European Agency for Safety and Health at Work

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The value of occupational safety and health and the societal costs of work-related injuries and diseases

European Risk Observatory
Literature Review

European Agency for Safety and Health at Work

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Executive summary

The need to improve working life in the European Union (EU) is still urgent today. In 2016, approximately 2.4 million non-fatal accidents requiring at least 4 days of absence from work and 3,182 fatal accidents were reported in EU Member States. In addition to these accident rates, figures from 2013 show that 7.9 % of the workforce suffered from occupational health problems, of which 36 % resulted in absence from work for at least 4 days (Eurostat, 2018a, 2018c).

These occupational injuries, diseases and deaths result in high economic costs to individuals, employers, governments and society. Negative effects may include costly early retirement, the loss of skilled staff, absenteeism as well as presenteeism (when employees go to work despite illness, increasing the likelihood of mistakes) and high medical costs and insurance premiums. In a previous project, the European Agency for Safety and Health at Work (EU-OSHA) estimated that 3.9 % of global gross domestic product (GDP) and 3.3 % of European GDP is spent on dealing with occupational injuries and diseases (EU-OSHA, 2017a). This percentage may vary widely between countries, in particular between western and non-western countries, depending on the industrial mix, legislative context and prevention incentives.

Understanding the magnitude of the problem calls for a reliable and comprehensive estimate of occupational injury and disease costs to society. It is vital for policy-makers to be aware of these costs to help them to set priorities. Insight into the financial consequences of occupational injury and disease provides governments, policy-makers and employers' organisations with relevant data for the purpose of developing occupational safety and health (OSH) policies and agreements. Moreover, insight into these costs will help to raise awareness of the magnitude of the problem and will contribute to a more efficient allocation of resources for OSH.

Earlier attempts have been made to estimate the financial burden of occupational injuries and diseases. Often, they are limited to one or more diseases, or to the consequences of a specific type of exposure. Only a few studies address the full burden of occupational diseases. EU-OSHA decided to address this large research gap in the field of OSH and initiated a project to estimate the costs of occupational injuries, diseases and deaths at a European level. The project involved a two-stage approach. The first stage started in 2015 and resulted in an overview of the availability and quality of the national and international data sources required for the development of cost estimation at a European level. It was concluded that in many countries the available data sources were insufficient for a reliable estimation of the economic burden of occupational injury and disease. However, in some countries the availability appears to be reasonably sound and may be sufficient to carry out a cautious estimation (EU-OSHA, 2017b). This was carried out in the second stage of the project, which is described in this report. The objective of this project was:

to estimate the cost of work-related injuries, diseases and deaths for five countries out of the EU-28 countries, Norway and Iceland.

For the country selection, the following criteria were taken into account:

- data availability and quality;
- geographical coverage;
- main type of industry (services, industry, agriculture);
- insurance system (healthcare, social security).

The first criterion is the most important; data of sufficient quality must be available to enable the estimation of economic burden. Since we also wanted to represent the diversity of countries in the EU, we took into account three other criteria: geographical coverage, economic structure (dominant industry types) and the national insurance system. For geographical coverage, we distinguished between 'north', 'west', 'central' and 'south'. For economic structure, we distinguished between countries with a higher or lower percentage of people employed in services than the EU average (= 73.1 %). For insurance system, we distinguish between Beveridgean, Bismarckian and mixed systems. Table 1 presents the final country selection.

Table 1: Selected countries and their characteristics

Countries	Data availability/quality ([a])	Geographical location	Insurance system ([a])	% employed in services ([b])
Finland	Good	North	Mixed	73.1
Germany	Good but no friction costs	West	Bismarckian	73.9
The Netherlands	Good	West	Bismarckian	82.9
Italy	Good, limited on friction costs	South	Beveridgean	72.4
Poland	Good but no friction costs	Central	Bismarckian	58.3

([a]) EU-OSHA (2017b).; ([b]) Labour Force Survey 2015 (Eurostat).

Injuries, diseases and deaths are associated with different sorts of costs. First, there are direct costs, such as healthcare costs. Next, there are costs associated with productivity and output losses. In addition, there are costs associated with the impact on human well-being, that is, the impact on people's lives and health, that can be quantified and included in the burden estimate. In each case of occupational injury or disease, these elements are involved and the sum of the costs of all cases would produce an estimate of the total occupational burden of injury and disease. This way of arriving at a cost estimation is often known as a '*bottom-up approach*', building up from the individual components of costs to total costs.

In addition to a bottom-up approach, it is also possible to take a '*top-down*' approach. In such an approach, total costs are estimated by considering the total burden of injury and disease, and estimating the fraction that was caused by occupational factors. Subsequently, the costs associated with this occupational burden of injury and disease can be estimated. These costs are often expressed in terms of existing measure of overall health burden, such as disability-adjusted life years (DALYs) or quality-adjusted life years (QALYs) [1].

In the present study, both approaches are taken. A bottom-up model is built, taking into account direct costs, indirect costs and intangible costs (life and health impacts), and a top-down model is also built, based on the monetary value of 1 DALY. For both models, 2015 was used as the reference year, to enable the comparability of data across countries and between approaches.

Bottom-up model

The first step of the bottom-up approach is the estimation of the numbers of occupational injury cases and occupational disease cases, which is quite a challenge due to the high rates of underreporting associated with most data sources. Several sources served as input for the estimation. The estimation of the count of occupational injuries was based on European Statistics on Accidents at Work (ESAW) 2015, while the severity distribution (number of workdays lost) was based on the Labour Force Survey (LFS) 2013 ad hoc module. In some countries (in this study, Italy and Poland), a very high rate of underreporting was assumed, in particular for cases of non-fatal injuries. For those countries, we estimated the number of non-fatal cases based on the fatal to non-fatal ratio from countries where we expected more reliable data on non-fatal cases. Probably the reporting rate differs between countries mainly because of different social insurance systems that provide either incentives or disincentives for reporting through compensation regulation.

For the estimation of numbers of non-fatal occupational disease cases, different data sources were consulted leading to different scenarios for case counts. In the baseline scenario, we started with the count of compensated (accepted, recognised) and non-compensated (suspected) non-fatal cases for each country for most types of diseases, with the following exceptions: cancers, circulatory diseases,

[1] QALYs are a measure of years lived in perfect health gained whereas DALYs are a measure of years in perfect health lost.

respiratory diseases and musculoskeletal diseases, for which we estimated case counts from the database of the Global Burden of Disease (GBD) Study as registered by the Institute for Health Metrics and Evaluation (IHME), and used the attributable fractions derived from this database. We also defined a low-limit scenario (that is, compensated cases only), and a high-limit scenario (that is, all types of occupational disease estimated using attributable fractions). Data from the LFS 2013 ad hoc module (Eurostat, 2018b) were used to estimate the distribution of the non-fatal occupational disease cases by age, as well as severity (number of workdays lost). Finally, the estimation of the number of fatal occupational disease cases was also based on the IHME database and attributable fractions derived from this database. The figures presented in this summary are based on the baseline scenario.

In the model, three high-level cost categories were considered: *direct costs*, *indirect costs* and *intangible costs*. Direct costs include all healthcare-related products and services, whether paid for by the public sector, insurer, employer, worker or other stakeholder. We focused on four direct cost items: 1) healthcare costs paid for by the public sector/insurer; 2) public sector/insurer administration/overhead costs; 3) informal caregiving time from family and community; and 4) worker out-of-pocket costs for healthcare products and services, including costs associated with seeking care. We estimated six key subcomponents of indirect costs: 1) market output losses due to absenteeism and reduced work ability associated with permanent impairment; 2) payroll/fringe benefits associated with wages and salaries; 3) employer adjustment costs; 4) insurance administration costs associated with disability insurance/workers' compensation; 5) home production losses; and 6) presenteeism associated with paid employment activity. Finally, intangible costs refer to losses associated with health-related quality of life. Health-related quality of life is estimated in terms of quality-adjusted life years (QALYs) and then monetised.

The cost estimations began with incidence counts (cases) of work-related injuries and diseases to estimate the total costs in a particular cost category, which were then multiplied by the costs of the resources associated with the work-related injury or disease or a price weight, if the resources are measured in non-monetary units (for example months lost from paid employment due to work disability). Incidence counts have been stratified by sex, age bracket, type of injury (high-level ESAW categories) and severity (based on days absent from work). A representation of the formula is as follows:

Total (sub)category costs for a stratum = number of cases in the stratum × per case cost for the stratum

The results are presented below. Table 2 shows the estimation of the number of cases in each country and Table 3 presents the estimates of the costs. Finally, Table 4 presents the economic burden of occupational injury and disease by stakeholder.

Table 2: Estimation of numbers of cases of occupational injuries and diseases (2015 or closest year available)

	Occupational injuries		Occupational diseases	
Countries	**Non-fatal (a) (> 1 workday**	**Fatal (a)**	**Non-fatal (b)(c)**	**Fatal (b)**
Finland	63,407	35	67,795	628
Germany	1,158,865	450	1,088,793	13,924
The	99,880	35	220,368	3,262
Italy	1,257,987	543	638,448	10,524
Poland	697,337	301	454,090	4,663

(a) ESAW 2015 (the non-fatal cases in Poland and Italy are adjusted based on the fatal to non-fatal ratio). To estimate the number of non-fatal cases with 1-3 workdays lost, the severity distribution of the LFS 2013 was applied.

(b) IHME (2016).

(c) National sources: Finland — Finnish Institute of Occupational Health (2012); Germany — DGUV (2013); the Netherlands — NCvB statistiek (2015); Italy — Banche dati static (2015); Poland — Choroby Zawodowe W Polsce W (2014), in Szeszenia-Dąbrowska and Wilczyńska (2016).

Table 3: Estimated total economic burden for occupational injuries and diseases (2015)

Country		Finland	Germany	The Netherlands	Italy	Poland
Number of cases		131,867	2,262,031	323,544	1,907,504	1,156,394
Direct costs	In million EUR	484	10,914	2,137	8,491	1,882
Direct cost, % total		8	10	9	8	4
Indirect costs	In million EUR	4,362	70,658	6,468	58,961	19,588
Indirect cost, % total		72	66	69	56	45
Intangible costs	In million EUR	1,196	25,557	5,147	37,392	22,311
Intangible cost, % total		20	24	22	36	51
Total economic burden	In million EUR	6,042	107,129	23,751	104,844	43,781
Percentage of GDP		2.9	3.5	3.5	6.3	10.2
Per case cost	In million EUR	45,816	47,360	73,410	54,964	37,860
Per employed person	In million EUR	2,479	2,664	2,855	4,667	2,722
GDP per employed person	In million EUR	86,016	75,692	82,159	73,565	26,738

Table 4: Economic burden of occupational injury and disease distribution by stakeholder

Country	Employer		Worker		System/society	
	In million EUR	%	In million EUR	%	In million EUR	%
Finland	1,325	22	3,800	63	916	15
Germany	21,534	20	64,813	61	20,782	19
The Netherlands	3,484	15	17,235	73	3,032	13
Italy	20,632	20	70,391	67	13,821	13
Poland	5,007	11	34,421	79	4,353	10

Top-down model

The top-down model in the present study is based on DALYs, that is, disability-adjusted life years. The DALY is a measure of overall disease burden, expressed as the number of healthy years lost due to early death or due to living with ill health. DALYs are calculated by disease category and are the sum of life years lost due to premature mortality and 'healthy' life years lost due to disability. The latter is calculated by multiplying the number of cases by duration and the disease-specific disability weight. A disability weight is a weighting factor that reflects the severity of the disease on a scale from 0 (perfect health) to 1 (equivalent to death). The baseline variant in the present study is based on DALYs by cause, sex, age and country taken from the World Health Organization (WHO) Global Health Estimates: Global burden of disease estimates 2000-2016, as published by the WHO Department of Information, Evidence and Research in June 2018 (WHO, 2018a).

To determine the economic burden of occupational injury and disease, it is necessary to estimate which part of the total burden is caused by occupational exposures. Therefore, it is necessary to estimate the attributable fraction by injury/disease category, that is, the fraction of cases caused by occupational exposures. Since many diseases are not caused by, or at the most are only partly caused by, work exposures, we included some diseases at a higher level of aggregation than others in the assessment of the attributable fraction. In the present study, we used attributable fractions that were derived from the 2015 Global Burden of Disease (GBD) Study (IHME, 2016). In the 2015 GBD Study, risk factors were included, as well as an estimation of disease burden attributable to risk factors, including occupational risk factors (IHME, 2016). From these data, it was possible to deduce the attributable fraction by comparing the number of DALYsoccupational risks x cause with the total number of $DALYs_{cause}$ (year 2016 data). In the final step of our cost estimation model, we assigned a monetary value to DALYs. The value of DALYs lost to occupational exposure represents the economic burden of occupational injury and disease.

In the literature, three broad methodological approaches to estimating the monetary value of 1 DALY can be identified: 1) the human capital approach, 2) the willingness-to-pay (WTP) approach and 3) the value of a statistical life year (VSLY) approach. In the human capital approach, the monetary value of 1 DALY is based on the loss of economic productivity due to ill health, disability or premature mortality. A drawback of the human capital monetisation approach is that only part of an individual's welfare is measured. Life beyond paid work is not valued. Theoretically, the two other monetisation approaches considered in this report, the WTP and the VSLY approaches, do include valuations for broader aspects of life. The WTP approach is based on the preferences of survey respondents to pay for health gains. The value of statistical life (VSL) represents a total monetary value of an average adult towards the life expectancy age; hence, it is a value for the total remaining lifetime of an average person in case of no accident or illness, which in fact is often also obtained with WTP surveys. The drawback of both the WTP and the VSLY approaches is that values are based on surveys and valuation methods that are highly sensitive to the questions asked. As a result of the sensitivity to the methods used, the variance in values found across studies is quite wide. Variance in values is also wide in the human capital approach. For example, according to the recommendations of the WHO Commission on Macroeconomics and Health, the monetary indicator varies between one time GDP per capita and three times GDP per capita (Harvard School of Public Health and World Economic Forum, 2011).

In conclusion, within each monetisation approach, the range of monetary values found in the literature was wide. Therefore, we worked with the minimum, mean, median and maximum of these values in our models. Table 5 contains the results based on the top-down approach by country, according to different monetisation approaches.

Table 5: Estimation of the total costs by country according to the central scenario

	Germany	Finland	Italy	The Netherlands	Poland
DALYs					
Total occupational DALYs	1,236.855	64,516	853,817	248,464	507,068

	Germany	Finland	Italy	The Netherlands	Poland
Percentage of total DALYs	4.9	4.2	5.1	5.7	4.0
Occupational DALYs per 10,000 employed persons	308	265	380	299	315

	Million EUR	% of GDP	Million EUR	% of GDP	Million EUR	% of GDP	Million EUR	% of GDP	Million EUR	% of GDP
COSTS										
Human capital approach										
Minimum	24,597	0.8	1,419	0.7	13,530	0.8	5,290	0.8	2,692	0.6
Average	55,429	1.8	3,106	1.5	31,475	1.9	11,879	1.7	6,929	1.6
Median	39,712	1.3	2,291	1.1	23,865	1.4	8,708	1.3	4,656	1.1
Maximum	138,404	4.5	7,393	3.5	69,671	4.2	30,114	4.4	17,037	4.0
WTP approach										
Minimum	32,324	1.1	1,637	0.8	20,929	1.3	3,276	0.5	5,118	1.2
Average	66,251	2.2	5,814	2.8	42,895	2.6	14,613	2.1	9,676	2.3
Median ([a])	66,251	2.2	4,335	2.1	42,895	2.6	13,953	2.0	8,863	2.1
Maximum	100,177	3.3	17,453	8.3	64,861	3.9	30,767	4.5	15,861	3.7
VSLY/VOLY approach										
Minimum	60,609	2.0	4,214	2.0	52,304	3.2	9,649	1.4	12,790	3.0
Average	191,939	6.3	9,345	4.5	133,789	8.1	38,016	5.6	43,836	10.2
Median	166,943	5.5	8,633	4.1	126,876	7.7	33,248	4.9	31,026	7.2
Maximum	420,489	13.8	19,425	9.3	256,120	15.5	77,016	11.3	119,149	27.7

([a]) Median and average WTP approach values are the same for Germany and Italy because, for these two countries, we could include only two European central reference values, hence the minimum and maximum values as reported in the table.

Results of both models compared

In the bottom-up model, the total estimated economic burden of work-related injuries and diseases — including fatal and non-fatal cases — ranges from 2.9 % of GDP in Finland to 10.2 % in Poland. In the top-down model, the economic burden is highly dependent on the monetisation approach used. In the human capital approach, the work-related economic burden varies from 0.6 % to 4.5 %, dependent on the monetisation method, with less variance among countries. In the WTP approach, percentages are higher and vary from 0.5 % to 8.3%. The VSLY approach yields the highest values, with estimates of the economic burden of occupational injury and disease at 1.4 % of GDP at the minimum and 27.7 % at the maximum. In this approach, variance among countries is also higher. The approach that comes closest to the results of the bottom-up approach is the VSLY approach if we consider the average or median value of the different studies. In addition, the rank ordering of countries in terms of magnitude of economic burden relative to their GDP is similar to that derived from the bottom-up model, with the highest value for Poland (average 10.2 % and median 7.2 % of GDP) and the lowest value for Finland (average 4.5 % and median 4.1 % of GDP). The similarity between the VSLY approach in the top-down model and the bottom-up model may be explained by the inclusion of health and life impacts in the VSLY approach. Health and life impacts, described as ‘intangible costs’ in the bottom-up approach, are a substantial part of the total costs in the bottom-up model, varying from 20 % to almost 51 %.

In comparing the outcomes of the two cost estimation models, it is important to realise that they do not estimate identical phenomena. Although they were both used to provide estimates of the economic burden of occupational injury and disease, the components of these models are very different. The bottom-up model provides more detailed information for policy-makers, such as direct, indirect and intangible costs, as well as costs by stakeholder. However, the top-down model has the advantages that far less time is needed to construct the model, and country and regional comparisons are easier since internationally harmonised sources can be used.

Country comparison

In comparing the countries, we see in most scenarios that the economic burden of occupational injury and disease is relatively high in Poland and Italy, compared with Germany, Finland and the Netherlands. In Poland, at least part of this may be explained by the sector structure. The workforce in Poland consists of a relatively high number of people working in agriculture or industry. Although the percentage of people working in industry in Italy is above average, the explanation for the relatively high burden is less clear than in Poland. The relatively high burden is partly attributable to the number of DALYs lost to occupational lung cancer. However, the main difference from the other countries under study is the number of DALYs lost to injuries, ‘unintentional injuries’ as well as ‘transport injuries’.

Implications for future projects

In this project on the economic burden of occupational injury and disease, countries were selected based on the expectation that they had sufficient data of good quality to enable an estimation to be made. However, data were often lacking, the quality of data was poor and alternative sources had to be explored to allow a reasonable estimation. In particular, for the bottom-up model, which consists of several components, the search for appropriate data was quite a challenge, particularly for formal healthcare costs. Therefore, the first step to enable a cost estimation of this sort in all European countries would be to build up and harmonise the data collected. There are a number of issues to be considered in order to achieve this. First, the count of occupational injuries and diseases should be improved for all economic burden estimation models, whether they are inputs for a bottom-up approach or used to estimate DALYs. In the present project, it was not possible to base the bottom-up model on incident cases of occupational diseases from country reporting. However, data on the cases of injuries and diseases has to come from somewhere for both the top-down and bottom-up models, ideally from reliable, country-specific sources so that meaningful cross-country comparisons can be made. If they are approximated through generic, international sources, then cross-country comparison is less meaningful for both models. Moreover, country-specific data on the healthcare costs of injuries and diseases appeared to be very difficult to obtain. Finally, it would be helpful to come to a consensus on the way to value life and health impacts for both the top-down and bottom-up models.

1. Introduction

1.1 Background

The European Agency for Safety and Health at Work (EU-OSHA) aims to contribute to the improvement of working life in the European Union (EU). Its mission is to develop, gather and provide reliable and relevant information, analysis and tools to advance knowledge, raise awareness and exchange occupational safety and health (OSH) information and good practice that will serve the needs of those involved in OSH. Further development of OSH policies and improving existing measures are essential in achieving safe and healthy workplaces.

The need to improve working life in the EU is still urgent. In 2016, approximately 2.4 million non-fatal work-related injuries requiring at least 4 days of absence from work and 3,182 fatal accidents were reported in EU Member States. The incidence of fatal work-related injuries varies among Member States. In 2016, incidence rates per 100,000 workers ranged from 1.0 or less in the United Kingdom and the Netherlands to over 4.0 in Romania, Latvia and Estonia. With regard to non-fatal work-related injuries, incidence rates range from less than 100 per 100,000 people employed in Bulgaria and Romania to over 3,000 per 100,000 in France. In addition to these injury rates, figures from 2013 show that 7.9 % of the workforce suffered from work-related health problems, of which 36 % resulted in absence from work for at least 4 days (Eurostat, 2018a).

These work-related injuries and diseases result in high economic costs to individuals, employers and system/society. Negative effects may include costly early retirement, the loss of skilled staff, absenteeism as well as presenteeism (when employees go to work despite feeling ill, increasing the likelihood of mistakes), and high medical costs and insurance premiums. Several estimates of the financial consequences of work-related injuries and health problems have been made. In a previous project, EU-OSHA estimated that 3.9 % of global gross domestic product (GDP) and 3.3 % of European GDP is spent on dealing with work-related injuries and diseases (EU-OSHA, 2017a). This percentage may vary widely among countries, in particular between western and non-western countries and depending on the working conditions in the country. At the national level, the United Kingdom estimated the financial impact of work-related injuries and diseases to amount to GBP 14 billion (EUR 16.21 billion as at 16 April 2019, HSE, ND), which is 0.8 % of its GDP, however, excluding long-term diseases such as cancer. In the Netherlands, direct medical costs (EUR 76 million) and absenteeism (EUR 200 million) are estimated to amount to EUR 276 million (Bakhuys Roozeboom et al., 2011). It could be argued, then, that not only these direct costs (for example healthcare costs) and indirect costs (costs associated with sick leave, productivity loss) should be included, but also the impact that these diseases have on the well-being of workers and their families.

In conclusion, the magnitude of the work-related burden of disease is large and results in considerable costs. Adequate policies aimed at reducing work-related injuries and diseases are needed. Therefore, a reliable and comprehensive estimate of these costs is required. It is vital for policy-makers to be aware of these costs to help them set priorities. Insight into the financial consequences of work-related injuries and diseases provides governments, policy-makers and employers' organisations with relevant data for the purpose of developing OSH policies and agreements. Moreover, insight into these costs will help to raise awareness of the magnitude of the problem and will contribute to a more efficient allocation of resources for OSH.

1.2 Objective of the study

Earlier attempts have been made to estimate the financial burden of work-related injuries and diseases. Often, they are limited to one or more diseases. For example, in 2016 a research report was issued by the Health and Safety Executive (HSE) in the United Kingdom: *Costs to Britain of work-related cancer* (Zand et al., 2016). Some studies are limited to the consequences of a specific type of exposure. A recent example is the study of Tompa et al. (2017) on the economic burden caused by asbestos exposure. Only a few studies address the full burden of work-related disease. An example is Leigh (2011), who carried out a study on the economic burden of work-related injury and disease in the United States. Another example is a study from Safe Work Australia (2015) on the cost of work-related injury and disease in Australia. In 2017, EU-OSHA carried out an international comparison of the cost of work-related injuries and diseases, covering all WHO world regions and the EU member countries (EU-OSHA, 2017a).

Most previous studies have not addressed all work-related injuries and diseases. This is a challenging task, since it requires analyses of far more data sources than for single disease estimates or single risk factor estimates (Leigh, 2011). A cost estimation in Europe is an even bigger challenge, since not all data sources are available at the European level and, even if they are, the data are not always well harmonised and differences in sampling or in cultural values may hinder international comparisons (Venema et al., 2009; Agilis, 2015). Another challenge in estimating the costs of the work-related burden of disease is assigning values to the life and health impacts. If we do not value them, policy-makers might overlook them, and they will be assigned zero weight in any trade-offs.

EU-OSHA decided to address this large research gap in the field of OSH and initiated a project to estimate the costs of work-related injuries and diseases at the European level. The project involved a two-stage approach. The first stage started in 2015 and resulted in an overview of the availability and quality of the national and international data sources required for the development of a cost estimation model at the European level. It was concluded that in many countries the available data sources were insufficient for a reliable estimation of the work-related burden of disease. However, in some countries the availability appeared reasonably sound and potentially sufficient to carry out a cautious cost estimation (EU-OSHA, 2017b). This was carried out in the second stage of the project, which is described in this report. The objective of this project was *to estimate the cost of work-related injuries and diseases for five countries out of the EU-28 countries, Norway and Iceland*. In the estimation of costs, the following aspects were considered:

- apart from pure financial costs, it is important to value life and health impacts;
- different cost bearers should be distinguished: employers, workers and their families, and system/society at large;
- to enable prevention measures, it is important to differentiate between sectors and between causes of injuries and diseases;
- methodology should be fully transparent and reproducible.

1.3 Approach

1.3.1 Country selection

Although EU-OSHA's final objective was in principle to estimate the cost of work-related injuries and diseases for all countries in the EU-28 plus Norway and Iceland, the present project was limited to five countries. This pragmatic approach was taken because it was expected that not all countries would have sufficient data available. Therefore, the present project can also be considered a pilot study in which the feasibility of undertaking an estimation of the total costs for the EU-28 plus Norway and Iceland is explored. The following criteria were taken into account in the country selection:

- data availability and quality;
- geographical coverage;
- main type of industry (services, industry, agriculture);
- insurance system (healthcare, social security).

The first criterion is the most important: sufficient data of sufficient quality must be available to enable the cost estimation. Since we also wanted to represent the diversity of countries in the EU, we also took the three other criteria into account: geographical coverage, economic structure (dominant industry types) and the national insurance system. For geographical coverage, we distinguished between 'north', 'west', 'central' and 'south'. Another assumption we made is that the total burden of work-related disease will be higher in countries with a higher percentage of the workforce employed in industry and agriculture than in countries with a high percentage employed in services. Therefore, we distinguished between countries with a higher percentage employed in services than the EU average and those with a lower percentage employed in services than the EU average. Finally, we assumed that the national insurance system related to healthcare and social security may affect the costs of the work-related burden of disease, in particular the cost bearers. In Europe, two main systems prevail: the Bismarckian system and the Beveridgean system. In the Bismarckian system, healthcare is financed by insurance, while, in the Beveridgean system, healthcare is financed by taxes. Some European countries have mixed systems. We distinguish between Beveridgean, Bismarckian and mixed systems. Appendix 1 contains each country's characteristics in terms of these criteria.

The quality assessment was carried out in two steps. First, a preliminary assessment was done based on the conclusions of the previous phase of the project (EU-OSHA, 2017b). Since no data were collected at this stage, quality assessment was based on the available documentation of the databases. For all countries under study, we checked the availability and quality of sources on work-related injuries and diseases. With regard to costs, we checked the main cost categories: healthcare costs and productivity costs (wages but also bonuses and employers' social security contributions) and friction costs (for example recruitment and rehabilitation costs). For intangible costs (life and health impacts), it was already clear that no sufficient country-specific data were available and that we had to rely, at least partly, on international figures. Based on this information and the diversity criteria, we selected a long list of seven countries.

In the second step of the quality assessment, more information was gathered on the availability and quality of the data and on the exact data needed to build the models for cost estimation. The data needs to be defined by the model builders was more specific than what was covered in the previous project. For instance, the previous project identified a number of national and international sources for total healthcare costs, but the data required for one of the models (the bottom-up model) in the present study had to be available per injury/disease case and differentiated by type of injury/disease. Therefore, we examined data sources for each of the seven pre-selected countries to verify to what extent the previously identified sources corresponded to the exact specifications of the data requirements for the present project, and to identify additional sources where necessary. The results of the two steps of the quality assessment are presented in Appendix 1. Table 1.3.1 presents the final country selection.

Table 1.3.1: Countries selected and their characteristics

Country	Data availability/quality ([a])	Geographical location	Insurance system ([a])	% employed in services ([b]) **EU average = 73.1 %**
Finland	Good	North	Mixed	73.1
Germany	Good but no friction costs	West	Bismarckian	73.9
The Netherlands	Good	West	Bismarckian	82.9
Italy	Good, limited on friction costs	South	Beveridgean	72.4
Poland	Good but no friction costs	Central	Bismarckian	58.3

([a]) EU-OSHA (2017b).

([b]) Labour Force Survey 2015 (Eurostat).

1.3.2 Two different models

Injuries and diseases are associated with different sorts of costs. First, there are direct costs, such as healthcare costs. Next, there are costs associated with losses in productivity and earning capacity. In addition, there are costs associated with the impact on human well-being, that is, the impact on people's lives and health, that should be assigned a value and included in the burden estimate. In each case of work-related injury or diseases, these elements are involved and the sum of the costs of all cases would produce an estimate of the total work-related burden of disease. This way of arriving at a cost estimation is often known as a 'bottom-up model', building up from costs per case to total costs.

In addition to a 'bottom-up' model, it is also possible to apply a 'top-down' model. In such a model, the total costs are estimated by considering the total burden of disease and estimating the fraction that was caused by work-related factors. Subsequently, the costs associated with this work-related burden of disease can be estimated. These costs are often expressed in terms of existing summary measures of health, such as disability-adjusted life years (DALYs) or quality-adjusted life years (QALYs) [2].

In the present study, both models are applied. A bottom-up model is built, taking into account direct costs, indirect costs and intangible costs (life and health impacts), and a top-down model is also built, based on the monetary value of 1 DALY.

It is important to note that the bottom-up model and the top-down model do not necessarily measure the same phenomenon from a different starting point. It should be borne in mind that in the top-down model we essentially monetise the value of a (healthy) life year lost. This includes the intrinsic value of human life which, according to welfare economic theory, goes well beyond simply accounting for lost production. For example, various intangible aspects of life, such as the value of being embedded in social relations and interacting in society, are important aspects of life to take into account in an 'all inclusive' valuation approach. An important difference from the bottom-up model is that healthcare costs are not explicitly captured in a monetary value of life years — if at all.

1.3.3 Organisation of the work

For this study, a consortium was formed consisting of employees from three organisations: TNO (the Netherlands Organisation for Applied Scientific Research), VVA (Valdani Vicari & Associati) and IWH (Institute for Work & Health). The study was divided into four tasks:

Task 1: Development of a cost calculation model based on cases of work-related injuries and diseases (bottom-up model)

Task 2: Development of a cost estimation model based on the economic value of a DALY (top-down model)

Task 3: Data collection

Task 4: Data analysis and comparison of the findings

For both models, 2015 was used as the reference year, to enable the comparison of data across countries and between approaches. A reference year later than 2015 would bring data gaps for some sources, while an earlier year might produce outdated results.

This report presents the results of the study and is structured as follows:

- Chapter 2 describes the methods and results of the bottom-up model.
- Chapter 3 describes the methods and results of the top-down model.
- Chapter 4 contains the comparison of the different models and a discussion of the results.

[2] QALYs are a measure of years lived in perfect health gained whereas DALYs are a measure of years in perfect health lost.

2 Bottom-up model

2.1 Methods: bottom-up model

The bottom-up model in the present project draws on methods synthesised from a number of studies, specifically the following: 1) a study on the economic burden of lung cancer and mesothelioma due to occupational and para-occupational asbestos exposure (Tompa et al., 2017); 2) a study on the economic burden of occupational injury and disease in the United States (Leigh, 2011); and 3) a study on the cost of work-related injury and disease for Australian employers, workers and the public sector (Safe Work Australia, 2015). These studies are all based on the bottom-up model and use incident cases of work-related injuries and diseases as the starting point, and estimate the direct, indirect and intangible costs associated with these cases. We advance the methods used in these studies in a number of ways. In particular, we have provided more specificity to issues such as the distribution of severity of work-related injuries and diseases, included estimates for presenteeism associated with both types of incidents and included health-related quality of life values. The latter was included in only Tompa et al. (2017). The sources on which our expansion of the methods were based are referenced in the details provided below.

2.1.1 Estimation of cases

- **Work-related injury cases**

Data on non-fatal work-related injury incidence for the year 2015 were derived from different data sources. The total count of injuries with more than 3 days lost was drawn from European Statistics on Accidents at Work (ESAW) in 2015, issued by Eurostat (Eurostat, 2018a). The data cover both non-fatal and fatal cases. To indicate the severity of the injuries, we distinguished between cases with more than 3 working days lost, cases with 1-3 working days lost and cases with no working days lost. Since ESAW contain only cases with more than 3 working days lost, cases with 3 or fewer days lost were estimated using the distribution of severity in the 2013 ad hoc module of the Labour Force Survey (LFS) (> 3 days lost, 1-3 days lost and 0 days lost), as indicated in Table A4a (Appendix 4; Eurostat, 2018b). The results are shown in Table 2.1.1a. For Germany and the Netherlands, no data were available in the LFS 2013 ad hoc module. To estimate the number of cases with less than 3 days lost for these countries, we used the distribution from Switzerland, as a conservative assumption. As illustrated in Table A4a, Switzerland has one of the lowest levels of reported work-related injuries resulting in sick leave, just slightly higher than the Scandinavian countries and the United Kingdom.

Table 2.1.1a: Estimation of fatal and non-fatal work-related injuries (2015)

Severity	More than 3 days lost		1-3 days lost		No days lost		Fatal cases ([b])
Country	**Per cent ([a])**	**Count ([b])**	**Per cent ([a])**	**Count ([c])**	**Per cent ([a])**	**Count ([c])**	
Finland	26	42,045	13	21,362	61	97,933	35
Germany	39	845,005	14	313,859	47	1,031,806	450
The Netherlands	39	72,829	14	27,051	47	88,928	35
Italy	76	295,156	11	42,673	13	50,538	543
Poland	84	81,850	6	6,216	10	9,363	301

Sources: ESAW 2015 and LFS 2013 (Eurostat).

([a]) Persons reporting an accident at work resulting in sick leave by period off work [hsw_ac3] (2013). Accidents at work and other work-related health problems (source LFS), Eurostat (2018b).

([b]) ESAW fatal and non-fatal accidents at work, by sex, age groups, injury groups and NACE Rev. 2 economic sectors [hsw_mi07] (2015), Eurostat (2018a).

(c) Calculated number using the percentage based on the LFS and the count from ESAW.

In Table 2.1.1b, the ratio of fatal to non-fatal injuries is presented. Non-fatal injuries with no workdays lost were excluded in the baseline and only used for sensitivity analysis. The table shows a more or less similar ratio in Finland, Germany and the Netherlands, but a much higher ratio (relatively more fatal cases) in Italy and Poland. These higher ratios are probably an indication of a high rate of underreporting of non-fatal injuries (Kurppa, 2015). Presumably the reporting rate differs between countries mainly because of different social insurance systems that provide either incentives or disincentives for reporting through compensation regulation. Kurppa calculated a coefficient ratio of fatal to non-fatal injuries. In the EU-15, 4,011 fatal and 4,048,491 registered non-fatal work injuries occurred in 2005. Thus, for each fatality there were 1,009 registered non-fatal work injuries. Using this ratio, non-fatal injuries in Italy and Poland are not within the range. To address this issue, we used the ratio of fatal to non-fatal injuries for Germany (39) as a baseline ratio to adjust the non-fatal injury case counts for Poland and Italy. We then ran a sensitivity analysis using the lowest (35) and highest (55) fatal to non-fatal injuries ratios, which were for the Netherlands and Finland, respectively. We did not change the baseline injury count for Germany, the Netherlands and Finland. For these three countries, our baseline-estimated number of non-fatal injuries (more than 3 lost days) is close to that estimated by Kurppa (2015). We also considered the sensitivity of the baseline results using 10-20 % underreporting similar to Leigh (2011) across all five countries. For more details about the sensitivity analyses, see section 2.1.6.

Table 2.1.1b: Adjusted estimation of fatal and non-fatal work-related injury incidence (2015)

Country	Non-fatal cases (> 1 day lost) (a)	Fatal cases (b)	Fatal to non-fatal ratio *100,000	Adjustment ratio for non-fatal cases underreporting (sensitivity analysis range)	Adjusted non-fatal cases (sensitivity analysis range) (c)	
Finland	63,407	35	55	Baseline: 1 (+1.1, +1.2)	63,407	(69,748-76,088)
Germany	1,158,865	450	39	Baseline: 1 (+1.1, +1.2)	1,158,865	(1,274,751-1,390,638)
The Netherlands	99,880	35	35	Baseline: 1 (+1.1, +1.2)	99,880	(109,867-119,855)
Italy	337,829	543	161	Baseline: 2.7 (+1.9, +3.5)	1,257,987	(983,714-1,531,192)
Poland	88,066	301	342	Baseline: 6.9 (+5.2, +8.6)	697,337	(545,300-848,783)

Sources: ESAW 2015 and LFS 2013 (Eurostat).

(a) Calculated number based on count in ESAW 2015 and distribution in LFS 2013 (as in Table 2.1.1a).

(b) ESAW fatal and non-fatal accidents at work, by sex, age groups, injury groups and NACE Rev. 2 economic sectors [hsw_mi07] (2015).

(c) Owing to rounding, columns and rows may not sum.

To estimate injury severity distribution (for cases with more than 3 workdays lost), we used ESAW by Eurostat (Eurostat, 2018a), as indicated in Table A4b, Appendix 4. The severity distribution was assumed to be similar for both sexes, all age brackets and all injury types. For Germany and Poland, no ESAW data were available on injury severity distribution, so we used other EU countries' injury severity distribution. However, this assumption could have affected the indirect cost estimates. To address this issue, we ran sensitivity analyses using the injury distribution of Austria and Belgium. We selected these two countries because of their permanent disability magnitude, being one of the most influential parameters affecting indirect costs. In Austria, only 1 % of all work-related injuries are recognised as causing permanent disability (the lowest among EU countries), whereas in Belgium it is about 19 % (the highest) (Table A4b, Appendix 4). For the baseline assumption, we used the injury severity distribution of Switzerland and Italy for Germany and Poland, respectively. We selected these two countries because of their data availability and industrial similarities. More details about the sensitivity analyses are described in section 2.1.6.

- **Work-related disease cases**

To estimate non-fatal work-related disease cases, different data sources were consulted. We used the relevant national reports of each country as a starting point. However, incidence numbers appear to be affected by a high rate of underreporting, so we made some adjustments. We began with the count of compensated (accepted, recognised) and non-compensated (suspected) non-fatal cases for each country for most types of diseases, with the following exceptions: cancers, circulatory diseases, respiratory diseases and musculoskeletal disorders. For these diseases, we did not use the national sources but estimated case counts based on data in the database of the Burden of Disease (BoD) Study as registered by the Institute for Health Metrics and Evaluation[3] (IHME). For the cases we took 2015 as the reference year. Then, we derived the attributable fraction[4] from the 2016 BoD study data in the IHME database. This approach follows that of Safe Work Australia (2015), where cases of cancers, circulatory diseases and respiratory diseases were estimated using attributable fractions due to presumed high levels of undercompensation. We also estimated cases of musculoskeletal disorders using attributable fractions for the same reason. The above approach to identifying disease incidence for the five countries under study served as the baseline for our analysis. We also defined a lower bound scenario (that is, including only compensated cases), and an upper bound scenario (that is, including all types of work-related diseases estimated using attributable fractions). Three different scenarios for work-related disease incidence are presented in Table 2.1.1c below. Finally, we used data from the LFS 2013 ad hoc module (Eurostat, 2018c) to estimate the distribution of the non-fatal work-related disease cases by age, as well as severity (based on working days lost).

[3] The Global Burden of Disease (GBD) Study aims to provide decision makers with accurate and accessible data on the relative harm that health problems cause across time, geography, age and sex. The GBD Study is coordinated by the IHME (IHME, 2016).

[4] 'Attributable fraction' refers to the proportion of the total burden of disease that is caused by occupational risks. We used the same attributable fractions as in the top-down model. The method used to determine the attributable fractions is described in section 3.1.1. The fractions themselves are presented in Appendix 4.

Table 2.1.1c: Estimation of work-related non-fatal disease incidence based on different data sources; reference year is 2015 unless sources were unavailable (see sources)

Country	Finland			Germany			The Netherlands			Italy			Poland		
Type	L ([a])	B ([a])([f])	H ([f])	L ([b])	B ([b])([f])	H ([a])([f])	L ([c])	B ([a])([f])	H ([f])	L ([d])	B ([d])([f])	H ([f])	L ([e])	B ([e])([f])	H ([f])
Cardiovascular disorders		988	988	919	17,569	17,569	63	3,959	3,959	156	9,146	9,146		7,793	7,793
Hearing disorders	533	1,075		534	1,075		2,489	6,223		1,699	5,181		169	423	
Pulmonary disorders	651	4,847	4,847	751	73,695	73,695	133	13,476	13,476	1,155	31,803	31,803	1,031	39,031	39,031
Musculoskeletal disorders	173	58,230	58,230	23,924	949,609	949,609	2,227	181,586	181,586	12,258	558,623	558,623	98	397,551	397,551
Infectious diseases			88,654	356	717	3,284,019	3	8	690,697	5	14	907,526	660	1,650	740,553
Stomach, liver, kidney or digestive problem			3,479	356	717	66,621	34	85	10,090	48	145	35,762	5	13	46,716
Stress, depression, anxiety			58,206	3,104	6,253	733,144	2,631	6,578	149,753	199	607	529,221	167	418	233,643
Skin problems	336	944		662	1,334		229	573		172	525		93	233	
Headache, eyestrain				4,231	8,523		10	25		33	101		10	25	
Other not elsewhere mentioned	83	329	269,178	1,364	2,748	6,462,826	254	635	728,867	2,673	8,154	3,086,708	118	295	2,606,437
Nasopharynx cancer					2	2				917	1	1			
Larynx cancer		17	17		504	504		127	127		741	741		149	149

Country	Finland			Germany			The Netherlands			Italy			Poland		
Tracheal, bronchus and lung cancer		760	760		17,450	17,450		5,062	5,062		14,836	14,836		3,722	3,722
Non-melanoma skin cancer		334	334		3,577	3,577		617	617		3,451	3,451		1,540	1,540
Breast cancer		52	52		916	916		209	209		465	465		199	199
Ovarian cancer		32	32		515	515		112	112		504	504		100	100
Bladder cancer		74	74		1,628	1,628		424	424		2,375	2,375		643	643
Mesothelioma		108	108		1,876	1,876		646	646		1,719	1,719		279	279
Leukaemia		5	5		80	80		25	25		54	54		27	27
Other neoplasms					4	4		1	1		2	2		1	1
Total	**1,776**	**67,797**	**484,966**	**36,202**	**1,088,793**	**11,614,036**	**8,073**	**220,368**	**1,785,652**	**19,314**	**638,448**	**5,182,938**	**2,351**	**454,090**	**4,078,383**

L, low scenario (that is, only includes compensated cases); B, baseline scenario (that is, compensated and non-compensated cases with the exceptions for cancers, circulatory diseases, respiratory diseases and musculoskeletal diseases that were estimated using attributable fractions); H, high scenario (that is, all types of work-related disease estimated using attributable fractions).

(a) Finnish Institute of Occupational Health (2012).

(b) DGUV (2013).

(c) NCvB statistiek (2015).

(d) Banche dati static (2015).

(e) Szeszenia-Dąbrowska and Wilczyńska (2016).

(f) IHME database 2015 and 2016. IHME (2016).

The incidence of fatal work-related disease was derived from the IHME database. We estimated case counts from IHME (2015) data using attributable fractions for fatal occupational diseases from IHME (2016). Case counts are presented in Table 2.1.1d. However, IHME (2016) does not provide attributable fractions for bladder cancer, digestive diseases, neurological diseases, mental disorders, genitourinary diseases or musculoskeletal disorders. So, there are no data on the number of deaths caused by these diseases. More details about attributable fractions from the IHME for work-related fatal diseases are presented in Appendix 3.

Table 2.1.1d: Estimation of fatal work-related diseases in 2015

Type	Finland	Germany	The Netherlands	Italy	Poland
Communicable diseases	5	322	66	61	130
Nasopharynx cancer	0	1	0	0	0
Larynx cancer	2	84	15	127	56
Tracheal, bronchus and lung cancer	269	6,511	1,739	5,973	2,094
Breast cancer	8	167	33	74	50
Ovarian cancer	29	501	119	483	95
Mesothelioma	99	1,660	601	1,666	228
Leukaemia	2	39	7	21	12
Other neoplasms	1	18	4	8	8
Circulatory diseases	88	1,725	238	551	949
Respiratory diseases — COPD	98	2,353	411	1,012	968
Respiratory diseases — pneumoconiosis	26	512	27	543	61
Respiratory diseases — asthma	1	31	2	5	12
Total	**629**	**13,923**	**3,261**	**10,526**	**4,663**

Source: IHME database, 2015-2016.

2.1.2 Estimation of costs

The approach taken to estimate costs is best described as having three broad categories — direct costs, indirect costs and intangible costs. Each of these three broad categories has subcategories of costs that fall to various stakeholders; the three primary ones are 1) workers and their families; 2) employers; and 3) the health and safety system and public sector.

In the core bottom-up model, we did not focus on stakeholder disaggregation but rather the identification of unique costs (that is, avoiding double counting) associated with each broad category. Thus, the aggregation of the three broad categories of costs sums to the societal-level economic burden. Efforts have been made to not include transfer payments or other forms of double counting in these three broad categories. Below, we describe the cost items associated with each of the three categories.

All three reference studies noted above began with incidence counts (cases) of work-related injuries and diseases to estimate the total costs in a particular category/subcategory, which were then multiplied by the resources associated with being a case and a price weight if the measure of resources is in non-monetary units (for example months lost from paid employment due to work disability). Incidence counts have been stratified by sex, age bracket, type of injury (high-level ESAW categories) and severity (based on days absent from work). A representation of the formula is as follows:

Total (sub)category costs for a stratum = number of cases in the stratum × per case cost for the stratum

- **Direct costs**

This category of costs is meant to include all healthcare-related products and services, whether paid for by the public sector, insurer, employer, worker or other stakeholder. We focused on four direct cost items: 1) formal healthcare costs paid for by the public sector/insurer; 2) public sector/insurer administration/overhead costs; 3) informal caregiving time from family and community; and 4) worker out-of-pocket costs for healthcare products and services, including resource costs associated with seeking care. Ideally, these costs should reflect the lifetime resource implications of being a case compared with the counterfactual. Thus, data are needed on the cost of the entire treatment paradigm which, in principle, may extend for months or years in cases of serious injury/disease, particularly if a person experiences a permanent residual impairment as a result of being a case. As the above equation suggests, an important consideration is the quality of the data on which the number of cases and per case costs are based. This is where we can adopt some practices from the above-noted studies. They used administrative-level data wherever possible. For the healthcare costs, the studies cited took a creative approach due to the lack of available data. For example, Leigh (2011) used a top-down model based on an aggregate value of national healthcare spending (that is, hospitals, professional services, pharmaceuticals and medical device costs) from Hartman et al. (2009). The Safe Work Australia (2015) study used total healthcare treatment costs from an administrative data source. In the present study, we were also hindered by the lack of available data. Therefore, a creative approach was needed. Below we describe the approach used and its similarity to the studies mentioned above.

Formal healthcare costs

The data on direct healthcare costs incurred within the healthcare system proved to be the most challenging to collect. Total cost of disease accounts are usually published in every country, but for the model we ideally needed the cost data differentiated by type of disease, sex and age. In addition, we needed cost per case data and for the complete treatment cycle. In this specific configuration, the data were not publicly available in any country. Therefore, we used macro-level data on healthcare expenditures by International Classification of Diseases (ICD) code ICD9/10 over a calendar year, divided by the number of cases served in that ICD9/10 code in a calendar year. This approach is similar to Leigh's top-down study to estimate healthcare costs. No distinction is made between severity levels, that is, the costs reflect the average cost and the average severity level.

Formal healthcare costs of injuries

We estimated the healthcare cost of injury cases based on their severity (that is, lost days). We assume that injuries with 3 lost days or less are superficial cases, so we assume a nominal cost of EUR 100 including standard assessment and general practitioner (GP) visit, similar to HSE (2011). This cost is meant to represent the average cost for a GP visit and medication used. We did not consider any informal care costs for these cases.

For injury cases with more than 3 days lost, we used the healthcare data of hospitalised and non-hospitalised injury cases based on Italian National Ministry of Health. We used the Consumer Price Index for Medical Services and Paramedical Services to estimate 2015 values for the other four countries. This research project was coordinated by the Consumer Safety Institute, the Netherlands, with financial support from the European Commission under the Public Health Programme. We extracted the healthcare cost for each type of injury for the Netherlands, and then estimated the healthcare costs for the other four countries, using relative healthcare price indices for hospital services based on the 'International Comparisons of Health Prices and Volumes' adjustment ratio (Lorenzoni and Koechlin, 2017). For Germany, the value was 92; Finland, 91; the Netherlands, 107; Italy, 81; and Poland, 28. Note that the average of all the Organisation for Economic Co-operation and Development (OECD) members is 100.

Table 2.1.2a: Estimated average healthcare costs per case of work-related injuries (cases with more than 3 days lost) in 2015 (EUR)

Injury	Germany	Finland	The Nether-lands	Italy	Poland
Wounds and superficial injuries	3,849	3,807	4,476	3,389	1,171
Bone fractures	3,849	3,807	4,476	3,389	1,171
Dislocations, sprains and strains	912	902	1,060	803	277
Traumatic amputations (loss of body parts)	22,338	22,095	25,980	19,667	6,799
Concussions and internal injuries	6,500	6,429	7,560	5,723	1,978
Burns, scalds and frostbites	7,441	7,360	8,654	6,551	2,265
Poisonings and infections	1,957	1,935	2,276	1,723	595
Drownings and asphyxiations	2,174	2,151	2,529	1,914	662
Effects of sound, vibration and pressure	912	902	1,060	803	277
Effects of temperature extremes, light and radiation	912	902	1,060	803	277
Shocks	3,398	3,361	3,952	2,992	1,034

Sources: Italy National Ministry of Health (2015) (no permanent link available); Lorenzoni and Koechlin (2017).

Formal healthcare costs of diseases

For both fatal and non-fatal disease cases, we used the same healthcare costs, which can be considered as the costs incurred after the diagnosis of the disease. Data were made available by the Germany Federal Statistical Office (Destatis). The data are for only hospitalised cases. We estimated costs for the other countries using the same method as described in the above section, that is, by using price indices for hospital services based on the ‘International Comparisons of Health Prices and Volumes’ adjustment ratios. The healthcare cost for each type of work-related disease is presented in Table 2.1.2b below.

Table 2.1.2b: Estimated average healthcare costs of work-related diseases in 2015 (EUR)

Disease	Germany	Finland	The Nether-lands	Italy	Poland
Heart disease or attack or other problems in the circulatory system	3,336	3,300	3,880	2,937	1,015
Hearing problem	149	147	173	131	45

Disease	Germany	Finland	The Nether-lands	Italy	Poland
Breathing or lung problem	1,353	1,338	1,574	1,191	412
Bone/joint/muscle problem	1,206	1,193	1,403	1,062	367
Infectious disease (virus/bacteria or other type of infection)	171	169	199	151	52
Stomach/liver/kidney or digestive problem	683	676	794	601	208
Stress/depression/anxiety	3,953	3,910	4,598	3,480	1,203
Skin problem	637	630	741	561	194
Headache and/or eyestrain	1,193	1,180	1,388	1,050	363
Other types of health problem	1,193	1,180	1,388	1,050	363
Nasopharynx cancer	11,775	11,647	13,695	10,367	3,584
Larynx cancer	19,633	19,420	22,834	17,286	5,975
Tracheal, bronchus and lung cancer	20,403	20,181	23,730	17,963	6,210
Non-melanoma skin cancer	5,757	5,695	6,696	5,069	1,752
Breast cancer	6,232	6,164	7,248	5,487	1,897
Ovarian cancer	8,121	8,032	9,445	7,150	2,472
Bladder cancer	9,313	9,212	10,832	8,200	2,835
Mesothelioma	15,704	15,533	18,264	13,826	4,779
Leukaemia	41,429	40,979	48,184	36,476	12,609
Other neoplasms	11,005	10,885	12,799	9,689	3,349

Sources: Federal Statistical Office (Destatis), GENESIS-Tabelle: 23631-0003 (2015); Lorenzoni and Koechlin (2017).

Disease treatment episode

The healthcare costs used in our analysis are the costs incurred in 1 year, which may be a realistic treatment period for most cases, but for more serious cases healthcare costs may be incurred for periods longer than 12 months. To estimate healthcare costs of work-related injuries and diseases, we need to consider the average treatment episode for each condition. In this study, we considered that the maximum treatment time for each injury would be 1 year. For work-related diseases, we defined the duration as indicated in Table 2.1.2c, based on a study by the HSE (2011) on the costs to Britain of workplace injuries and work-related ill health. The study did not include cancer. Since cancer may also be considered a serious disease that may require longer treatment, we assumed that the duration of cancer treatment was 2 years.

Table 2.1.2c: Work-related disease treatment episode (in years)

Type of disease	Treatment episode (years)	Type of disease	Treatment episode (years)
Cardiovascular disorders	2	Stress, depression, anxiety	2
Hearing disorders	1	Skin problems	1
Pulmonary disorders	2	Headache, eyestrain	1
Musculoskeletal disorders	2	Other not elsewhere mentioned	1
Infectious diseases	1	Cancer	2
Stomach, liver, kidney or digestive problems	1		

Source: HSE (2011), p. 42.

Insurance administration costs

Healthcare administration/overhead costs incurred by the public sector/insurer are estimated as a percentage of the costs of healthcare treatment. Data were retrieved from the annual accounts of national health insurance providers. Regarding the proportion of cases covered by social insurance, these data were taken from national OSH agencies or occupational health authorities. The percentage used can vary by country and is based on evidence of the average percentage identified from the source mentioned in the Table 2.1.2d.

Table 2.1.2d: Administration costs of healthcare insurance

Country	Administrative costs (% of healthcare costs)
Finland ([a])	2.9
Germany ([b])	5.4
The Netherlands ([c])	3.9
Italy ([d])	1.9
Poland ([e])	1.0

(a) Kela (2015), p. 43.
(b) Techniker Krankenkasse (2016).
(c) CZ (2016).
(d) OECD (2017).
(e) NFZ (2018).

Informal caregiving costs

We assumed that, for all cases with less than 6 months lost, an average of 1 hour of informal care was received for each day absent from work (Tompa et al., 2017). This was a conservative assumption, due to lack of data on the actual time spent by family and community for caregiving. For cases of permanent disability or ill health (who lost more than 6 months), we considered informal caregiving costs up to only 6 months. We did not consider informal care costs for fatal cases. The value of caregiving time (the price weight) is based on the wage rate earned in the paid-labour market by someone providing similar caregiving services — Finland (EUR 12) (Statistics Finland, 2016), Germany and Italy (EUR 19) (Destatis, 2015), the Netherlands (EUR 25) (CBS/StatLine, 2017) and Poland (EUR 5) (ZUS, 2018).

Out-of-pocket costs

Out-of-pocket costs comprise the co-payment required by an individual for healthcare services received by the public sector/insurer and other costs incurred for seeking care, such as transportation and accommodation, and the purchase of services and products not covered by the public sector/insurer. The latter is estimated as a percentage of the cost of healthcare services received from the public sector/insurer. The percentage is based on country-specific information as indicated in Table 2.1.2e. This cost category offered the opportunity to include a range of out-of-pocket cost items.

Table 2.1.2e: Estimated out-of-pocket healthcare costs

Country	Percentage of out-of-pocket costs
Finland ([a])	18.5
Germany ([b])	13.2
The Netherlands ([c])	14.7
Italy ([a])	20.2
Poland ([d])	23.0

(a) EC (2016).
(b) The Commonwealth Fund (2017a).
(c) The Commonwealth Fund (2017b).
(d) EC (2017).

- ### Indirect costs

For the estimation of indirect costs, we considered non-fatal and fatal work-related injuries/disease cases separately by age and sex, similar to Leigh (2011), Tompa et al. (2017) and HSE (2011). The distinction is important, since losses for fatal cases are based on the counterfactual of living a standard life expectancy. For non-fatal cases, losses are only temporary in most cases; the exception is the small number of permanent impairments, the losses associated with which extend until death. There are six key subcomponents of indirect costs, which we estimated separately: 1) market output losses due to absenteeism and reduced work ability associated with permanent impairment; 2) payroll/fringe benefits associated with wages and salaries; 3) employer adjustment costs, 4) insurance administration costs associated with disability insurance/workers' compensation; 5) home production losses; and 6) presenteeism associated with paid employment activity.

For the indirect cost data requirements, an examination of data sources had already shown that the data availability from internationally harmonised sources was very good. To ensure comparability between countries, it was decided to use internationally harmonised data wherever possible. Most indirect cost data were retrieved from Eurostat, with some data also taken from the OECD and the European Working Conditions Survey. For some sources, data were not available for the reference year, 2015, so the closest year available was used, with appropriate adjustments being made in line with the relevant consumer price index (CPI). For the wage rate for domestic production and family caregiving, we relied on national sources. In one country (Poland), these data were not available, so we used the legal minimum wage as a proxy.

Market output losses

For market output losses, we assumed that the marginal product of labour is equal to the wage rate. This common assumption in economics allows us to use the human capital approach to estimate market output losses. As noted earlier, the incidence counts of work-related injuries and diseases were stratified by severity, measured in terms of days absent. Thus, we used data on days absent from work to estimate output losses based on the human capital approach. In our application of the human capital approach, the price weights used were average wage rates. To that we added a percentage to cover fringe/payroll benefits. For injuries and diseases with less than 1 day lost, we did not consider productivity losses, home production losses, insurance administrative costs or employer adjustment costs. For all cases in which less than 6 months were lost, individuals were assumed to have returned to work without any change in their long-term productivity. For cases of permanent impairment, we assumed output losses for a fraction of individuals that continued for the remainder of their working careers (that is, until age 65). For fatal cases, losses were assumed for the remainder of a standard work life, (that is, until age 65). Loss estimates were based on the counterfactual of average labour market earnings of the working age population, stratified by sex and age bracket. All earnings beyond the reference year, 2015, were discounted to the reference year. A 1 % productivity growth factor was considered for earnings beyond 2017 based on Tompa et al. (2017). For the calendar years 2015, 2016 and 2017, actual labour market earnings data were available.

Standard retirement ages may vary across countries, and some countries do not have a mandatory retirement age. We used an age of 65 years for all countries. The Tompa et al. (2017) study considered labour market earnings and the probability of labour market participation until an age of 85 years to estimate output losses associated with premature mortality, as Canadian data were available until this age. The Safe Work Australia (2015) study estimated output losses from premature mortality based on a retirement age of 62 years.

Output loss for permanent disability

We assumed that cases with more than 6 working months lost were permanent disability cases. To estimate the loss of output/earnings of permanent disability cases, we needed to know how many people returned to work and what their earnings were after returning to work in order to estimate long-term output losses. For this purpose, country-specific data were not available. Instead, we used data from a Canadian study of an Ontario workers' compensation sample of claimants with permanent impairments that drew on tax file data (Tompa et al., 2014). That study matched permanent impairment claimants with uninjured controls to assess long-term earning losses. Based on that study, we assumed that on average men lose 33 % and women lose 38 % (average of 35 %) of their earnings. A percentage was added to account for payroll/fringe benefits.

Payroll/fringe benefits

As noted, we added a percentage for payroll/fringe benefits to all estimates of market output losses based on the human capital approach. This component was necessary to ensure that the price weights were appropriately adjusted for the full wage. For estimation of the average payroll/fringe benefits across industrial sectors, we divided the average 'employers' social contributions and other labour costs paid by employer' by 'total labour costs', for each country. We also estimated the lower and higher ranges of fringe benefits using different industrial sector values as illustrated in Table 2.1.2f. Input data were identified through Eurostat.

Table 2.1.2f: Payroll costs, percentage of gross earnings in 2015

Country	Average	Low	High
Finland	22	20	24
Germany	23	19	35
Netherland	24	22	26
Italy	28	28	28
Poland	19	17	29

Source: Eurostat, Labour cost levels by NACE Rev. 2 activity (lc_lci_lev), 2015.

Employer adjustment costs

This subcomponent of indirect costs accounts for expenses incurred by employers to replace a worker unable to fulfil their full duties due to work-related injury or disease. Adjustment costs include all employer costs. They include other workers working overtime, hiring temporary workers or recruiting and training a replacement worker in cases of permanent exit from the paid-labour force by an injured or ill worker, but also insurance premiums, production disturbances and administrative costs. We assumed that adjustment costs would vary depending on the severity of the injury or disease as measured by days absent from work. The method we used is adapted from the HSE (2011). For fatal cases, we assumed the adjustment costs are equal to 6 months of average wages and benefits based on Tompa et al. (2017). For non-fatal cases with more than 3 working days lost, we considered the items listed in Table 2.1.2g.

Table 2.1.2g: Estimation of employer adjustment cost

Item	Description of the cost	Calculation formula
Production disturbance	The costs associated with work reorganisation and recruitment and training of temporary or permanent replacement staff, to maintain output	0.5 days × daily managerial income
Administrative costs	The time spent initiating and managing claims for sick pay and state benefits, and compensation and insurance payouts	2.5 h for routine case × wage for clerical staff

Source: Based on HSE (2011).

Other insurance administration costs

Another subsection of indirect cost is social insurance administration expenses. This refers to the administration of wage-replacement benefits and other related services provided by disability insurance programmes such as workers' compensation schemes. The actual wage-replacement benefits were not included in our estimates, as these are simply transfer payments, not resources expended. We estimated these administrative costs as a percentage of market output losses. We used country-specific percentages identified from various sources for this purpose as indicated in Table 2.1.2h. However, no data were available for Finland and Poland; for these countries, we used the same percentage as used for Germany. The values for Italy and the Netherlands are not much different, so using either of these values to replace missing values would not have resulted in a substantive difference.

Table 2.1.2h: Other insurance administration costs in 2015

Country	Insurance Administration Costs (% of lost wages)
Finland ([a])	10.1
Germany ([a])	10.1
The Netherlands ([b])	11.5
Italy ([c])	12.2
Poland ([a])	10.1

(a) DGUV (2015).
([b]) Achmea (2015).
([c]) INAIL (2015).

Home production loss costs

Home production may include different activities such as housework, taking care of plants and animals, cooking food, house cleaning and car maintenance, and other personal activities based on Haddix et al. (2003). In accordance with Tompa et al. (2017), workers who were off work due to work-related injury or disease were assumed not to be able to fulfil home production tasks. Once they returned to work, it was assumed that they also returned to regular home production activities. For individuals with permanent impairment, it was assumed that they were not able to undertake home production activities for the remainder of their lifetimes. For fatal injuries and diseases, the home production losses included a standard remaining lifetime of losses in home production.

To estimate the value of home production losses, we used data on time spent in home production activities along with the wage rate of domestic services to estimate the value of home production losses. For the estimation of an average wage for home production activities, we used the average of different occupational wage codes, such as personal service activities, repair of personal and household goods, and home care and social work activities. We assumed no fringe benefits for home production.

Table 2.1.2i provides details of the average time spent on home production activities in different countries and Table 2.1.2j provides the average hourly wage for personal and household services.

Table 2.1.2i: Average time spent on home production activities per day

Country	**Home production time (hours per day)**
Finland ([a])	**Men: 2.55; women: 3.68**
Germany ([b])	**Men: 2.15; women: 3.36**
The Netherlands ([c])	Men: 1.95; women: 3.45
Italy ([d])	Men: 2.18; women: 5.11
Poland ([e])	Men: 2.65; women: 4.75

(a) Statistics Finland, Time Use Survey (2009-2010).
(b) Destatis (2015).
(c) SCP (2012).
(d) OECD (2016).
(e) OECD (2016).

Table 2.1.2j: Average hourly wage for household activities

Country	Hourly wage (EUR)
Finland ([a])	**Men: 12; women: 12**
Germany ([b])	**Men: 19; women: 14**
The Netherlands ([c])	Men: 25; women: 25
Italy ([d])	Men: 19; women: 14
Poland ([e])	Men: 5; women: 5

(a) Statistics Finland (2016); (b) Destatis (2015).; (c) CBS/StatLine (2017), (d) Same as Germany, as national collective agreements (as of January 2016) for personal and household services did not report the hourly wage; (e) ZUS (2018).

Presenteeism

The last subcomponent of indirect costs is presenteeism associated with paid-labour market activity. We used a method similar to Schultz et al. (2009) in which presenteeism after return to work is based on total costs (that is, medical and pharmacy costs + absenteeism costs + presenteeism costs). In this method, we first matched each category of injury and disease with 18 different health problems that were identified by Schultz et al. (2009). Then we used the presenteeism to total cost ratio for each disease and injury to calculate the presenteeism cost, by age and sex.

Presenteeism costs were considered for all non-fatal cases with 1 day to 6 months (183 days) of lost days, and for cases with more than 6 months of lost days where the individual returned to work. For work-related injuries and diseases without days lost from work, we assumed no presenteeism.

For work-related injuries, presenteeism was assumed to be an issue only after return to work, whereas for work-related diseases presenteeism was assumed to be an issue both before work absence and after return to work. Therefore, the value of presenteeism used in disease cases is twice the value used in injury cases (with equal numbers of days lost).

Table 2.1.2k: Average ratio of presenteeism costs to total costs (a) by type of work-related injury/disease

Type of disease	Presenteeism to total cost ratio	Types of injury	Presenteeism to total cost ratio
Cardiovascular disorders	0.28	Wounds and superficial injuries	0.17
Hearing disorders	0.33	Bone fractures	0.17
Pulmonary disorders	0.56	Dislocations, sprains and strains	0.17
Musculoskeletal disorders	0.60	Traumatic amputations (loss of body parts)	0.17
Infectious diseases	0.14	Concussions and internal injuries	0.17
Stomach, liver, kidney or digestive problems	0.67	Burns, scalds and frostbites	0.17
Stress, depression, anxiety	0.62	Poisonings and infections	0.17
Skin problems	0.33	Drownings and asphyxiations	0
Headache, eyestrain	0.70	Effects of sound, vibration and pressure	0
Other, not mentioned elsewhere	0.33	Effects of temperature extremes, light and radiation	0
		Shocks	0

Source: Schultz et al. (2009).

(a) Total costs = healthcare (that is, medical and pharmacy) costs + absenteeism costs + presenteeism costs.

- **Intangible costs**

The intangible cost component accounts for losses associated with health-related quality of life. We used two approaches to estimate such values. For cases of temporary and permanent disability, we used an approach similar to that used by the HSE (2011) (Appendix 5). However, we did not include the health-related quality of life losses for injury and disease cases with less than 3 days' work lost. For fatal cases, we estimated the value of lost years of life based on the average for the population, adjusted for sex, age and life expectancy. Health-related quality of life was estimated in terms of quality adjusted life years (QALYs) [5], using the sources shown in Table 2.1.2l, and QALYs were monetised using a price weight of EUR 41,100 per QALY based on the National Institute for Health and Care Excellence (NICE) (2013) values. Since no data were available for the Netherlands, we used the German values.

Table 2.1.2l: Measures used to estimate average health-related quality of life of the general population (QALYs)

Country	Instrument
Germany ([a])	**EQ-5D-5L**
Finland ([b])	**EQ-5D-3L**
The Netherlands ([a])	EQ-5D-5L
Italy ([c])	EQ-5D-3L, EQ-5D-5L
Poland ([d])	EQ-5D-5L

([a]) Huber et al. (2017).
([b]) Saarni et al. (2006).
([c]) Scalone et al. (2015).
([d]) Golicki and Niewada (2017).

2.1.3 Costs by stakeholders

Depending on the characteristics of the social security systems in each country, the economic burden borne by each stakeholder, namely workers, employers and the system/public sector will be different. For costs by stakeholder, we used an *ex post* approach, similar to that used by Safe Work Australia (2015), where stakeholder costs are based on where costs fall after an incident has occurred. Table 2.1.3a presents details of the items considered for each stakeholder. For the wage-replacement benefits, we used several national references. Details are provided in Table 2.1.3b.

Table 2.1.3a: Main framework for estimation of the costs by stakeholder

Category	Employer	Worker	System/public sector
Direct costs	Share of formal heath care costs	Share of formal healthcare cost	Share of formal healthcare cost
		Informal caregiver costs	
		Out-of-pocket costs	
Indirect costs	Share of wages replaced based on (see Table 2.1.3b)	Share of wage losses not compensated (see Table 2.1.3b)	Share of wage replaced (see Table 2.1.3b)
	Employer adjustment costs	Fringe/payroll benefit losses	Other insurance administration costs
	Presenteeism	Home production losses	
Intangible costs		Total monetary value of health-related quality of life losses	

[5] QALYs are a measure of years lived in perfect health gained whereas DALYs are a measure of years in perfect health lost.

Table 2.1.3b: Percentage of lost wages by stakeholder

Country	Employer	Worker	System	Sources
		Finland		
< 30 days lost	100	0	0	https://www.kela.fi/sairauspaivaraha https://www.palkkaus.fi/cms/article/sairausajan_palkka https://www.kela.fi/sairaanhoito_laakarinpalkkiot https://www.kela.fi/documents/10180/0/Sairaanhoitokorvausten+taksat+6.6.2018/c33a166c-4d0b-4bd9-a776-8cd46455de39 https://www.kela.fi/laakkeet http://www.tvk.fi/en/workers-compensation-and-insurance/compensation/benefits/compensation-for-death/ http://www.tvk.fi/en/workers-compensation-and-insurance/compensation/benefits/compensation-for-death/ https://www.tvk.fi/uutiset/tyotapaturma--ja-ammattitautilain-mukaiset-euromaarat-2018/
30-180 days lost	0	30	70	
Permanent disability	0	30	70	
Fatal	0	35	65	
		Germany		
< 30 days lost	100	0	0	https://www.tk.de/tk/basiswissen-fuer-arbeitgeber/entgeltfortzahlung/krankheit/343706 https://www.tk.de/tk/basiswissen-fuer-arbeitgeber/entgeltfortzahlung/krankheit/343706 https://www.bghw.de/arbeitnehmer/unsere-leistungen/hinterbliebenenleistungen
30-180 days lost	0	20	80	
Permanent disability	0	20	80	
Fatal cases	0	20	80	
The Netherlands				
< 30 days lost	70	30	0	https://www.uwv.nl/particulieren/ziek/ziek-met-werkgever/inkomen-tijdens-ziekte/detail/loondoorbetaling-tijdensziekte https://www.zorgwijzer.nl/faq/eigen-risico https://www.rijksoverheid.nl/onderwerpen/algemene-nabestaandenwet-anw/vraag-en-antwoord/wanneer-heb-ik-rechtop-een-nabestaandenuitkering-anw-uitkering http://www.letselschade-kenniscentrum.nl/schadevergoeding-bij-overlijden.php
30-180 days lost	70	30	0	
Permanent disability	0	25	75	
Fatal cases	0	40	60	
		Italy		
< 30 days lost	60	40	0	http://www.adpmi.org/p/ticket_sanitari_una_guida https://data.oecd.org/healthres/health-spending.htm http://ftp.iza.org/dp9772.pdf http://www.adnkronos.com/salute/sanita/2017/04/04/ticket-sanita-riforma-vista-quanto-paga-chi-esente_dh4XyCCaARP5gN0UumIM5L.html?refresh_ce http://www.adnkronos.com/soldi/economia/2018/07/26/chi-paga-stipendio-durante-malattia_wJgVT2FOKSVHXT2B2zV9KL.html?refresh_ce
30-180 days lost	75	25	0	
Permanent disability	0	25	75	
Fatal cases	0	30	70	

Country	Employer	Worker	System	Sources
				https://www.giesse.info/it/infortunio-sul-lavoro-chi-paga/ https://www.inail.it/cs/internet/attivita/prestazioni/prestazioni-economiche/rendita-ai-superstiti.html
Poland				
< 30 days lost	80	20	0	https://gratka.pl/regiopraca/portal/porady/zus/kiedy-zasilek-chorobowy-wynosi-100-80-kiedy-70-proc-pensji https://porady.pracuj.pl/kto-wyplaca-chorobowe-pracodawca-czy-zus/ http://www.nfz-warszawa.pl/dla-swiadczeniodawcow/recepty-leki-apteki/informacje-ogolne/ogolne-zasady-odplatnosci-za-leki/ https://kadry.infor.pl/kadry/bhp/wypadki_przy_pracy_i_choroby_zawodowe/44210,Jakie-swiadczenia-z-tytulu-smiertelnego-wypadku-przy-pracy-przysluguja-czlonkom-rodziny-zmarlego.html
30-180 days lost	0	20	80	
Permanent disability	0	20	80	
Fatal cases	0	35	65	

2.1.4 General assumptions of the model

The following are relevant items and general assumptions made across all five countries:

- The reference year is 2015.
- Costs are in 2015 euros, adjusted using country-specific healthcare price indices for formal healthcare costs, and relevant CPI for all goods and services for all other items.
- Lifetime costs were considered in the burden estimates — this is particularly relevant for cases of premature mortality and permanent disability.
- Future resource flows were discounted to the calendar year 2015 using a 3 % discount rate.
- All monetary amounts were discounted, including the monetary values of lost QALYs.
- A 1 % productivity growth rate was assumed for labour-market activity.
- Retirement age was assumed to be 65 years.

2.1.5 Data collection process

As a prerequisite of the data collection process, the specifications of the data required for the models were defined by the model builders. To this end, a data needs table template was developed that included fields for the type of data, their purpose in the model, their linkages with other data in the model, the required differentiation of the data and potential proxies to uses if the data were unavailable. This covered data on cases of work-related diseases and deaths and on direct, indirect and intangible costs. The data collection process was iterative, with a constant exchange between the data collectors and the model builders. This approach ensured that the model builders were always up to date about data availability and could adapt their models accordingly if needed. An overview of the final data needs and sources used for the models are provided in Appendix 2.

2.1.6 Sensitivity analysis

Given the number of data elements required for the bottom-up model and the variety of assumptions needed to proxy for the various cost components, it is important to consider the sensitivity of the findings to key parameters. Therefore, we estimated the impact on the total cost of work-related injuries and diseases for each country from several single-variable, sensitivity analysis scenarios[6]. The parameters and ranges to consider were based on our knowledge of what data elements and assumptions were most likely to be an issue. We also turned to the literature to see what sensitivity analysis considerations were made in other studies. The research team discussed the sensitivity analysis possibilities at several meetings, which resulted in incremental parameters being considered. A summary of the key scenarios considered for sensitivity analysis is listed below.

High-level economic parameters: these scenarios considered the effect of the discount rate and productivity growth rate. These parameters were varied to assess their impact.

The underreporting of incidence: these scenarios considered the effect of underreporting of work-related injuries and disease across all severity categories. It is known that the rate of underreporting varies by country (Kurppa, 2015), so we considered the underreporting of each country separately using three scenarios of low, medium and high severities as explained in each section and also in the following tables.

Healthcare costs: high-quality data on healthcare costs were not available, so we derived the costs per case from aggregated data that are unlikely to cover the full costs. To assess the impact of varying healthcare costs, we ran sensitivity analyses in which we changed our baseline cost based on the Finland healthcare data (as lower bound) and Poland healthcare data (as higher bound). We used data from these countries because they contain data on both hospitalised and non-hospitalised cases, from the Finnish National Institute for Health and Welfare (THL)[7] and Narodowy Fundusz Zdrowia (NFZ, National Health Fund)[8], respectively. We also considered the effect of varying healthcare administration costs.

Productivity/output loss costs: these costs are based on workdays lost for injuries and diseases up to retirement for fatal cases and cases with permanent disability. Under these scenarios, we considered the effect of varying the retirement age, using 60 and 70 years as the range. We also considered the effect of varying the fringe/payroll benefit rate, annual working days, average earnings loss for permanent disability cases, presenteeism effect and insurance administration costs.

Intangible costs: various approaches exist for monetising QALYs, and the monetised values are highly dependent on the approach taken. In the scenarios in the present study, we considered the effect of higher and lower bounds for the monetary value of a QALY. For the estimation of loss of QALY range for temporary and permanent disability cases, we also used different scenarios similar to those used by the HSE (2011) (Appendix 5).

Looking across the different sensitivity analysis scenarios helped to identify which parameter had the largest impact on the cost estimation. Details of the specific categories and range of values considered are presented by country in Table 2.1.6a to Table 2.1.6e. The results of the sensitivity analyses for each country are presented in tornado graphs in the results section (Figure 2.2.4a to Figure 2.2.4e) to help facilitate a comparison.

[6] Note that probabilistic sensitivity analysis was not possible, as distributional information on point estimates for much of the input data was not available. It is common practice in peer-reviewed and high-end grey literature to undertake single-variable sensitivity analysis in cost-of-illness/economic-burden studies undertaken at the country level. This was the case in the studies by Leigh (2011) and Tompa et al. (2017), to name just two of many.

[7] Permanent direct link is not available.

[8] https://prog.nfz.gov.pl/app-jgp/KatalogJGP.aspx

Table 2.1.6a: Model parameters for sensitivity analysis for Finland

Scenarios	Baseline	Lower limit	Upper limit	Source [1] *refers to the baseline value,* [2] *to the lower limit and* [3] *to the upper limit*
A) High-level economic assumptions				
A.1. Discount rate (%)	3	1	5	[1,2,3]Drummond (2015)
A.2. Productivity growth rate (%)	1	0	2	[1]Tompa et al. (2017), [2,3]this study
B) Incidence inclusion and underreporting rate				
B.1. Injury underreporting rate (more than 3 days lost category) (%)	0	10	20	[1,2,3]This study
B.2. Injuries with more than 3 lost days (% of all)	26	26	26	[1,2,3]Eurostat (2018b)
B.3. Injuries with 1-3 lost days (%)	13	13	13	[1,2,3]Eurostat (2018b)
B.4. Injuries with no lost days (% of all)	Not included	Not included	61	[3]Eurostat (2018b)
B.5. Injury (more than 3 lost days) severity distribution	Finland	Austria	Belgium	[1,2,3]Eurostat (2018a)
B.6. Disease incidence scenarios				[1]Compensated cases, [2]compensated + non-compensated + selected AF cases, [3]only AF cases
Fatal	629	115	629	
Non-fatal diseases	67,797	1,776	484,966	
B.7. Injury and disease incidence (both)	B.4 + B.6	B.4 + B.6	B.4 + B.6	
C) Healthcare costs				
C.1. Healthcare costs of injuries and diseases (% change)	0	-82	81	[1,2,3]This study
D) Productivity losses				
D.1. Fringe/payroll benefit rate (%)	22	20	24	[1]Eurostat lc_lci_lev (2015)
D.2. Annual working days (for productivity/output loss)	205	170	174	[1]OECD, (2015)
D.3. Productivity loss until the age of	65	60	70	[1,2,3]This study
D.4. Wage-replacement rate (%)	80	70	90	[1,2,3]This study
D.5. Consider presenteeism effect for x % of cases	90	80	100	[1]Safe Work Australia (2015), [2,3]this study
D.6. Average informal care time for permanent injuries (days)	225	183	550	[1]Safe Work Australia (2015), [2,3]this study
D.7. Average informal care time for permanent diseases (days)	190	183	550	[1]Safe Work Australia (2015), [2,3]this study
D.8. Average earnings loss of permanent disability cases (%)	35	33	38	[1,2,3]Tompa et al. (2014)
E) Administrative costs				
E.1. Healthcare insurance administration costs (%)	3	0	10	[1,2,3]This study
E.2. Other insurance administration costs (%)	10	0	15	[1]DGUV (2015), [2,3]this study
F) Intangible costs				
F.1. Monetary value of a QALY (EUR)	41,096	27,397	61,644	[1,2,3]NICE (2013)
F.2. Loss of QALY range for injuries and diseases	Median	Low	High	[1,2,3]HSE (2011), p. 45-50

Table 2.1.6b: Model parameters for sensitivity analysis for Germany

Scenarios	Baseline	Lower limit	Upper limit	Source [1] refers to the baseline value, [2] to the lower limit and [3] to the upper limit
A) High-level economic assumptions				
A.1. Discount rate (%)	3	1	5	[1,2,3]Drummond (2015)
A.2. Productivity growth rate (%)	1	0	2	[1]Tompa et al. (2017), [2,3]this study
B) Incidence inclusion and underreporting rate				
B.1. Injury underreporting rate (more than 3 days lost category) (%)	0	10	20	[1,2,3]This study
B.2. Injuries with more than 3 lost days (% of all)	39	39	39	[1,2,3]Eurostat (2018b)
B.3. Injuries with 1-3 lost days (%)	14	14	14	[1,2,3]Eurostat (2018b)
B.4. Injuries with no lost days (% of all)	Not included	Not included	47	[3]Eurostat (2018b)
B.5. Injury (more than 3 lost days) severity distribution ([a])	Switzerland	Austria	Belgium	[1,2,3]Eurostat (2018a)
B.6. Disease incidence scenarios				[1]Compensated cases, [2]compensated + non-compensated + selected AF cases, [3]only AF cases
Fatal	13,923	2,343	13,923	
Non-fatal diseases	1,088,793	36,202	11,614,036	
B.7. Injury and disease incidence (both)	B.4 + B.6	B.4 + B.6	B.4 + B.6	
C) Healthcare costs				
C.1. Healthcare costs of injuries and diseases (% change)	0	-82	81	[1,2,3]This study
D) Productivity losses				
D.1. Fringe/payroll benefit rate (%)	23	19	35	[1]Eurostat lc_lci_lev (2015)
D.2. Annual working days (for productivity/output loss)	171	170	174	[1]OECD (2015)
D.3. Productivity loss until the age of	65	60	70	[1,2,3]This study
D.4. Wage-replacement rate (%)	80	70	90	[1,2,3]This study
D.5. Consider presenteeism effect for x % of cases	90	80	100	[1]Safe Work Australia (2015), [2,3]this study
D.6. Average informal care time for permanent injuries (days)	225	183	550	[1]Safe Work Australia (2015), [2,3]this study
D.7. Average informal care time for permanent diseases (days)	190	183	550	[1]Safe Work Australia (2015), [2,3]this study
D.8. Average earnings loss of permanent disability cases (%)	35	33	38	[1,2,3]Tompa et al. (2014)
E) Administrative costs				
E.1. Healthcare insurance administration costs (%)	5	0	10	[1,2,3]This study
E.2. Other insurance administration costs (%)	10	0	15	[1]DGUV (2015), [2,3]this study
F) Intangible costs				
F.1. Monetary value of a QALY (EUR)	41,096	27,397	61,644	[1,2,3]NICE (2013)
F.2. Loss of QALY range for injuries and diseases	Median	Low	High	[1,2,3]HSE (2011), p. 45-50

([a]) Switzerland data were used to estimate Germay's injury severity distribution (> 3 lost days), since no data were available from Germany.

Table 2.1.6c: Model parameters for sensitivity analysis for the Netherlands

Scenarios	Baseline	Lower limit	Upper limit	Source *[1] refers to the baseline value, [2] to the lower limit and [3] to the upper limit*
A) High-level economic assumptions				
A.1. Discount rate (%)	3	1	5	[1,2,3]Drummond (2015)
A.2. Productivity growth rate (%)	1	0	2	[1]Tompa et al. (2017), [2,3]this study
B) Incidence inclusion and underreporting rate				
B.1. Injury underreporting rate (more than 3 days lost category) (%)	0	10	20	[1,2,3]This study
B.2. Injuries with more than 3 lost days (% of all)	39	39	39	[1,2,3]Eurostat (2018b)
B.3. Injuries with 1-3 lost days (%)	14	14	14	[1,2,3]Eurostat (2018b)
B.4. Injuries with no lost days (% of all)	Not included	Not included	47	[3]Eurostat (2018b)
B.5. Injury (more than 3 lost days) severity distribution	The Netherlands	Austria	Belgium	[1,2,3]Eurostat (2018a)
B.6. Disease incidence scenarios				[1]Compensated cases, [2]compensated + non-compensated + selected AF cases, [3]only AF cases
Fatal	3,261	525	3,261	
Non-fatal diseases	220,368	8,073	1,785,652	

A) High-level economic assumptions				
A.1. Discount rate (%)	3	1	5	[1,2,3]Drummond (2015)
A.2. Productivity growth rate (%)	1	0	2	[1]Tompa et al. (2017), [2,3]this study
B) Incidence inclusion and underreporting rate				
B.1. Injury underreporting rate (more than 3 days lost category) (%)	0	10	20	[1,2,3]This study
B.2. Injuries with more than 3 lost days (% of all)	39	39	39	[1,2,3]Eurostat (2018b)
B.3. Injuries with 1-3 lost days (%)	14	14	14	[1,2,3]Eurostat (2018b)
B.4. Injuries with no lost days (% of all)	Not included	Not included	47	[3]Eurostat (2018b)
B.5. Injury (more than 3 lost days) severity distribution	The Netherlands	Austria	Belgium	[1,2,3]Eurostat (2018a)
B.6. Disease incidence scenarios				[1]Compensated cases, [2]compensated + non-compensated + selected AF cases, [3]only AF cases
Fatal	3,261	525	3,261	
Non-fatal diseases	220,368	8,073	1,785,652	
B.7. Injury and disease incidence (both)	B.4 + B.6	B.4 + B.6	B.4 + B.6	

Scenarios	Baseline	Lower limit	Upper limit	Source [1] *refers to the baseline value,* [2] *to the lower limit and* [3] *to the upper limit*
C) Healthcare costs				
C.1. Healthcare costs of injuries and diseases (% change)	0	-82	81	[1,2,3]This study
D) Productivity losses				
D.1. Fringe/payroll benefit rate (%)	24	22	27	[1]Eurostat lc_lci_lev (2015)
D.2. Annual working days (for productivity/output loss)	178	170	174	[1]OECD (2015)
D.3. Productivity loss until the age of (years)	65	60	70	[1,2,3]This study
D.4. Wage-replacement rate (%)	80	70	90	[1,2,3]This study
D.5. Consider presenteeism effect for x % of cases	90	80	100	[1]Safe Work Australia (2015), [2,3]this study
D.6. Average informal care time for permanent injuries (days)	225	183	550	[1]Safe Work Australia (2015), [2,3]this study
D.7. Average informal care time for permanent diseases (days)	190	183	550	[1]Safe Work Australia (2015), [2,3]this study
D.8. Average earnings loss of permanent disability cases (%)	35	33	38	[1,2,3]Tompa et al. (2014)
E) Administrative costs				
E.1. Healthcare insurance administration costs (%)	4	0	10	[1,2,3]This study
E.2. Other insurance administration costs (%)	10	0	15	[1]Achmea (2015), [2,3]this study
F) Intangible costs				
F.1. Monetary value of a QALY (EUR)	41,096	27,397	61,644	[1,2,3]NICE (2013)
F.2. Loss of QALY range for injuries and diseases	Median	Low	High	[1,2,3]HSE (2011), p. 45-50

Table 2.1.6d: Model parameters for sensitivity analysis for Italy

Scenarios	Baseline	Lower limit	Upper limit	Source [1] refers to the baseline value, [2] to the lower limit and [3] to the upper limit
A) High-level economic assumptions				
A.1. Discount rate (%)	3	1	5	[1,2,3]Drummond (2015)
A.2. Productivity growth rate (%)	1	0	2	[1]Tompa et al. (2017), [2,3]this study
B) Incidence inclusion and underreporting rate				
B.1. Injury underreporting rate (more than 3 days lost category) (%)	272	191	353	[1,2,3]This study
B.2. Injuries with more than 3 lost days (% of all)	76	76	76	[1,2,3]Eurostat (2018b)
B.3. Injuries with 1-3 lost days (%)	11	11	11	[1,2,3]Eurostat (2018b)
B.4. Injuries with no lost days (% of all)	Not included	Not included	13	[3]Eurostat (2018b)
B.5. Injury (more than 3 lost days) severity distribution	Italy	Austria	Belgium	[1,2,3]Eurostat (2018a)
B.6. Disease incidence scenarios				[1]Compensated cases, [2]compensated + non-compensated + selected AF cases, [3]only AF cases
Fatal	10,526	1,255	10,526	
Non-fatal diseases	638,448	19,314	5,182,938	
B.7. Injury and disease incidence (both)	B.4 + B.6	B.4 + B.6	B.4 + B.6	
C) Healthcare costs				
C.1. Healthcare costs of injuries and diseases (% change)	0	-82	81	[1,2,3]This study
D) Productivity losses				
D.1. Fringe/payroll benefit rate (%)	28	28	28	[1]Eurostat lc_lci_lev (2015)
D.2. Annual working days (for productivity/output loss)	215	170	174	[1]OECD (2015)
D.3. Productivity loss until the age of (years)	65	60	70	[1,2,3]This study
D.4. Wage-replacement rate (%)	80	70	90	[1,2,3]This study
D.5. Consider presenteeism effect for x % of cases	90	80	100	[1]Safe Work Australia (2015), [2,3]this study
D.6. Average informal care time for permanent injuries (days)	225	183	550	[1]Safe Work Australia (2015), [2,3]this study
D.7. Average informal care time for permanent diseases (days)	190	183	550	[1]Safe Work Australia (2015), [2,3]this study
D.8. Average earnings loss of permanent disability cases (%)	35	33	38	[1,2,3]Tompa et al. (2014)
E) Administrative costs				
E.1. Healthcare insurance administration costs (%)	5	0	10	[1,2,3]This study
E.2. Other insurance administration costs (%)	12	0	15	[1]INAIL (2015), [2,3]this study
F) Intangible costs				
F.1. Monetary value of a QALY (EUR)	41,096	27,397	61,644	[1,2,3]NICE (2013)
F.2. Loss of QALY range for injuries and diseases	Median	Low	High	[1,2,3]HSE (2011), p. 45-50

Table 2.1.6e: Model parameters for sensitivity analysis for Poland

Scenarios	Baseline	Lower limit	Upper limit	Source [1] refers to the baseline value, [2] to the lower limit and [3] to the upper limit
A) High-level economic assumptions				
A.1. Discount rate (%)	3	1	5	[1,2,3]Drummond (2015)
A.2. Productivity growth rate (%)	1	0	2	[1]Tompa et al. (2017), [2,3]this study
B) Incidence inclusion and underreporting rate				
B.1. Injury underreporting rate (more than 3 days lost category) (%)	692	519	864	[1,2,3]This study
B.2. Injuries with more than 3 lost days (% of all)	84	84	84%	[1,2,3]Eurostat (2018b)
B.3. Injuries with 1-3 lost days (%)	6	6	6	[1,2,3]Eurostat (2018b)
B.4. Injuries with no lost days (% of all)	Not included	Not included	10	[3]Eurostat (2018b)
B.5. Injury (more than 3 lost days) severity distribution ([a])	Italy	Austria	Belgium	[1,2,3]Eurostat (2018a)
B.6. Disease incidence scenarios				[1]Compensated cases, [2]compensated + non-compensated + selected AF cases, [3]only AF cases
Fatal	4,663	135	4,663	
Non-fatal diseases	454,090	2,351	4,078,383	
B.7. Injury and disease incidence (both)	B.4 + B.6	B.4 + B.6	B.4 + B.6	
C) Healthcare costs				
C.1. Healthcare costs of injuries and diseases (% change)	0	-82	81	[1,2,3]This study
D) Productivity losses				
D.1. Fringe/payroll benefit rate (%)	19	17	29	[1]Eurostat lc_lci_lev (2015)
D.2. Annual working days (for productivity/output loss)	245	170	174	[1]OECD (2015)
D.3. Productivity loss until the age of (years)	65	60	70	[1,2,3]This study
D.4. Wage-replacement rate (%)	80	70	90	[1,2,3]This study
D.5. Consider presenteeism effect for x % of cases	90	80	100	[1]Safe Work Australia (2015), [2,3]this study
D.6. Average informal care time for permanent injuries (days)	225	1836	550	[1]Safe Work Australia (2015), [2,3]this study
D.7. Average informal care time for permanent diseases (days)	190	183	550	[1]Safe Work Australia (2015), [2,3]this study
D.8. Average earnings loss of permanent disability cases (%)	35	33	38	[1,2,3]Tompa et al. (2014)
E) Administrative costs				
E.1. Healthcare insurance administration costs (%)	1	0	10	[1,2,3]This study
E.2. Other insurance administration costs (%)	10	0	15	[1]DGUV (2015), [2,3]this study
F) Intangible costs				
F.1. Monetary value of a QALY (EUR)	41,096	27,397	61,644	[1,2,3]NICE (2013)
F.2. Loss of QALY range for injuries and diseases	Median	Low	High	[1,2,3]HSE (2011), p. 45-50

([a]) Italy data were used to estimate Poland's injury severity distribution (> 3 lost days), since no data were available from Poland.

2.2 Results: bottom-up model

2.2.1 Cases by country

We begin with a presentation of the counts of injury and disease cases stratified by sex and by fatal versus non-fatal cases. Cases per employed person are also presented, to provide a basis for comparison between countries. Table 2.2.1a provides counts of injury cases. The highest number of non-fatal work injury cases per 100,000 employed persons is in Italy, at 5,602, followed by Poland, at 4,338, Germany, at 2,883, Finland, at 2,603, and finally the Netherlands, at 1,201. The ranking for fatal work injuries is: Italy, at 2.4, Poland, at 1.9, Finland, at 1.4, Germany, at 1.1, and the Netherlands, at 0.4. The distributions of injuries by sex vary slightly by country, with women representing the lowest proportion of cases in Germany, at 26 %, and the highest in Poland, at 36 %.

Table 2.2.1a: Incidence of work-related injuries in 2015

Country	Sex	Work-related non-fatal injuries (1-3 lost days)	Work-related non-fatal injuries (> 3 lost days)	Work-related fatal injuries	Total injuries	% of total	Non-fatal injuries per 100,000	Fatal injuries per 100,000
Finland	Male	14,358	28,261	31	42,650	67		
	Female	7,003	13,784	4	20,791	33		
	Total	**21,362**	**42,045**	**35**	**63,442**		**2,603**	**1.4**
Germany	Male	232,164	625,057	421	857,642	74		
	Female	81,695	219,949	29	301,673	26		
	Total	**313,859**	**845,005**	**450**	**1,159,315**		**2,883**	**1.1**
The Netherlands	Male	17,476	47,051	35	64,563	65		
	Female	9,574	25,777	0	35,352	35		
	Total	**27,051**	**72,829**	**35**	**99,915**		**1,201**	**0.4**
Italy	Male	115,848	801,285	514	917,648	73		
	Female	43,055	297,799	29	340,883	27		
	Total	**158,904**	**1,099,084**	**543**	**1,258,530**		**5,602**	**2.4**
Poland	Male	31,406	413,512	285	445,203	64		
	Female	17,818	234,605	16	252,439	36		
	Total	**49,224**	**648,117**	**301**	**697,642**		**4,338**	**1.9**

Sources: ESAW 2015 and LFS 2013 (Eurostat), adjusted for underreporting as described in section 2.1.1.

Table 2.2.1b: Incidence of work-related diseases in 2015

Country	Sex	Work-related non-fatal diseases	Work-related fatal diseases	Total diseases	% of total	Non-fatal diseases per 100,000	Fatal diseases per 100,000
Finland	Male	38,086	397	38,483	56		
	Female	29,711	232	29,943	44		
	Total	**67,797**	**629**	**68,425**		**2,808**	**26**
Germany	Male	620,004	8,453	628,457	57		
	Female	468,789	5,471	474,259	43		
	Total	**1,088,793**	**13,923**	**1,102,716**		**2,742**	**35**
The Netherlands	Male	127,634	2,011	129,644	58		
	Female	92,735	1,250	93,985	42		
	Total	**220,368**	**3,261**	**223,629**		**2,688**	**39**
Italy	Male	393,403	7,065	400,468	62		
	Female	245,045	3,460	248,505	38		
	Total	**638,448**	**10,526**	**648,973**		**2,889**	**47**
Poland	Male	272,667	2,870	275,537	60		
	Female	181,423	1,793	183,216	40		
	Total	**454,090**	**4,663**	**458,753**		**2,852**	**29**

Source: IHME database, case counts and attributable fractions as described in section 2.1.1.

Table 2.2.1b presents counts of disease cases. The highest rate of non-fatal diseases per 100,000 workers is in Italy, at 2,889, followed by Poland, at 2,852, Finland, at 2,808, Germany, at 2,742, and finally the Netherlands, at 2,688. The ranking for fatal diseases is: Italy, at 47, the Netherlands, at 39, Germany, at 35, Poland, at 29, and Finland, at 26. The distribution of diseases by sex varies slightly by country, with women representing the lowest proportion of cases in Italy, at 38 %, and the highest in Finland, at 44 %.

2.2.2 Costs by country

- **Total costs**

Table 2.2.2a presents the total costs of work-related injuries and diseases for the baseline scenario for the five countries. In the table, costs are presented in the three broad categories of direct, indirect and intangible costs. In addition, the percentage of the total cost that each category represents is presented for each of these categories. Finally, per case costs and the percentage of the total cost per GDP for each country are presented to facilitate the comparison of costs across countries.

For all five countries, indirect costs represent the largest proportion of total costs (with the exception of Poland), ranging from a high of 72 % for Finland to a low of approximately 45 % for Poland. Intangible costs account for the second highest proportion, ranging from a high of 51 % for Poland to a low of 20 % for Finland and the Netherlands. Note that, because we use the same monetary value for a year of perfect health, the relative value of intangible costs for Poland is disproportionately high compared with the direct and indirect costs. This is because the price weights for Poland used to estimate direct and indirect costs were generally lower than for the other four countries in this study. Direct costs range from 8 % for Finland to 4 % for Poland.

Average per case costing is highest for the Netherlands, at EUR 73,410, followed by Italy, at EUR 54,964, Germany, at EUR 47,360, Finland, at EUR 45,816, and finally Poland, at EUR 37,860. In contrast, the total costs as a percentage of GDP are highest for Poland, at 10.2 %, followed by Italy, at 6.3 %, Germany and the Netherlands, at 3.5 %, and finally Finland, at 2.9 %. In terms of costs per employed person, the value is highest for Italy, at EUR 4,667, followed by the Netherlands, at EUR 2,855, Poland, at EUR 2,722, Germany, at EUR 2,664, and finally Finland, at EUR 2,479.

In what follows, we look at direct, indirect and intangible costs separately for each of the five countries. These costs may vary on a per case and a per employed person basis for a variety of reasons. Underreporting may vary by country (even with our efforts to address this issue) and price weight for resources may vary. The severity of cases may also vary, as well as age at the time of the work-related injury (these factors have implications for the magnitude of health-related quality of life losses). Severity may vary due to the level of prevention efforts, as well as the industrial mix. The latter has a bearing on the inherent underlying risk levels. The age distribution of the employed persons may also vary, and thus the age at the time of work-related injury.

Table 2.2.2b and Table 2.2.2c present the total costs for work-related injuries and diseases separately. For injuries, average per case costs are highest for Italy, at EUR 57,814, followed by the Netherlands, at EUR 54,861, Poland, at EUR 35,359, Germany, at EUR 25,831, and finally Finland, at EUR 25,601. For disease, average per case costs are highest for the Netherlands, at EUR 81,697, followed by Germany, at EUR 69,993, Finland, at EUR 64,558, Italy, at EUR 49,437, and finally Poland, at EUR 41,662.

Table 2.2.2a: Total economic burden for work-related injuries and diseases (costs are in million EUR)

Country	Sex	Total number of cases	Direct costs	Direct costs, % total	Indirect costs	Indirect costs, % total	Intangible costs	Intangible costs, % total	Total economic burden	Per case costs	% of GDP	Per employed person costs	Cases per 100,000	GDP per employed person
Finland	Male	81,133	306		2,781		670		3,757					
	Female	50,734	178		1,581		526		2,284					
	Total	**131,867**	**484**	**8**	**4,362**	**72**	**1,196**	**20**	**6,042**	**45,816**	**2.9**	**2,479**	**5,411**	**86,016**
Germany	Male	1,486,099	7,469		46,981		16,259		70,708					
	Female	775,932	3,446		23,677		9,298		36,420					
	Total	**2,262,031**	**10,914**	**10**	**70,658**	**66**	**25,557**	**24**	**107,129**	**47,360**	**3.5**	**2,664**	**5,625**	**75,692**
The Nether-lands	Male	194,207	1,365		9,896		3,178		14,440					
	Female	129,337	771		6,571		1,969		9,311					
	Total	**323,544**	**2,137**	**9**	**16,468**	**69**	**5,147**	**22**	**23,751**	**73,410**	**3.5**	**2,855**	**3,889**	**82,159**
Italy	Male	1,318,116	6,167		46,175		27,202		79,543					
	Female	589,388	2,324		12,786		10,191		25,300					
	Total	**1,907,504**	**8,491**	**8**	**58,961**	**56**	**37,392**	**36**	**104,844**	**54,964**	**6.3**	**4,667**	**8,491**	**73,565**
Poland	Male	720,740	1,213		11,821		14,334		27,368					
	Female	435,655	669		7,766		7,977		16,412					
	Total	**1,156,394**	**1,882**	**4**	**19,588**	**45**	**22,311**	**51**	**43,781**	**37,860**	**10.2**	**2,722**	**7,190**	**26,738**

Table 2.2.2b: Total economic burden for work-related injuries (costs are in million EUR)

Country	Sex	All cases	Direct costs	Direct costs, % total	Indirect costs	Indirect costs, % total	Intangible costs	Intangible costs, % total	Total economic burden	Per case costs	% of GDP	Per employed person costs	Cases per 100,000	GDP per employed person
Finland	Male	42,650	126		831		224		1,181					
	Female	20,791	58		279		105		443					
	Total	**63,442**	**184**	**11**	**1,111**	**68**	**329**	**20**	**1,624**	**25,601**	**0.8**	**667**	**2,603**	**86,016**
Germany	Male	857,642	4,052		13,788		5,225		23,065					
	Female	301,673	1,383		3,814		1,685		6,882					
	Total	**1,159,315**	**5,435**	**18**	**17,603**	**59**	**6,909**	**23**	**29,946**	**25,831**	**1.0**	**745**	**2,883**	**75,692**
The Nether-lands	Male	64,563	386		2,398		766		3,550					
	Female	35,352	211		1,308		412		1,931					
	Total	**99,915**	**598**	**11**	**3,706**	**68**	**1,178**	**21**	**5,481**	**54,861**	**0.8**	**659**	**1,201**	**82,159**
Italy	Male	917,648	4,145		34,382		18,331		56,858					
	Female	340,883	1,392		8,268		6,242		15,903					
	Total	**1,258,530**	**5,537**	**8**	**42,650**	**59**	**24,574**	**34**	**72,761**	**57,814**	**4.4**	**3,239**	**5,602**	**73,565**
Poland	Male	445,203	773		6,838		8,245		15,856					
	Female	252,439	400		3,834		4,577		8,812					
	Total	**697,642**	**1,173**	**5**	**10,672**	**43**	**12,823**	**52**	**24,668**	**35,359**	**5.7**	**1,534**	**4,338**	**26,738**

Table 2.2.2c: Total economic burden for work-related diseases (costs are in million EUR)

Country	Sex	All cases	Direct costs	Direct costs, % total	Indirect costs	Indirect costs, % total	Intangible costs	Intangible costs, % total	Total economic burden	Per case costs	% of GDP	Per employed person costs	Cases per 100,000	GDP per employed person
Finland	Male	38,483	180		1,949		446		2,576					
	Female	29,943	119		1,302		421		1,841					
	Total	**68,425**	**300**	**7**	**3,251**	**74**	**867**	**20**	**4,417**	**64,558**	**2.1**	**1,813**	**2,808**	**86,016**
Germany	Male	628,457	3,417		33,193		11,034		47,644					
	Female	474,259	2,063		19,863		7,613		29,539					
	Total	**1,102,716**	**5,480**	**7**	**53,055**	**69**	**18,647**	**24**	**77,182**	**69,993**	**2.5**	**1,919**	**2,742**	**75,692**
The Nether-lands	Male	129,644	979		7,499		2,412		10,890					
	Female	93,985	560		5,263		1,557		7,380					
	Total	**223,629**	**1,539**	**8**	**12,761**	**70**	**3,969**	**22**	**18,270**	**81,697**	**2.7**	**2,196**	**2,688**	**82,159**
Italy	Male	400,468	2,022		11,793		8,870		22,686					
	Female	248,505	932		4,518		3,948		9,398					
	Total	**648,973**	**2,954**	**9**	**16,311**	**51**	**12,818**	**40**	**32,083**	**49,437**	**1.9**	**1,428**	**2,889**	**73,565**
Poland	Male	275,537	441		4,983		6,089		11,512					
	Female	183,216	268		3,932		3,400		7,600					
	Total	**458,753**	**709**	**4**	**8,915**	**47**	**9,489**	**50**	**19,113**	**41,662**	**4.4**	**1,188**	**2,852**	**26,738**

- **Direct costs: total**

Table 2.2.2d presents the direct costs for work-related injuries and diseases together. Per case direct costs are highest for the Netherlands, at EUR 6,604, followed by Germany, at EUR 4,825, Italy, at EUR 4,825, Finland, at EUR 3,667, and finally Poland, at EUR 1,627.

Table 2.2.2d: Direct costs for work-related injuries and diseases (costs are in million EUR)

Country	Sex	All cases	Direct costs	Per case costs	% of GDP	Per employed person
Finland	Male	81,133	306			
	Female	50,734	178			
	Total	**131,867**	**484**	**3,667**	**0.231**	**198**
Germany	Male	1,486,099	7,469			
	Female	775,932	3,446			
	Total	**2,262,031**	**10,914**	**4,825**	**0.359**	**271**
The Netherlands	Male	194,207	1,365			
	Female	129,337	771			
	Total	**323,544**	**2,137**	**6,604**	**0.313**	**257**
Italy	Male	1,317,049	6,167			
	Female	588,992	2,324			
	Total	**1,906,041**	**8,491**	**4,451**	**0.514**	**378**
Poland	Male	719,418	1,213			
	Female	434,905	669			
	Total	**1,154,324**	**1,882**	**1,627**	**0.438**	**117**

- **Direct costs: injuries**

Note that the formal healthcare costs for injuries were proxied for all countries using the data for Italy. The healthcare cost for each type of injury for Italy was adjusted for other countries using price indices for hospital services based on 'International Comparisons of Health Prices and Volumes' (Lorenzoni & Koechlin, 2017), so variations in per case costing are due to variations in the price indices, as well as differences in the mix of injuries. Table 2.2.2e provides details. Per case direct costs for injuries range from a high of EUR 5,980 for the Netherlands to a low of EUR 1,681 for Poland. On a per employed person level, the range is from a high of EUR 246 for Italy to a low of EUR 72 for the Netherlands.

Table 2.2.2e: Direct costs for work-related injuries (costs are in million EUR)

Country	Sex	Total number of injuries	Direct costs	Per case costs	% of GDP	Per employed person costs
Finland	Male	42,650	126			
	Female	20,791	58			
	Total	**63,442**	**184**	**2,900**	**0.09**	**75**
Germany	Male	857,642	4,052			
	Female	301,673	1,383			
	Total	**1,159,315**	**5,435**	**4,688**	**0.18**	**135**

Country	Sex	Total number of injuries	Direct costs	Per case costs	% of GDP	Per employed person costs
The Netherlands	Male	64,563	386			
	Female	35,352	211			
	Total	**99,915**	**598**	**5,980**	**0.09**	**72**
Italy	Male	917,648	4,145			
	Female	340,883	1,392			
	Total	**1,258,530**	**5,537**	**4,399**	**0.34**	**246**
Poland	Male	445,203	773			
	Female	252,439	400			
	Total	**697,642**	**1,173**	**1,681**	**0.27**	**73**

- **Direct costs: diseases**

As with injuries, formal healthcare costs for diseases were proxied for all countries using price indices for hospital services based on 'International Comparisons of Health Prices and Volumes', using reference values from Germany. So variations in per case costing are due to variations in the price indices, as well as differences in the mix of injuries. Table 2.2.2f provides details. Per case costs for diseases are higher than for injuries, ranging from a high of EUR 6,883 for the Netherlands to a low of EUR 1,545 for Poland. Per employed person costs range from a high of EUR 185 for the Netherlands to a low of EUR 44 for Poland. As is apparent from Table 2.2.2f, Poland is at the bottom of the cost ranking in all cases due to lower prices in that country.

Table 2.2.2f: Direct costs for work-related diseases (costs are in million EUR)

Country	Sex	Total number of disease cases	Direct costs	Per case costs	% of GDP	Per employed person costs
Finland	Male	38,483	180			
	Female	29,943	119			
	Total	**68,425**	**300**	**4,379**	**0.143**	**123**
Germany	Male	628,457	3,417			
	Female	474,259	2,063			
	Total	**1,102,716**	**5,480**	**4,969**	**0.180**	**136**
The Netherlands	Male	129,644	979			
	Female	93,985	560			
	Total	**223,629**	**1,539**	**6,883**	**0.225**	**185**
Italy	Male	400,468	2,022			
	Female	248,505	932			
	Total	**648,973**	**2,954**	**4,552**	**0.179**	**131**
Poland	Male	275,537	441			
	Female	183,216	268			
	Total	**458,753**	**709**	**1,545**	**0.165**	**44**

- **Direct costs: subsets**

Table 2.2.2g provides subsets of direct costs for work-related injuries and diseases. The largest subset of direct costs is related to formal healthcare costs, followed by informal caregiver costs and out-of-pocket costs, and finally healthcare insurance administrative costs.

Table 2.2.2g: Direct cost subsections of work-related injuries and diseases (costs are in million EUR)

Country		Formal healthcare costs	Healthcare insurance administrative costs	Informal caregiver costs	Out-of-pocket costs	Total
Finland	Total	327	10	87	60	484
	%	**68**	**2**	**18**	**13**	**100**
Germany	Total	7,230	388	2,343	954	10,914
	%	**66**	**4**	**21**	**9**	**100**
The Netherlands	Total	1,276	50	623	188	2,137
	%	**60**	**2**	**29**	**9**	**100**
Italy	Total	5,199	99	2,143	1,050	8,491
	%	**61**	**1**	**25**	**12**	**100**
Poland	Total	1,113	11	502	256	1,882
	%	**59**	**1**	**27**	**14**	**100**

- **Indirect costs: total**

As noted earlier, indirect costs account for the largest proportion of the total costs for four of the five countries (the exception being Poland). Table 2.2.2h provides details of indirect costs for work-related injuries and diseases. The highest per case indirect costs are incurred by the Netherlands, at EUR 50,898, followed by Finland, at EUR 33,078, then Germany, at EUR 31,237, Italy, at EUR 30,910, and finally Poland, at EUR 16,939.

Table 2.2.2h: Indirect costs for work-related injuries and diseases (costs are in million EUR)

Country	**Sex**	**All cases**	**Indirect costs**	**Per case costs**	**% of GDP**	**Per employed person costs**
Finland	Male	81,133	2,781			
	Female	50,734	1,581			
	Total	131,867	**4,362**	**33,078**	**2.1**	**1,790**
Germany	Male	1,486,099	46,981			
	Female	775,932	23,677			

Country	Sex	All cases	Indirect costs	Per case costs	% of GDP	Per employe d person costs
	Total	2,262,031	**70,658**	**31,237**	**2.3**	**1,757**
The Netherlands	Male	194,207	9,896			
	Female	129,337	6,571			
	Total	323,544	**16,468**	**50,898**	**2.4**	**1,980**
Italy	Male	1,318,116	46,175			
	Female	589,388	12,786			
	Total	1,907,504	**58,961**	**30,910**	**3.6**	**2,625**
Poland	Male	720,740	11,821			
	Female	435,655	7,766			
	Total	1,156,394	**19,588**	**16,939**	**4.6**	**1,218**

- ### Indirect costs: injuries

Indirect costs for injuries range from a high of EUR 37,094 for the Netherlands to a low of EUR 15,298 for Finland. Per employed person costs range from a high of EUR 1,899 for Italy to a low of EUR 456 for Finland.

Table 2.2.2i: Indirect costs for work-related injuries (costs are in million EUR)

Country	Sex	Total injuries	Indirect costs	Per case costs	% of GDP	Per employed person costs
Finland	Male	42,650	831			
	Female	20,791	279			
	Total	**63,442**	**1,111**	**17,510**	**0.53**	**456**
Germany	Male	857,642	13,788			
	Female	301,673	3,814			
	Total	**1,159,315**	**17,603**	**15,184**	**0.58**	**438**
The Netherlands	Male	64,563	2,398			
	Female	35,352	1,308			
	Total	**99,915**	**3,706**	**37,094**	**0.54**	**446**
Italy	Male	917,648	34,382			
	Female	340,883	8,268			
	Total	**1,258,530**	**42,650**	**33,889**	**2.58**	**1,899**
Poland	Male	445,203	6,838			
	Female	252,439	3,834			
	Total	**697,642**	**10,672**	**15,298**	**2.48**	**664**

Indirect costs: diseases

Indirect costs per case for diseases are much higher than for injuries. This is because fatalities make up a larger proportion of the total number of cases, probably due to an underreporting of non-fatal cases. Fatal cases result in the loss of a remaining standard life expectancy, which includes loss of labour market activity over that period (as well as loss of home production), so costs are generally higher for fatal cases than for non-fatal cases. Indirect costs range from a high of EUR 67,065 per case for the Netherlands to a low of EUR 19,434 for Poland. Per employed person costs range from a high of EUR 1,534 for the Netherlands to a low of EUR 554 for Poland.

Table 2.2.2j: Indirect costs for diseases (costs are in million EUR)

Country	Sex	Total disease	Indirect costs	Per case costs	% of GDP	Per employed person costs
Finland	Male	38,483	1,949			
	Female	29,943	1,302			
	Total	**68,425**	**3,251**	**47,512**	**1.55**	**1,334**
Germany	Male	628,457	33,193			
	Female	474,259	19,863			
	Total	**1,102,716**	**53,055**	**48,113**	**1.74**	**1,319**
The Netherlands	Male	129,644	7,499			
	Female	93,985	5,263			
	Total	**223,629**	**12,761**	**57,065**	**1.87**	**1,534**
Italy	Male	400,468	11,793			
	Female	248,505	4,518			
	Total	**648,973**	**16,311**	**25,133**	**0.99**	**726**
Poland	Male	275,537	4,983			
	Female	183,216	3,932			
	Total	**458,753**	**8,915**	**19,434**	**2.07**	**554**

Indirect costs: subsets

Table 2.2.2k provides subsets of indirect costs for work-related injuries and diseases. The largest subset of indirect costs is related to market output losses and home production losses, followed by presenteeism, fringe/payroll benefits, administrative costs and finally employer adjustment costs.

Table 2.2.2k: Indirect cost subsets for work-related injuries and diseases (costs are in million EUR)

Country		Market output losses	Fringe/payroll benefit costs	Employer adjustment costs	Other insurance administrative costs	Home production losses	Presenteeism	Total costs
Finland	Total	929	205	41	92	1,213	351	4,362
	%	**21**	**5**	**1**	**2**	**28**	**8**	**100**

Country		Market output losses	Fringe/payroll benefit costs	Employer adjustment costs	Other insurance administrative costs	Home production losses	Presenteeism	Total costs
Germany	Total	18,804	4,417	773	1,885	17,519	7,164	70,658
	%	**27**	**6**	**1**	**3**	**25**	**10**	**100**
The Netherlands	Total	3,818	921	159	437	5,281	1,987	16,468
	%	**23**	**6**	**1**	**3**	**32**	**12**	**100**
Italy	Total	7,640	2,121	483	949	2,913	1,841	58,961
	%	**13**	**4**	**1**	**2**	**5**	**3**	**100**
Poland	Total	2,264	421	157	218	2,697	709	19,588
	%	**12**	**2**	**1**	**1**	**14**	**4**	**100**

- **Intangible costs: total**

Intangible costs refer to the monetary values of health-related quality of life losses as measured by QALYs. The price weight we used for 1 QALY was EUR 41,000 for all five countries. The highest total intangible costs are for Poland, at EUR 19,294, followed by Italy, at EUR 19,603, the Netherlands, at EUR 15,908, Germany, at EUR 11,298, and finally Finland, at EUR 9,071.

Table 2.2.2l: Intangible costs for work-related injuries and diseases (costs are in million EUR)

Country	Sex	All cases	Lost QALYs	Intangible costs	Per case cost	% of GDP	Per employed person costs
Finland	Male	81,133	16,315	670			
	Female	50,734	12,790	526			
	Total	**131,867**	**29,105**	**1,196**	**9,071**	**0.57**	**491**
Germany	Male	1,486,099	395,630	16,259			
	Female	775,932	226,246	9,298			
	Total	**2,262,031**	**621,876**	**25,557**	**11,298**	**0.84**	**636**
The Netherlands	Male	194,207	77,336	3,178			
	Female	129,337	47,908	1,969			
	Total	**323,544**	**125,244**	**5,147**	**15,908**	**0.75**	**619**
Italy	Male	1,318,116	661,910	27,202			
	Female	589,388	247,971	10,191			
	Total	**1,907,504**	**909,881**	**37,392**	**19,603**	**2.26**	**1,664**

Country	Sex	All cases	Lost QALYs	Intangible costs	Per case cost	% of GDP	Per employed person costs
Poland	Male	720,740	348,793	14,334			
	Female	435,655	194,115	7,977			
	Total	**1,156,394**	**542,908**	**22,311**	**19,294**	**5.19**	**1,387**

- **Intangible costs: injuries**

Surprisingly, for injuries the highest costs per case are for Italy, at EUR 19,526, and the lowest are for Finland, at EUR 5,192. Per employed person, indirect costs range from a high of EUR 1,094 for Italy to a low of EUR 135 for Finland.

Table 2.2.2m: Intangible costs for injuries (costs are in million EUR)

Country	Sex	Total injuries	Lost QALYs	Monetary loss HRQL*	Per case costs	% of GDP	Per employed person costs
Finland	Male	42,650	5,458	224			
	Female	20,791	2,557	105			
	Total	**63,442**	**8,015**	**329**	**5,192**	**0.2**	**135**
Germany	Male	857,642	127,131	5,225			
	Female	301,673	40,993	1,685			
	Total	**1,159,315**	**168,125**	**6,909**	**5,960**	**0.2**	**172**
The Netherlands	Male	64,563	18,643	766			
	Female	35,352	10,016	412			
	Total	**99,915**	**28,659**	**1,178**	**11,788**	**0.2**	**142**
Italy	Male	917,648	446,066	18,331			
	Female	340,883	151,900	6,242			
	Total	**1,258,530**	**597,966**	**24,574**	**19,526**	**1.5**	**1,094**
Poland	Male	445,203	200,638	8,245			
	Female	252,439	111,379	4,577			
	Total	**697,642**	**312,017**	**12,823**	**18,380**	**3.0**	**797**

*Health-Related Quality of Life

- **Intangible costs: diseases**

For diseases, the highest cost per case is for Poland at EUR 20,684 and the lowest is for Finland, at EUR 12,667. Per employed person indirect costs range from a high of EUR 590 for Italy to a low of EUR 356 for Finland.

Table 2.2.2n: Intangible costs for diseases (costs are in million EUR)

Country	Sex	Total disease	Lost QALYs	Monetary loss HRQL*	Per case cost	% of GDP	Per employed person
Finland	Male	38,483	10,857	446			
	Female	29,943	10,233	421			
	Total	**68,425**	**21,090**	**867**	**12,667**	**0.41**	**356**
Germany	Male	628,457	268,499	11,034			
	Female	474,259	185,253	7,613			
	Total	**1,102,716**	**453,752**	**18,647**	**16,910**	**0.61**	**464**
The Netherlands	Male	129,644	58,693	2,412			
	Female	93,985	37,892	1,557			
	Total	**223,629**	**96,585**	**3,969**	**17,749**	**0.58**	**477**
Italy	Male	400,468	215,843	8,870			
	Female	248,505	96,071	3,948			
	Total	**648,973**	**311,915**	**12,818**	**19,752**	**0.78**	**571**
Poland	Male	275,537	148,155	6,089			
	Female	183,216	82,736	3,400			
	Total	**458,753**	**230,891**	**9,489**	**20,684**	**2.21**	**590**

*Health-Related Quality of Life

2.2.3 Costs by stakeholder

Table 2.2.3a presents the total costs for each country stratified by the three key stakeholders, namely the employer, the worker and the system/society. Note that an *ex post* approach was used to calculate these costs, similar to the approach used on the study by Safe Work Australia (2015). We focused on the percentage of total costs by stakeholder for comparison purposes. Across all five countries, workers bear the highest costs: the percentage of total costs ranges from a high of 79 % for Poland to a low of 61 % for Germany. Costs for employers account for the second highest cost category for all countries, ranging from a high of 22 % for Finland to a low of 11 % for Poland. System/societal costs represent the lowest proportion of the costs across the five countries, with a range of 19 % for Germany to a low of 10 % for Poland.

Table 2.2.3a: Economic burden of work-related injury and disease distribution by stakeholder (costs are in million EUR)

Country	Employer	%	Worker	%	System/society	%
Finland	1,325	22	3,800	63	916	15
Germany	21,534	20	64,813	61	20,782	19
The Netherlands	3,484	15	17,235	73	3,032	13
Italy	20,632	20	70,391	67	13,821	13
Poland	5,007	11	34,421	79	4,353	10

2.2.4 Sensitivity analyses

The range of parameters considered for sensitivity analyses were provided in the methods section 2.1. We reiterate that probabilistic sensitivity analysis was not possible, as distributional information on point estimates for much of the input data was not available. It is common practice in peer-reviewed and high-end grey literature to undertake single-variable sensitivity analysis in cost-of-illness/economic burden studies undertaken at country level. This was the case for the studies by Leigh (2011), Safe Work Australia (2015) and Tompa et al. (2017), to name just three of many.

The parameter that has the biggest impact on the overall result is the estimation of non-fatal disease cases using attributable fractions from the IHME (2016) for all types of non-fatal diseases. We used the IHME attributable fraction approach for only a subset of non-fatal diseases for our baseline estimates. When we use attributable fractions across all types of non-fatal diseases, the counts are substantially inflated and, as a result, the total burden for each country is increased substantially. In Table 2.2.4a we provide details of the counts by type of non-fatal disease by country, as estimated using the attributable fractions from the IHME. The table also shows the results of a comparison of the total counts identified using this method with the total from our baseline. The percentage changes in counts are also provided. The changes are substantial, ranging from a 798 % increase for Poland to a 538 % increase for Germany. The attributable fraction method of estimating occupational case counts is very different from the reported cases method or our mixed method used for the baseline. This dramatic increase in non-fatal disease counts increases the estimated economic burden for each country substantially. With this method, the percentage of GDP is highest for Poland, at 39.0 %, and lowest for Finland, at 12.5%. Whether or not these higher case counts and their higher related proportions of GDP, that is, higher economic burdens, are more robust than those calculated using our baseline method is difficult to discern. In this study, they will function as upper level bounds.. All values for these estimates are shown on the right side, at the bottom, of the tornado diagrams in Figure 2.2.4a to Figure 2.2.4e (identified as B6 and B7).

Table 2.2.4a: Non-fatal disease counts based on attributable fractions (based on IHME, 2016)

Type	Finland	Germany	The Netherlands	Italy	Poland
Communicable diseases	88,654	1,956,059	690,697	907,526	740,553
Nasopharynx cancer	0	1	0	1	0
Larynx cancer	17	480	127	741	149
Tracheal, bronchus and lung cancer	760	14,587	5,062	14,836	3,722
Non-melanoma skin cancer	334	2,988	617	3,451	1,540
Breast cancer	52	7	209	465	199
Ovarian cancer	32	0	112	504	100
Bladder cancer	74	1,564	424	2,375	643
Mesothelioma	108	1,481	646	1,719	279
Leukaemia	5	34	25	54	27
Other neoplasms	0	3	1	2	1
Circulatory diseases	988	11,225	3,959	9,146	7,793
Respiratory diseases — COPD	1,809	30,277	6,521	16,578	11,991
Respiratory diseases — pneumoconiosis	40	511	48	489	485
Respiratory diseases — asthma	2,992	19,514	6,896	14,692	26,537

Type	Finland	Germany	The Netherlands	Italy	Poland
Respiratory diseases — other	6	42	11	45	18
Digestive diseases	3,479	41,081	10,090	35,762	46,716
Neurological diseases	27,903	284,373	97,080	344,636	207,768
Mental disorders	58,206	245,726	149,753	529,221	233,643
Genitourinary diseases	4,575	54,901	13,398	43,685	38,520
Musculoskeletal disorders	58,230	526,575	181,586	558,623	397,551
Other non-communicable diseases	236,700	3,754,180	618,389	2,698,387	2,360,148
Total from attributable fractions	**484,966**	**11,614,036**	**1,785,652**	**5,182,938**	**4,078,383**
Total from baseline	**67,797**	**1,088,793**	**220,368**	**638,448**	**454,090**
% increase from baseline	**615**	**538**	**710**	**712**	**798**

Tornado diagrams are provided in Figures 2.2.4a to 2.2.4e. These diagrams provide a visualisation of the relative magnitude of impact of varying a single parameter within the sensitivity range identified. In the diagrams, each row represents a specific parameter that was varied to assess the sensitivity of the total economic burden (based on percentage GDP) to that parameter. The range of percentage GDP values is represented as a horizontal bar in blue to the left and orange to the right of the baseline value. Each range contains the low and high percentage values around the baseline value listed at the end of the bar representing the range. Each of these tornado diagrams is set out so that the parameter ranges that have a larger impact on economic burden, as measured by percentage GDP, are at the bottom. Non-fatal disease counts estimated using attributable fractions from the IHME are at the bottom, because these have the largest impact. In general, each country was affected differently by varying different parameters in the sensitivity analyses.

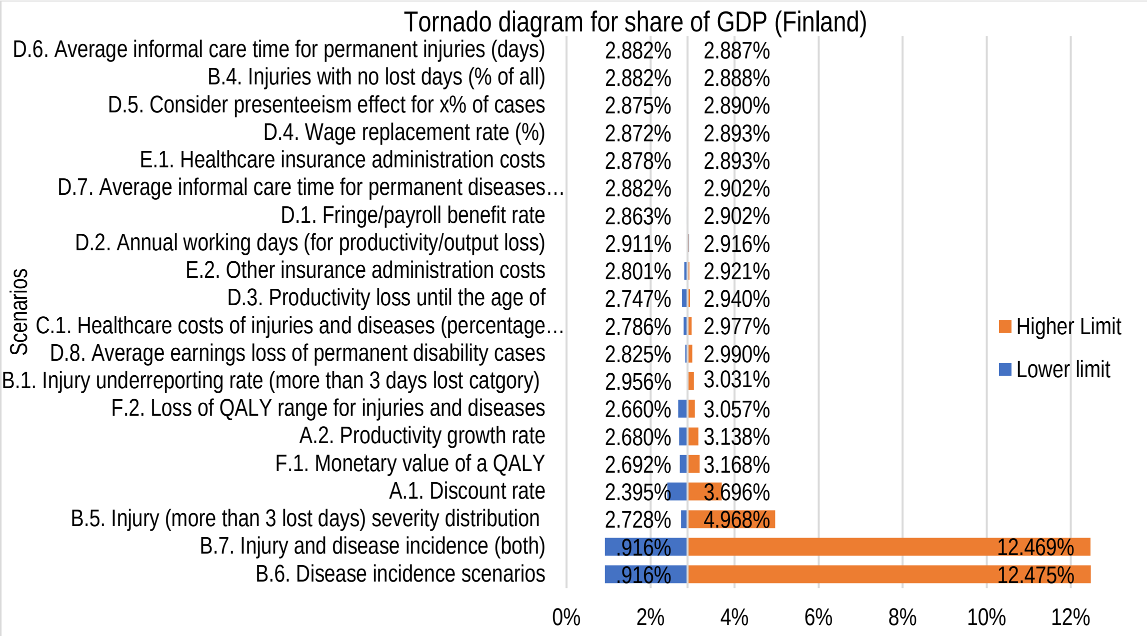
Excluding the attributable fraction sensitivity analysis (B6 and B7 at the bottom of the tornado diagram in Figure 2.2.4a), the three parameters with the largest impact for Finland are:

- B.5 (severity distribution of injuries resulting in greater than 3 days lost based on data from Belgium or the Netherlands, rather than Finland);
- A.1 (discount rates of 1 % or 5 %, rather than 3 %);
- F.1 (monetary value of a QALY of EUR 27,397 or EUR 61,644, rather than EUR 41,096).

The percentage of GDP ranges resulting from varying each of these parameters are as follows:

- for B.5: 2.7 % to 5.0 % of GDP;
- for A.1: 2.4 % to 3.7 % of GDP;
- for F.1: 2.7 % to 3.2 % of GDP.

Figure 2.2.4a: Sensitivity analysis for Finland



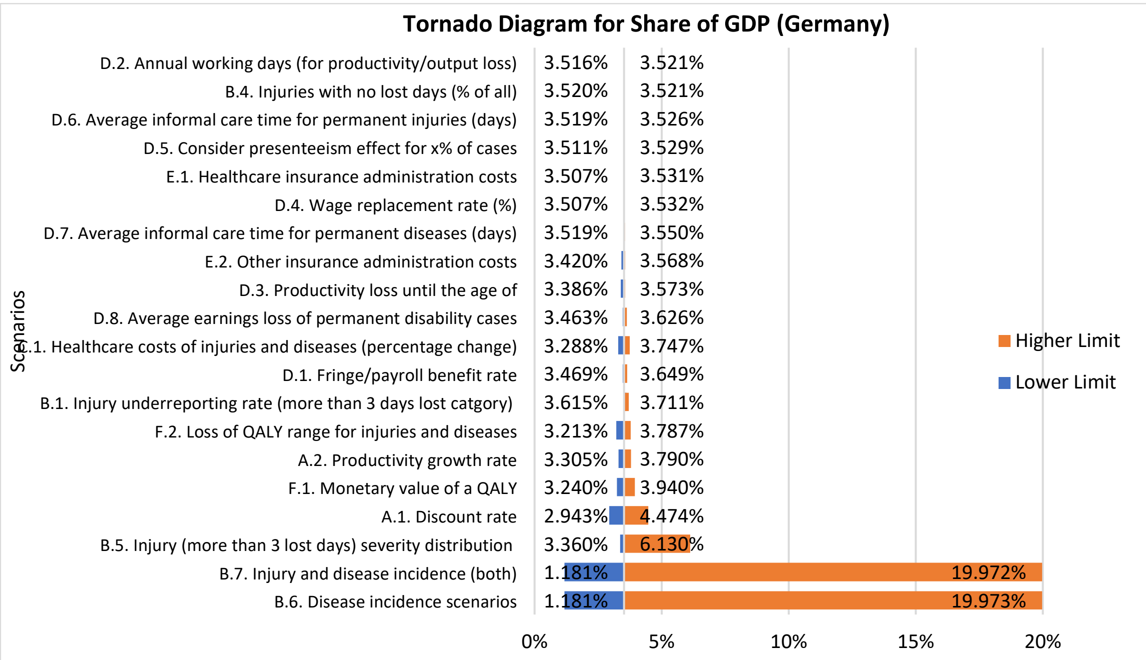
For Germany (see Figure 2.2.4b), the three parameters with the largest impact (after B6 and B7) are:

- B.5 (details noted above for Finland);
- A.1 (details noted above for Finland);
- F.1 (details noted above for Finland).

The percentage of GDP ranges resulting from varying each of these parameters are as follows:

- for B.5: 3.4 % to 6.1 % of GDP;
- for A.1: 2.9 % to 4.5 % of GDP;
- for F.1: 3.2 % to 3.9 % of GDP.

Figure 2.2.4b: Sensitivity analysis for Germany



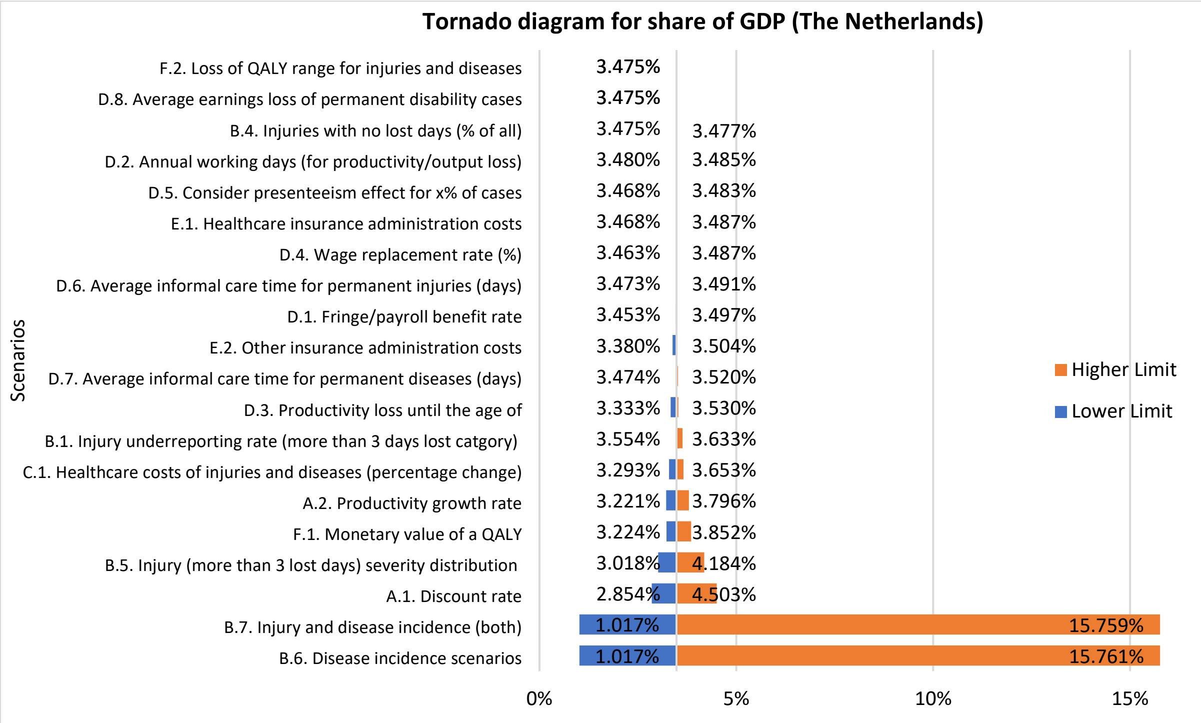
For the Netherlands (see Figure 2.2.4c), the three parameters with the largest impact (after B6 and B7) are:

- A.1 (details noted above for Finland);
- B.5 (details noted above for Finland);
- F.1 (details noted above for Finland).

The percentage of GDP ranges resulting from varying each of these parameters are as follows:

- for A.1: 2.9 % to 4.5 % of GDP;
- for B.5: 3.0 % to 4.2 % of GDP;
- for F.1: 3.2 % to 3.9 % of GDP.

Figure 2.2.4c: Sensitivity analysis for the Netherlands



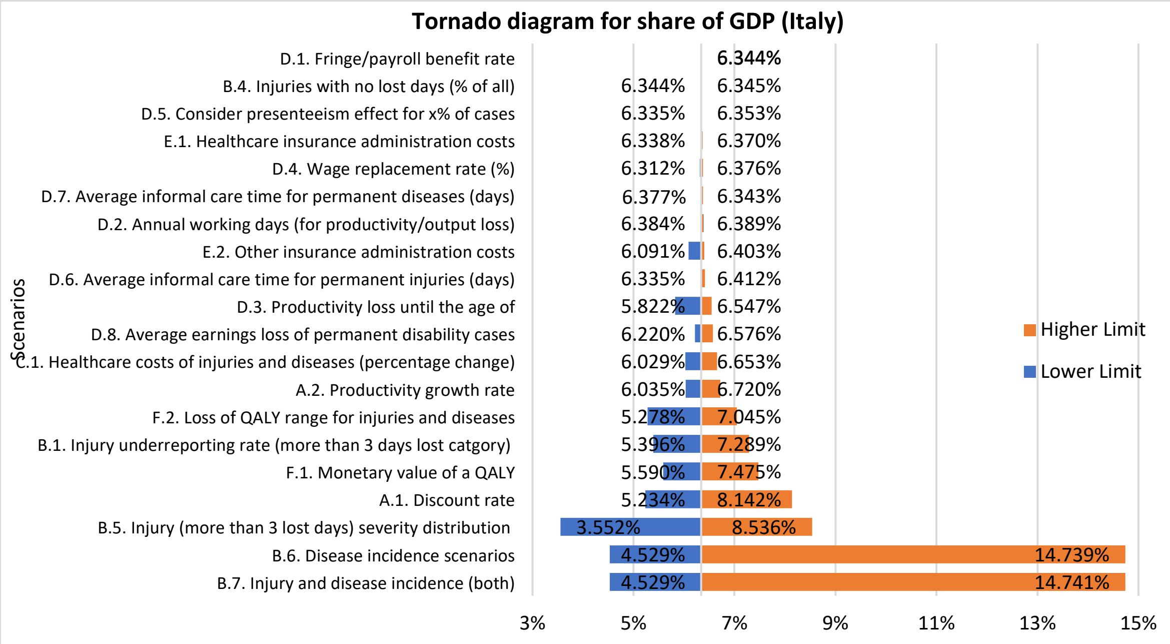
For Italy (see Figure 2.2.4d), the three parameters with the largest impact (after B6 and B7) are:

- B.5 (details noted above for Finland);
- A.1 (details noted above for Finland);
- F.1 (details noted above for Finland).

The percentage of GDP ranges resulting from varying each of these parameters are as follows:

- for B.5: 3.6 % to 8.5 % of GDP;
- for A.1: 5.2 % to 8.1 % of GDP;
- for F.1: 5.6 % to 7.5 % of GDP.

Figure 2.2.4d: Sensitivity analysis for Italy



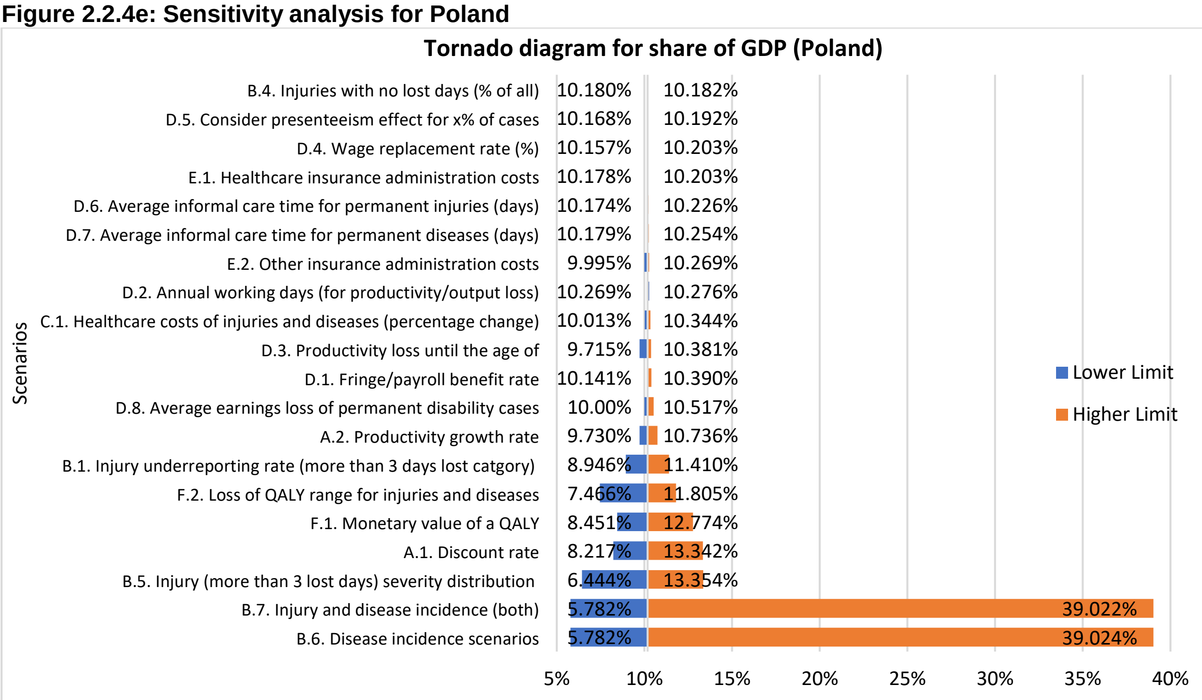
For Poland (see Figure 2.2.4e), the three parameters with the largest impact (after B6 and B7) are:

- B.5 (details noted above for Finland);
- A.1 (details noted above for Finland);
- F.1 (details noted above for Finland).

The percentage of GDP ranges resulting from varying each of these parameters are as follows:

- for B.5: 6.4 % to 13.4 % of GDP;
- for A.1: 8.2 % to 13.3 % of GDP;
- for F.1: 8.5 % to 12.8 % of GDP.

Figure 2.2.4e: Sensitivity analysis for Poland



3 Top-down model

3.1 Methods: top-down model

A top-down model to estimate the costs of the work-related burden of disease starts from the total burden of disease. From there, the part attributed to occupational risks needs to be determined and monetised. In the present study, the top-down model was based on DALYs, that is, disability-adjusted life years. The DALY is a measure of overall disease burden, expressed as the number of years lost or lived with disabilities due to ill health, disability or early death. DALYs are calculated by disease as the sum of life years lost to premature mortality and 'healthy' life years lost to disability. The latter is calculated by multiplying the number of cases by duration and the disease-specific disability weight. A disability weight is a weighting factor that reflects the severity of the disease on a scale from 0 (perfect health) to 1 (equivalent to death). The baseline variant in the present study is based on DALYs by cause, sex, age and country from the World Health Organization's (WHO's) global burden of disease estimates 2000-2016, as published by the WHO Department of Information, Evidence and Research in June 2018 (WHO, 2018a).

To determine the work-related burden of disease, it is necessary to estimate which part of the total burden is caused by occupational risks. It is known that some diseases are mainly caused by work, such as pneumoconiosis, while other diseases have a more multifactorial origin, such as musculoskeletal diseases. Therefore, it is necessary to estimate the attributable fraction, that is, the part caused by occupational exposure, by disease. Since many diseases are not caused by work, or at most only marginally caused by work, in our study the assessment of the attributable fraction is limited to a selection of diseases. In section 3.1.1, we describe the methods applied to assess the attributable fraction.

Our top-down model for cost estimation is based on the total burden of disease, expressed in 'physical units', that is, DALYs (number of years), meaning that the number of cases by disease is not included. Therefore, it is not possible to distinguish between different cost categories, such as healthcare costs, productivity losses or intangible costs such as life and health impacts. To estimate the monetary value of 1 DALY, we considered a DALY broadly equivalent to a QALY and monetised the burden of disease using a life year value. In the literature, various approaches have been taken for monetising life years. In section 3.1.2, we consider these different approaches and how we dealt with them in the present study.

3.1.1 Attributable fractions

The attributable fraction is the proportion of a disease that is caused by occupational risks. In the top-down model of the present study, we included total DALYs, that is, work-related plus non-work-related DALYs, from the WHO's Global Health Estimates (WHO, 2018a), by all causes, aggregated to 34 categories of which the sum still matches the total DALY numbers as published by the WHO. Attributable fractions, however, come from different sources. We worked with two methods to estimate the attributable fractions. Primarily, we used attributable fractions that were derived from the 2015 Global Burden of Disease (GBD) Study (IHME, 2016). Where needed due to missing data in the IHME database, we complemented these with attributable fractions obtainined from the literature. Below we further explain both sources of attributable fractions.

Currently the World Health Organization (WHO) and the International Labour Organization (ILO) are developing a joint methodology for estimating the national and global work-related burden of disease and injury (WHO/ILO joint methodology), with contributions from a large network of experts. This work will lead to broader agreed attributable fractions for an extended range of diseases. However, first results of this project will only be published in 2020, so that these findings could not be used for our cost estimation model.

- **Attributable fractions based on the Global Burden of Disease Study**

In the 2015 GBD Study, risk factors are included, as well as an estimation of the disease burden attributable to risk factors, including occupational risks (IHME, 2016). From these data, it is possible to deduce the attributable fraction by confronting the number of $DALYs_{occupational\ risks\ *\ cause}$ with the total number of $DALYs_{cause}$ (year 2016 data).

Which method the GBD Study researchers followed to estimate the fraction attributable to occupational risks is not altogether clear. According to a report on the findings of the GBD Study:

'The attributable burden analysis began with a hierarchical list of risks that contribute to health outcomes. The structure of that list allows for the quantification of the amount of responsibility that any given risk has in causing any given health cause. That depended on extensive research into risk-outcome pairs, in which GBD researchers conducted reviews of existing research to establish the likelihood that a risk will cause a particular health outcome. The extent to which a particular risk is likely to cause a particular outcome is a key part of estimating attributable burden' (IHME, 2016; p. 56).

Another report on the GBD Study (GBD Risk Factors Collaborators, 2016) described which occupational risk factors were included in the analysis. These risk factors mainly concern exposure to substances, ergonomic factors and work-related injuries.

The attributable fractions derived from the IHME database are shown in Appendix 3.

- **Attributable fractions from the literature**

In addition to deriving attributable fractions from the IHME database, we also searched the literature for attributable fractions. Most of those in the literature originated from the Finnish study of Nurminen and Karjalainen (2001); some scholars and external reviewers of the present study claimed that these fractions are 'outdated' and not per se applicable to other European countries. However, their results have been used in recent studies. In a study from 2016 on the burden of work-related cancer, it was concluded that *'these fractions were the best available to us at this moment'* (RIVM, 2016, p. 55 — methodological annex). In the RIVM 2016 study, researchers combined attributable fractions from the Finnish study of Nurminen and Karjalainen (2001) with attributable fraction estimates of the United Kingdom's HSE (Rushton et al., 2012). Another study by Hämäläinen et al. (2017) used mostly attributable fractions from the study of Nurminen and Karjalainen (2001) but updated the attributable fractions for respiratory diseases, with a differentiation of 'COPD' (chronic obstructive pulmonary disease), 'asthma' and 'other respiratory diseases'. For mental disorders, more recent attributable fractions are available from a study by Sultan-Taïeb et al. (2013).

The drawback of using attributable fractions from the literature is that the studies of both Nurminen and Karjalainen (2001) and Hämäläinen et al. (2017) focused on work-related deaths. However, some diseases do not cause death directly, but still have a major impact on health and disability. In particular, mental disorders that are caused by psychosocial factors and musculoskeletal diseases, which are caused largely by occupational risks, have a high impact on health but they are not fatal.

Considering the drawbacks of using the attributable fractions from the literature, we would emphasise that these literature-based attributable fractions are primarily used in the present study to complement the set of IHME-derived attributable fractions. However, the origin of the attributable fractions derived from the IHME database is not always clear and might also be biased in some way. For instance, we know that not all occupational risks are included. Therefore, we will show the results of the cost estimation in a model variant where attributable fractions from the literature are used.

Our general modelling approach is to apply ranges wherever possible in the main calculation steps. Similar to the study of RIVM (2016), we therefore combined all attributable fractions per disease from the literature sources that were available to us and determined the lower, central and upper values. Similar to our baseline variant of the model based on IHME-derived attributable fractions, we subsequently implemented the central value attributable fractions for males and females separately in our variant of the cost models that is fully based on attributable fractions from the literature — a model variant that we have applied as sensitivity analysis — or to complement the set of IHME-derived attributable fractions in our baseline variant[9]. In Appendix 3, the attributable fractions, as drawn from the literature, are shown.

[9] In our Excel calculation models, it is thus possible to select a low or high attributable fractions variant; this holds for both IHME-derived attributable fractions and attributable fractions obtained from literature sources. However, we have not presented results based on these low or high attributable fractions variants in this report.

- **Comparison of the attributable fractions**

Table 3.1.1a presents the attributable fractions derived from the literature and those from the IHME database. The attributable fractions in the IHME database differ among countries, while in the literature all countries are assigned the same value. In both the literature and in the IHME database, for most diseases separate values are available for men and women. In both methods, we have applied the attributable fractions for men and women separately and calculated the total number of occupational DALYs in each country as the sum of both sexes. For unknown reasons, some diseases do not have an attributable fraction in the IHME database[10]. In the results section, where results are shown from both methods to determine the attributable fraction, we used the value from the literature, if the attributable fraction from the IHME database was not available. For musculoskeletal diseases, no literature on attributable fractions was found. Instead, we used the attributable fraction based on the GBD Study in our 'attributable fractions based on literature approach'.

Table 3.1.1a shows that for some diseases the attributable fraction derived from the literature differs widely from the attributable fraction derived from the IHME database. In particular, the attributable fraction for circulatory diseases is estimated to be much higher in the literature than in the IHME database. For communicable diseases and nasopharynx cancer, we see the same. In contrast, lung cancer and larynx cancer are assigned a much higher attributable fraction in the IHME database than in the literature.

Table 3.1.1a: Attributable fractions (%) derived from the literature and those based on the IHME database

Selection of diseases	Literature ([a])	IHME Finland ([b])	IHME Germany ([b])	IHME Netherlands ([b])	IHME Italy ([b])	IHME Poland ([b])
Communicable diseases	6.7	0.6	1.5	1.5	0.6	1.4
Nasopharynx cancer	12.5	0.1	0.2	0.1	0.2	0.2
Larynx cancer	5.6	12.9	12.0	17.0	15.5	5.9
Tracheal, bronchus and lung cancer	17.1	28.9	28.7	34.0	34.3	16.2
Non-melanoma skin cancer	8.3					
Breast cancer	0.1	1.2	1.3	1.3	0.9	1.1
Ovarian cancer	1.3	5.4	5.8	6.9	8.8	2.5
Bladder cancer	8.3					
Mesothelioma	84.9	96.3	96.1	97.8	96.9	89.5
Leukaemia	0.6	0.6	0.6	0.7	0.5	0.5
Other neoplasms	3.2	0.0	0.0	0.0	0.0	0.0
Circulatory diseases	12.4	1.4	1.6	1.8	1.0	1.6
Respiratory diseases — COPD		12.7	13.1	11.3	10.0	13.6

[10] We did contact the IHME for further explanation and received the answer that 'most likely diseases/causes on your list for which no DALYs due to occupational risks are available have no or only a weak relation to work'.

Selection of diseases	Literature ([a])	IHME Finland ([b])	IHME Germany ([b])	IHME Netherlands ([b])	IHME Italy ([b])	IHME Poland ([b])
Respiratory diseases — pneumoconiosis	100.0	100.0	100.0	100.0	100.0	100.0
Respiratory diseases — asthma	n.a.	9.3	10.7	10.3	8.6	10.1
Respiratory diseases — other	1.0	n.a.	n.a.	n.a.	n.a.	n.a.
Digestive diseases	2.1	n.a.	n.a.	n.a.	n.a.	n.a.
Neurological diseases	3.5	n.a.	n.a.	n.a.	n.a.	n.a.
Mental disorders	17.5 (m) 20.7 (f)	n.a.	n.a.	n.a.	n.a.	n.a.
Genitourinary diseases	1.3	n.a.	n.a.	n.a.	n.a.	n.a.
Musculoskeletal diseases		8.5	8.1	7.6	6.5	11.2
Other non-communicable diseases	0.0	1.8	3.4	2.1	2.5	3.1
Injuries — transport	3.1	7.3	14.4	10.4	19.0	9.5
Injuries — unintentional	5.4	4.4	9.0	6.7	13.1	6.2
Injuries — self-harm	0.4	n.a.	n.a.	n.a.	n.a.	n.a.
Injuries — interpersonal violence	1.1	n.a.	n.a.	n.a.	n.a.	n.a.

n.a., not available; m, males; f, females.

([a]) For details of sources with regard to attributable fractions based on the literature, see Appendix 3.

([b]) For details of sources with regard to attributable fractions based on the IHME database, see section above 'Attributable fractions based on the GBD study'.

- ## Selection of diseases

Table 3.1.1a shows the granularity of main disease categories and some disease subcategories for which we included attributable fractions in our cost calculation model. In this section of the report, we explain our rationale for the selection of diseases for inclusion in our cost calculation model.

Rationale

First, our basic modelling approach was to include all main disease categories with a further breakdown into subcategories wherever possible, that is, we included all subcategories of diseases for which we could separately derive an attributable fraction from the year 2016[11] occupational DALYs in the IHME-database. Communicable diseases are included as an aggregated category because diseases such as

[11] IHME DALY data by cause multiplied by occupational risks were available for only reference year 2016. We therefore derived attributable fractions for this year and projected values for the year 2015 IHME DALYs, the base year of our calculation model.

HIV infection contribute only a very small part to the occupational burden of disease in Europe[12]. An attributable fraction could be derived from the IHME database at this aggregated level[13]. As described earlier, IHME-derived fractions were subsequently applied to the preferred DALY data source, that is, the WHO's Global Health Estimates 2016 (WHO, 2018a). Notwithstanding this, the classification system of the IHME database and the maximum level of detail for which we could derive attributable fractions were instrumental to our selection of diseases to include in our calculation model[14]. Table 3.1.1b gives an overview of the main disease categories available in the IHME database.

Table 3.1.1b: Main disease categories included in the IHME database

Level	Code	Disease
Total	**All causes**	
A	**Communicable, maternal, neonatal, and nutritional diseases**	
	A.1	HIV/AIDS and tuberculosis
	A.2	Diarrhoea, lower respiratory, and other common infectious diseases
	A.3	Neglected tropical diseases and malaria
	A.4	Maternal disorders
	A.5	Neonatal disorders
	A.6	Nutritional deficiencies
	A.7	Other communicable, maternal, neonatal, and nutritional diseases
B	**Non-communicable diseases**	
	B.1	Neoplasms
	B.2	Cardiovascular diseases
	B.3	Chronic respiratory diseases
	B.4	Cirrhosis and other chronic liver diseases
	B.5	Digestive diseases
	B.6	Neurological disorders
	B.7	Mental and substance use disorders
	B.8	Diabetes, urogenital, blood and endocrine diseases

[12] From the WHO DALY source data (year 2015) we could calculate the relative burden of HIV as a percentage of total DALYs (comprising both work-related and non-work-related DALYs): Germany 0.1 %; Finland 0.0 %; Italy 0.3 %; Netherlands 0.1 %; and Poland 0.1 %.

[13] This derived attributable fraction however reflects the relative contribution of all underlying disease categories, hence we did not exclude any of the communicable diseases — only included them at a more aggregated level because of their weaker linkages to the occupational burden of disease.

[14] Our DALY cost calculation model for each country is in the form of a Microsoft Excel file (a single file for each country) in which all calculation steps can be followed from source data to final results in interlinked numbered sheets. The Excel file has a 'content sheet' in which all calculation steps are explained.

Level	Code	Disease
	B.9	Musculoskeletal disorders
	B.10	Other non-communicable diseases
C	**Injuries**	
	C.1	Transport injuries
	C.2	Unintentional injuries
	C.3	Self-harm and interpersonal violence
	C.4	Forces of nature, conflict and terrorism, and executions and police conflict

An adjunct to our basic principle to include all main diseases categories with further breakdowns if we could derive attributable fractions from the IHME database at this level is that we have not selected all possible causes in our primary data download. Causes with no linkages to work were excluded up front — primarily some specific causes within the main level of non-communicable diseases (that is, causes within mental and substance use disorders, diabetes mellitus (B.8.1), acute glomerulonephritis (B.8.2), haemoglobinopathies and haemolytic anaemias (B.8.6), endocrine, metabolic, blood, and immune disorders (B.8.7), and forces of nature, conflict and terrorism, and executions and police conflict (C.4)). We have therefore constructed the total number of DALYs per country as a sum of selected causes from the IHME database. These DALYs were derived in an early stage of our model development compared with the IHME grand total by 'all causes' on the logical condition that total DALYs ('sum of selected IHME causes') is less than the IHME grand total ('DALYs all causes').

Second, we have included some additional detail in the disease category breakdown of our cost model for diseases, which we know from literature sources, that have a relatively strong relation to occupational risks. Compared with the diseases for which we were able to derive attributable fractions from the IHME database, we have primarily added more differentiation in neoplasms (= cancers) based on insights from the RIVM (2016) study on the burden of work-related cancer.

Third, we wanted to include at least the same disease categories as those reported by Hämäläinen et al. (2017):

- communicable diseases;
- malignant neoplasms;
- neuropsychiatric conditions;
- circulatory diseases;
- respiratory diseases, differentiated into COPD, asthma and others;
- digestive diseases;
- genitourinary diseases.

Moreover, EU-OSHA requested that we ensured that our top-down cost calculation model could be compared with the model of Dr Takala and colleagues as reported previously by EU-OSHA (2017a). In that model ,five main categories were included: 1) cancers, 2) musculoskeletal diseases, 3) circulatory diseases, 4) injuries and 5) other diseases.

Fourth, we wanted to include mental disorders caused by psychosocial factors (that is, depressive disorders and anxiety disorders that have a relatively strong relation to work-related stress) as a separate category in our cost model.

Level of detail used to derive attributable fractions from occupational DALYs in the IHME database

After exclusion of some of the IHME disease categories in our primary download of DALYs (as explained in the previous paragraph), we could broadly group the DALY data to derive attributable fractions in the following categories:

a) communicable, maternal, neonatal and nutritional diseases;
b) neoplasms;
c) circulatory diseases;
d) respiratory diseases;
e) digestive diseases;
f) neurological disorders;
g) mental and substance use disorders;
h) genitourinary diseases (in the IHME database known as ‘diabetes, urogenital, blood, and endocrine diseases’);
i) musculoskeletal disorders;
j) other non-communicable diseases;
k) injuries.

Within these categories, some diseases are to some extent caused by occupational risks, while others are not or are at most marginally related to work. Below, we explain how we dealt with the disease categories and the level of aggregation we tried to base the derivation of attributable fractions based on available DALYs by occupational risks multiplied by cause in the IHME database. We applied attributable fractions from the literature in our calculation model only for those disease categories for which we could not derive attributable fractions from the IHME database, these being categories that were relevant to include due to a strong relationship to work based on literature insights.

(a) Communicable, maternal, neonatal and nutritional diseases

Most diseases in this category are not related to work. Therefore, we did not include subcategories of communicable diseases (for example HIV infection) separately, but included the main disease category as a whole and derived the attributable fraction from the IHME database at this level of aggregation.

(b) Neoplasms

Many of the diseases in this category are, at least partly, caused by occupational risks. In the present study, we show more detail than, for example, that shown inHämälainen et al. (2017) and EU-OSHA (2017a), and present cancer subcategories with a relatively high attributable fraction, according to, for example, the RIVM (2016) study, separately. All other neoplasms (comprising ‘other malignant neoplasms’ and ‘other neoplasms’) are considered together in the disease category ‘other neoplasms’ in our calculation model:

- nasopharynx cancer;
- larynx cancer;
- tracheal, bronchus and lung cancer;
- non-melanoma skin cancer;
- breast cancer;
- ovarian cancer;
- bladder cancer;
- mesothelioma;
- leukaemia;
- other neoplasms.

(c) Circulatory diseases

This disease category contains different cardiovascular and circulatory diseases. All are included in the present study at the aggregation level of the main category as a whole.

(d) Respiratory diseases

Diseases in this category have a high attributable fraction. For that reason, we followed the same differentiation as Hämälainen et al. (2017):

- COPD;
- pneumoconiosis;
- asthma;
- other.

(e) Digestive diseases

Most diseases in this category are not related to work. We therefore included this disease category as a whole and tried to derive an attributable fraction from the IHME database at this main level of aggregation.

(f) Neurological disorders

Some of the diseases in this category are (partly) related to work. We therefore included this disease category as a whole and tried to derive an attributable fraction from the IHME database at this main level of aggregation.

(g) Mental and substance disorders

Although most of the disorders in this category are not related to work, mental disorders are partly caused by psychosocial risks at work and as such are considered an important work-related disease category. Within this main disease category, we therefore selected depressive and anxiety disorders for inclusion in our cost model and tried to derive attributable fractions for only these two mental disorders from the IHME database.

(h) Diabetes, urogenital, blood and endocrine diseases

As explained before, within this main disease category we excluded some subcategories in our primary data download from the IHME database: diabetes mellitus (B.8.1), acute glomerulonephritis (B.8.2), haemoglobinopathies and haemolytic anaemias (B.8.6), and endocrine, metabolic, blood and immune disorders (B.8.7). As a result, the attributable fraction derived for the category genitourinary diseases in our cost calculation breakdown comprises only chronic kidney diseases (B.8.3), urinary diseases and male infertility (B.8.4), and gynaecological diseases (B.8.5).

(i) Musculoskeletal disorders

We included this category as a whole and derived an attributable fraction from the IHME database on this main level of aggregation.

(j) Other non-communicable diseases

This main disease category in the IHME classification contains a wide diversity of diseases, most of which are not related to work: congenital birth defects (B10.1), skin and subcutaneous diseases (B10.2), sense organ diseases (B10.3), oral disorders (B10.4) and sudden infant death syndrome (B10.5). Since we could derive an attributable fraction from the IHME database for this main disease category, we included the category other non-communicable diseases (B10) as a whole in our cause breakdown in the calculation models.

(k) Injuries

Work-related injuries are an important part of the work-related burden of disease. Therefore, we have chosen to include more detail than, for example, Hämälainen et al. (2017) or EU-OSHA (2017a) and tried to derive attributable fractions from the IHME database for the following injury categories:

- injuries — transport;
- injuries — unintentional;
- injuries — self-harm;
- injuries — interpersonal violence.

As explained earlier, we excluded injuries due to forces of nature, conflict and terrorism, executions and police conflicts in our primary download from the IHME database. This injury subcategory is thus not captured in the IHME-derived attributable fractions for injuries.

Application of IHME-derived attributable fractions to WHO DALYs

As explained before, the IHME-derived attributable fractions per disease category were applied to the WHO-sourced DALY numbers in our baseline variant of the top-down cost calculation models. For this purpose, we needed to aggregate the WHO DALY data in such a way that it could be aligned with the disease categories for which we could derive attributable fractions from the IHME database, plus the additional categories that we included based on indications for a strong relationship to work in literature sources.

For transparency reasons, we decided to keep all non-communicable diseases with no or presumably only a marginal relationship to work in our primary data download from the WHO. This was easy to implement, as the WHO-sourced data can be directly downloaded in Excel, whereas with the IHME data individual causes had to be selected before downloading. In our aggregation of the WHO DALY source data to match the list of causes included in our cost model, we therefore excluded the category ‘other non-communicable diseases’ (code B.10 in the IHME classification hierarchy). Instead, we show all underlying subcategories of ‘other non-communicable diseases’ separately, as well as previously mentioned non-communicable diseases that we excluded up front in our IHME DALY data download. These are the rows marked in yellow in Table 3.1.1c. As a result, the grand total in our aggregated WHO DALY source data still matches the grand total of DALYs (that is, work-related + non-work-related).

Table 3.1.1c: Diseases included in the model after aggregation of WHO DALY source data

TNO_Cause_No	TNO_Cause_Name
1	Communicable diseases
2	Nasopharynx cancer
3	Larynx cancer
4	Tracheal, bronchus and lung cancer
5	Non-melanoma skin cancer
6	Breast cancer
7	Ovarian cancer
8	Bladder cancer
9	Mesothelioma
10	Leukaemia
11	(all) Other neoplasms
12	Circulatory diseases (cardiovascular diseases)

TNO_Cause_No	TNO_Cause_Name
13	Respiratory diseases — COPD
14	Respiratory diseases — pneumoconiosis
15	Respiratory diseases — asthma
16	Respiratory diseases — other
17	Digestive diseases
18	Neurological diseases
19	Mental disorders (depressive disorders and anxiety disorders)
20	Genitourinary diseases
21	Musculoskeletal diseases
C.	Diabetes mellitus
D.	Endocrine, blood, immune disorders
G.	Sense organ diseases
E (-19)	Mental and substance use disorders (excluding depressive and anxiety disorders)
L.	Skin diseases
N.	Congenital anomalies
O.	Oral conditions
P.	Sudden infant death syndrome
23	Injuries — transport
24	Injuries —unintentional
25	Injuries — self-harm
26	Injuries — interpersonal violence
III.B3	Collective violence and legal intervention
27	Total DALYs WHO; ages 15-70+

The coding in the rows marked in yellow (TNO_Cause_NO C. to P., and III.B3) matches the main categories in the WHO's Global Health Estimates classification (WHO, 2018a). Code 'E (-19)' is a TNO-construct; depressive disorders and anxiety disorders are allocated to TNO_Cause_No 19 'mental disorders'. All other categories under WHO's Global Health Estimates code 'Mental and substance use disorders' remained in cause E (-19), that is, bipolar disorder, schizophrenia, alcohol use disorders, drug use disorders, eating disorders, autism and Asperger syndrome, childhood behavioural disorders, idiopathic intellectual disability, and other mental and behavioural disorders.

We could not derive attributable fractions from the IHME database for the following causes:

- non-melanoma skin cancer;
- bladder cancer;
- respiratory diseases — other;
- digestive diseases;
- neurological diseases;
- mental disorders (depressive disorders and anxiety disorders);
- genitourinary diseases;
- injuries — self-harm; and
- injuries — interpersonal violence.

For these causes, attributable fractions are based on the central value attributable fractions that we obtained from the literature sources available to us.

For Global Health Estimate causes G. 'Sense organ diseases' and L. 'Skin diseases', we have applied the IHME-derived attributable fraction for TNO_Cause_No 22 'other non-communicable diseases'. For all other causes marked in yellow in Table 3.1.1c , we made the (ad hoc) assumption that there is no relationship to work, hence we applied an attributable fraction of 0.0 %.

Note: for TNO_cause category 11 '(all) Other neoplasms', we have applied the IHME-derived attributable fraction, fully consistent with our general modelling approach. However, this fraction is very low, in the order of 0.001 %. At the same time, this 'other neoplasms category' accounts for a relatively large proportion of the total DALYs in each of the five countries included in our model. This implies that the model outcomes are particularly sensitive to any changes in the attributable fraction for these 'other' cancer types, for example if one decided to apply the IHME-derived fraction for overall neoplasms, which are in the order of 8-15 %.

3.1.2 Monetisation approaches

In the literature, three broad methodological approaches to estimating the monetary value of a DALY can be identified: 1) the human capital approach, 2) the willingness-to-pay approach and 3) the value of a statistical life year approach. Below we describe the approaches and the monetary values of the DALYs that result from them. This section will end with a short evaluation of the different approaches.

- **Human capital approach**

As stated before, to estimate the monetary value of a DALY, or in other words to estimate the costs of the loss of a year in good health, proxies are needed to cover all costs associated with diseases and death. In the human capital approach, the monetary value of a DALY is based on the loss of economic productivity due to ill health, disability, or premature mortality. In the human capital approach the number of working years lost are multiplied with an output or annual earnings proxy.

In the literature various output or income variables are used to do this. They differ widely in range. Dalal and Svanstöm (2015), for example, use GDP per capita for the monetary valuation of DALYs, while the Harvard School of Public Health and World Economic Forum (2011) used three times GDP per capita for the same purpose. A variation on GDP per capita is GDP per employed person or GDP per employee, as used in the estimation of Takala et al. (2017). Some argue that, from a broader welfare perspective 'beyond GDP', it is better to take a household income and consumption perspective rather than to focus on gross production or GDP (for example Stiglitz et al., 2009). This line of reasoning is taken onboard by the OECD (2012), who state that 'Actual individual consumption per inhabitant' might be a better indicator to value a life year in the context of environmental, health and transport policy. In similar vein to the 'Stiglitz recommendations' regarding welfare beyond GDP, we have included yet another monetary valuation indicator that takes a household consumption rather than production perspective: the European Union Statistics on Income and Living Condition's (EU-SILC's) median equivalised disposable income. In short, there is no consensus on the right indicator to estimate the monetary value of a DALY in the human capital approach. In the present study we have included eight different monetary indicators under the umbrella of the human capital approach:

a. GDP per capita (based on recommendations of the WHO Commission on Macroeconomics and Health (Harvard School of Public Health and World Economic Forum, 2011); Dalal and Svanström, 2015);
b. GDP per employed person (based on Takala et al., 2017);
c. median annual earnings per full-time equivalent (FTE) (based on RIVM, 2016, who value productivity loss due to mortality or morbidity with mean annual earnings of workers in each individual country. We, however, prefer to use median annual earnings per country as there are rather large income differences per occupation, age and sex);
d. adjusted gross disposable income of households per capita (based on Stiglitz et al., 2009);
e. median equivalised net income per person (based on Stiglitz et al., 2009);
f. mean consumption expenditure per household (based on Stiglitz et al., 2009; OECD, 2012);
g. mean consumption expenditure per adult equivalent (in households) (OECD, 2012); and
h. Three times GDP per capita (based on recommendations of the WHO Commission on Macroeconomics and Health (Harvard School of Public Health and World Economic Forum, 2011)).

Table 3.1.2a presents the values of these indicators for the countries under study. It shows that these values differ widely. The lowest value is the mean consumption expenditure, the highest is three times GDP per capita which is more than five times as much. Consequently, the cost estimation is highly dependent on the choice of indicator. To demonstrate the range of these values in the cost estimation, in the results section, we will present the results for the minimum, the mean, the median and the maximum value of the indicators as presented in Table 3.1.2a.

Table 3.1.2a: Value in euros by country of different indicators of the monetary value of a DALY based on the human capital approach

		Finland	Germany	The Netherlands	Italy	Poland
a.	**GDP per capita ([a])**	38,200	37,300	40,400	27,200	11,200
b.	**GDP per employed person ([b])**	86,016	75,692	82,159	73,565	26,738
c.	**Median annual earnings per full-time equivalent ([c])**	38,517	34,885	37,475	28,851	9,160
d.	**Adjusted gross disposable income of households per capita ([d])**	29,231	28,854	25,767	20,998	8,546
e.	**Median equivalised net income per person ([e])**	23,763	20,668	21,292	15,846	5,556
f.	**Mean consumption expenditure per household ([f])**	32,818	29,330	32,623	28,702	9,205
g.	**Mean consumption expenditure per adult equivalent (in households) ([g])**	21,999	19,887	21,559	18,145	5,308
h.	**3 times GDP per capita ([a])**	114,600	111,900	121,200	81,600	33,600

([a]) Eurostat (nama_10_pc) 2015.

([b]) Eurostat (nama_10_pc AND lfsa_pganws) 2015.

(c) Eurostat (earn_ses_annual) 2014.

(d) Eurostat (tec00113) 2015.

(e) Eurostat (ilc_di03).

(f) Eurostat (hbs) 2010.

(g) Eurostat (hbs) 2010; Destatis (continuous household budget surveys) 2015.

A drawback of the human capital monetisation approach is that only part of an individual's welfare is measured since only the productive or working time lost is taken into account. Life beyond paid work (for example remaining life years after retirement and leisure time — including during the economically active lifetime between 15 and 75 years), pain and suffering as well as the intrinsic value of life as such (for example taking part in society, interaction within social networks, and so on) is not valued. Theoretically, the two other monetisation approaches considered in this report, the *willingness-to-pay* (WTP) and the *value of a statistical life year* (VSLY) approaches do include valuations for broader aspects of life.

- **Willingness-to-pay approach**

The WTP approach is based on preferences of survey respondents to pay for health gains. Most literature is focused on the willingness to pay for a QALY. Although these values actually relate to health improvements, we consider them to be reversely applicable to value a loss in healthy life years or quality of life as represented by DALYs.

To assess the willingness to pay for a gain in health is rather a challenge. In most surveys, a contingent valuation approach is taken, meaning that respondents are asked to state their willingness to pay for a given health improvement. Techniques differ widely. Sometimes respondents are asked to value an improvement in health-related quality of life, sometimes also length of life is involved. In most surveys, respondents are asked to take an individual perspective, while in others a societal perspective is asked for (Ryen and Svensson, 2015). For example, Schlander et al. (2017a, 2017b) found, in their European meta-study on the economic value of a statistical life year (VSLY — see also the next paragraph), 41 European studies, yielding 49 unique VSLY estimates. In fact, the underlying methodology used to estimate VSLYs in these European studies was a WTP survey. Of these 49 unique estimates, Schlander et al. (2017a, 2017b) stated that 27 are based on stated preference/contingent valuation survey techniques.

In the report of the EuroVaq project (2010) on the European value of a QALY, two approaches were distinguished: a *chained approach* and a *direct approach*. In the latter, respondents were asked directly their WTP for a whole QALY. In the chained approach, the underlying basic principle used was to estimate WTP per QALY by breaking the exercise down into two distinct components: first a utility assessment (using standard gamble and time trade-off methods), followed by a WTP component (such that eventually the WTP for one QALY could be obtained by 'multiplying up', that is, combining both utility and duration time — WTP for a known fraction of a QALY — into the monetary value corresponding to one full QALY).

Differences in estimates may derive from several causes. First, changes in the quality of life are estimated as lower than changes in length of life. The consequence is that if length of life is part of the valuation exercise, the WTP value will be higher (Ryen and Svensson, 2015). Differences may also result from the survey techniques applied to assess the WTP value. It is known that the direct approach results in lower WTP values than the chained approach. Other changes may derive from methodologies, national differences, perspective taken, and sample population (general population or specific patient groups) (Ryen and Svensson, 2015).

In the present study, for the WTP approach, we included the estimates for DALYs or QALYs, where possible based on (mean or median) values from primary estimates in dedicated studies for each of our five countries (see Table 3.1.2b). For countries for which no primary estimates are available, we have used European central values as found in the literature. For all five countries included in our model, the following two European reference values are included from the meta-study of Ryen and Svensson (2015):

a. median European WTP reference estimate (Ryen and Svensson, 2015) and
b. trimmed mean European WTP reference value (upper bound) (Ryen and Svensson, 2015).

For Italy and Germany we did not find additional WTP estimates for a DALY (or QALY) during our literature review. For this reason, the abovementioned median and trimmed mean European reference values are the only two monetary values included in the WTP approach of our cost estimation model for Germany and Italy.

For the Netherlands and Poland, on the other hand, the meta-study of Ryen and Svensson (ibid) provides either country-specific WTP estimates (the Netherlands), or central estimates for a subset of European Member States (including both the Netherlands and Poland). From the column 'mean estimates' of Table IV in the meta-study of Ryen and Svensson, combining both two central values as well as additional country-specific estimates mentioned in Ryen and Svensson (2015) we derived the following three additional monetary WTP values for the Netherlands:

c. mean national estimate low value (Ryen and Svensson, 2015);
d. mean national estimate central value (Ryen and Svensson, 2015); and
e. mean national estimate high value (Ryen and Svensson, 2015).

For Poland only two additional estimates to the overall European central values are included, based on the central values from a study for a subset of European Member States as mentioned in Ryen and Svensson (2015).

In addition to the estimates of Ryen and Svensson (2015), we obtained a further two WTP estimates for a QALY in the Netherlands from the literature:

f. Dutch WTP-QALY (purely other regarding perspective) (Bobinac et al., 2013) and
g. Dutch WTP-QALY (social-inclusive-individual perspective) (Bobinac et al., 2013)

For Finland we were also able to include estimates from national studies, in addition to the earlier mentioned overall European reference values:

h. lower WTP-QALY value (often used threshold value) (Hallinen and Soini, 2011);
i. maximum WTP-QALY (reference value for cost effectiveness studies (Hallinen and Soini, 2011);
j. mean undiscounted incremental WTP for a life year gained (Soini et al., 2012);
k. mean discounted incremental WTP for a life year gained (Soini et al., 2012);
l. lower incremental WTP-QALY (metabolic disease) (Soini et al., 2012); and
m. upper incremental WTP-QALY (cancer) (Soini et al., 2012)

Table 3.1.2b presents an overview of the WTP estimates included in the cost models for the five countries under study. As mentioned before, some countries have national sources for the willingness to pay for a QALY, while in other countries only European estimates were available. For each of our five countries we have derived the minimum, maximum, mean and median monetary WTP value for a DALY based on the full available range of values per country.

The reference year for most of the literature sources was 2010. Our cost model has 2015 as the base year. For our study we therefore converted the estimates found in the literature to year 2015 values, based on Eurostat's Harmonised Indices of Consumer Prices (HICPs — prc_hicp_aind; 'all-items HICP').

Table 3.1.2b: Value in euros by country of different indicators of the monetary value of a DALY based on the willingness-to-pay approach

	Finland	Germany	The Netherlands	Italy	Poland
a. Median European WTP reference estimate ([a])	26,134	26,134	26,134	24,512	10,093
b. Trimmed mean European WTP reference value (upper bound) ([a])	80,994	80,994	80,994	75,966	31,280
c. Mean national estimate low value ([a])			13,186		13,186
d. Mean national estimate central value ([a])			21,772		21,772
e. Mean national estimate high value ([a])			123,828		
f. WTP-QALY (purely other regarding perspective) ([b])			56,156		
g. WTP-QALY (social-inclusive-individual perspective) ([b])			89,633		
h. Lower WTP-QALY value ([c])	53,996				
i. Maximum WTP-QALY ([c])	129,590				
j. Mean undiscounted incremental WTP for a life year gained ([d])	62,808				
k. Mean discounted incremental WTP for a life year gained ([d])	71,573				
l. Lower incremental WTP-QALY (metabolic disease) ([d])	25,369				
m. Upper incremental WTP-QALY (cancer) ([d])	270,528				

([a]) Ryen and Svensson (2015).

([b]) Bobinac et al. (2013).

([c]) Hallinen and Soini (2011).

([d]) Soini et al. (2012).

Both the meta-study of Ryen and Svensson (2015) and the OECD (2012) study point out that the size of risk changes is one of the primary determinants of people's willingness to pay for a health state improvement or to avoid a health risk. The study of OECD (2012) proves that another important determinant of people's willingness to pay is the income level of the population under study. As a result of this finding, the OECD (2012) therefore recommends scaling European central reference WTP values for a DALY or QALY up or down, depending on the level of GDP per capita in relation to the European benchmark value.

Because the 2015 GDP per capita levels in Italy and Poland were lower than the average GDP per capita in the EU-28, we have scaled down the European central reference values (first two rows in Table 2.3.2b) for Italy and Poland, based on the ratio (GDP per $capita_{country}$/GDP per $capita_{EU\text{-}28}$)[15]. In order not to increase the difference in monetary WTP values for a DALY any further, we have decided not to scale-up the European central reference values in our cost model for Germany, Finland and the Netherlands. All three countries have a GDP per capita level that exceeds the EU-28 average in 2015.

Table 3.1.2b makes clear that, as in the human capital approach, monetary values for a DALY differ widely. Consequently, the cost estimation is highly dependent on the choice of monetary WTP indicator. To demonstrate the range of these values in the cost estimation, in the results section, we present the results for each country based on the minimum, the mean, the median and the maximum value that we derived from the full range of available monetary estimates per country as presented in Table 3.1.2b.

- **Value of statistical life year approach**

The value of statistical life (VSL) represents a total monetary value of an average adult towards the life expectancy age, hence a value for the total remaining lifetime of an average person in the case of no injury or disease. These values are preferably based on stated preference or revealed preference techniques to assess the willingness to pay to prevent the death of an unidentified individual or to prevent non-fatal health impacts, or the willingness to accept (for example by means of a wage premium) a certain health risk. The VSL is not a monetary value that as such can be directly used for monetary valuation of DALYs or QALYs, which are metrics of single life years. The value of statistical life must therefore first be converted to a discounted stream of annual life year values over the remaining lifetime of the subject, that is, the value of a statistical life year (VSLY[16]), taking into account an appropriate discount rate.

In the literature, several methods can be identified to convert a VSL into a VSLY. Often life tables are used to calculate remaining life expectancy, taking into account mortality rates between *age x* and *age x + 1* — by gender and age (and, for example, incorporating risk seeking behaviour by younger individuals) — rather than using the life expectancy at birth to convert the VSL into a discounted stream of annual life year values. Moreover, a quality adjusted life expectancy could also be calculated, taking into account health status changes probability weights as well as wealth (income) development over time.

Methodological choices will influence the life year values. Elements that contribute to different life year values are, for example: the age that is used for the 'average adult' (and hence the remaining life years), the discount rate to apply, whether or not future income developments are taken into account, and so on. Researchers in the EuroVaq project (2010) concluded that the key variables that influence the results (that is, the value of a statistical life year) are the value of statistical life itself and the discount rate to convert this lump-sum VSL to annual streams.

Similar to our workflow regarding the WTP approach we reviewed the literature to find either European central reference values for a statistical life year from meta-studies or specific country values from primary studies in each of our five target countries. Again, the latter could be either mentioned in meta-studies or obtained from official national government documents (for example regarding the use of VSL in road and traffic safety policy domains) or dedicated research papers.

Our general approach was again to include the European reference values in the cost models of all five target countries (including base year conversion based on Eurostat's HICP and GDP per capita scaling, similar to our description in the section entitled 'Willingness-to-pay approach'), and complement these

[15] In doing so we implicitly assume a marginal elasticity to utility with respect to income to be 1. We are aware that, for example, in the methodological literature of the World Bank and OECD it is stated that income elasticities in the order of 0.6-0.8 can be applied. Application of income elasticities other than 1 would result in different converted life year values. The same applies for the base year scaling based on the HICP. Now we have only kept the monetary value constant in real terms over time, without indexing by changes in GDP/capita over time. From the literature it is known that the value of health is expected to increase with real income. We, however, did not want to increase differences in life year values between the five countries any further.

[16] In literature sources also referred to as value of a life year 'VOLY'. Both terms can be used interchangeably. We prefer to use value of a statistical life year (VSLY) throughout the main text of this report. Some indicator names of monetary values that we obtained from the literature refer to VOLY.

values with country-specific values to the maximum extent possible based on availability of estimates in the literature we reviewed. For all five countries we have included the following 12 European central reference value of statistical life year values[17], most of which are either obtained from meta-studies or European Commission funded research projects:

a. European central VSLY value (rounded, discounted) (NewExt, 2003);
b. median European reference VSLY value (VSL converted values @ 4 %) (CAFE, 2005);
c. median European reference VSLY value (converted VSL) (ECHA, 2016);
d. European central VSLY value (undiscounted) (NewExt, 2003);
e. European reference VSLY value 'if no more context specific estimates are available' (upper) (European Commission 2009, referred to in OECD, 2012);
f. median European WTP-QALY (converted VSL) value (Ryen and Svensson, 2015);
g. median European (overall) reference VOLY estimate (lower) (Schlander et al., 2017a, 2017b);
h. European central value (rounded, discounted) — upper bound (NewExt, 2003);
i. median European (overall) reference VOLY estimate (central) (VSL converted @ 3 %) (Schlander et al., 2017a, 2017b);
j. median European (overall) reference VOLY estimate (upper) (Schlander et al., 2017a, 2017b);
k. European central value (rounded, undiscounted) — lower bound (NewExt, 2003); and
l. median European reference value (converted upper bound VSL — cancer) (ECHA, 2016).

To complement these European central reference estimates, we also included national estimates in our study. In some cases we could only obtain a country-specific value of statistical life value which we then had to convert ourselves. For our own conversion we used a discount rate of 3 % and selected the remaining life expectancy for an average adult at age 40 years. We applied the VSL conversion formula of Schlander et al. (2017a, 2017b):

$$VSLY = \frac{VSL \cdot (1+r)^{t-1} \cdot r}{(1+r)^{t} - 1}$$

r being the discount rate (of 3 %) and *t* the expected remaining life years (at age 40 years).

For Germany we included eight additional VSLY estimates in the cost model:

m. six different German VSLY estimates (revealed preference studies — Wage Risk) (Schlander et al., 2017a, 2017b);
n. German VSLY for employees in Germany (own VSL conversion @ 3 %) (Sprengler, 2004); and
o. German VSLY for persons killed in traffic accidents (own VSL conversion @ 3 %) (Bundesanstalt für Straßenwesen, 2018).

For Finland we included three additional VSLY estimates in the cost model:

p. median northern Europe reference VOLY estimate (central) (VSL converted @ 3 %) (Schlander et al., 2017a, 2017b) and
q. value of statistical life year (road and rail projects) (own VSL conversion @ 3 %) Finnish Transport Agency (two estimates, respectively a year 2010 and 2013 reference value which we both converted into a 2015 value).

For Italy we included two additional VSLY estimates in the cost model:

r. Italian VSLY value (based on contingent valuation) (Schlander et al., 2017) and
s. two different Italian VSLY values (based on stated preference in Discrete Choice Experiment) (Schlander et al., 2017a, 2017b).

[17] Values for Italy and Poland are scaled down based on their GDP per capita ratio to the EU-28 average.

For the Netherlands we included five additional VSLY estimates in the cost model:

t. two different Dutch VSLY values (based on stated preference, Discrete Choice Experiment) (Schlander et al., 2017a, 2017b);
u. converted VSL to VSLY (@ 2.5 %) undiscounted future life years (lower) (EuroVaq, 2010);
v. converted VSL to VSLY (@ 2.5 %) discounted future life years and income development (lower) (EuroVaq, 2010); and
w. converted VSL to VSLY (deaths in traffic accidents) (@ 3 %) (Rijkswaterstaat, 2016).

For Poland we included three additional VSLY estimates in the cost model:

x. Polish VSLY value (wage risk) (Schlander et al., 2017a, 2017b) and
y. converted life year value to euros (two estimates, lower and upper value respectively) (Polish Social Insurance Institution, 2015)

Table 3.1.2c presents an overview of the value of statistical life year estimates included in the cost models for the five countries under study. Reference years differ by source. Similar to the other approaches, values differ widely. Consequently, the cost estimation is highly dependent on the choice of estimate. To demonstrate the range of these values in the cost estimation, in the results section, we present the results for each country based on the minimum, the mean, the median and the maximum value of the indicators that we derived from the full range of available monetary estimates per country as presented in Table 3.1.2c.

Table 3.1.2c: Value in euros by country of different indicators of the monetary value of a DALY based on the value of a statistical life year approach

	Finland	Germany	The Netherlands	Italy	Poland
a. European central VSLY value (rounded, discounted) ([a])	66,908	66,908	66,908	62,755	25,840
b. Median European reference VSLY value (VSL converted values @ 4 %) ([b])	69,584	69,584	69,584	65,265	26,874
c. Median European reference VSLY value (converted VSL) ([c])	65,313	65,313	65,313	61,259	25,224
d. European central VSLY value (undiscounted) ([a])	100,361	100,361	100,361	94,132	38,760
e. European reference VSLY value 'if no more context specific estimates are available' (upper) ([d])	133,815	133,815	133,815	125,509	51,680
f. Median European WTP-QALY (converted VSL) value ([e])	118,637	118,637	118,637	111,273	45,818
g. Median European (overall) reference VOLY estimate (lower) ([f])	136,133	136,133	136,133	127,684	52,576
h. European central value (rounded, discounted) — upper bound ([a])	202,061	202,061	202,061	189,519	78,037

	Finland	Germany	The Netherlands	Italy	Poland
i. Median European (overall) reference VOLY estimate (central) (VSL converted @ 3 %) ([f])	158,432	158,432	158,432	148,598	61,188
j. Median European (overall) reference VOLY estimate (upper) ([f])	180,732	180,732	180,732	169,514	69,800
k. European central value (rounded, undiscounted) — lower bound ([a])	301,084	301,084	301,084	282,396	116,281
l. Median European reference value (converted upper bound VSL — cancer) ([c])	295,949	295,949	295,949	277,579	114,297
m. National VSLY estimates (revealed preference studies — Wage Risk) ([f])		74,993			
m. National VSLY estimates (revealed preference studies — Wage Risk) ([f])		99,990			
m. National VSLY estimates (revealed preference studies — Wage Risk) ([f])		144,986			
m. National VSLY estimates (revealed preference studies — Wage Risk) ([f])		199,980			
m. National VSLY estimates (revealed preference studies — Wage Risk) ([f])		274,973			
m. National VSLY estimates (revealed preference studies — Wage Risk)		339,966			
n. National VSLY for employees (own VSL conversion @ 3 %) ([g])		90,772			
o. National VSLY for persons killed in traffic accidents (own VSL conversion @ 3 %) ([h])		49,002			
p. Median northern Europe reference VOLY estimate (central) (VSL converted 3 %) ([f])	161,036				
q. National VSLY 2010 (road and rail projects) (own VSL conversion @ 3 %) ([i])	98,387				
q. National VSLY 2015 (road and rail projects) (own VSL conversion @ 3 %) ([i])	84,287				
r. National VSLY value (based on contingent valuation) ([f])				159,984	

	Finland	Germany	The Netherlands	Italy	Poland
s. National VSLY value (based on stated preference in Discrete Choice Experiment) (f)				174,983	
s. National VSLY value (based on stated preference in Discrete Choice Experiment) (f)				299,970	
t. National VSLY values (based on stated preference in Discrete Choice Experiment) (f)			179,982		
t. National VSLY values (based on stated preference in Discrete Choice Experiment) (f)			309,969		
u. Converted VSL to VSLY (@ 2.5 %) undiscounted future life years (lower) (j)			38,836		
v. Converted VSL to VSLY (@ 2.5 %) discounted future life years and income development (upper) (j)			125,883		
w. Converted VSL to VSLY (deaths in traffic accidents) (@ 3 %) (k)			117,392		
x. Polish VSLY value (wage risk)[6]					234.977
y. Converted life year value to euros (lower) (l)					174,478
y. Converted life year value to euros (upper) (l)					180,932

(a) NewExt (2003).

(b) CAFE (2005).

(c) ECHA (2016).

(d) EC (2009), referred to in OECD (2012).

(e) Ryen and Svensson (2014).

(f) Schlander et al. (2017a, 2017b).

(g) Sprengler (2004).

(h) Bundesanstalt für Straßenwesen (2018).

(i) Finnish Transport Agency (2015).

(j) EuroVaq (2010).

(k) Rijkswaterstaat (2016).

(l) Polish Social Insurance Institution (2015).

- **Evaluation of the different top-down monetisation approaches**

As stated earlier, to estimate the costs of the work-related burden of disease in a top-down approach, with data on the number of DALYs as a starting point for the cost model, we take a DALY as broadly equivalent to a QALY and monetise the burden of disease using a life year value based on three approaches: 1) human capital approach, 2) WTP approach and 3) value of a statistical life year approach (VSLY), which in fact also relies on WTP estimates. Each of the three monetisation approaches has its own focus. The human capital approach is focused on productivity loss, the WTP approach is focused on (small) changes in the risk of death or injury, while the value of a statistical life year (VSLY) approach is, often for pragmatic reasons due to a lack of data, focused on discounted streams of the value of statistical life (VSL) over the remaining life expectancy of an average adult. The VSL itself is in fact obtained through WTP estimations for changes in the risk of death and injury, and summed across a population to estimate the total value of one avoided fatality or injury (or disease), which represents the total resources society is willing to invest to reduce risk such that there is one fewer expected case.

A drawback of the human capital approach to monetary value DALYs remains that only part of an individual's welfare is measured — lifetime beyond paid work is not explicitly taken into account (for example the value of pain and suffering and the intrinsic value of life). Another concern with the human capital approach, as stressed by Mishan (1976), is that individual preferences are not taken into account. In a WTP approach, a broader set of impacts are included in the values, so the value of health in roles outside of paid work and the intrinsic value of health are captured. Therefore, the monetary values based on the WTP approach are usually higher than those based on the human capital approach. A drawback of the WTP approach is that values are based on surveys and valuation methods that are highly sensitive to the questions asked.

Depending on how questions are worded, valuations may capture more than just the value of health outcomes. As a result of the sensitivity to methods, the variance in values found across studies is quite wide. Willingness-to-pay values may be influenced by factors such as ability to pay, attitudes to risk, social security provisions, level of information/education on risks, age profile, and characteristics of the risk in question. Willingness-to-pay requires a good elicitation method/survey design in order to gather meaningful values.

From a theoretical welfare economics perspective, where the value of a QALY (that is, a health state improvement or alternatively, the value to avoid a health state deterioration and prevent DALYs operating) represents a utility, there should be one societal willingness-to-pay value for a QALY (or DALY). Only in a pure utility representation (that is, non-monetary terms) are all QALYs equal. There could be several reasons why different people might be willing to pay more or less for some QALY gain of the same magnitude, depending on the subjective views and contextual factors of the individuals questioned.

In line with this, regression analysis in literature sources (for example Ryen and Svennsson, 2015; RIVM, 2016; Sund and Svensson (2017) prove that there are several violations against the view that 'a QALY is a QALY is a QALY' when it comes to its monetary value. There appears to be no constant willingness to pay for a QALY. For this reason the RIVM (2016) researchers concluded that a 'common' societal value for a quality or disability adjusted life year is not appropriate. Instead of assuming a single monetary value, the RIVM (ibid) researchers state that it may be appropriate to consider more than one value for sensitivity purposes. It is exactly for this reason that we incorporated minimum, mean, median and maximum WTP values in our cost models. This, however, might make the interpretation and meaningfulness of the results more difficult to understand.

The VSLY approach suffers from the same drawbacks as the WTP approach since it is also based on WTP values. Schlander et al. (2017a, 2017b) state that, similar to some WTP studies, there is large heterogeneity between the estimates of the value of statistical life of different studies. The meta-study of these authors suggests that the empirical willingness to pay for a statistical life year might be substantially higher than thresholds currently used for cost-effectiveness studies in, for example, Health Technology Assessments, which are in the order of 75,000-80,000 euros in some countries. In addition, Ryen and Svensson (2015) found that WTP estimates based on converted value of statistical life values are on average 5.4-7.5 times higher than estimates based on stated preference studies. The Harvard School of Public Health and World Economic Forum (2011) found that the economic burden of non-communicable diseases is much higher if a value of statistical life approach is used compared with a human capital approach based on GDP per capita, even if the three times GDP per capita method is used (to — by proxy — theoretically account for values of life beyond productivity losses). Schlander et al. (2017, 2017b) found that the median value of a statistical life year is about 5.10 times larger than GDP per capita.

3.1.3 Final model

Our final model is based on three datasets:

1. Year 2015 DALYs by disease, for men and women separately, for the aggregated age group 15-70+ years, taken from the WHO's Global Health Estimates 2016, as published by the WHO Department of Information, Evidence and Research in June 2018 (WHO, 2018a).
2. Attributable fractions (AFs) to determine the number of occupational DALYs. These fractions (applied as a percentage to the total DALYs of dataset number 1, as described above), are determined in two ways:
    a. Derived AFs from the GBD study as published in the database of the IHME (IHME, 2016). The fraction of occupational DALYs as a percentage of total DALYs is calculated on year 2016 data for which DALYs by occupational risks multiplied by cause were available from IHME, and subsequently projected on year 2015 DALY data.
    b. Complementary AFs for disease categories included in our model but for which no AFs could be derived from IHME, are obtained from literature sources.
3. Monetary values for a life year (for which we assumed that monetary values for a QALY are reversely applicable to DALYs), following three different approaches: human capital approach (HCA), willingness-to-pay approach (WTP) and value of a statistical life year approach (VSLY), which in fact also relies on WTP estimates. Within each monetisation approach, the range of monetary values as found in the literature were large. Therefore, we worked with the minimum, mean, median and maximum of these values in our calculation models.

3.1.4 Sensitivity analysis

Similar to the bottom-up model, probabilistic sensitivity analysis was not possible, as distributional information on point estimates for much of the input data was not available. Apart from that, the top-down model delivers cost estimations for the burden of work-related illnesses and injuries by multiplication of three datasets: 1) DALYs, 2) attributable fractions (AFs; percentage of DALYs that can be attributed to work-related causes) and 3) monetary values for a DALY. Each dataset has its own specificities and uncertainties as described below. The consequence is that we could not meaningfully estimate an overall confidence interval. However, it is possible to show how sensitive the results are for a different origin of DALYs, a different source of AFs or a different method to monetise the value of a DALY.

DALYs (1) are obtained from the WHO Global Health Estimates 2016 and are provided as a single number, but with a cell-colour scheme to indicate some level of uncertainty per illness category and per age group category in each country. For the purpose of our cost estimation model, the WHO DALY source data are aggregated to a single age group (15-70+ years) as well as aggregated across illness categories. At this working level, we therefore have single DALY values without full statistical background information on confidence intervals. However, DALYs could also be obtained from the IHME database. To demonstrate the consequences for the cost estimation, the results are shown of DALYs originating from the WHO database as well as from the IHME database.

AFs (2) are derived from the IHME database. With this DALY source data we did not have any further statistical background information on the variance in IHME's DALY data. The same holds for our model variant (used for sensitivity analysis) based on AFs as found in the literature. Outcomes of the cost model differ depending on the choice of AFs from IHME or literature. Therefore, in the results section we will show the consequences when different attributable fractions are applied.

As explained in section 3.1.2 we have collected monetary values for a DALY (3) under three different approaches: the human capital approach, the willingness-to-pay approach and the statistical life year approach. Within all these approaches, outcomes of the cost estimation may vary according to the choice for a specific monetary indicator and its methodological underpinnings and parameterisation. Because of the large variation in possible monetary values, we report the final results under all three monetary estimation methods and for the full range within each method (that is, minimum, average, median and maximum).

3.1.5 Cost drivers by country

Country differences are highly dependent on the population and on the economic situation. Therefore, we take into account these figures in the discussion of the results. To allow country comparison we not only present the total costs but also the costs as a percentage of the GDP. Other national characteristics that may affect the work-related burden of disease are healthcare costs, sector structure and number of employed persons. In the discussion of the country differences we take these characteristics into account.

3.2 Results: top-down model

3.2.1 Central scenario

This scenario is based on the value of the DALY according to the WHO database and the attributable fractions as derived from the IHME database. Results from alternative scenarios will be compared with the results of this scenario. Table 3.2.1 shows the results for each monetisation approach separately. Since the ranges of the monetary value of the DALY are also very broad within the three monetisation approaches, we will work with the trimmed mean and trimmed ranges of estimates found in the literature, resulting in a minimum, average, median and maximum estimation of the total costs per country for each approach.

Table 3.2.1: Estimation of the total costs by country according to the central scenario

	Finland		Germany		The Netherlands		Italy		Poland	
DALYs:										
Total occupational DALYs		64,516		1,236.855		248,464		853.817		507,068
Percentage of total DALYs		4.2		4.9		5.7		5.1		4.0
Occupational DALYs per 10,000 employed persons		265		308		299		380		315
Costs:										
	Million EUR	% of GDP	Million EUR	% of GDP	Million EUR	% of GDP	Million EUR	% of GDP	Million EUR	% of GDP
Human capital approach										
Minimum	1,419	0.7	24,597	0.8	5,290	0.8	13,530	0.8	2,692	0.6

	Finland		Germany		The Netherlands		Italy		Poland	
Average	3,106	1.5	55,429	1.8	11,879	1.7	31,475	1.9	6,929	1.6
Median	2,291	1.1	39,712	1.3	8,708	1.3	23,865	1.4	4,656	1.1
Maximum	7,393	3.5	138,404	4.5	30,114	4.4	69,671	4.2	17,037	4.0
WTP approach										
Minimum	1,637	0.8	32,324	1.1	3,276	0.5	20,929	1.3	5,118	1.2
Average	5,814	2.8	66,251	2.2	14,613	2.1	42,895	2.6	9,676	2.3
Median ([a])	4,335	2.1	66,251	2.2	13,953	2.0	42,895	2.6	8,863	2.1
Maximum	17,453	8.3	100,177	3.3	30,767	4.5	64,861	3.9	15,861	3.7
VSLY/VOLY approach ([b])										
Minimum	4,214	2.0	60,609	2.0	9,649	1.4	52,304	3.2	12,790	3.0
Average	9,345	4.5	191,939	6.3	38,016	5.6	133,789	8.1	43,836	10.2
Median	8,633	4.1	166,943	5.5	33,248	4.9	126,876	7.7	31,026	7.2
Maximum	19,425	9.3	420,489	13.8	77,016	11.3	256,120	15.5	119,149	27.7

([a]) Median and average WTP-values are the same in Germany and in Italy because for these two countries we could only include two European central reference values, hence the minimum and maximum values as reported in the table.

([b]) VSLY/VOLY: Value of Statistical Life Year/ Value of Life Year

Table 3.2.1 shows that about 5 % of the total burden of disease in the countries under study could be attributed to occupational risks. Although the highest percentage was found in the Netherlands (5.7 %), the work-related burden of disease seems to be smaller according to the occupational DALYs per employed person. Apparently, the total burden of disease is relatively small in this country.

The estimated costs of work-related diseases are highly dependent on the monetisation approach. The lowest estimates come from the human capital approach, the estimation according to the willingness-to-pay approach is higher and the estimation according to the VSLY/VOLY (Value of Statistical Life Year/ Value of Life Year) approach is considerably higher, in particular for Poland. Country differences are also considerably larger when the VSLY/VOLY approach is applied.

3.2.2 Alternative data source for DALYs

For the central scenario in the top-down model of the present study we used the WHO database as the source of DALYs (WHO, 2018a). However, the IHME database contains DALYs as well. Both are based on the GBD study (IHME, 2016), the underlying years lived with disability (YLD) in the WHO DALYs ‘draw heavily from the work of the Institute of Health Metrics and Evaluation (IHME) at the University of Washington, and their many collaborators in the Global Burden of Disease 2016 Study’, as can be read in the WHO’s technical paper regarding their methods and data sources for global burden of disease estimates 2000-2016 (WHO, 2018b, p. ii). However, following the GBD 2010 study, based on analysis by WHO and UN interagency groups, the WHO no longer endorsed the GBD results and released its own regional- and country-level estimates of DALYs based on a different estimation of cause-specific mortality that is consistent with the WHO's Global Health Estimates (WHO, 2018a). In Table 3.2.2, the results are presented of the scenario in which DALYs were derived from the IHME database.

Table 3.2.2 Estimation of the total costs by country if DALYs were retrieved from the IHME database

	Finland		Germany		The Netherlands		Italy		Poland	
DALYs:										
Total occupational DALYs		64,711		1,220,605		248,217		866,382		507,607
Percentage of total DALYs		4.5		5.3		6.0		5.5		4.4
Occupational DALYs per 10,000 employed persons		266		304		298		386		316
Costs:										
	Million EUR	% of GDP	Million EUR	% of GDP	Million EUR	% of GDP	Million EUR	% of GDP	Million EUR	% of GDP
Human capital approach										
Minimum	1,424	0.7	24,274	0.8	5,285	0.8	13,729	0.8	2,694	0.6
Average	3,115	1.5	54,701	1.8	11,867	1.7	31,938	1.9	6,936	1.6
Median	2,298	1.1	39,191	1.3	8,700	1.3	24,216	1.5	4,661	1.1
Maximum	7,416	3.5	136,586	4.5	30,084	4.4	70,697	4.3	17,056	4.0
WTP approach										
Minimum	1,642	0.8	31,899	1.0	3,273	0.5	21,237	1.3	5,123	1.2
Average	5,832	2.8	65,380	2.1	14,599	2.1	43,526	2.6	9,687	2.3
Median ([a])	4,348	2.1	65,380	2.1	13,939	2.0	43,526	2.6	8,872	2.1
Maximum	17,506	8.4	98,861	3.2	30,736	4.5	65,816	4.0	15,878	3.7
VSLY/VOLY approach										
Minimum	4,226	2.0	59,813	2.0	9,640	1.4	53,074	3.2	12,804	3.0
Average	9,373	4.5	189,418	6.2	37,978	5.6	135,757	8.2	43,883	10.2
Median	8,659	4.1	164,750	5.4	33,215	4.9	128,743	7.8	31,059	7.2
Maximum	19,483	9.3	414,964	13.6	76,940	11.3	259,889	15.7	119,276	27.7

([a]) Median and average WTP-values are the same in Germany and in Italy because for these two countries we could only include two European central reference values, hence the minimum and maximum values as reported in the table.

Comparing the results of Tables 3.2.1 and 3.2.2, we can conclude that it hardly matters for the final cost estimation if DALYs are retrieved from the WHO database or from the IHME database. We see some differences in the proportion of occupational DALYs as part of the total DALYs, but the total occupational DALYs and as a consequence also the cost estimation are rather similar.

3.2.3 Alternative attributable fractions

As shown in paragraph 3.1.1, attributable fractions derived from the GBD study are different from those based on the literature review. In the central scenario the attributable fractions as derived from the GBD study have been applied. If the attributable fractions from the literature are applied, results may diverge from those of the central scenario. In Table 3.2.3 the results are presented of the scenario in which the attributable fractions from the literature review are applied. In this table, DALYs are based on those retrieved from the IHME database.

Table 3.2.3: Estimation of the total costs by country according to the scenario using attributable fractions based on the literature

	Finland		Germany		The Netherlands		Italy		Poland	
DALYs:										
Total occupational DALYs	90,798		1,493,009		265,538		960,501		762,569	
Percentage of total DALYs	6.4		6.4		6.5		6.2		6.7	
Occupational DALYs per 10,000 employed persons	373		371		319		428		474	
Costs:										
	Million EUR	% of GDP	Million EUR	% of GDP	Million EUR	% of GDP	Million EUR	% of GDP	Million EUR	% of GDP
<u>Human capital approach</u>										
Minimum	1,997	1.0	29,691	1.0	5,654	0.8	15,220	0.9	4,048	0.9
Average	4,371	2.1	66,909	2.2	12,695	1.9	35,407	2.1	10,420	2.4
Median	3,224	1.5	47,937	1.6	9,307	1.4	26,847	1.6	7,002	1.6
Maximum	10,405	5.0	167,068	5.5	32,183	4.7	78,377	4.7	25,622	6.0
<u>WTP approach</u>										
Minimum	2,303	1.1	39,018	1.3	3,501	0.5	23,544	1.4	7,697	1.8
Average	8,183	3.9	79,971	2.6	15,618	2.3	48,255	2.9	14,552	3.4
Median ([a])	6,101	2.9	79,971	2.6	14,911	2.2	48,255	2.9	13,329	3.1

	Finland		Germany		The Netherlands		Italy		Poland	
Maximum	24,563	11.7	120,924	4.0	32,881	4.8	72,966	4.4	23,853	5.5
VSLY/VOLY approach										
Minimum	5,930	2.8	73,161	2.4	10,313	1.5	58,839	3.6	19,235	4.5
Average	13,152	6.3	231,690	7.6	40,628	5.9	150,505	9.1	65,925	15.3
Median	12,150	5.8	201,518	6.6	35,533	5.2	142,729	8.6	46,660	10.8
Maximum	27,338	13.0	507,572	16.7	82,309	12.0	288,121	17.4	179,186	41.7

([a]) Median and average WTP values are the same for Germany and Italy because for these two countries we could only include two European central reference values, hence the minimum and maximum values as reported in the table.

Comparing the results in Table 3.2.3 and Table 3.2.2[18], it can be concluded that in the scenario where the attributable fractions from the literature were applied, the cost estimation turns out to be higher than in the central scenario. In some countries the difference is much larger than in other countries. In Poland the application of the attributable fractions from the literature leads to a 50 % higher cost estimation of the work-related burden of disease, irrespective of the monetisation approach, while in the Netherlands the difference is only 7 %.

3.2.4 Main diseases by country

Table 3.2.4 shows the occupational DALYs by disease and by country per 10,000 persons employed. Only the diseases with a relatively large contribution to the total work-related burden of disease are shown. Since the estimation of the DALYs by disease is highly dependent on the method to estimate the attributable fraction, the results of both methods are shown.

[18] Since the results presented in Table 3.2.3 are based on the DALY values of the IHME database, results should be compared to those of Table 3.2.2 which are based on the same DALY values.

Table 3.2.4: Occupational DALYs per 10,000 employed persons by diseases, for two different methods to estimate the fraction that is caused by occupational exposure

	Finland		Germany		The Netherlands		Italy		Poland	
	AF IHME	AF lit	AF IHME	AF lit	AF IHME	AF lit	AF IHME	AF lit	AF IHME	AF lit
Occupational DALYs per 1,000 employed persons										
Tracheal, bronchus and lung cancer	47	27	65	38	82	37	83	43	53	57
Musculoskeletal diseases	57	57	53	53	45	45	47	47	68	68
Mental disorders	52	52	48	48	48	48	53	53	35	35
Injuries — unintentional	14	13	20	8	11	6	33	9	32	22
Neurological diseases	22	22	18	18	16	16	25	25	17	17
Respiratory diseases — COPD	13	15	20	20	18	20	13	17	17	17
Circulatory diseases	17	135	18	129	12	72	11	118	27	190
Injuries — transport	7	2	12	2	7	2	26	4	19	6
Other non-communicable diseases	9	0	18	0	9	0	14	0	18	0
Mesothelioma	8	7	7	6	12	11	11	10	3	3
Respiratory diseases — asthma	6	10	5	7	4	7	4	7	4	7
Digestive diseases	4	4	4	4	2	2	4	4	6	6
Bladder cancer	1	1	2	2	2	2	4	4	4	4
Genitourinary diseases	2	2	2	2	2	2	2	2	2	2
Communicable diseases	1	7	2	11	2	10	1	9	3	14

	Finland		Germany		The Netherlands		Italy		Poland	
Ovarian cancer	2	0	2	0	2	0	3	0	1	1
Respiratory diseases — pneumoconiosis	2	2	2	2	0	0	2	2	1	1

BoD, burden of disease; IHME, Institute of Health Metrics and Evaluation (in particular the global burden of disease study 2016); AF IHME, attributable fraction based on the IHME database; AF lit, attributable fraction based on the literature.

As already shown in section 3.1.1 (Table 3.1.1a), large differences can be seen between both estimations of the attributable fraction, in particular for circulatory diseases. According to the literature, in Poland 40 % of the occupational DALYs can be attributed to circulatory diseases, while it is only 8.5 % according to the AFs derived from the IHME database. Italy has relatively many DALYs lost to work-related injuries if applying the AFs from the IHME, but not if the values from the literature are used.

Although country differences were found, results are rather similar. In all countries, diseases with the largest contribution to the work-related burden of disease are work-related lung cancer, musculoskeletal diseases and mental disorders. According to the AFs reported in the literature, we may also add circulatory diseases. In Poland, work-related mental disorders occur less, and work-related musculoskeletal disorders more frequently. According to the AF from the IHME, work-related lung cancer occurs more often in Italy and the Netherlands. This is partly due to the relatively high attributable fraction in these countries. In Poland, lung cancer occurs more frequently but according to the IHME the AF is lower.

Diseases for which the AF is very high, such as pneumoconiosis, do not contribute highly to the work-related burden of disease, since they are not frequently reported.

4 Conclusions and discussion

4.1 Comparison of the results of both models

In the bottom-up model, the total estimated economic burden of work-related injuries and diseases — including fatal and non-fatal cases— ranges from 2.9 % of GDP in Finland to 10.2 % in Poland. If intangible costs are not included, the estimate ranges from 2.1 % in Finland to 5.2 % in Poland. In the top-down model, the economic burden is highly dependent on the monetisation approach used. In the human capital approach, the work-related economic burden varies from 0.6 % to 4.5 %, depending on the method used, with less variance between countries. In the WTP approach, percentages are higher and vary from 0.5 % to 8.3 %. The VSLY approach yields the highest values and estimates the work-related economic burden of disease at 1.4 % of GDP at a minimum and 27.7 % at a maximum. In this approach, variance between countries is also higher. The approach that comes closest to the results of the bottom-up model is the VSLY approach, if we consider the average or median value of the different studies. In addition, the rank ordering of countries in the VSLY approach in terms of magnitude of economic burden relative to GDP is similar to that in the bottom-up model, with the highest value for Poland (average 10.2 % and median 7.2 % of GDP) and the lowest value for Finland (average 4.5 % and median 4.1 % of GDP). The similarity between the VSLY approach of the top-down model and the bottom-up model may be explained by the inclusion of health and life impacts in the VSLY approach. Health and life impacts, in the bottom-up model described as ‘intangible costs’, are a substantial part of the total costs in the bottom-up model, varying from 20 % to almost 50 %.

4.2 Strengths and limitations of both models

In comparing the outcomes of the two cost estimation models, it is important to realise that they do not estimate identical phenomena. Although they are both used to provide estimates of the economic burden of work-related injury and disease, the components of these models are very different. Neither model can be said to be better or more precise than the other. Ultimately, they provide different information and may serve different purposes. Depending on how the results of the cost estimation will be used, one model might be preferable over the other. Below are some considerations regarding the application of the bottom-up and top-down models.

- *Granularity of data*
  The bottom-up model is based on incident cases and builds up the cost components from that starting point. Given the granularity of the country-specific data available to populate the cost components, it is possible to compare components of the burden at a point in time (for example a comparison of the costs of work-related productivity loss and the formal healthcare costs), or over time (for example changes in home production loss costs).

- *Comparability of results*
  Comparing the economic burden of work-related injuries and diseases across countries at a point in time and within a country over time is an important aspect of such studies. Using the bottom-up model makes the results more comparable with most of the published studies, such as HSE (2015), Leigh (2011) and Safe Work Australia (2015), since they also used a bottom-up model. In addition, using national data sources (for example healthcare costs, out-of-pocket costs, labour income, employment and probability of survival) with a bottom-up model lends itself well to cross-country comparisons on these components and allows for a better interpretation of the results. However, cross-country comparisons of the top-down model estimates have their shortcomings, particularly if country-specific attributable fractions are not used. Moreover, national data sources may not always be comparable due to differences in data collection methods. The advantage of a top-down model based on DALYs is that country-specific DALYs may be less sensitive to changes over time due to their formulation using high-level international data.

- *Cost categories*
  The bottom-up model offers substantial insights into the various cost categories (for example costs within the healthcare system) that drive the total economic burden. In contrast, the top-down model based on DALYs uses a proxy measure for the value of good health to monetise the burden, but does not include any consideration of other components of the burden. The top-down model does not identify the cost component of the total burden such as healthcare costs, informal caregiving costs, out-of-pocket costs, home production loss costs, administrative costs and presenteeism-related costs.

- *Quality of life*
  The bottom-up model includes the value of health-related quality of life under the intangible costs component. This component has some parallels to monetised DALYs, although there are differences in how QALYs and DALYs are constructed. Monetising health-related quality of life poses challenges for both the bottom-up and top-down models. Different approaches to identifying price weights for QALYs and DALYs results in quite different values. For example, in the literature there are different WTP values. Moreover, the valuation of DALYs may have consequences for cross-country comparisons if they are monetised using GDP.
- *Uncertainty*
  The bottom-up model relies on the aggregation of many data points and therefore there is potential for some level of uncertainty in each of the input values. It is common to undertake sensitivity analysis to assess the impact on the results of varying the magnitude of key parameters. The top-down model is based on fewer data points, but the uncertainty is also very high. There is uncertainty in the measurement of DALYs themselves, the attributable fractions to estimate work-relatedness, and the monetary values of a life year. The latter can be based on a narrow or broader theoretical conceptualisation of quality of life.

- *Time needed to construct the model*
  Related to the above issue of data demands is the time required to collect and analyse the data for the bottom-up model. Executing the bottom-up model is far more time-consuming than the top-down model. The latter can be executed with international data that is readily available.

- *Stratification of the results*
  One of the positive features of the bottom-up model is stratification of cases by age bracket and sex. This stratification operates well for estimating indirect and intangible costs. Specifically, indirect and intangible costs are estimated based on the counterfactual of living a standard life expectancy with standard health profiles based on age bracket and sex specific data. This provides detail and precision that is not possible with the top-down model. Furthermore, the bottom-up model lends itself well to estimating the economic burden borne by different stakeholders (worker, employer and system), which is not possible with the top-down model as DALYs are a single metric for overall societal burden of which the monetised value should be interpreted as such.

Based on the issues mentioned above, we conclude that both models have their strengths and shortcomings. Although both models have difficulties in terms of monetising health and data reliability, the bottom-up model provides more detailed information for policy-makers such as direct, indirect and intangible costs, as well as costs by stakeholder. Furthermore, cross-country comparisons are more robust with this model. However, it is worth mentioning that a top-down model has the advantages that far less time is needed to construct the model, and country and regional comparisons are easier since internationally harmonised sources may be used.

4.3 Datasources — availability and quality

In the present study, numerous national and international data sources were used. Most of them were described in the report from the first phase of the project (EU-OSHA, 2017b). Based on these results, in the present project we chose to work with international data sources, since we expected a higher level of quality and more harmonised data collection, which would enable a cross-country comparison. The conclusions of the present study are:

- Underreporting seems to be a large problem in statistics on work-related injuries. In addition, ESAW, the statistics used in the present study, suffer from underreporting.
- No suitable data sources are available on work-related diseases.
- Survey data were available on work-related health problems, but they have serious drawbacks: diseases with a long latency period are often not reported, fatal work-related health shocks are excluded and workers themselves might not be the best people to assess the work-relatedness of their health problems.
- Measures such as employee income, fringe benefits, employment rate and probability of survival are well registered; however, we had limited data regarding the average earnings lost for permanent disability cases in all countries.

For most other cost categories, we had to rely on national sources. The comparability of these sources is often unclear. Data collection is not harmonised and is often collected by different institutions or for different means. For more details on the comparability, quality and availability of data sources in different European countries we refer to the report of the first phase of the project (EU-OSHA, 2017a).

4.4 Comparison with the literature

Cost estimations of the total work-related burden of disease (that is, not limited to one or more specific causes or risks) have been done before on a large scale by Safe Work Australia (2015) and Leigh (2011). Both used a bottom-up model and many methods used in the present study were derived from these studies (see section 3.1). However, intangible costs were not included in these studies. Leigh estimated that the work-related economic burden of disease amounted to 1.8 % of GDP in the USA; a lower percentage than the bottom-up model in the present study, but Leigh did not include intangible costs. In our estimation, intangible costs vary from 20 % to 50 % of the total costs, which makes the results in our five countries (ranging from 2.9 % to 10.2 % in Poland) more or less similar to those of Leigh in the United States. In Australia, costs were estimated higher than in the United States: at 4.1 % of GDP in 2012-2013. Taking into account that intangible costs were not included, this estimation is also higher than most countries in the present study. Several factors may have caused the difference in estimation. In the next paragraph, national characteristics that may have caused differences in cost estimation are discussed.

Recently, an economic cost estimation of the total work-related burden of disease was carried out (EU-OSHA, 2017a) using a top-down model[19]. In this model, occupational DALYs were also calculated per 10,000 employed persons. For Italy, the number of occupational DALYs per 10,000 employed persons was somewhat lower than in our study (309 versus 380), while this number was higher in other countries (Germany, Finland, the Netherlands, Poland; respectively, 333 versus 308, 333 versus 265, 313 versus 299, 323 versus 315). The costs of occupational DALYs as a percentage of GDP was calculated as the percentage of employed persons[20] and ranged from 3.1 % to 3.3 % meaning less cross-country

[19] Methodology of this study is available at the EU-OSHA website: https://osha.europa.eu/sites/default/files/publications/documents/international_comparison-of_costs_work_related_accidents.pdf. For the present study, the researchers were able to use an excel file containing more detailed data of this study.

[20] In the underlying Excel file of the model that Takala and colleagues estimated for the EU-OSHA publication mentioned in the previous footnote, monetary estimations were made by multiplying DALYs with GDP per employed persons. However, this indicator seems to be 'netted out' in the calculation step to express the economic burden as a percentage of GDP of the

differences than we find in our study. When we calculate the overall burden of work-related disease similar to the way it is done in the model for the EU-OSHA (2017a) study — that is, in line with the abovementioned number of occupational DALYs per 10,000 employed persons — we come to a range of 2.6 % to 3.8 % of the GDP of the five countries included in the calculation model.

The burden of work-related disease as a percentage of GDP stemming from the model for the EU-OSHA (2017a) publication is somewhat higher than the percentages in the present study if we multiply the average or median monetary values of the human capital or willingness-to-pay approach with the total number of occupational DALYs and subsequently express this result as a percentage of the GDP of the respective countries[21] (ranging from 1.1 % to 2.8 %).However, it is considerably lower than the percentages of GDP if we apply the average or median monetary values of the VSLY approach (ranging from 4.1 % to 10.2 %). Our conclusion is that the results of the model for the EU-OSHA (2017a) study, are more similar to the results of studies using a monetisation approach that has a smaller component of life impacts (that is, using a human capital approach).

4.5 Country comparison

Comparing the results of countries, we should keep in mind that various national differences may influence the results. Below we will consider the main characteristics:

- Reporting of cases
  All approaches are dependent on the reporting of work-related injuries or diseases. Although underreporting might be a problem in most countries, we assume that country differences will occur. In some countries registration systems are voluntary, in others they are obligatory. Incentives may or may not exist to report an accident or work-related disease. The insurance system might influence reporting behaviour: insurance-based systems provide a financial incentive while legal obligations to report injuries in non-insurance-based systems are not always followed. In the present study we adjusted the results for underreporting. However, uncertainty about the degree of underreporting is still present.

- Sector structure
  In agriculture and industry, more work-related injuries occur than in the service sector. In addition, in the service sector, less occupational risk factors are present. The table below shows the percentage working in the service sector, industry and agriculture of the countries under study. In the Netherlands, the percentage working in the service sector is very high compared with the other countries. For Poland, this is the opposite: relatively few work in the service sector, while many work in industry and agriculture. Based on the sector structure, we might expect a relatively high work-related burden of disease in Poland and a relatively low burden in the Netherlands.

Table 4.5a: Country differences — sector

Country	% employed in services	% employed in industry	% employed in agriculture
EU 28	73.1	21.9	5.0
Finland	73.1	22.4	4.5
Germany	73.9	24.6	1.5
The Netherlands	82.9	14.9	2.2

respective countries. The overall burden of disease therefore corresponds to the number of occupational DALYs as a percentage of the number of employed persons.

[21] That is, our way of calculating the burden of disease as an overall percentage of GDP is: (Total $DALYs_{occupational}$ * monetary value for a DALY)/GDP.

Country	% employed in services	% employed in industry	% employed in agriculture
Italy	72.4	23.9	3.7
Poland	58.3	30.2	11.5

Source: LFS 2015 (Eurostat).

- Healthcare costs
  The costs of healthcare vary between countries. In the table below we present the costs of two different diseases. We included musculoskeletal disorders because they are the most frequent work-related health problem (see Table 2.1.1c) and lung cancer because it is one of the most expensive work-related health problems (see Table 2.1.2b).

Table 4.5b: Differences in healthcare costs per case for a selection of diseases (based on Table 2.1.2b) *(EUR)*

Country	Musculoskeletal disorders	Lung cancer
Finland	1,193	20,181
Germany	1,206	20,403
The Netherlands	1,403	23,730
Italy	1,062	17,963
Poland	367	6,210

Sources: Polinder (2004); Lorenzoni and Koechlin (2017).

The table illustrates the variance among countries. In the Netherlands (and also in Germany and Finland) healthcare costs seem to be more expensive, while the costs of healthcare in Poland is much lower. This might have affected the results. Although the costs of the work-related burden of disease is already relatively high in Poland, higher healthcare costs in Poland may lead to more extreme results.

- *Economic situation*
  When following a top-down model, GDP per capita differences lead to different monetary outcomes. In addition, part of the bottom-up model, for example, the estimation of production losses, takes into account the economic situation. As a consequence, the cost estimation will be relatively high in countries with a high GDP per capita. Based on the economic situation, we might expect a higher cost estimation in the Netherlands, Finland and Germany, and a lower estimation in Italy and Poland. Note that while comparing DALYs or cases of work-related injuries and diseases, the economic situation is not involved.

In comparing the countries, we see in most scenarios that the work-related burden of disease is relatively high in Poland and Italy, compared with Germany, Finland and the Netherlands. Poland and Italy also have the highest proportion of intangible costs. However, if we do not include the intangible costs in both countries, the cost estimation is still relatively high. In Poland, at least part of it may be explained by the sector structure. The workforce in Poland consists of a relatively high number of people working in agriculture or industry (see Table 6.2.1). Although the percentage of people working in industry in Italy is above average, the explanation for the relatively high burden is less clear than in Poland. Partly, the relatively high work-related burden is caused by a relatively high number of DALYs lost to work-related lung cancer. However, the main difference with the other countries under study is the relatively high amount of DALYs lost to injuries, ‘unintentional injuries’ as well as ‘transport injuries’.

4.6 Final discussion

Top-down or bottom-up model?

In theory, the bottom-up model is more precise, given that it is built up from specific individual components and data. Moreover, the results of the bottom-up model give more insight into the different cost components. The results are more transparent. However, in practice issues with data availability and reliability result in measurement error. Another shortcoming is that it is very time-consuming to collect and analyse all the data needed. In conclusion, a bottom-up model is the preferable approach to come to a cost estimation of the work-related burden of disease, if reliable data sources are available as well as sufficient time and resources.

Life and health impacts — to be included or not?

Life and health impacts are an important part of the cost estimation in the present project, for the bottom-up model as well as for the top-down model. In the bottom-up model we see that the proportion of intangible costs is 20 % to 50 % of the total cost estimation. In the top-down model, monetisation approaches that include values of a life year come to much higher estimates than monetisation approaches that only count production losses. One very important argument for including life and health impacts is that if they are not monetised they probably will be ignored and not included in the trade-off. However, there is no consensus on the approach to estimate their value. This fact may hinder their credibility and their influence on the decision-making process. Consensus on the values of life and health impacts would increase their impact in decision making.

Feasibility of applying the models to the EU-28 plus Norway and Iceland

National data needed to estimate the work-related burden of disease using the top-down model are readily available in international databases, such as the WHO Global Health Estimates, the IHME database and Eurostat data. The monetisation is dependent on the preferred method. In the human capital approach, data are easily obtainable. For the other monetisation approaches, national values of willingness to pay or the value of a statistical life year may be preferred but it is also possible to use central reference European values[22]. Therefore, it is feasible to apply the top-down model in other countries.

The bottom-up model as described in the present study, could also be applied in other countries as long as the appropriate data are available. However, as noted before, executing the bottom-up model is far more time-consuming than the top-down model, at least when first undertaking the task. Countries such as Australia that have used the model repeatedly are likely to have systematised the process. The bottom-up model relies heavily on national sources. They differ in quality and availability. Although, the availability of the sources was examined in an earlier phase of this project, extracting the data and harmonising the classification was not easy and sometimes quite challenging. Note that the countries that were included in the present project were selected on the basis that they had sufficient data available to populate the model. We expect that data sources in the remaining countries of the EU-28 (plus Norway and Iceland) will have varying amounts of data available for such a model.

Data needed to improve the results — implications for future projects

As noted, in this project on the cost estimation of the work-related burden of injury and disease, countries were selected based on the expectation that they had sufficient data of good quality to enable the estimation. However, data were often lacking, quality was poor and alternative sources had to be explored to come to a reasonable estimation. In particular for the bottom-up model, which consists of several components, the search for appropriate data was quite a challenge at times. One of the main purposes of the sensitivity analysis section of this study, and specifically using several Tornado diagrams to do so, is to indicate the role and importance of each single input parameter on the final economic estimation (based on the GDP percentage). These diagrams illustrated which input parameter has a bigger impact on the final result, and consequently should be considered as a priority

[22] Which can be scaled to income levels in each country based on GDP/capita ratios combined with the researchers' choice of application of the order of magnitude of income elasticities.

in the data collecting process. Therefore, the first step to enable a cost estimation of this sort in all European countries would be to build up and harmonise the data collected in these countries. This raises a number of challenges. First, the count of work-related cases should be improved for all economic burden estimation models. This has been an ongoing challenge. Some initial efforts might be made through sector-specific studies in different countries focused on standardisation through estimates of underreporting. Survey methods might also help resolve the differences if a module in a labour force survey undertook a deep dive inquiry into injury and disease reporting/underreporting and the reasons behind it. In the present projects it was not possible to base the bottom-up model on incident cases of work-related diseases from country reporting. But data on incident cases for injuries and diseases has to come from somewhere for both the top-down and bottom-up models, ideally from reliable, country-specific sources so that meaningful cross-country comparisons can be made. If they are approximated through generic, international sources, then cross-country comparison is less meaningful for both models. Furthermore, country-specific data on the healthcare costs of injuries and diseases appeared to be very difficult to obtain. Finally, it would be helpful to come to a consensus on the way to value life and health impacts for both the top-down and bottom-up models.

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6 Appendix 1 — Country characteristics used for the country selection

Table A1a: Percentages employed in services, industry and agriculture by country. The highlighted percentages are above the EU average of persons employed in services

Country	% employed in services	% employed in industry	% employed in agriculture
EU-28	73.1	21.9	5.0
Belgium	80.4	18.3	1.3
Bulgaria	55.6	25.0	19.4
Czechia	59.9	36.8	3.3
Denmark	80.2	17.2	2.6
Germany	73.9	24.6	1.5
Estonia	67.4	28.8	3.7
Ireland	76.0	18.3	5.7
Greece	73.9	13.8	12.3
Spain	78.2	17.7	4.0
France	79.6	17.6	2.8
Croatia	63.7	26.9	9.5
Italy	72.4	23.9	3.7
Cyprus	69.3	27.1	3.6
Latvia	68.8	23.7	7.4
Lithuania	66.1	24.7	9.2
Luxembourg	79.4	19.5	1.2
Hungary	65.8	27.5	6.7
Malta	78.9	19.4	1.7
The Netherlands	82.9	14.9	2.2
Austria	72.5	23.0	4.4
Poland	58.3	30.2	11.5
Portugal	65.9	22.8	11.3

Country	% employed in services	% employed in industry	% employed in agriculture
Romania	42.0	28.6	29.4
Slovenia	62.4	29.3	8.3
Slovakia	65.6	31.1	3.3
Finland	73.1	22.4	4.5
Sweden	77.1	20.6	2.3
United Kingdom	83.0	15.6	1.4
Iceland	n.a.	n.a.	n.a.
Norway	76.9	20.6	2.5

Source: LFS 2015 (Eurostat).

Table A1b: Summary of the availability of data sources based on the previous project (EU-OSHA, 2017b) and the diversity conditions

Countries	Accidents	Work-related diseases	Additional labour costs	Conclusion on data availability and quality:	Geographical location	Insurance system	% employed in services > EU mean
Source national or international ([a])	international	international	national	n.a.	n.a.	international	international
Austria			?		West	Bismarckian	
Belgium					West	Bismarckian	Y ([b])
Bulgaria					Central	Bismarckian	
Croatia					South	Mixed	
Cyprus					South	Beveridgean	
Czechia					Central	Bismarckian	
Denmark					North	Beveridgean	Y
Estonia					North	Bismarckian	
Finland				OK	North	Mixed	mean
France					West	Bismarckian	Y
Germany					West	Bismarckian	Y

Countries	Accidents	Work-related diseases	Additional labour costs	Conclusion on data availability and quality:	Geographical location	Insurance system	% employed in services > EU mean
Greece					South	Beveridgean	Y
Hungary					Central	Bismarckian	
Iceland					North	Beveridgean	
Ireland					West	Beveridgean	Y
Italy					South	Beveridgean	
Latvia					North	Bismarckian	
Lithuania					North	Bismarckian	
Luxembourg			?		West	Bismarckian	Y
Malta			?		South	Beveridgean	Y
The Netherlands				OK	West	Bismarckian	Y
Norway					North	Beveridgean	Y
Poland					Central	Bismarckian	
Portugal					South	Beveridgean	
Romania					Central	Bismarckian	
Slovakia					Central	Mixed	
Slovenia					South	Bismarckian	
Spain					South	Beveridgean	Y
Sweden					North	Beveridgean	Y
United Kingdom					West	Beveridgean	Y

= sufficient sources

= almost sufficient

= some sources available

= no sources or insufficient/un-reliable

([a]) International sources are preferred, if available. The assessment of availability and reliability is based on the available documentation of several international sources. It is a preliminary assessment, since more information on the reliability of the data and the exact data needs of the models were only known after the first stage of the present project. ([b]) A 'Y' means that the percentage of persons employed in the service sector is above the EU average (see also Table 1 in this appendix).

Table A1c: The availability of data sources in the selected countries after the first step of the second phase for: Germany (DE), Finnland (FI), Croatia (HR), Italy (IT), the Netherlands (NL), Poland (PL), Slovakia (SK)

DATA NEED	DE	FI	HR	IT	NL	PL	SK
Number of work-related injuries	1	2	2	2	1	2	2
Work-related diseases	2	1	1	2	1	2	1
Occupational injuries — lifetime healthcare costs of treating cases	1	0	0	0	0	0	2
Occupational diseases — lifetime healthcare costs of treating cases	1	0	0	0	1	0	1
Compensation of employees/wage employed persons	1	1	1	1	1	2	1
Payroll costs	2	2	2	2	2	2	2
Probability of employment in the paid-labour force	2	2	2	2	2	2	2
Probability of employment for long-term disabled	1	1	1	1	1	1	1
Life expectancy	1	1	1	1	1	2	1
Life expectancy for long-term disabled	0	0	0	1	0	0	0
Home production time	1	1	1	2	1	1	0
Wage rate for home production time	1	0	0	2	1	1	0
Family caregiving time	1	0	0	0	0	0	0
Wage rate for family caregiving time	1	0	0	2	1	1	1
Out-of-pocket healthcare expense	1	0	0	0	0	0	0
Social insurance administrative expenses	1	0	0	1	0	0	0
Proportion of cases covered by social insurance	1	0	0	0	0	0	1
YLL, YLD, DALY	1	1	1	1	1	1	1
Retirement age	1	1	1	1	1	1	1
Average population (1 January + 31 December/2)	2	2	2	2	2	2	2
Economically active population	2	2	2	2	2	2	2
Employed persons	1	1	1	2	1	1	2
Labour volume of employed persons (FTE)	2	2	2	2	2	2	2
Gross value added	2	2	2	2	2	2	2
GDP	2	2	2	2	2	2	2
GDP per capita	2	2	2	2	2	2	2
(adjusted) Household disposable income	1	1	1	1	1	1	1
TOTAL	**35**	**27**	**27**	**36**	**29**	**32**	**32**

A score of 0 to 2 was used to indicate data availability (0 being not available and 2 being fully available). The coding should be read as follow: 0/red, no data available; 1/yellow, some data available; 2/green, all data available.

The five countries with the highest total score were Germany (DE), Italy (IT), the Netherlands (NL), Poland (PL), Slovakia (SK). On the recommendation of EU-OSHA, based on experience with previous research in those countries, Finland was however given preference over Slovakia. Therefore, the final five countries to be covered in the study are Germany, Finland, Italy, the Netherlands and Poland.

7 Appendix 2 — Data overview

Data need	Finland	Germany	The Netherlands	Italy	Poland
Incidence data					
Work-related injuries	Eurostat: ESAW 2015, LFS 2013	Eurostat: ESAW 2015, LFS 2013	Eurostat: ESAW 2015, LFS 2013	Eurostat: ESAW 2015, LFS 2013	Eurostat: ESAW 2015, LFS 2013
Work-related diseases	Finnish Institute of Occupational Health 2012 IHME database 2015, 2016	DGUV Statistics 2013 IHME database 2015, 2016	NCvB statistiek — Nationale Registratie Beroepsziekten (2015) IHME database 2015, 2016	EurostaBanche dati static, work-related injury and disease (2015) IHME database 2015, 2016	Szeszenia-Dabrowska and Wilczynska 2016 IHME database 2015, 2016
Direct costs					
Healthcare costs of treating work-related injuries and diseases per case	Federal Statistical Office (Destatis) Italy National Ministry of Health (2015) Lorenzoni and Koechlin (2017).	Federal Statistical Office (Destatis) Italy National Ministry of Health (2015) Lorenzoni and Koechlin (2017).	Federal Statistical Office (Destatis) Italy National Ministry of Health (2015) Lorenzoni and Koechlin (2017).	Federal Statistical Office (Destatis) Italy National Ministry of Health (2015) Lorenzoni and Koechlin (2017).	Federal Statistical Office (Destatis) Italy National Ministry of Health (2015) Lorenzoni and Koechlin (2017).
Disease treatment episode	HSE 2011	HSE 2011	HSE 2011	HSE 2011	HSE 2011
Insurance administration costs	Kela 2015	Techniker Krankenkasse 2016	CZ 2016	OECD 2017	NFZ 2018
Informal caregiving cost	Statistics Finland 2016	Destatis 2015	CBS/StatLine 2017	Destatis 2015	ZUS 2018
Healthcare out-of-pocket costs	EC 2016	The Commonwealth Fund 2017a	The Commonwealth Fund 2017b	EC 2016	EC 2017
Indirect costs					
Wage rates of individuals	Eurostat: [earn_ses_annual] (2014)	Eurostat: [earn_ses_annual] (2014)	Eurostat: [earn_ses_annual] (2014)	Eurostat: [earn_ses_annual] (2014)	Eurostat: [earn_ses_annual] (2014)
Payroll costs	Eurostat: [lc_lci_lev] 2015	Eurostat: [lc_lci_lev] 2015	Eurostat: [lc_lci_lev] 2015	Eurostat: [lc_lci_lev] 2015	Eurostat: [lc_lci_lev] 2015

Data need	Finland	Germany	The Netherlands	Italy	Poland
Probability of labour-force participation	Eurostat: [lfsa_ergan]	Eurostat: [lfsa_ergan]	Eurostat: [lfsa_ergan]	Eurostat: [lfsa_ergan]	Eurostat: [lfsa_ergan]
Participation rate of long-term disabled	Eurostat: [hlth_dlm010]; [hlth_dsi015]	Eurostat: [hlth_dlm010]; [hlth_dsi015] 2011/2012	Eurostat: [hlth_dlm010]; [hlth_dsi015]	Eurostat: [hlth_dlm010]; [hlth_dsi015]	Eurostat: [hlth_dlm010]; [hlth_dsi015]
Life expectancy (general population)	Eurostat: [demo_mlexpec]; [hlth_hlye]	Eurostat: [demo_mlexpec]; [hlth_hlye]	Eurostat: [demo_mlexpec]; [hlth_hlye]	Eurostat: [demo_mlexpec]; [hlth_hlye]	Eurostat: [demo_mlexpec]; [hlth_hlye]
Home production time	Statistics Finland time use survey 2009/2010	Destatis 2015	SCP 2012	OECD Time use survey 2013	OECD Time use survey 2013
Wage rate for home production time	Statistics Finland: wages, salaries and labour costs 2016	Destatis 2015	CBS/StatLine 2017	Destatis 2015	ZUS 2018
Intangible costs					
Health-related quality of life of general population	Huber et al. 2017	Saarni et al. 2006	Saarni et al. 2006	Scalone et al. 2015	Golicki and Niewada 2017
Top-down model					
DALY	BoD Study WHO/IHME	BoD Study WHO/IHME	BoD Study WHO/IHME	BoD Study WHO/IHME	BoD Study WHO/IHME
Life expectancy	Eurostat: [demo_mlexpec]	Eurostat: [demo_mlexpec]	Eurostat: [demo_mlexpec]	Eurostat: [demo_mlexpec]	Eurostat: [demo_mlexpec]
Compensation of employees/wage employed persons	Eurostat: [earn_ses_annual] 2014	Eurostat: [earn_ses_annual] 2014	Eurostat: [earn_ses_annual] 2014	Eurostat: [earn_ses_annual] 2014	Eurostat: [earn_ses_annual] 2014

Data need	Finland	Germany	The Netherlands	Italy	Poland
Average population (1 January + 31 December/2)	Eurostat: [demo_gind]; [demo_pjan]; [lfsa_pganws]	Eurostat: [demo_gind]; [demo_pjan]; [lfsa_pganws]	Eurostat: [demo_gind]; [demo_pjan]; [lfsa_pganws]	Eurostat: [demo_gind]; [demo_pjan]; [lfsa_pganws]	Eurostat: [demo_gind]; [demo_pjan]; [lfsa_pganws]
Economically active population	Eurostat: [lfsa_pganws]	Eurostat: [lfsa_pganws]	Eurostat: [lfsa_pganws]	Eurostat: [lfsa_pganws]	Eurostat: [lfsa_pganws]
Employed persons	Eurostat: [lfsa_pganws]; [nama_10_a10_e]; ILO: Employment by sex and economic activity	Eurostat: [lfsa_pganws]; [nama_10_a10_e]; ILO: Employment by sex and economic activity	Eurostat: [lfsa_pganws]; [nama_10_a10_e]; ILO: Employment by sex and economic activity	Eurostat: [lfsa_pganws]; [nama_10_a10_e]; ILO: Employment by sex and economic activity	Eurostat: [lfsa_pganws]; [nama_10_a10_e]; ILO: Employment by sex and economic activity
Labour volume of employed persons (fte)	Eurostat: [lfsa_ewhun2]	Eurostat: [lfsa_ewhun2]	Eurostat: [lfsa_ewhun2]	Eurostat: [lfsa_ewhun2]	Eurostat: [lfsa_ewhun2]
Gross value added	Eurostat: [nama_10_a10]	Eurostat: [nama_10_a10]	Eurostat: [nama_10_a10]	Eurostat: [nama_10_a10]	Eurostat: [nama_10_a10]
GDP	Eurostat: [nama_10_gdp]	Eurostat: [nama_10_gdp]	Eurostat: [nama_10_gdp]	Eurostat: [nama_10_gdp]	Eurostat: [nama_10_gdp]
GDP per capita	Eurostat: [nama_10_pc]	Eurostat: [nama_10_pc]	Eurostat: [nama_10_pc]	Eurostat: [nama_10_pc]	Eurostat: [nama_10_pc]
(adjusted) Household disposable income	Eurostat: [tec00113]; [nasa_10_nf_tr]	Eurostat: [tec00113]; [nasa_10_nf_tr]; Destatis: [63121]	Eurostat: [tec00113]; [nasa_10_nf_tr]	Eurostat: [tec00113]; [nasa_10_nf_tr]	Eurostat: [tec00113]; [nasa_10_nf_tr]
Median and mean equivalised income	Eurostat: [ilc_di03]	Eurostat: [ilc_di03]	Eurostat: [ilc_di03]	Eurostat: [ilc_di03]	Eurostat: [ilc_di03]
Actual individual consumption per inhabitant	Eurostat: [hbs_exp_t111]	Eurostat: [hbs_exp_t111]; Destatis: [63121-0001]	Eurostat: [hbs_exp_t111]	Eurostat: [hbs_exp_t111]	Eurostat: [hbs_exp_t111]

8 Appendix 3 — Attributable fractions

Attributable fraction were derived from the IHME database by confronting the number of DALYsoccupational risks * cause with the total number of $DALYs_{cause}$ (year 2016 data). For some diseases, no attributable fraction could be derived from the IHME database. For those diseases, we used the value found in the literature. The reference of the study is given in the footnote of the table below.

Table A3a: Attributable fractions used for non-fatal estimation in the present study

	Males					Female				
Type of health problem	**Finland (%)**	**Ger-many (%)**	**Nether-lands (%)**	**Italy (%)**	**Poland (%)**	**Finland (%)**	**Ger-many (%)**	**Nether-lands (%)**	**Italy (%)**	**Poland (%)**
Communicable diseases	0.8	1.8	1.8	0.7	1.8	0.4	1.1	1.1	0.4	1.0
Nasopharynx cancer	0.1	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.2
Larynx cancer	14.1	13.0	19.5	16.5	6.2	4.4	4.8	4.9	6.2	3.6
Tracheal, bronchus and lung cancer	37.4	36.2	47.4	41.5	18.9	11.7	13.6	14.1	14.8	9.4
Non-melanoma skin cancer ([a])	13.1	13.1	13.1	13.1	13.1	3.8	3.8	3.8	3.8	3.8
Breast cancer	0.9	1.0	1.0	0.8	0.9	1.3	1.3	1.3	0.9	1.1
Ovarian cancer	0.0	0.0	0.0	0.0	0.0	5.4	5.8	6.9	8.8	2.5
Bladder cancer ([a])	10.7	10.7	10.7	10.7	10.7	1.3	1.3	1.3	1.3	1.3
Mesothelioma	97.3	97.0	98.5	97.4	91.3	91.8	92.4	92.8	95.3	85.5
Leukaemia	0.5	0.6	0.6	0.5	0.5	0.8	0.7	0.8	0.5	0.7
Other neoplasms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Circulatory diseases	1.7	2.0	2.2	1.4	2.0	0.9	1.1	1.3	0.6	1.1
Respiratory diseases — COPD	14.5	16.4	14.2	12.9	15.2	9.4	8.9	7.5	5.5	10.8
Respiratory diseases — pneumoconiosis	100	100	100	100	100	100	100	100	100	100
Respiratory diseases — asthma	12.2	14.4	14.1	12.0	13.6	7.3	7.9	7.4	6.0	7.3
Respiratory diseases — other ([b])	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Digestive diseases ([a])	2.3	2.3	2.3	2.3	2.3	1.5	1.5	1.5	1.5	1.5

	Males					Female				
Neurological diseases (ª)	7.6	7.6	7.6	7.6	7.6	1.8	1.8	1.8	1.8	1.8
Mental disorders (ᶜ)	17.5	17.5	17.5	17.5	17.5	20.7	20.7	20.7	20.7	20.7
Genitourinary diseases (ª)	3.0	3.0	3.0	3.0	3.0	0.4	0.4	0.4	0.4	0.4
Musculoskeletal diseases	10.6	10.3	9.5	8.9	15.1	7.0	6.5	6.3	4.9	8.4
Other non-communicable diseases	2.5	4.7	3.0	3.7	4.2	1.3	2.4	1.4	1.5	2.2

(ª) Nurminen and Karjalainen (2001).

(ᵇ) Hämäläinen et al. (2017).

(ᶜ) Sultan-Taïeb et al. (2013).

Table A3b: Alternative attributable fractions for non-fatal disease estimation from the literature

Disease	Literature	AF total (%)	AF male (%)	AF female (%)
Communicable diseases	Nurminen and Karjalainen (2001)	6.7	10.2	2.1
Nasopharynx cancer	Nurminen and Karjalainen (2001)	12.5	24.0	6.7
Larynx cancer	1) RIVM (2016); 2) Nurminen and Karjalainen (2001);	5.6	6.1	1.1
Tracheal, bronchus and lung cancer	1) RIVM (2016); 2) Nurminen and Karjalainen (2001);	17.1	22.7	4.5
Non-melanoma skin cancer	Nurminen and Karjalainen (2001)	8.3	13.1	3.8
Breast cancer	1) RIVM (2016); 2) Nurminen and Karjalainen (2001);	0.1	0.0	0.1
Ovarian cancer	1. RIVM (2016); 2) Nurminen and Karjalainen (2001);	1.3	0.0	1.3
Bladder cancer	1) RIVM (2016); 2) Nurminen and Karjalainen (2001);	8.3	10.7	1.3
Mesothelioma	1) RIVM (2016); 2) Nurminen and Karjalainen (2001);	84.9	93.4	53.8
Leukaemia	1) RIVM (2016); 2. Nurminen and Karjalainen (2001);	0.6	0.8	0.4

Disease	Literature	AF total (%)	AF male (%)	AF female (%)
Other neoplasms	TNO adjustment based on: 1) Nurminen and Karjalainen (2001); 2) RIVM (2016); 3.) Hämäläinen et al. (2017)	3.2	4.4	0.6
Circulatory diseases	Nurminen and Karjalainen (2001)	12.4	14.4	6.7
Respiratory diseases — COPD	Hämäläinen et al. (2017)		18.0	6.0
Respiratory diseases — pneumoconiosis	Nurminen and Karjalainen (2001)	100	100	100
Respiratory diseases — asthma	Hämäläinen et al. (2017)		21.0	13.0
Respiratory diseases — other	Hämäläinen et al. (2017)	1.0	1.0	1.0
Digestive diseases	Nurminen and Karjalainen (2001)	2.1	2.3	1.5
Neurological diseases	Nurminen and Karjalainen (2001)	3.5	7.6	1.8
Mental disorders	Sultan-Taïeb et al. (2013)		17.5	20.7
Genitourinary diseases	Nurminen and Karjalainen (2001)	1.3	3.0	0.4
Musculoskeletal diseases	No AFs found in the literature (but IHME-derived AFs were available)	-	-	-
Other non-communicable diseases	No AFs found in the literature (but IHME-derived AFs were available)	-	-	-
Injuries — transport	Nurminen and Karjalainen (2001)	3.1	3.7	0.4
Injuries — unintentional	Nurminen and Karjalainen (2001)	5.4	6.5	0.4
Injuries — self-harm	Nurminen and Karjalainen (2001)	0.4	0.4	0.3
Injuries — interpersonal violence	Nurminen and Karjalainen (2001)	1.1	1.3	0.7

Type	% Male					% Female				
	Finland	Germany	The Netherlands	Italy	Poland	Finland	Germany	The Netherlands	Italy	Poland
Communicable, maternal, neonatal, and nutritional diseases	0.5	1.1	0.8	0.5	1.1	0.5	1.1	0.8	0.5	1.1
Nasopharynx cancer	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Larynx cancer	5.0	5.4	6.2	7.5	3.5	5.0	5.4	6.2	7.5	3.5
Tracheal, bronchus, and lung cancer	12.2	14.0	15.3	16.6	8.7	12.2	14.0	15.3	16.6	8.7
Breast cancer	0.9	0.9	0.9	0.6	0.9	0.9	0.9	0.9	0.6	0.9
Ovarian cancer						7.4	8.2	10.2	12.1	3.1
Mesothelioma	95.7	96.1	96.4	97.6	91.0	95.7	96.1	96.4	97.6	91.0
Leukaemia	0.4	0.4	0.4	0.3	0.4	0.4	0.4	0.4	0.3	0.4
Kidney cancer	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Cardiovascular diseases	0.4	0.5	0.6	0.2	0.5	0.4	0.5	0.6	0.2	0.5
Chronic obstructive pulmonary disease	7.6	6.1	4.7	3.7	9.2	7.6	6.1	4.7	3.7	9.2
Pneumoconiosis	100	100	100	100	100	100	100	100	100	100
Asthma	1.0	2.3	1.8	0.9	2.3	1.0	2.3	1.8	0.9	2.3

9 Appendix 4 — Injury severity distribution

Table A4a. Reporting an accident at work resulting in sick leave by period off work 2015 ([a])

Country	Total (%)	From 1 to 3 days (%)	More than 3 days (%)
Sweden	36.6	12.1	24.6
Finland	39.3	13.2	26.1
Norway	43.2	NA	NA
United Kingdom	43.9	15.1	28.8
Switzerland	52.9	14.3	38.6
France	59.2	8.2	50.9
Greece	59.6	NA	NA
Denmark	61.5	19.1	42.3
Latvia	64.9	NA	NA
Bulgaria	65.1	NA	NA
Portugal	65.6	11	54.6
Ireland	69	NA	NA
Slovakia	70.3	NA	NA
Estonia	71	NA	NA
Belgium	74.2	21.9	52.3
Hungary	78.4	NA	71
Slovenia	80.1	7.3	72.7
Spain	81.8	11.4	70.4
Lithuania	82	NA	NA
Luxembourg	82.9	20.8	62
Austria	84.5	18.5	66.1
Cyprus	85.3	NA	NA
Czechia	87	11.3	75.8
Italy	87	11	75.9
Malta	88.7	NA	NA

Country	Total (%)	From 1 to 3 days (%)	More than 3 days (%)
Poland	90.4	6.4	83.9
Romania	93.5	NA	NA
Croatia	96	NA	NA
The Netherlands	NA	NA	NA
Germany (until 1990 former territory of the FRG)	NA	NA	NA

([a]) Persons reporting an accident at work resulting in sick leave by period off work [hsw_ac3] (2013), Accidents at work and other work-related health problems (source: LFS).
http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=hsw_ac3&lang=en

Table A4b. Severity distribution of injuries (> 3 lost days) 2015 ([a])

Countries	From 4 to 6 days (%)	From 7 to 13 days (%)	From 14 to 20 days (%)	From 21 days to 1 month (%)	From 1 to 3 months (%)	From 3 to 6 months (%)	Permanent incapacity or 183 days or over (%)	Not specified (%)
Belgium	19	28	12	9	12	2	19	0
Bulgaria	2	8	10	8	30	25	17	0
Italy	13	19	12	11	20	3	9	13
The Netherlands	22	19	18	11	14	9	7	1
Croatia	5	17	12	10	19	8	7	22
France	13	26	15	11	21	7	7	0
Romania	7	13	9	12	33	11	6	8
Slovakia	1	10	13	11	25	8	6	27
Greece	5	15	13	8	31	10	6	12
Sweden	6	8	7	5	14	6	5	51
Luxembourg	20	25	12	9	21	9	4	0
Portugal	11	17	10	8	13	4	4	33
Lithuania	10	27	17	13	21	8	4	0
Hungary	11	17	10	8	14	4	4	32
United Kingdom	11	17	10	8	14	4	4	32

Countries	From 4 to 6 days (%)	From 7 to 13 days (%)	From 14 to 20 days (%)	From 21 days to 1 month (%)	From 1 to 3 months (%)	From 3 to 6 months (%)	Permanent incapacity or 183 days or over (%)	Not specified (%)
Finland	5	15	13	12	31	13	4	7
Spain	9	26	17	11	20	5	3	8
Slovenia	27	23	17	10	16	4	3	0
Switzerland	27	31	12	9	15	4	3	0
Denmark	15	30	15	12	20	5	3	0
Austria	6	22	17	15	21	6	3	12
Czechia	27	24	14	8	18	5	2	1
Poland	3	10	10	8	15	4	0	49
Latvia	17	41	16	8	15	3	0	0
Norway	7	17	16	17	29	14	0	0

([a]) Accidents at work by type of injury, severity and NACE Rev. 2 activity (A, C-N) [hsw_mi07] (2015), ESAW, http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=hsw_mi07&lang=en.

10 Appendix 5 — Non-fatal injury and disease cases intangible cost

For the estimation of health-related quality of life (HRQoL) losses for non-fatal work-related injury and disease cases, based on their severity level, we used HSE (2011) multipliers, as indicated in Table A5a and Table A5b, respectively. We used general population health-related quality of life and life expectancy as a counterfactual scenario and estimated the loss of QALY by age and sex based on severity (working days lost).

Table A5a. Health related quality of life losses because of work-related injuries by severity, adopted from HSE (2011)

Proxy injury	Minor	F	W	X	S	S
Lost days	**< 3 days**	**4-14 days**	**15-90 days**	**90-180 days**	**180-365 days**	**Never return**
Lost QALY multiplier (baseline)	0	0.002	0.01	0.03	0.1	0.19
Lost QALY multiplier (lower range)	0	0.001	0.004	0.012	0.04	0.076
Lost QALY multiplier (higher range)	0	0.004	0.02	0.055	0.151	0.233

Table A5b. Health related quality of life losses because of work-related diseases by severity, adopted from HSE (2011)

Proxy disease	Minor	F	W	2*W	S
Lost days	**< 3 days**	**4-30 days**	**30-90 days**	**> 90 days**	**Never return**
Lost QALY multiplier (baseline)	0	0.002	0.01	0.02	0.19
Lost QALY multiplier (lower range)	0	0.001	0.004	0.008	0.076
Lost QALY multiplier (higher range)	0	0.004	0.02	0.04	0.233

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The European Agency for Safety and Health at Work (EU-OSHA) contributes to making Europe a safer, healthier and more productive place to work. The Agency researches, develops, and distributes reliable, balanced, and impartial safety and health information and organises pan-European awareness raising campaigns. Set up by the European Union in 1994 and based in Bilbao, Spain, the Agency brings together representatives from the European Commission, Member State governments, employers' and workers' organisations, as well as leading experts in each of the EU Member States and beyond.

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