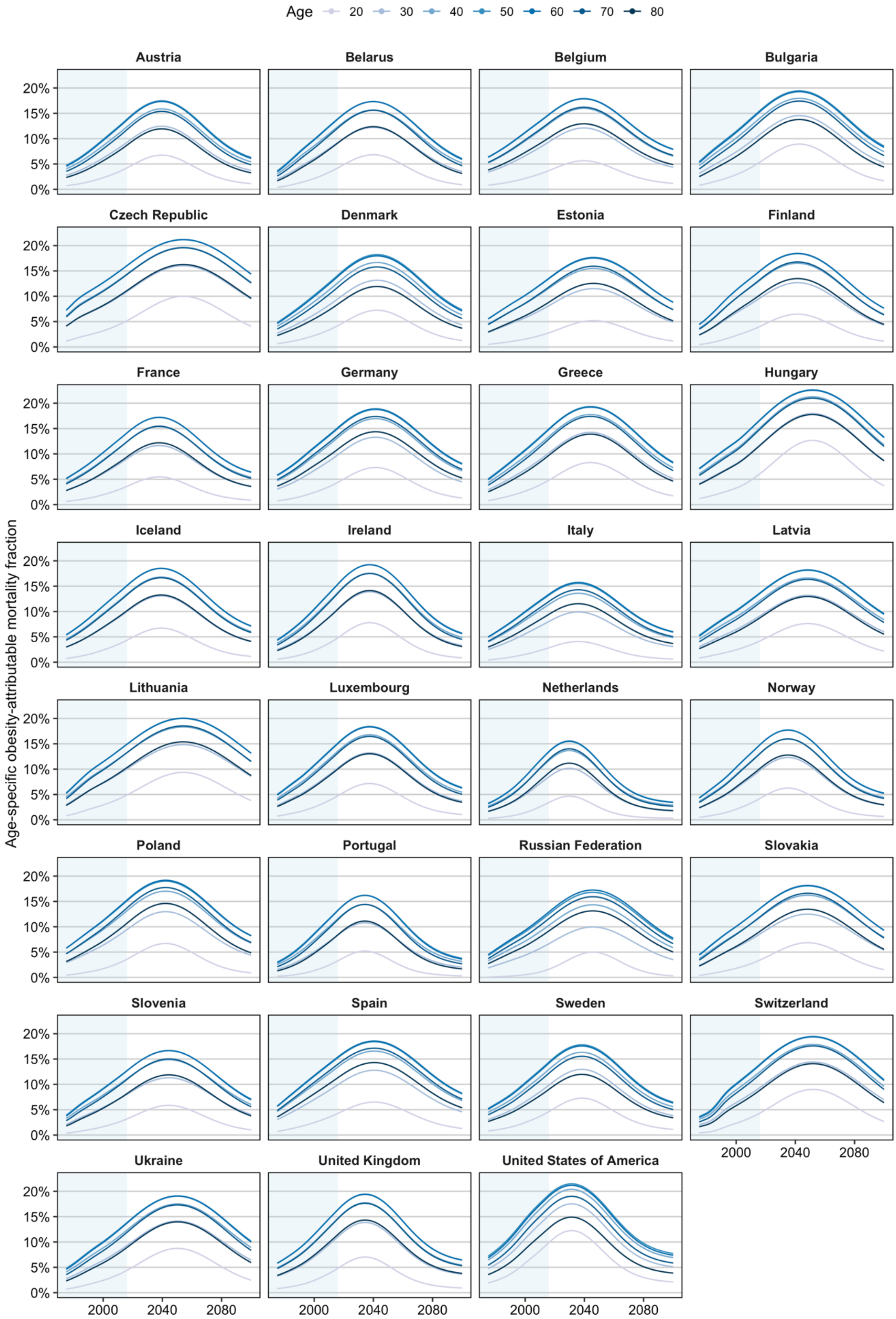
** In these populations, past obesity prevalence did not reach 20%, and therefore a maximum year could not be estimated;

*** For Russian women, age-standardised obesity prevalence in 1975 was already higher than 20%.

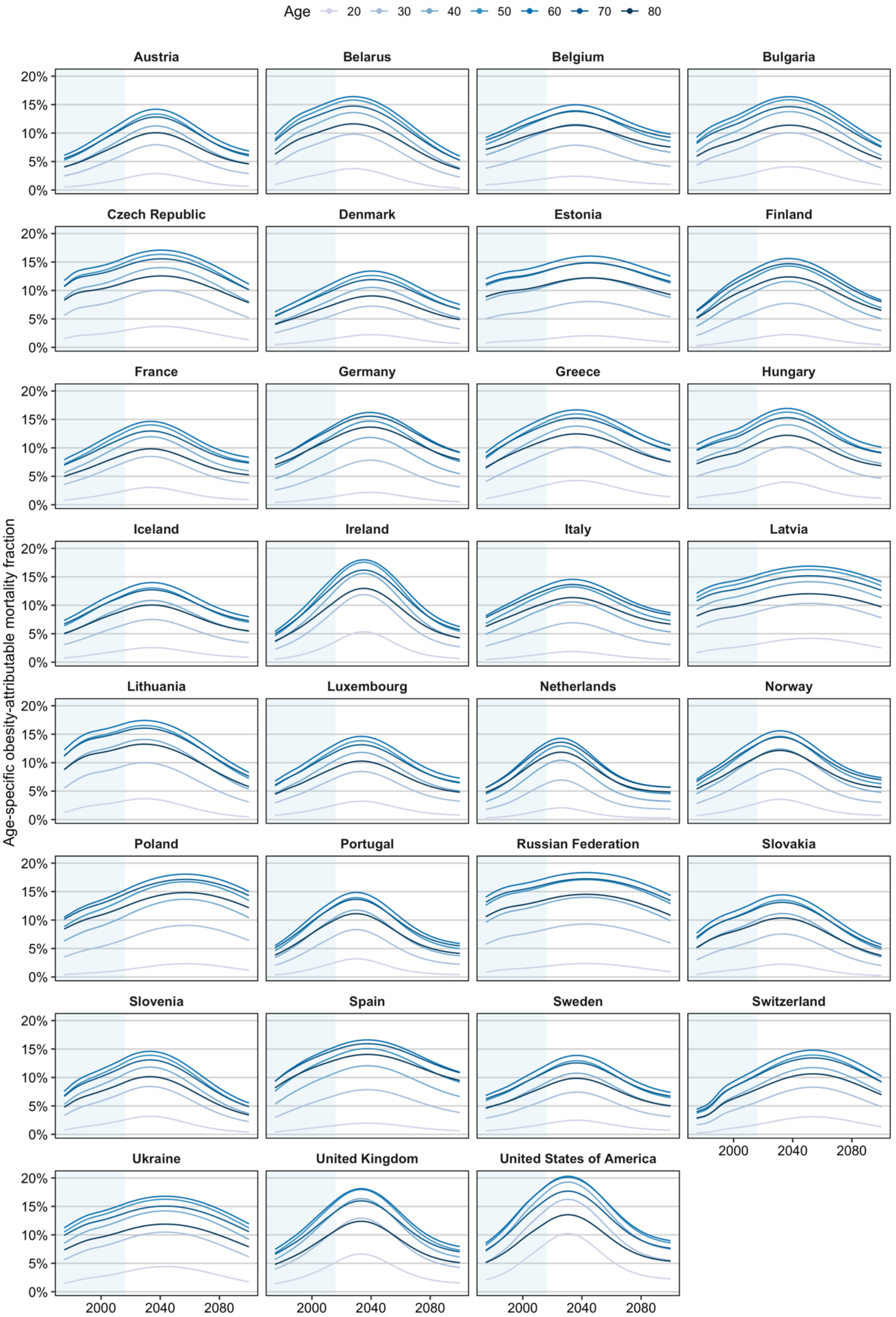
Appendix Figure 1. Past and projected age-standardized obesity prevalence (ages 20-84) and 95% projection intervals, 30 European countries and the USA, 1975-2100, by sex



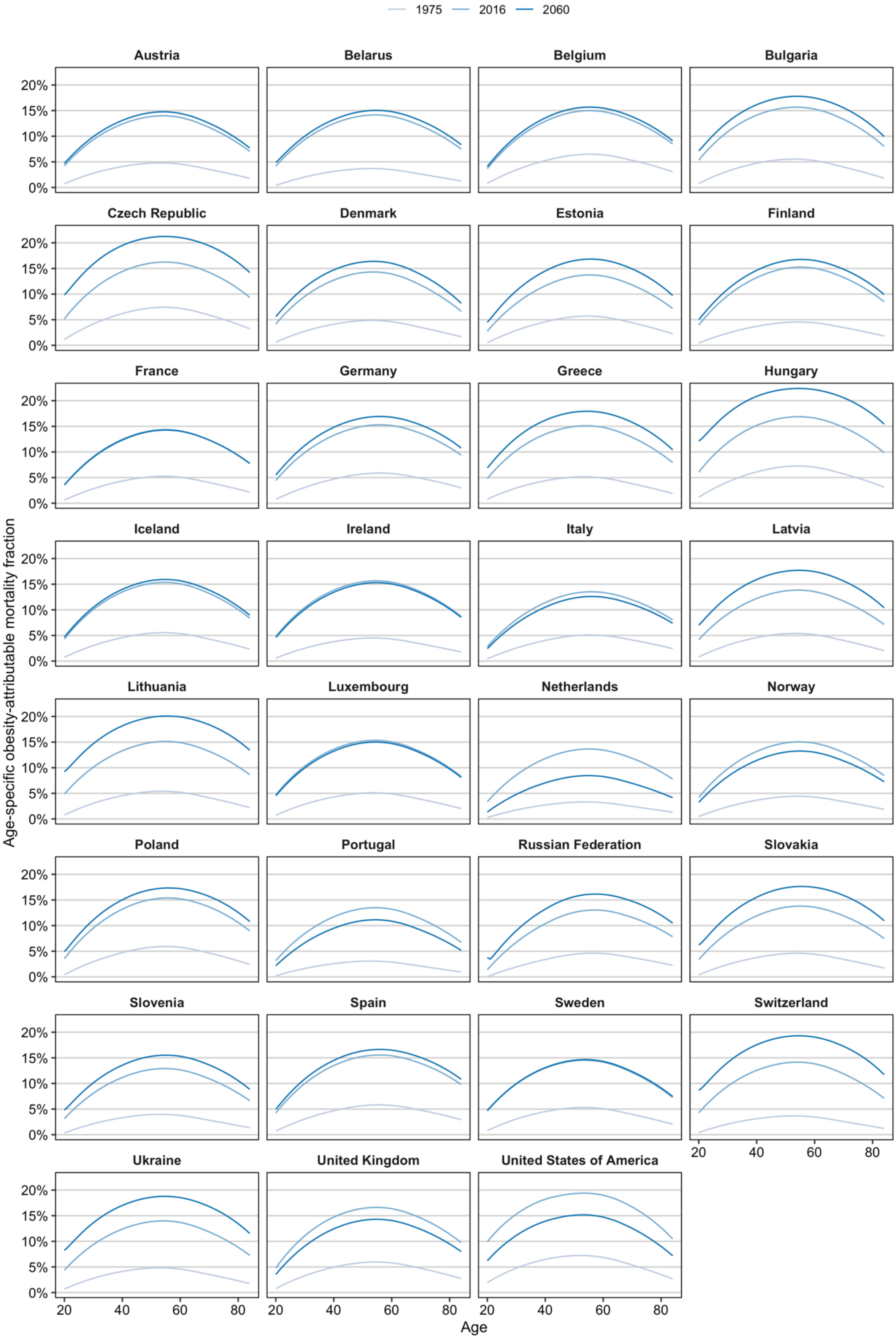
Appendix Figure 2a. Estimated and projected age-specific obesity-attributable mortality fractions (OAMF), 1975-2100, 30 European countries and the USA, by country, men, selected ages (20, 30, 40, 50, 60, 70, 80)



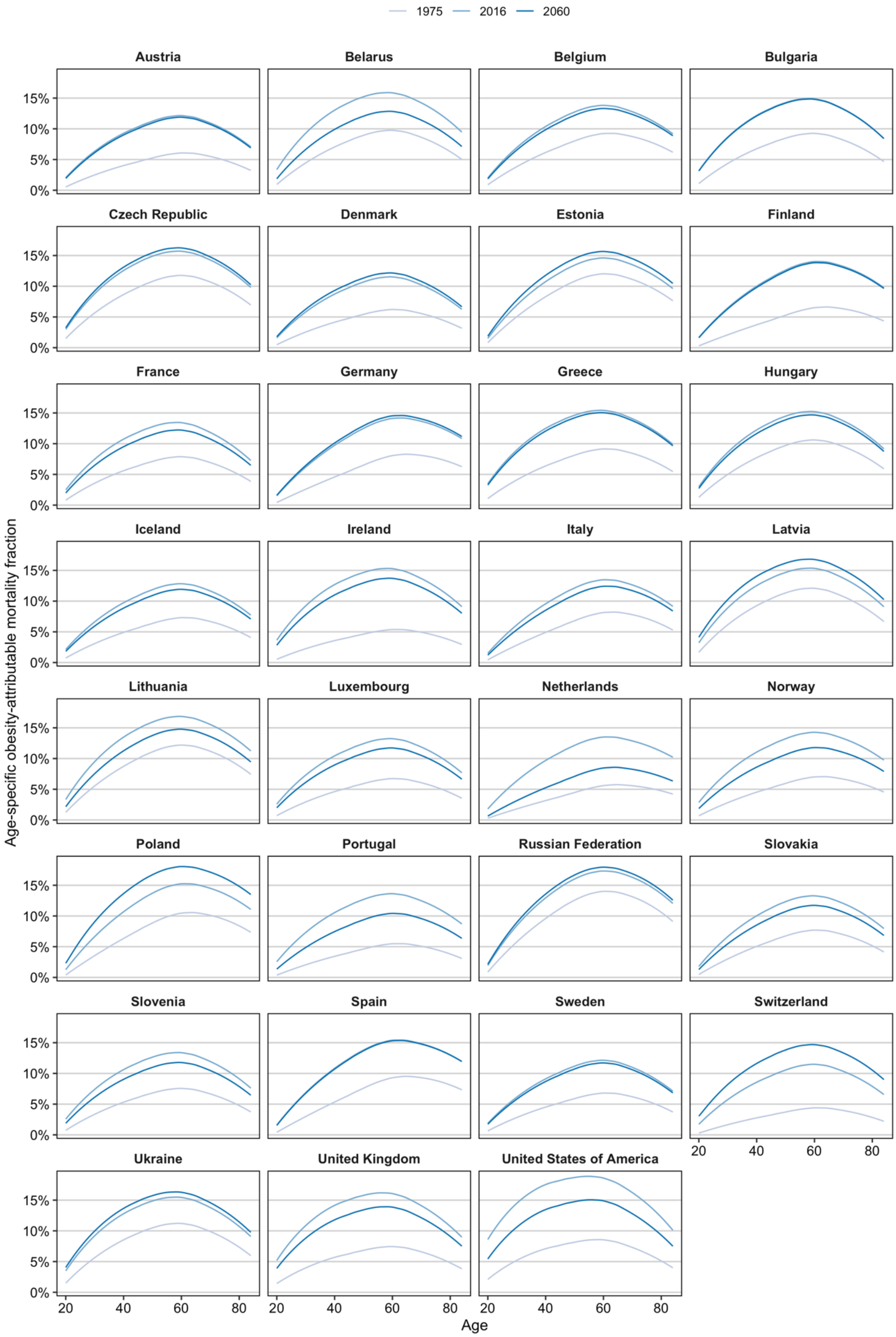
Appendix Figure 2b. Estimated and projected age-specific obesity-attributable mortality fractions (OAMF), 1975-2100, 30 European countries and the USA, by country, men, selected ages (20, 30, 40, 50, 60, 70, 80)



Appendix Figure 3a. Past, current, and future age patterns of the obesity-attributable mortality fractions, selected years 1975-2100 (1975, 2016, 2060), 30 European countries and the USA, by country, men, 20-84



Appendix Figure 3b. Past, current, and future age patterns of the obesity-attributable mortality fractions, selected years 1975-2100 (1975, 2016, 2060), 30 European countries and the USA, by country, women, 20-84



Obesity is considered an important public health challenge in Europe. Largely unknown is however how obesity prevalence, and – particularly – obesity-attributable mortality will likely evolve in the long-term future.
We project obesity-attributable mortality into the long-term future using the underlying epidemic wave pattern for 30 European countries.
We used national obesity prevalence estimates, by sex and age (20-84), for the years 1975 up to 2016, from the NCD Risk Factor Collaboration Study 2017. Obesity prevalence is projected by applying the age-period Lee-Carter model to the transformed logit of prevalence, and by linearly extrapolating the speed of change from 2000 onwards (from 1980 onwards for Eastern European women). Through the application of the population-attributable fraction formula – using age- and sex-specific RRs from a meta-review - we obtained the associated past and future age- and sex-specific obesity-attributable mortality fractions (OAMF). We obtained all-age estimates of OAMF through direct standardisation.
We project that, for the 18 Western European countries, on average, age-standardised obesity-attributable mortality (20-84) will increase from 11.7% in 2016 to 15.0% in 2039 among men, and from 11.1% in 2016 to 12.5% in 2036 among women. For the 12 Eastern European countries, obesity-attributable mortality is expected to increase, on average from 12.1% in 2016 to 16.6% in 2047 among men, and from 12.4% in 2016 to 13.7% in 2040 among women. Subsequently, obesity-attributable mortality is projected to decline, and expected to reach in 2060 average levels of 12.0% (men) and 10.3% (women) in Western Europe, and 15.6% (men) and 12.3% (women) in Eastern Europe. Thus, by applying our projection model to the NCD-RisC 2017 obesity prevalence estimates we project that, on average, around 2040 the share of mortality due to obesity will have reached its maximum at 14.3%, for the 30 European countries included in our analysis.

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