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Copenhagen Economics
Stockholm

Multiple benefits of energy renovations of the Swedish building stock

Report commissioned by the Swedish Energy Agency
and the National Board of Housing, Building and Planning

22 December 2016

Copenhagen Economics

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Preface

The Swedish government is currently in the process of designing a new building strategy, including a program for renovating the existing building stock. Building renovations are interesting for a number of reasons including: 1) they improve the overall quality of the living environment and may have social effects in terms of improving neighbourhood social dynamics etc., and 2) they can reduce the energy consumption of buildings.

In addition to these two 'classical' reasons, it has been established that building renovations that reduce energy consumption will also have other – often positive – implications. These so called 'multiple benefits' are benefits that accrue in addition to the direct savings in energy bills and may entail health effects from better outdoor air quality and indoor environment.

Omission of these multiple benefits may lead to suboptimal choices when designing policy. However, quantifiable estimates of their magnitude are limited, rendering them scarcely used in actual policy making.

In order to shed light on these multiple benefits in a Swedish context, the Swedish Energy Agency and the National Board of Housing, Building and Planning commissioned Copenhagen Economics to assess and quantify to what extent there are likely multiple benefits from energy related renovations of the Swedish building stock.

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Executive summary

Improving energy efficiency is a priority for the European Commission and the EU Member States, which is illustrated by the EU 2030 objective of saving 27 per cent of energy relative to a reference scenario. An important source for saving energy is through building renovations. Energy savings are, however, not the only valid argument in favour of pursuing energy efficiency renovations, as it is now well established that there are *multiple benefits* to be captured by investing in energy efficiency renovations of buildings.[1] These can include health benefits from reduced outdoor air pollution, benefits in terms of security of energy supply, and health and productivity gains from a better indoor climate. If these benefits are significant, they can change the overall business case for energy renovations since there are further gains to add to the benefit side.

In order to shed light on multiple benefits in a Swedish context, we have assessed to what extent there are likely multiple benefits from energy related renovations of the Swedish building stock. Our assessment is based on a technical scenario for building renovations until 2030.[2] This scenario includes relatively ambitious renovations in buildings resulting in an average reduction in energy consumption of up to 50 per cent for a typical building. The majority of savings are expected to take place in single-dwelling houses – 46 per cent in 2030 – whereas multi-dwelling and non-residential buildings constitute 41 and 13 per cent of savings respectively. Based on the sources of heating for the Swedish building stock, we estimate that the renovation scenario will reduce consumption of biomass by 9.8 TWh, production using waste heat, other fuels and heat pumps by, 3.2 TWh, nuclear power by 2.1 TWh and coal, gas and oil by 0.2 TWh. The reductions stem both from decreases of e.g. locally burned biomass and oil, and from the use of fuels as inputs in electricity and district heating production.

Based on expected energy prices, we find that these energy savings are worth around 8.5 billion SEK yearly in 2030. Projected energy prices are associated with substantial uncertainty, and using the Swedish Energy Agency's price span of +/-10 per cent, savings may instead amount to between 7.6 billion and 9.3 billion. The uncertainty around energy prices may be even higher in practice.

Regarding benefits additional to energy savings we find that, in particular, reduced outdoor air pollution and increased indoor air quality can deliver significant benefits, cf. Figure below. The value from reduced outdoor pollution is estimated to between 1.9 and 2.1 billion SEK in 2030, of which reduced NO_x and SO_2 represents 400 million SEK based traditional damage cost estimates from the Swedish Transport Administration. Gains stem primarily from reduced district heating generation based on biomass. Attributing this value can be difficult, as air pollution is windborne, and may not necessarily give rise to damages in the

[1] See e.g. Copenhagen Economics, (2012) *Multiple benefits of investing in energy efficient renovation of buildings*, IEA (2014) *Capturing the Multiple Benefits of Energy Efficiency*, and the COMBI project.

[2] Based on a project done by Profu, CIT and WSP. This project included two different scenarios, of which we have been asked to assess one. The scenarios are estimated to 2050, while we only consider the medium term up until 2030.

same area as the polluting source. Indeed, some benefits may even be attributed to neighbouring countries.

The remainder of benefits from outdoor air pollution (1.5 to 1.7 billion SEK) represent the value of reduced $PM_{2.5}$ emission, which is significantly more uncertain. This is both due to the wide span of estimates of $PM_{2.5}$ damage costs from different sources, and due to the fact that the analysis does not take into account the geographical area where emissions are made, a very important impact for the valuation.

Assessing multiple benefits from Swedish building renovations

	Importance in a Swedish context	Yearly value in 2030
Energy savings	◕	7.6 – 9.3 billion SEK *Public budget impact: 1.1 billion SEK*
Health benefits	◑	1.9 – 2.1 billion SEK outdoors 0.4 – 1.1 billion SEK indoors
Reduced CO2 emissions	◔	0.13 billion SEK
Renewable energy investments	◔	*Not relevant to quantify*
Security of energy supply	◔	*Not relevant to quantify*
Increased economic activity	○	*Not relevant to quantify*

Source: Copenhagen Economics.

It is important to consider whether the existing degree of air pollution from energy generation is likely to also be prevalent going forward. For example, the new NEC Directive sets stricter national limits on outdoor air emissions, which implies that polluters will have to take measures to reduce their emissions in order to reach the limits set out in the Directive.[3] If air pollution from energy generation is reduced going forward, the multiple benefit from doing energy renovations should similarly be lower.

Improved indoor air quality is potentially a large source of value for Swedish society. Prevalence of, e.g., asthma and respiratory diseases, and especially so called sick building syndrome are undesired consequences of poor indoor air quality. While there are relatively

[3] See for example: http://www.consilium.europa.eu/en/press/press-releases/2016/06/30-air-quality/

well-established methodologies for estimating the value to society from reducing these conditions, it is less clearly established to what extent building renovations will reduce these conditions. In particular, it requires that renovations have a broader focus than just on energy savings, and especially on delivering better ventilation and lighting. Based on information about the prevalence of sick building syndrome and assuming that symptoms of this is alleviated in all the renovated office buildings until 2030, this will increase productivity among office workers by around 0.4 to 1.1 billion SEK per year in 2030. While not quantified here, these improvement will also likely improve quality of life of the affected persons. As with outdoor air pollution, improvements being made exogenously in the business as usual scenario will affect the assed value of improved indoor air quality.

In addition, improved indoor air in schools is likely to improve students' learning abilities. Concretely, it has been estimated that improved ventilation in schools has increased the rate of students passing exams in reading and maths by about 3 per cent.[4]

Conversely, we find that neither the benefits in terms of energy security, decarbonisation[5] nor the reduced need for renewable energy investments are sizeable in a Swedish context. This is quite contrary to many other European countries, where decarbonisation is more challenging and energy security a more pronounced challenge.

Moreover, macroeconomic benefits such as increased economic activity to support a depressed economy from increased renovations are not likely to be important for Sweden Actual GDP has already surpassed structural GDP, and is likely to remain around the structural level for many years to come. Hence, any economic stimulus from increased renovations contribute to the potential overheating of the economy and may trigger countermeasures in the fiscal and monetary policy. In case of an economic downturn in the future, a renovation programme would be seen as a benefit in terms of stimulating economic activity and increasing short run employment.

We find that public budgets are likely to be negatively affected by reduced tax income from energy-related taxes, and positively affected by the value of energy savings in houses used by the public sector. In 2030, the net effect of this for public budgets is a structural reduction of 1.08 billion SEK, of which 1.2 is negative impact from reduced taxes, and 0.12 billion is a positive impact from energy savings in houses used by the public sector. The main driver of this deficit is the reduced tax revenue from electricity taxes.

Multiple benefits can have a more or less extensive effect on the benefits in a cost-benefit analysis of a given renovation project or programme. It is, however, very important to also remember the cost side of the analysis, and assess this carefully. In energy savings alone can drive the business case when taking into all relevant costs including transaction costs such as the value of time and hassle, renovations should just be undertaken. When the business case built on just energy savings is less clear, including multiple benefits becomes more important.

4 Haverinen-Shaughnessy et al (2011).
5 Reduced CO_2 emissions is estimated to have a value of about 130 million SEK per year in 2030.

In a fully-fledged cost-benefit analysis, it is also important to consider other solutions that can deliver on the same benefits, and whether these are more efficient options. A competing solution for e.g. achieving reduced air pollution could be technologies to reduce SO_2 or NO_x from biomass-based energy generation. Whether such alternatives exist should also be evaluated.

It is not obvious whether multiple benefits depend linearly on the renovation ambition. Particularly, the type of houses included in the renovation strategy will significantly affect the outcome, as the sources used for heating differs significantly. For example, when looking at a scenarios that excludes renovations of single-dwelling houses, significantly less energy using local biomass is reduced, as this is a large source of heating for single-welling house. This in turn reduces the $PM_{2.5}$ benefit, as locally fired biomass gives rise to large $PM_{2.5}$ emissions.

Chapter 1

Assessing the impacts of building renovations

Improving energy efficiency is a priority for the European Commission and the EU Member States. This is illustrated by the EU 2030 objective of saving 27 per cent of energy relative to a reference scenario. Renovating buildings is a key method of improving energy efficiency. In Sweden, the building stock represents approximately 34 per cent of the total energy use, and a large potential for reducing energy use is deemed to be available through renovations of the existing building stock.[6] As estimated by the Swedish Energy Agency, about 35 per cent of heat loss typically occurs through windows, 20 per cent through walls, and 15 per cent through ventilation, roofs and floors.[7] Focusing on renovating these areas is thus an opportunity to save large amounts of energy. The purpose of Sweden's national strategy for energy efficiency renovations is to ensure that these opportunities are utilised, when cost effective.[8]

1.1 Multiple benefits in a cost-benefit analysis

Energy savings are not the only valid argument in favour of pursuing energy efficiency renovations. It is now well established that there are *multiple benefits* to be captured by investing in energy efficiency renovations of buildings.[9] These can include health benefits from reduced outdoor air pollution, benefits in terms of energy security, and health and productivity gains from a better indoor climate. If these benefits are substantial and positive, they can change the overall business case for energy renovations since there are further gains to add to the benefit side. They would thus increase the net benefits of an investment subject to a cost-benefit analysis[10], and could make unprofitable projects (looking at energy savings only, compared to costs) profitable. Extending the analysis to include such side effects may also imply that some *negative* effects, which should be seen as costs, detract from the net benefits. For example, if indoor air quality decreases because of insulation measures that reduce air flow; this would have a negative effect on the cost-benefit analysis. When weighing in multiple benefits in a cost-benefits analysis, it is very important to remember these costs and others, and assess these carefully. Figure 1 shows the relationship between benefits and cost in a cost-benefit analysis.

6 The Swedish Energy Agency, (2016) *Energy in Sweden*.

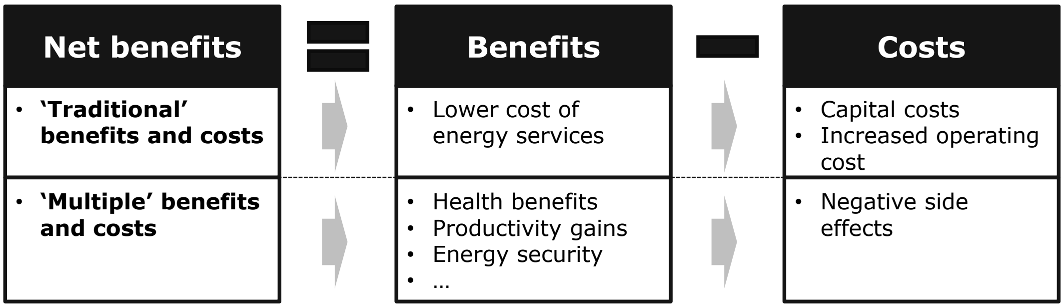
7 The Swedish Energy Agency, (2015) *Uppvärmning*.

8 A number of studies have suggested that the net cost of investing in renovating the existing building stock is not only low, but is in fact negative. This means, that through the induced energy savings, investments in energy efficiency renovation of buildings will pay for themselves at current energy prices. While this may be true, especially in countries where building renovations have not received much attention, other countries may already have reaped these low hanging fruits – or at least some of them.

9 See e.g. Copenhagen Economics, (2012) *Multiple benefits of investing in energy efficient renovation of buildings* and IEA (2014) *Capturing the Multiple Benefits of Energy Efficiency*.

10 In a cost-benefit analysis, the expected costs and benefits of an investment are compared. If the discounted flow of benefits exceeds the discounted flow of costs over the lifetime of the investment, the net present value (NPV) of the investment is positive and a common decision rules says that the investment should go ahead.

Figure 1 Multiple benefits in a cost-benefit analysis

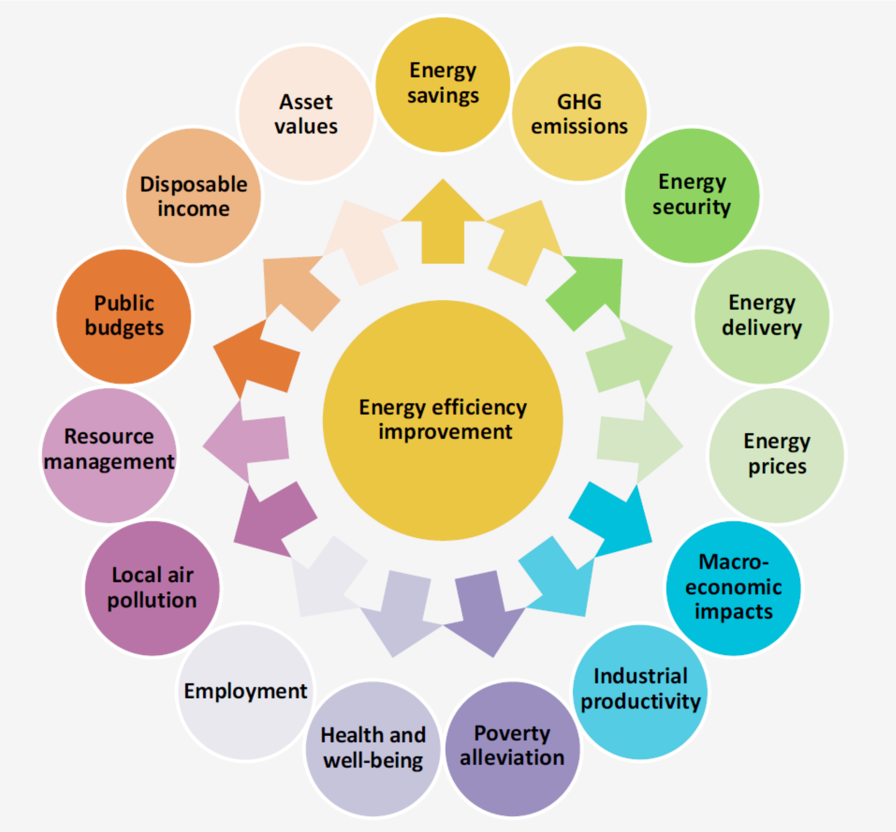


Source: Copenhagen Economics.

We focus the analysis on the multiple benefits described below and assess their importance in a Swedish context. Enhancing energy efficiency of the existing building stock induces benefits through several channels. While some of these benefits occur directly through reduced energy consumption, other benefits occur more indirectly through e.g. improved health over several years. In addition, some of these benefits have direct effects on public budgets while others are benefits to occupants and owners of buildings, and society at large without having specific public finance effects.

Our categorisation of multiple benefits differs slightly from previous categorisations, e.g. by the IEA, cf. Figure 2 The IEA framework includes a number of individually specified benefits, where we collect similar types of effects into aggregate groups, and eliminate effects which risk leading to double counting.

Figure 2 "Wheel of benefits" of energy efficiency improvements from the IEA



Source: IEA (2014) *Capturing the Multiple Benefits of Energy Efficiency.*

A few examples of where we adopt a different approach than the IEA wheel:

- *Asset values* is not a separate benefit, as this reflect the underlying benefits such as saved energy consumption and increased indoor air climate.
- *Energy prices* is not a separate benefit, but can go into the value of energy savings. When energy savings are very large it may also affect terms of trade effects which we would treat as a *macro-economic impact*.
- *Industrial productivity* stems directly from *energy savings*
- *Employment* we would consider as a macroeconomic benefit
- *Local air pollution* we would consider in the same group as *health and well-being*
- *Disposable income* would be covered by *energy savings* and/or *poverty alleviation*

Based on this logic, we construct the following six categories of benefits, see Figure 3. In the following section we discuss these elements generically, and in chapter 2 we go in depth with the benefits in a Swedish context.

Figure 3 Potential multiple benefits of energy renovations

	Benefit	Public budget implication
Energy savings	Value of energy savings, accruing to the occupant and/or owner of building	Reduced tax income from energy related taxes Reduced energy subsidies
Health benefits	Reduced need for investing in renewable energy technologies	Reduced subsidies for renewable energy
Reduced CO2 emissions	Reduced health care costs and increased productivity from better outdoor and indoor air quality, accruing to individuals, buyers of labour and the general public	Reduced payments of sickness benefits and pensions
Renewable energy investments	Reduced emissions of CO_2 and other greenhouse gases	—
Security of energy supply	Improved energy security from reduced reliance on energy	—
Increased economic activity	Increased economic activity in periods of economic downturn, accruing to the general public	Reduced unemployment benefits and increased tax revenue

Source: Copenhagen Economics.

Energy savings through reduced energy consumption are a direct benefit of increased energy efficiency. In privately owned buildings the benefits typically accrue to the owner or the user of the building, while in publicly owned buildings these benefits are split between the users of the buildings and the public. Given the distribution of benefits between public entities, this can improve public budgets. The benefit from energy savings implicitly also includes the avoided capital cost of building additional power plants, as these capital costs are included in the price of electricity.[11]

As energy-efficient renovation of buildings reduce energy consumption, they have a negative effect on public budgets through reduced tax revenue from energy consumption taxes. This effect is not a benefit but rather a transfer. Reversely, as energy consumption goes down, subsidies linked to energy consumption also decrease creating a positive budget impact. Two relatively widespread types of subsidies are: 1) socially driven subsidies to energy consumption, e.g., of the elderly or 'fuel poor' and 2) subsidies of energy production typically for renewable energy production, but in some countries also for fossil fuel installations.

A more indirect benefit occurs through *health benefits*. Most energy efficiency measures improve the indoor temperature and ventilation, which in turn creates significant benefits

[11] Over time, consumers will pay for both the variable costs and the capital costs of energy production plants. By considering the retail price of electricity when we calculate the benefits from reduced energy bills, we therefore include the capital cost of new energy production facilities. We do not consider benefits from avoided investments in grid infrastructure.

for people who live and work in the buildings. Health benefits also occur as power and heat production from power plants, district heating plants and local heating is reduced. Power and heat generated in these facilities give rise to air pollution such as NO_x and SO_2, and by reducing energy consumption this air pollution can be reduced. Most of these benefits accrue to the individuals whose health is improved as a result of the energy efficiency measures and to the society in general. Public budgets can also be affected by this through fewer sickness benefits and early retirement pensions. In addition, combustion of fossil fuels creates emissions of CO_2 and other greenhouse gases. A reduction of these emissions contribute to reduced risk of global warming, and to meeting Sweden's long term ambitions of a carbon free economy.

An additional benefit concerns *renewable energy investments*. In most countries, renewable energy targets are set as share of total energy production or consumption. When this is the case, a reduction in energy consumption/production will make the renewable energy target easier to achieve, and require less costly energy production to be deployed. Ultimately, as economies are striving to achieve a full decarbonisation of their economies, these targets will requires less expansion of renewable energy, if energy consumption is lower.

Energy-efficient renovations leading to reduced energy consumption can increase *security of energy supply,* by reducing fuel dependence. Such benefits depend on the degree of availability, accessibility, affordability and acceptability of existing fuel sources.

Energy-efficient renovations can *increase economic activity*, increasing GDP and reducing employment. This can also affect budgets through a reduced need to pay out unemployment benefits and increasing tax revenue from the increased economic activity. Positive effects from this include, increased tax revenue (including VAT, labour income tax, corporate income tax etc.) from increased activity and employment and reduced unemployment expenses. Whether this is a relevant benefit depends, however, on whether there is spare capacity in the economy. Moreover, net tax revenue will only increase if the increased renovations are not being driven by public subsidies.

1.2 Identifying the energy saving potential

The building types included are multi-dwelling buildings, single-dwelling buildings, and part of non-residential buildings: offices and schools. The latter two categories represent about half of the energy used for heating in non-residential buildings.

The calculations are based on estimated energy savings by Profu, CIT and WSP using the HEFTIG model at the request of the National Board of Housing, Building and Planning and the Swedish Energy Agency. Profu, CIT and WSP assess different scenarios for energy savings until 2050 in two different model runs; one from 2015 and one from 2016. We were asked to estimate the benefits of a *maximum (MAX)* energy savings scenario, where buildings are assumed to be subject to a state-of-the-art-renovation which yields up to 50 per cent energy savings, at various rates given type of the building.[12] This is compared with a *business as usual (BAU)* scenario, where no additional energy savings investments are made. An overview of the assessment by Profu, CIT and WSP, and the energy efficiency measures included the two scenarios entail is outlined in Box 1.

Box 1 Renovation scenarios used in the analysis

Profu, CIT and WSP have at the request of the Swedish Energy Agency used a programme called HEFTIG to simulate the effect of different energy saving measures in the building stock for the total energy use in Sweden.

The estimates used for the purpose of this study are described in the document *Fallstudier till HEFTIG* from 2015 (for single-dwelling buildings) and *En intervjustudie och analys i HEFTIG* (for multi-dwelling and non-residential buildings) from 2016. In these documents, two energy saving scenarios are described: a *maximum* scenario and an *Alternative 1* scenario.

The Alternative 1 scenario includes measures such as insulating attics, painting and sealing of windows, changing cellar doors and installing exhaust air heat pumps. The Alternative 1 scenario estimates 30 per cent energy savings in the overall building stock up to 2050.

The maximum energy efficiency scenario covers extensive areas of renovations such as improving the building envelope, ventilation, heating, warm water and indoor lighting. Renovations include, for example, additional insulation of facade, replacement of windows, replacement of ventilation systems, replacement of thermostats and adjustment of heating systems, as well as adjustments to lighting.

The maximum scenario for multi-dwelling buildings estimates a 56 per cent reduction in energy consumption per typical building up to 2050. The maximum scenario for single-dwelling buildings estimates a 46 per cent reduction. For offices 39 per cent reduction is estimated in the maximum scenario and for schools the corresponding reduction is 55 per cent.

The *business as usual* scenario assesses the development of energy consumption without the implementation of additional energy savings measures. A reduction in total energy consumption occurs nevertheless, due to a general downward trend in energy consumption in the Swedish building stock.

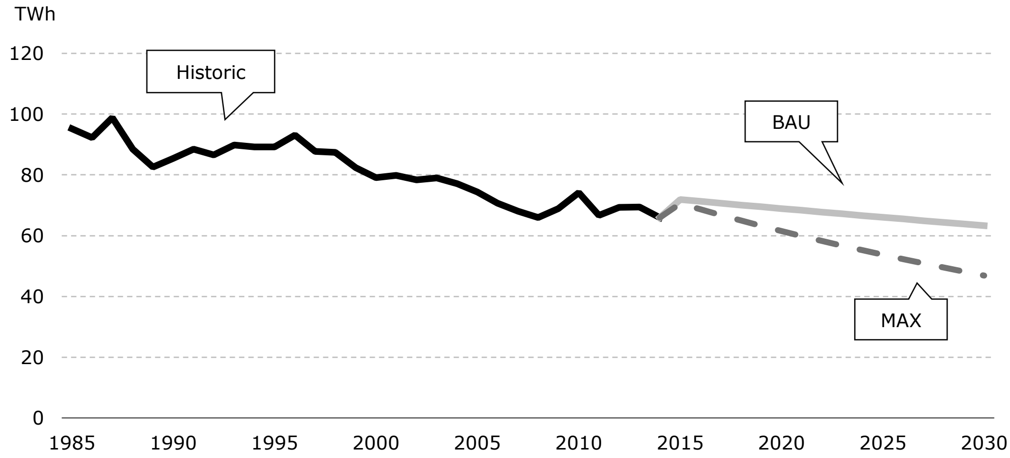
Worth noting is the uncertainty of these estimates, given the possibility that energy savings measures do not, in fact, reduce energy use by as much as engineering studies suggest.

Source: Scenarios from Profu, CIT and WSP.

[12] Rollout rate for multi-dwelling buildings: Buildings from 1950s are renovated during the next 20 years, buildings from the Million homes programme (1961-1975) are renovated during the next 10 years and all other buildings have a renovation cycle of 40 years. This entails that buildings constructed in 1981 or later will not be renovated until after 2020. Facade insulation is assumed to be possible for only 70 per cent of buildings. Rollout rate for single-dwelling buildings: rollout rate for single-dwelling buildings is assumed to correspond to turnover rate of single-dwelling buildings. In 2013, 55 000 single-dwelling buildings were sold, corresponding to an annual turnover rate of ca 3 per cent. Rollout rate for schools: Buildings from 1950s are renovated during the next 20 years, buildings from the Million Homes Programme (1961-1975) are renovated during the next 10 years and all other buildings have a renovation cycle of 40 years. Rollout rate for office buildings: A rollout rate has been calculated based on an assumption that office buildings are renovated every 10 years which implies that 10 per cent are renovated each year.

In 2015, the buildings included in this study used 72 terawatt-hours (TWh) of energy for heating and hot water, cf. Figure 4. In the business as usual scenario, this figure is estimated to drop to around 63 TWh in 2030. With the maximum energy savings measures, an additional 16 TWh energy can be saved, or around 25 per cent of consumption in 2030.

Figure 4 Energy consumption for heating with and without energy savings measures based on scenarios

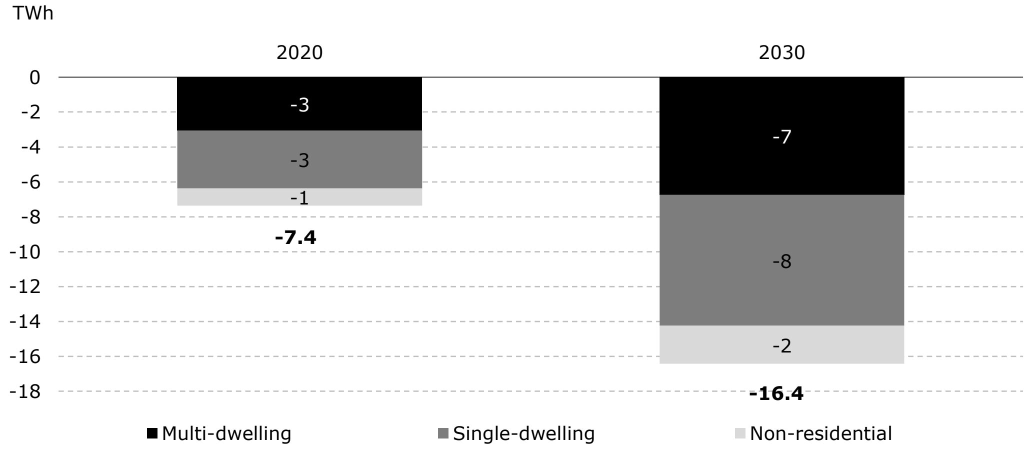


Note: The figure includes energy consumption for heating and hot water in multi- and single-dwelling as well as office and school buildings. The figure does not include other non-residential buildings such as churches, hotels, restaurants, shops, warehouses, and sports facilities, due to lack of data for energy saving potential in these. In 2014, these other non-residential buildings used approximately 10 TW hours of energy for heating and hot water. As historic values and projections come from different sources, they are not fully comparable. For example, historic values which are based on the Swedish Energy Agency's statistics over Energy in Sweden 2016 are not subject to temperature correction, in contrast to projected values.

Source: Scenarios from Profu, CIT and WSP study HEFTIG (2016 for multi-dwelling and non-residential buildings and 2015 for single-dwelling buildings) and historic consumption from the Swedish Energy Agency (Energy in Sweden 2016).

In the following, we will assess the period up to 2030. We assume that by 2030 the total savings are estimated to be around 16 TWh for all types of buildings included. The largest savings are estimated for single-dwelling houses – 46 per cent. These are the buildings using most energy today, cf. Figure 5. Multi-dwelling buildings represent the second largest share of savings, 41 per cent in 2030 while non-residential houses represent the smallest share with around 13 per cent of total savings in 2030.

Figure 5 Energy savings per building type



Note: The figure shows the energy savings potential for the maximum savings scenario compared to the business as usual scenario. Savings are net values of the decrease from savings for heating and increase from installing energy saving measures. Figures may not add up to sum due to rounding.

Source: Copenhagen Economics based on scenarios from Profu, CIT and WSP study HEFTIG (2016 for multi-dwelling and non-residential buildings and 2015 for single-dwelling buildings), historic consumption by the Swedish Energy Agency (2016), *Energy in Sweden*; and statistics on dwelling stock by Statistics Sweden (2015).

District heating is the main source of energy for room heating in Swedish buildings, constituting 50 per cent of supply, followed by electricity at 30 per cent and biomass, gas, and oil at 20 per cent. District heating is particularly prevalent for multi-dwelling and non-residential buildings (about 80 per cent), while electricity is the main source in single-family buildings (about 45 per cent). Based on the assumed renovation of different building types, we estimate that the largest energy savings potential is in district heating, totalling 9.4 TWh, cf. Table 1. Energy consumption from electricity and biomass is estimated to fall by around 4.2 and 2.7 TWh respectively, and oil and gas by around 0.2 TWh compared to consumption in the business as usual scenario.[13]

The savings for district heating are assumed to affect input fuel used for production according to their current shares. For electricity, we estimate that 50 per cent of savings will occur in nuclear power, and 50 per cent in thermal power. This means approximately 2.1 TWh of nuclear and thermal power will be reduced by 2030. Hydro and wind power are renewable, which means these will likely not be reduced given Sweden’s ambitions to make the electricity system renewable. As the production of nuclear power struggles with economic profitability, this is also treated as a marginal production source.

[13] In the analysis, the input shares of the current heating systems are used to estimate savings, which means that inputs in heating production are reduced in their current proportions. A more elaborate way of analysing this decrease would have been through an energy market model such TIMES Sweden to estimate the reduced shares, this was however not possible due to the limited scope of the study.

Table 1 Energy savings per production source

TWh	2020	2030
Oil and gas	0.1	0.2
Biomass	1.2	2.7
District heating	4.2	9.4
of which:		
Biomass	*2.6*	*5.8*
Other fuels	*0.5*	*1.1*
Heat pumps	*0.4*	*0.8*
Waste heat	*0.3*	*0.7*
Coal, gas and petroleum products	*0.4*	*0.9*
Electric boilers	*0.0*	*0.0*
Electricity	1.8	4.2
of which:		
Hydropower	*0.0*	*0.0*
Nuclear power	*0.9*	*2.1*
Windpower	*0.0*	*0.0*
Thermal power	*0.9*	*2.1*
Total	**7**	**16.4**

Note: The table shows the energy savings potential for the maximum savings scenario compared to the business-as-usual scenario. Savings are net values of the decrease from savings for heating and increase from installing energy saving measures. Figures may to sum due to rounding.

Source: Copenhagen Economics based on scenarios from Profu, CIT and WSP study HEFTIG (2016 for Multi-dwelling and non-residential buildings and 2015 for Single dwelling buildings) and historic consumption from the Swedish Energy Agency (2016), *Energy in Sweden*; and statistics on dwelling stock by Statistics Sweden (2015).

Chapter 2

Multiple benefits of energy-efficient renovations in Sweden

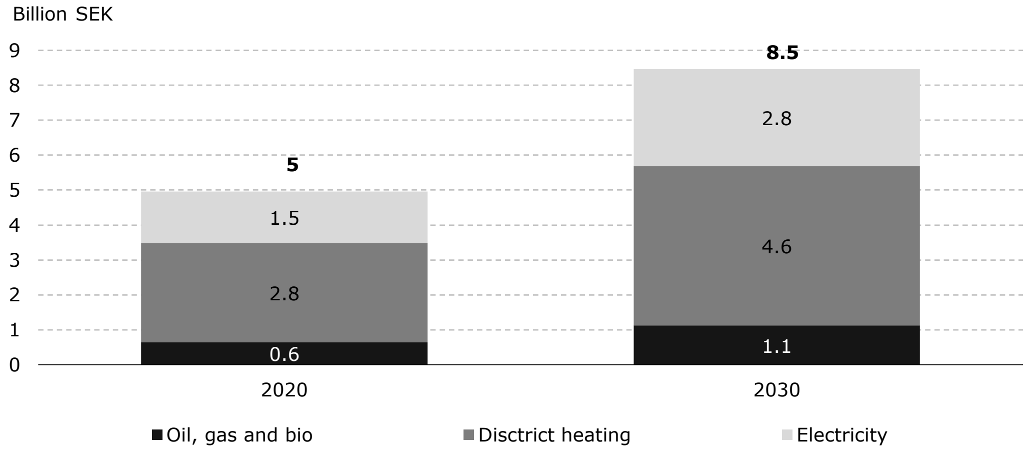
This chapter describes the calculated multiple benefits in a Swedish context, and discusses the impact of benefits not relevant to quantify. The chapter also quantifies the public budget impacts resulting of energy-efficient renovations, stemming from reduced energy taxes and energy savings in publically used buildings. All calculations and assumptions are elaborated on in the appendix, while the main text describes the primary results. The appendix also contains calculations for three alternative scenarios: 1) the maximum energy-efficient renovation scenario excluding single-dwelling buildings, 2) a less ambitious scenario for energy-efficient renovations, 3) and a less ambitious scenario excluding single-dwelling buildings.

2.1 Energy savings

The most direct and also the most significant benefit from energy-efficient renovation of buildings is the savings resulting from lower energy consumption. In the maximum scenario, the accumulated potential for energy efficiency in 2020 would save energy costs of 5 billion SEK, accounting for the energy savings from reduced heating, and the increased energy use of installing energy efficiency measures. These savings can be increased by 8.5 billion SEK in 2030, cf. Figure 6.[14] In privately owned buildings, benefits of energy savings typically accrue to the owner or the user of the building, while in publicly owned buildings the benefits will accrue to the public or the users of publicly owned rental apartments.

14 See appendix for an in-depth description of input data and calculations.

Figure 6 Value of energy savings until 2030 in maximum scenario, annual



Note: Value of energy savings is discounted using annual discount rate of 4 per cent based on the National Board of Housing, Buildings and Planning. 2015 prices. Figures may not add up to sum due to rounding.

Source: Copenhagen Economics based on *Fallstudier till HEFTIG* (2015) and *Renoveringsnivåer för flerbostadshus, skolor och kontor, en intervjustudie och analys i HEFTIG* (2016) by CIT Energy Management, WSP Sverige AB, Profu; Energy in Sweden 2016 by Swedish Energy Agency and statistics on dwelling stock by Statistics Sweden. For energy prices see the Appendix.

The energy savings are calculated based on the TW hours of saved energy from the scenarios, and the price of energy without taxes and grid tariffs. The estimated values are dependent on the realisation of the projected prices, which are subject to uncertainty. If prices evolve differently than expected, the value of energy savings will also vary. The Swedish Energy Agency's uses a span of 10 per cent for sensitivity analyses, i.e. estimating that future prices vary by 10 per cent. This would give an interval between 4.5 million and 5.5 million in 2020, and 7.6 million to 9.3 million in 2030.

2.2 Renewable energy investments

Sweden has a legally adopted target of using at least 50 per cent renewable energy as a share of total energy use by the year 2020. This target has already been reached and is therefore no longer binding for decisions towards 2020. This implies that reduced energy consumption in buildings will not affect Sweden's ability to reach the 2020 target, and consequently there are no multiple benefits related to this.

Going forward, the current government is aiming at achieving a fully decarbonised energy sector in the near future.[15] Meeting such an objective will require less expansion of renewable energy sources if energy consumption is lower. Whether this is the best approach to reducing greenhouse gas emission is among others a question of, which measures are the least costly.

[15] Regeringskansliet, (2015) *Mål för förnybar energi.*

2.3 Health benefits

Outdoor air pollution
Pollution is costly to society. Part of the cost includes treatment of individuals affected by the pollution in terms of medication, hospitalisation and reduced worker productivity. However the largest cost to society stems from the general impacts on the individuals well-being. Sweden is one of the countries in Europe which experiences the lowest concentrations of air pollutants in urban areas. Despite this, the health impact of exposure to ambient air pollution is still an important issue in the country and the concentration levels, especially of nitrogen oxides (NO_X) and particles (PM_{10} and $PM_{2.5}$), exceed the air quality standards at street level in many urban areas.[16]

By reducing energy consumption, power and heat production from plants that give rise to air pollution can also be reduced. District heating plants and local heating generate NO_x and SO_2 which can cause morbidity or even death if too concentrated in the air.[17] $PM_{2.5}$ and PM_{10}[18] that form in the atmosphere as a result of emissions of SO_2 and NO_x constitutes a large source of pollution, and a very costly one for individuals when levels in air are high. Scientific studies have for example linked increases in daily small particle exposure with increased respiratory and cardiovascular hospital admissions, emergency department visits and deaths.[19]

We assess that energy savings for consumption are 16.4 TWh in 2030, split between district heating (57%), electricity (25%), biomass (17%), and gas and oil burners (1%). For electrical and district heating, some heat and electric losses occur in the distribution network; 12 per cent on average for district heating in 2014[20], and 7 per cent for electricity the same year[21]. To estimate the effect from reduced emissions from production, we account for these losses. The figures of reduced production used are shown in Table 2.

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16 IVL, (2014) *Quantification of population exposure to NO_2, $PM_{2.5}$ and PM_{10} and estimated health impacts in Sweden 2010*.
17 Thomson et al. (2013) *Housing improvements for health and associated socio-economic outcomes.*
18 PM10 are inhalable particles, with diameters that are generally 10 micrometres and smaller and PM2.5 are fine inhalable particles with diameters of 2.5 micrometres and smaller. Particles less than 10 micrometres in diameter pose the greatest problems since they can travel deeply into the respiratory tract, reaching the lungs and even the bloodstream. These are also the ones hardest to measure.
19 Website: https://www.health.ny.gov/environmental/indoors/air/pmq_a.htm.
20 Distribution losses as a share of district heating production from Energy in Sweden 2016.
21 Distribution losses as a share of electricity production excluding of export and imports from Energy in Sweden 2016.

Table 2 Reduced production, annual

TWh	2020	2030
Oil and gas	0.1	0.2
Biomass	1.2	2.7
District heating	4.8	10.6
of which:		
Biomass	*3.0*	*6.6*
Other fuels	*0.6*	*1.3*
Heat pumps	*0.4*	*0.9*
Waste heat	*0.4*	*0.8*
Coal, gas and petroleum products	*0.4*	*1.0*
Electric boilers	*0.0*	*0.1*
Electricity	2.0	4.5
of which:		
Nuclear power	*1.0*	*2.2*
Thermal power	*1.0*	*2.2*
Total	**8.1**	**18.0**

Note: Reduction in production is calculated based on energy savings per fuel (cf. Table 1) and losses occurring in district heating (12%) and electricity production (7%).

Source: Copenhagen Economics based on scenarios from Profu, CIT and WSP study HEFTIG (2016 for multi-dwelling and non-residential buildings and 2015 for single-dwelling buildings) and historic consumption from the Swedish Energy Agency (Energy in Sweden 2016); and statistics on dwelling stock by Statistics Sweden (2015).

We firstly assess the effect of reduced energy production for emissions of SO_2 and NO_x. Out of the fuels in the Swedish energy system, SO_2 emissions are highest for oil and NO_x are highest for natural gas.[22] As both of these fuel represent a very small share of energy consumption for heating in buildings, the estimated value of reduced emissions from these is also low. Local biomass combustion and biomass combustion also has a relatively high degree of NO_x emissions while low SO_2 emissions.

For district heating, we have calculated the average emission factors based on the respective inputs in production. As biomass makes up a large share, this has a heavy impact of on overall emissions from district heating.[23]

For electricity, we estimate that 50 per cent of savings will occur in nuclear power, and 50 per cent in thermal power. Only the reductions in thermal energy production has an impact on emissions, as nuclear production creates close to zero SO_2, NO_x emissions.

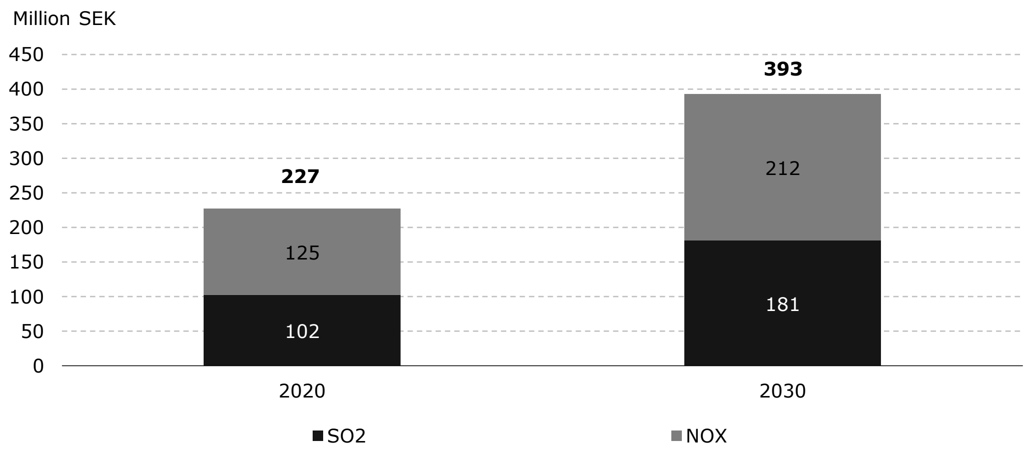
22 See Table A.4 in Appendix.

23 We count waste into the biomass category, which means biomass used in district heating has different emission factors from those of locally fired biomass combustion, which are primarily wood based. There are also difference in filtering methods enhancing the difference.

To estimate the monetary value of reduced emissions, we use cost estimates from ASEK, as recommended by the Swedish Transport Administration.[24]

Based on the assessment, we find that reduced emission in 2020 from energy savings are worth around 227 million SEK, and 393 in 2030, cf. Figure 7. The slightly larger share of savings stems from SO_2, as NO_x emissions are reduced to a greater extent. The volume of emission savings for NO_2 in 2030 are around 3,000 tonnes, and 1,300 tonnes for SO_2, which represents 2 and 5 per cent of total Swedish emission in 2014 for NO_x and SO_2 respectively.[25]

Figure 7 Value of reduced outdoor air pollution, annual



Note: Annual discount rate of 4 per cent, and 2015 prices. Calculations are based on the local and regional/global socio-economic cost of air pollution as valued by the Swedish Transport Agency. The local valuation includes impact on mortality and morbidity, while the regional costs includes health impacts and some environmental impacts, such as eutrophication and acidification. This means that what we call 'health benefits' are not strictly limited to health, but contains some impacts on other parameters. These should still be seen as a socioeconomic value stemming from reduced energy consumption.

Source: Copenhagen Economics, based on Swedish Transport Agency, (2016), *Kostnad för luftföroreningar,* Swedish Environment Protection Agency (2016), *Emission Factors and Heating Values,* historic consumption from the Swedish Energy Agency, (2016) *Energy in Sweden*; and Statistics Sweden (2015) *Dwelling Stock*.

Another source of emissions is $PM_{2.5}$, which is, as mentioned, very costly for individuals. A relatively small amount of particles are emitted from district heating production (from coal and biomass), and very small amounts stem from heating oil and natural gas used for local use. A large amount comes from locally burned biomass: almost 30 per cent of Sweden's total emissions of $PM_{2.5}$ came from stationary biomass combustion and biomass combustion in the residential sector in 2014.[26]

[24] The Swedish Transport Administration, (2016) *Analysmetod och samhällsekonomiska kalkylvärden för transportsektorn: ASEK 6.0. Kapitel 11 Kostnad för luftföroreningar*

[25] Emissions of NO_X were about 136 thousand tonnes in 2014. Emissions of SO_2 were nearly 24 thousand tonnes the same year. Source: The Swedish Environmental Protection Agency (2016), *Informative Inventory Report Sweden 2016*.

[26] The Swedish Environmental Protection Agency (2016), *Informative Inventory Report Sweden 2016*.

The valuation of small particles is highly dependent on where emissions occur, specifically the degree of pollution in the area where the emissions occur. Estimations from ASEK of the cost of $PM_{2.5}$ emissions in the most polluted areas (metropolitan areas) are 12 times as high as costs in less polluted ones (medium-sized cities). The valuation of $PM_{2.5}$ emissions in rural areas is zero.[27] Due to the aggregated nature of our analysis, we are only able to estimate reductions on a municipal level, i.e. identifying the estimated reduction in energy consumption per Swedish municipality. This means that 1) the simplified assumption that energy is produced and consumed in the same place can create a large bias, and 2) geographical distribution *within* municipalities can have the same effect. Some areas within municipalities are very densely populated where others are not.

In addition and adding to the uncertainty, valuations of the damage costs of $PM_{2.5}$ vary significantly depending on the estimating source. Damage costs for urban areas vary from 155 SEK (Germany) up to 13,077 SEK per emitted kg of $PM_{2.5}$ (Sweden), cf. Table 3. The highest estimate for Sweden is more than 77 times higher than the lowest. Using the highest values for Sweden (ASEK) and the same geographical split as for the NO_x and SO_2 calculations above yield benefits of almost 4.3 billion in 2030, while using the lowest Swedish value (urban and rural from EcoSenseLE/ExternE) yields benefits of 214 million the same year[28].

The most detailed and extensive study on the health impacts from $PM_{2.5}$ that we have been able to find is by IVL,[29] where population exposure to small particles is quantified in detail. Using their estimates of the total costs of $PM_{2.5}$ and the total emissions of $PM_{2.5}$ in 2010, and the estimate in their sensitivity analysis based on European Commission data, would yield a span of 1.0 to 1.2 billion in benefits in 2020, and from 1.9 to 2.1 billion in 2030.[30] These values are highly uncertain for the aforementioned reasons, and given that the valuation used for all geographical areas is the same.

27 The Swedish Transport Administration, (2016) *Analysmetod och samhällsekonomiska kalkylvärden för transportsektorn: ASEK 6.0. Kapitel 11 Kostnad för luftföroreningar*

28 Discounted at 4 per cent yearly.

29 IVL, (2014) *Quantification of population exposure to NO_2, $PM_{2.5}$ and PM_{10} and estimated health impacts in Sweden 2010.*

30 2015 year values, discounted at 4 per cent yearly.

Table 3 Value of $PM_{2.5}$, SEK

SEK/kg		Low	Central	High	Source
Sweden	Metropolitan areas		13 077		ASEK
Sweden	Suburban areas		3 304		ASEK
Sweden	Medium cities		3 210		ASEK
Sweden	Rural		0		ASEK
Sweden	Urban		168		EcoSenseLE/ExternE
Sweden	Rural		168		EcoSenseLE/ExternE
Sweden	High stack		60		EcoSenseLE/ExternE
Sweden	Average		1 693		IVL
EU	Average	1 474	1 980	4 296	IVL
Denmark/Copenhagen	Urban		2 449		Danish Ministry of Transport
Denmark/Copenhagen	Rural		52		Danish Ministry of Transport
Denmark	Urban	562	1 811	9 851	Danish Ministry of Transport
Denmark	Rural	9	18	70	Danish Ministry of Transport
Germany/Stuttgart	Urban		2 157		ExternE
Germany/Stuttgart	Rural		183		ExternE
Germany/Stuttgart	Urban		155		BeTa
Germany/Stuttgart	Rural		52		BeTa

Note: High stack refers to emissions released over 200m above ground. Values are adjusted or discounted.

Source: Values for Sweden are calculated using the EcoSenseLE tool, based on the Impact Pathway Approach developed within ExternE, the European Commission projects NEEDS and CASES. Other values can be found in the Danish Ministry of Transport (2004).

Important to note is that the scenario we are looking at compares the impact from maximum energy savings measures compared to measures in a business as usual scenario. There are, however, external factors that can affect the benefits in the business as usual scenario, and potentially reduce the calculated benefits. Changes happening exogenously, i.e. unrelated to the measures we analyse, can affect the size of the impacts. For example, on 30 June 2016 the Council and the European Parliament reached a provisional agreement on a directive to reduce emissions of air pollutants. This new NEC Directive sets stricter national limits from 2020 to 2029 and from 2030 onwards.[31] This means that polluters will have to take measures to reduce their emissions, to reach the limits set out in the Directive. If pollution (exogenously) reaches a level where it no longer poses a problem in terms of premature death and morbidity, the decrease in emissions from energy savings should no longer be seen as s benefit.

Indoor air quality

Inhabitants in industrialised countries spend more than 90 per cent of their time in an indoor environment (home, transportation, work).[32] This makes the indoor environment

[31] See for example: http://www.consilium.europa.eu/en/press/press-releases/2016/06/30-air-quality/

[32] US Environmental Protection Agency, (2016) *The Inside Story: A Guide to Indoor Air Quality.*

an important factor for people's health and comfort. While indoor air climate in Sweden generally is quite good[33], there are potential improvements to be made.

As typical goals for energy-efficient renovations include, in addition to saving energy, improvement of issues such as lighting and ventilation systems, they can positively affect parameters such as indoor temperature, humidity, air flow, visual and acoustic environment and the occurrence of indoor air pollutants. Improvements of these parameters can, in turn, create significant benefits for people who live and work in the buildings. For example, a study by Olesen finds that the indoor environment is perceived by office workers to have the highest influence on their own performance – higher than job satisfaction and job stress.[34]

There is however a risk that if the renovations of the building stock solely focus on energy efficiency, i.e. without taking into account the maintenance and improvement of the ventilation systems, the indoor air exchange can significantly worsen as a result of improved airtightness of the buildings. Thus, while insulation of building envelope improves building energy efficiency, it can also result in poorer indoor air quality. Consequently, there can be a trade-off to some extent between energy efficiency and ventilation quality of a building. The renovation scenario which we consider does indeed include measure to improve ventilation and air quality.[35]

Some of these impacts can be quantified, while others are harder to measure. We focus here on the quantification of and *reduced sick-building syndrome* stemming from overall improvement in indoor air climate in office and school buildings. These is an areas where we have relatively good data available, and where the outcome likely is affected by the energy savings measures defined in the scenarios.[36] As has been mentioned, there are a number of other, potentially impactful effects from renovations, such as a better visual environment from better light, and an improved acoustic environment from windows with enhanced sealing.

We have also quantified to effect *reduced incidence of asthma* stemming from reduced humidity and mould indoors, which can be a large benefit in countries where this is an issue. We find however, that this impact is very small in Sweden, at most a gain of 12 million can be made in 2030 from reduced incidence of asthma in the analyses scenario. This shows that, as mentioned, indoor air quality in Sweden is relatively good. See the Appendix for an overview of the calculations.

It is also important to note, that these are what-if scenario analyses, where we have aggregated over a number of studies for our calculations. Given that the underlying methodology

33 ECORYS, (2016) *The relationship between quality of dwelling, socioeconomic data and well-being in EU28 and its member states. Initial results.*

34 Olesen B., (2014) *Thermal comfort assessment of Danish occupants exposed to warm environments and preferred local air movement.*

35 CIT Energy Management, WSP Sverige AB, Profu, (2015) *Fallstudier till HEFTIG.*

36 For example, the maximum scenario specifies installation of new ventilation systems or adjustment of existing ones for all building types. Furthermore, change of thermostats and adjustment of the heating systems is specified for both multi- and non-residential buildings.

of these studies can vary to a relatively great extent, it should be emphasised that our estimates are subject to uncertainty, and that constructing these numbers is not an exact science. Health benefits other than the ones quantified in this study can be potentially great. However, the scope of the study limits a more thorough analysis of these.

Reduced sick building syndrome in offices

In typical office buildings, the cost of labour is a factor of around 100 higher than energy costs, which make the performance of people at their work significantly more important than energy costs.[37] Low indoor air quality in non-residential buildings in Sweden can potentially be very costly. For example, according to the National Board of Housing, Building and Planning, 23 per cent of non-residential buildings did not pass the obligatory ventilation control in 2015.[38]

So-called sick buildings syndrome includes a range of symptoms thought to be linked to spending time in buildings with insufficient ventilation, indoor air pollution and room temperatures above or below comfort levels. Sick buildings syndrome typically creates tiredness, mental fatigue, headache, eye irritation, dizziness and other symptoms typically not attributable to a specific illness.[39] The symptoms usually improve or disappear altogether when a person leaves the building.[40] There is substantial evidence that the occurrence of sick buildings syndrome has a negative effect on work performance; various studies report a productivity reduction of between 5 and 10 per cent due to bad indoor air quality.[41]

About 14 per cent or 1 million of approximately 7 million people in Sweden aged between 18 and 80 have at least one health symptom that depends on the indoor environment according to a survey by the National Board of Health and Welfare.[42] These are all symptoms typically attributed to sick buildings syndrome, e.g. tiredness, headache, itching, burning, eye irritation, an irritated, stuffy or runny nose, hoarseness, and a dry throat or cough. Of the 7 million, approximately 1.8 million are office workers, which means that up to 250,000 persons spending time in offices are affected.

Below we quantify the economic benefit of reduced sick buildings syndrome based on an assumption that sick building symptoms in office buildings will be addressed by the maximum renovations. This is likely valid given that the maximum scenario for office buildings includes measures to improve ventilation as well as indoor temperature, i.e. they address the most important causes of sick building syndrome.[43] In addition, the learning environment in schools is also affected positively by the renovations as a better exchange and flow of air significantly improves students' cognitive performance and ability to learn. We do not quantify this effect given the uncertainty of the connection between economic impact

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37 Olesen, (2014) *Indoor Environment-Health-Comfort and Productivity*.
38 National Board of Housing, Building and Planning (2016) *Obligatorisk Ventilationskontroll*.
39 Swedish Work Environment Authority, (2016) *Inomhusmiljö och hälsobesvär*.
40 National Health Agency (2014) *Sick buildings syndrome*.
41 Olesen B., (2014) *Thermal comfort assessment of Danish occupants exposed to warm environments and preferred local air movement*.
42 The National Board of Health and Welfare, (2009) *Miljöhälsorapport*.
43 CIT Energy Management, WSP Sverige AB, Profu, (CIT Energy Management, WSP Sverige AB, Profu, 2015) *Fallstudier till HEFTIG*.

and student performance, but the results from some studies investigating at these effects are described in Box 2.

Box 2 Effects of classroom ventilation rate on students' performance

Around 15 per cent of Swedish schools fail to achieve the required air quality in classrooms, causing pupils to spend their time in rooms with insufficient oxygen levels[44]. This has negative consequences for concentration, performance, and absenteeism among schoolchildren. The link between performance and a healthy indoor air climate in schools is established in several studies. One study reports that CO_2 concentration that exceeds recommended levels in classrooms leads to reduced attention and concentration among students, which over time may have harmful effects on pupils' educational attainment.[45] Another study finds that an increase in ventilation in classroom with poor indoor climate increases the proportion of students passing a standardised test linearly by 2.7 per cent for reading, and 2.9 per cent for math.[46] Better ventilation in schools is also reported to reduce sick leave as well as asthma symptoms related to school environment.
[47][48]

In the long-run, the socioeconomic benefits from ensuring a good level of ventilation in Swedish schools are significant.[49] An OECD study from 2010 found that countries with better PISA test scores achieve higher growth rates. Improvements in PISA scores of 10 points corresponds to a growth increase of 0.17 per cent due to the higher productivity of a better educated population.[50] Additionally, better ventilation reduces teachers' absenteeism which improves impacts on public budgets. A Danish study found that a reduction of teacher absenteeism of approximately 0.2 per cent (as a result of better air quality) decreases the total wage bill in public schools by about 27 billion DKK yearly, and gives annual public savings avoiding approximately 40 million in replacement costs.

Source: See sources in box.

Around 19 per cent of office buildings are expected to be renovated until 2020 and an additional 15 per cent are expected to be renovated by 2030 according to the maximum scenario. Assuming sick-building symptoms of all people in these buildings are addressed by the planned renovations, prevalence is likely reduced for 47,500 persons in office buildings until 2020 (19 per cent of 250,000) and an additional 37,500 until 2030 (15 per cent of 250,000). The renovations would increase productivity of these persons.

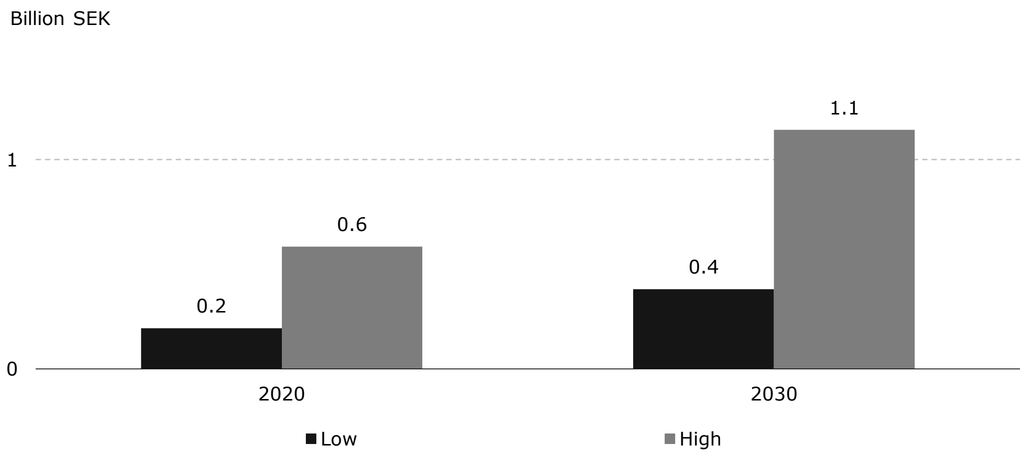
As mentioned out above, the reported productivity decrease due to bad indoor air quality varies between 5 and 10 per cent.[51] Most studies measure this decrease as a result of at least *two* symptoms of sick buildings syndrome. As the Swedish survey of the symptoms of the sick buildings syndrome only reports how many respondents have at least *one* symptom of

44 The Public Health Agency in Sweden, (2015) *Inomhusmiljön i skolan.*
45 Coley et al., (2007) *The effect of low ventilation rates on the cognitive function of a primary school class.*
46 Haverinen-Shaughnessy et al., (2011) *Association between substandard classroom ventilation rates and students' academic achievement.*
47 Shendell DG et al., (2004) *Associations between classroom CO_2 concentrations and student attendance in Washington and Idaho.*
48 Smedje G at al., (2000) *New ventilation systems at select schools in Sweden—effects on asthma and exposure.*
49 Slotsholm, (2012) *Samfundsøkonomiske konsekvenser af bedre luftkvalitet i grundskolen.*
50 OECD, 2010.
51 Olesen B., (2014) *Thermal comfort assessment of Danish occupants exposed to warm environments and preferred local air movement.*

sick buildings syndrome, we cannot know how many of these have more than one. In order to be conservative, we assume that between a third and half of the respondents claiming to have at least one symptoms of sick buildings syndrome also has at least one other symptom. This translates to between 5,800 and 8,700 persons until 2020 and an additional 9,400 to 14,100 persons until 2030 avoiding symptoms of sick building syndrome as a result of the analysed renovations.

The value of increased productivity among these people is estimated to be between 200 million and 0.6 billion SEK per year in 2020, and between 400 million and 1.1 billion per year SEK in 2030, cf. Figure 8. The valuation is based on the average number of hours worked per year in Sweden, and the average contribution to GDP per hour.[52] While not quantified here, these improvement will also likely improve quality of life of the affected persons.

Figure 8 Annual productivity gain resulting from reduction in sick building syndrome



Note: Annual discount rate of 4 per cent. 2015 prices.

Source: Copenhagen Economics based on National Board of Housing, Buildings and Planning (2010), Socialstyrelsen (2009) *Hälsorapport,* Statistics Sweden (2015) *Arbetskraftsundersökningarna,* National Institute of Economic Research (2016), *Produktion per arbetad time,* Olesen B., (2014) *Thermal comfort assessment of Danish occupants exposed to warm environments and preferred local air movement.*

As has been mentioned, the benefits identified are not generally the result of renovations that focus solely on energy efficiency. Rather, some measure of improved ventilation is generally necessary to achieve the calculated benefits. Insulation of the Swedish building stock have historically had adverse effects, where the sealing of buildings has resulted in too low ventilation rates.[53] This counteracts the positive impacts of energy efficiency investments. Put differently, the benefits derived above will not be reaped by energy efficiency measures

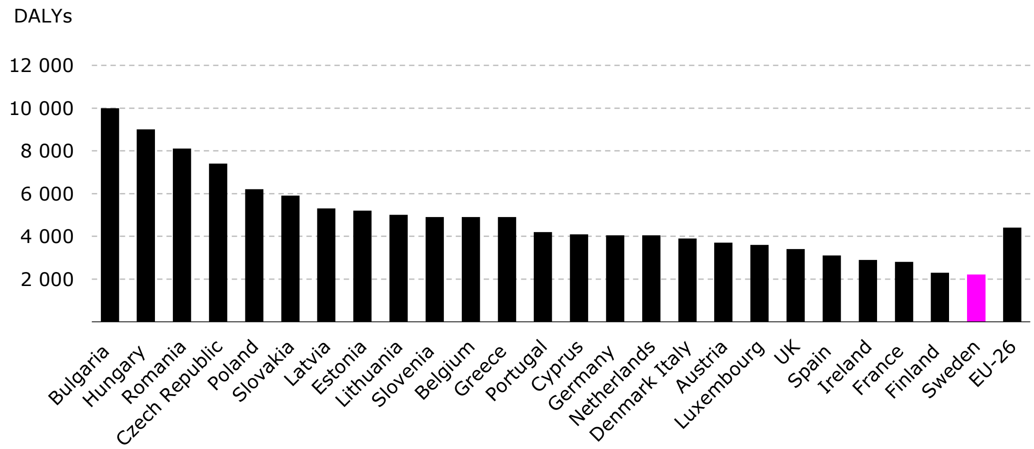
52 See appendix for an in-depth description of input data and calculations.

53 During the energy crisis of the 1970s, insulation measures aimed at reducing energy consumption often reduced natural ventilation from e.g. windows, while neglecting to compensate with improved artificial ventilation measures. This resulted in poor air circulation indoors. Source: Sikander, (2016), *Lufttäthet - Kan ett hus bli för tätt?.*

alone, but also requires a focus on measures that improves indoor air quality specifically. As with outdoor air pollution, improvements made exogenously in the business as usual scenario will also affect the assessed value of improved indoor air quality from the renovation strategy.

While there are benefits of improving indoor air quality that can potentially be sizeable, it is worth noting that the impact is likely small compared to other European countries. Sweden ranks lowest in the EU on the number of disability adjusted life years (DALYs), a measure of premature mortality and years lived with a disability, lost as a consequence of indoor pollution, at half the EU-26 average, cf. Figure 9.

Figure 9 Total DALYs lost per million inhabitants and year due to indoor air pollution in Europe, 2010



Note: DALY stands for disability adjusted life years.

Source: Asikainen et al (2012), *Health implications of alternative potential ventilation guidelines.*

2.4 CO_2 benefit

Combustion of fossil fuels creates emissions of CO_2 and other greenhouse gases. A reduction of these emissions contribute to reduced risk of global warming, and to meeting Sweden's long term ambitions of a carbon free economy.

All heat and electricity production in fossil power plants in Sweden takes place within the European Union's Emissions Trading System (EU ETS)[54], hence most of the reduction in CO_2 emissions will be within the EU ETS. Only oil and natural gas for individual heating is not included in the EU ETS.

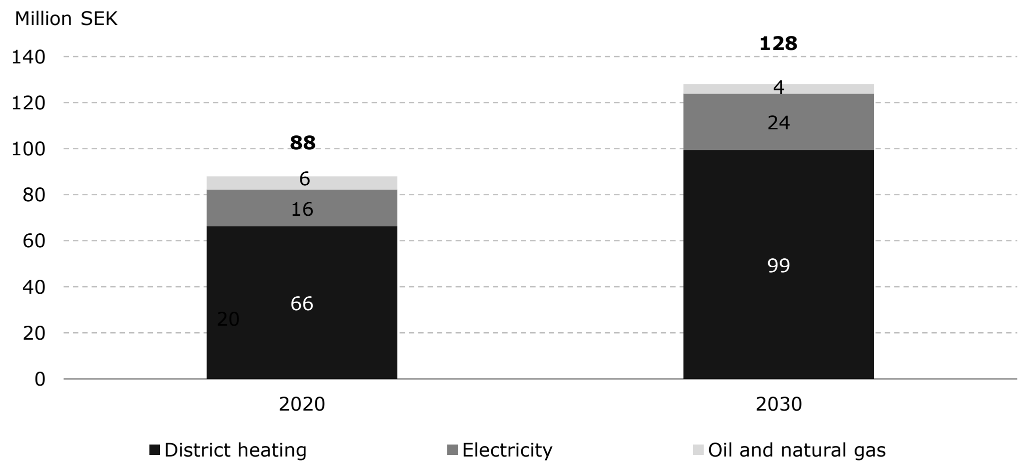
The total reduction in CO_2 emissions in 2020 is estimated to 470 thousand tonnes, of which 75 per cent will be in district heating, 18 per cent in electricity and the remaining 6 per cent in oil and gas. The corresponding reduction in 2030 is estimated to 1012 thousand tonnes,

[54] Ingenjörsvetenskapsakademien (IVA), (2015) *Skatter och subventioner vid elproduktion, en specialstudie.*

of which 78 per cent in district heating, 19 per cent in electricity and the remaining 3 per cent in oil and gas. This translates to a total value of 88 million SEK in 2020, of which 66 million stems from district heating, 16 million from electricity production and remaining 6 million from oil and gas heating. The corresponding reduction in 2030 is 128 million SEK, of which 99 stems from district heating, 24 million SEK in electricity and 4 million SEK in oil and gas, cf. Figure 10.

For the prices and further explanation of assumptions underlying them, see the Appendix.

Figure 10 Annual value of reduction in CO_2 emissions



Note: Based on Thomson-Reuters Point Carbon (2016) forecast of CO_2 emission price of 24 EUR (228 SEK) within EU ETS in 2030. 2015 prices.

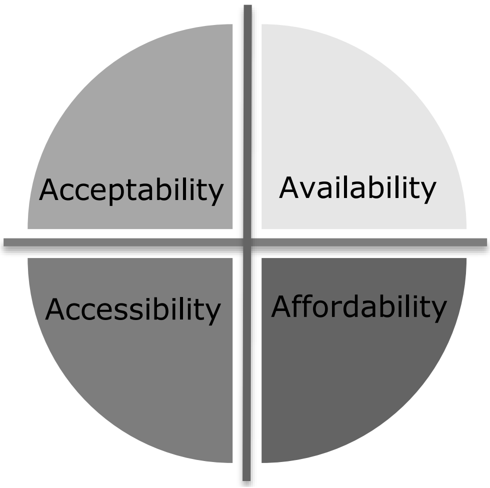
Source: Copenhagen Economics based on price forecast from Thomson Reuters Point Carbon (2016), CO_2 emission factors from Swedish Environmental Protection Agency (2016) *Emission factors and heating values,* fuel shares from Swedish Energy Agency (2016), *Energy in Sweden.*

2.5 Security of energy supply

Security of energy supply is a broad concept capturing measures of a country's reliability in terms of energy sources. Historically, energy security has been linked to being dependent on energy sources – primarily oil – from potentially unstable foreign region. More recently, energy security has in some countries been related to dependence on natural gas imports especially from Russia. Going forward, questions have also been raised regarding availability of biomass, especially if biomass is going to play a large role in transitioning European economies.

One common approach to define the concept of energy security is to use the 'four As' framework comprising availability, affordability, accessibility and acceptability, cf. Figure 11.

Figure 11 The four As: a framework for understanding security of energy supply



Source: Kruyt et al., (2009) *Indicators for energy security*

Availability: if a resource is geologically available in a region, i.e. the existence of the energy resource. Indicators used to measure the availability dimension are global resource depletion, reserves to production ratios and diversity in energy type.

Affordability: if energy is available at an affordable price for end consumers, and is profitable for investors.

Accessibility: if resources can easily be accessed from other regions. This includes geopolitical elements such as political stability and other risks. This dimension is often measured by, e.g., import dependency and net import of energy sources and where the imports come from.

Acceptability: an energy source is considered acceptable in terms of, e.g., environmental and societal elements. Important elements are, e.g., climate change implication and other environmental impacts such as air pollution and waste treatment.

Reducing energy use in buildings will similarly reduce energy demand, and therefore affect the four As. The key input fuels to consider are the ones which are used at the margin to generate heat and electricity, namely biomass and nuclear power. The two fuels which are typically considered subject to energy security concerns, oil and natural gas, are therefore not affected by reducing energy demand from buildings in Sweden as these are simply not important in electricity and heat generation. Instead, we argue that there may be limited benefits linked to energy security, primarily related to the acceptability criteria, cf. Figure 12.

Figure 12 Limited benefits from security of energy supply

Availability	◔	The substituted fuels were already readily available in Sweden, hence providing no clear benefit To some extent, it is discussed if biomass is available in larger scale as a fuel sources for the global decarbonisation due to its use of land and potential spill over to food prices.
Affordability	◔	Reducing energy consumption saves on the energy bill but is likely to increases other costs, primarily the costs of installing the renovation. If renovations are providing energy savings in addition to the costs, they will have a positive effect on affordability
Accessibility	○	The substituted fuels were already readily accessible for Sweden, hence providing no clear benefit
Acceptability	◑	Sweden's use of nuclear power is debated in terms of acceptability. Energy savings in large scale will contribute to the economic hardship of the current nuclear plants and may 'push them out of the market'. This will have a positive effect on acceptability

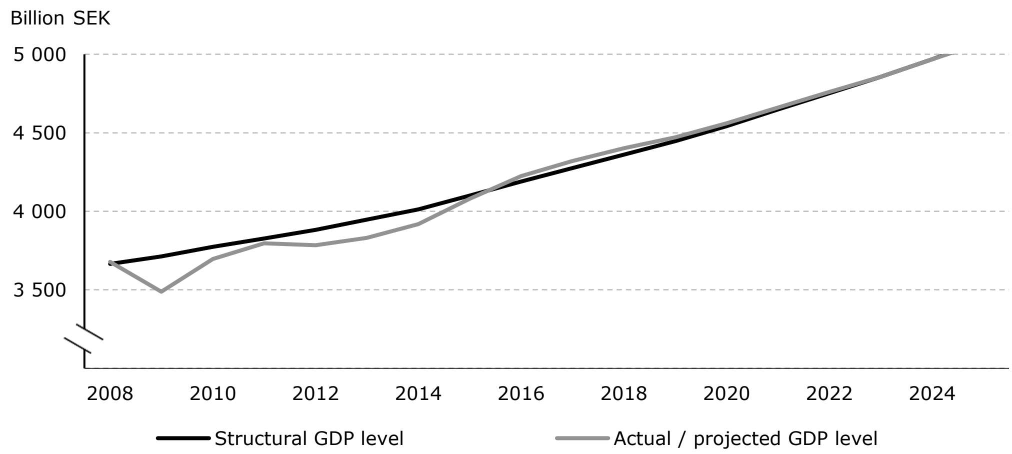
Source: Copenhagen Economics

2.6 Increased economic activity

Increased investments in energy-efficient renovations will stimulate economic activity, and potentially move people from unemployment to employment. Whether or not this is the case depends on the output gap, i.e. on current GDP and employment being above or below their structural levels. If the economy is in a downturn, then investment in energy-efficient renovations can mobilise resources that would otherwise not be used. Reversely, if there is no spare capacity and the economy is in an upturn – i.e. GDP and employment are over structural levels – the macroeconomic benefit to the total economy from increased investments in energy efficiency renovations is zero, as energy-efficient renovations will move resources from other economic activity. This means other, perhaps more needed investments are crowded out.

Swedish GDP is currently above its structural level, cf. Figure 13. While between 2009 and 2015 Swedish GDP was below its structural level, in 2016 it is expected to increase 0.6 per cent above the structural level and stay above until at least 2025. This implies that the stimulus effects driven by energy renovation initiatives should not be considered a benefit in this period, but could be in the future at times when GDP is below its structural level.

Figure 13 Output gap



Note: GDP forecast only available until 2025.

Source: Statistics Sweden and National Institute of Economic Research, 2016.

2.7 Public budget effects

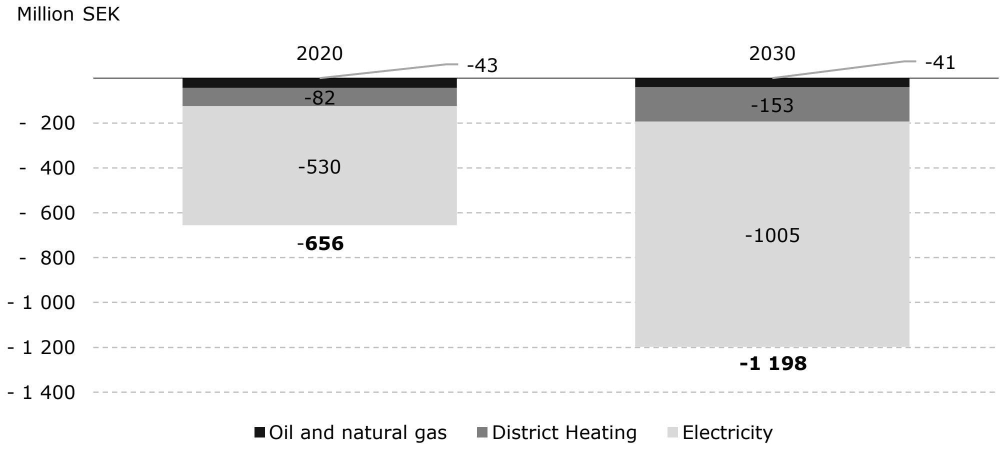
Energy savings from building renovations are also likely to affect public budgets. While primarily being transfers unrelated to economic welfare, reduced public income will also give rise to a marginal cost of public funds (MCPF) effect. This captures the idea that in order to finance public expenditure, the government is imposing a deadweight loss on the labour market by distorting labour decisions when imposing taxes.[55]

Reduced tax income

As energy consumption decreases, so does public income from energy related taxes. We find that the expected reduction in energy consumption in the maximum scenario will give rise to a loss of tax revenue from energy and CO_2 taxes of 0.66 billion annually in 2020, and 1.2 billion annually in 2030, cf. Figure 14.[56] The majority of the decrease stems from reduced electricity taxes given the fact that most district heating production of heat is covered by the EU ETS, mostly stemming from savings in single-dwelling houses. As much district heating production is exempt from both CO_2 and energy taxes, the effect for reduced district heating is small. The same goes for local biomass combustion, which is completely exempt from these taxes.

55 In Sweden, MCPF is set at 1.3.
56 See appendix for an in-depth description of input data and calculations.

Figure 14 Reduced tax income from maximum energy savings, annual



Note: Annual discount rate of 4 per cent based on National Board of Housing, Buildings and Planning. 2015 prices. Figures may not add up to sum due to rounding.

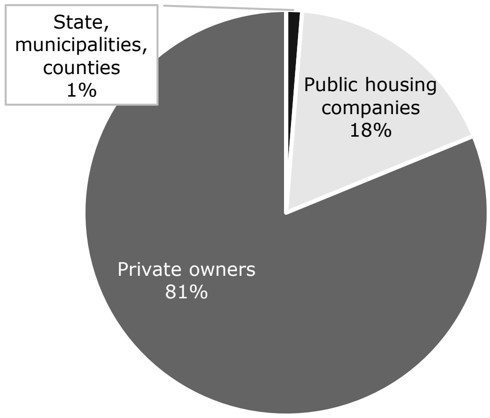
Source: Copenhagen Economics based on current energy tax rates from Swedish Tax Agency, future changes in tax rates as decided by the Swedish Government (2016), historical fuel input from Swedish Energy Agency (2016), *Energy in Sweden,* heating values from Swedish Energy Agency (2016), *Värmevärden från Energimyndighetens datalager (DW),* Statistics Sweden and the Swedish Energy Agency (2015), *Combined heat and power generation, 1983–2014* and Statistics Sweden (2015), *Dwelling Stock.*

Reducing energy consumption will reduce public income from *unit-based* fuel and electricity taxes according to Figure 14. Potentially, some portion of *non-unit based* taxes can also be affected by decreased energy consumption, such as property tax on power plants and power tax (*effektskatt*) on nuclear power plants. This would be the case, if the energy reductions were so large that they affected the overall price of electricity or the utilisation of these plants.

We judge that this is likely not the case, since the reduced electricity consumption from the renovation scenarios are not immense, and unlikely to have significant implications for the price of electricity in Sweden and given its interconnectedness to other countries. However, the economic viability of Swedish nuclear plants has been debated especially given the large expansion of subsidised wind energy, and it is possible that reduced energy consumption may be a deciding factor in a potential decision to shut down.

Energy savings in publically owned buildings
While the public sector owns about 19 per cent of Sweden's building stock (cf. Figure 15), only 1 per cent of these are utilised by the state, counties or municipalities themselves. The remaining 18 per cent are public housing companies. Thus, the value of savings that accrue to the public budgets is one per cent of the value of total energy savings, or 72 MSEK in 2020 and 119 MSEK in 2030. Benefits from energy savings in public housing companies are likely to accrue to the occupants of the buildings.

Figure 15 Division of value between public and privately owned buildings



Note: Based on share of ownership for the respective building type in 2015.

Source: Statistics Sweden, 2016.

2.8 Looking across the multiple benefits

The analysis focuses on the multiple benefits of energy efficiency renovations and their importance in a Swedish context. Multiple benefits can have a more or less extensive effect on the benefit side of a cost-benefit analysis of energy efficiency renovations.

Our analysis points to the fact that the value of energy savings is the largest gain from energy efficiency investments. Indoor air quality is also a potentially large sources of benefits if the undertaken renovations also focus on improving air quality for example through improved air circulation and temperature regulation. Outdoor air pollution is also a potentially large source of benefits. This depends strongly on the valuation of reducing small particles ($PM_{2.5}$) which is disputed and uncertain.

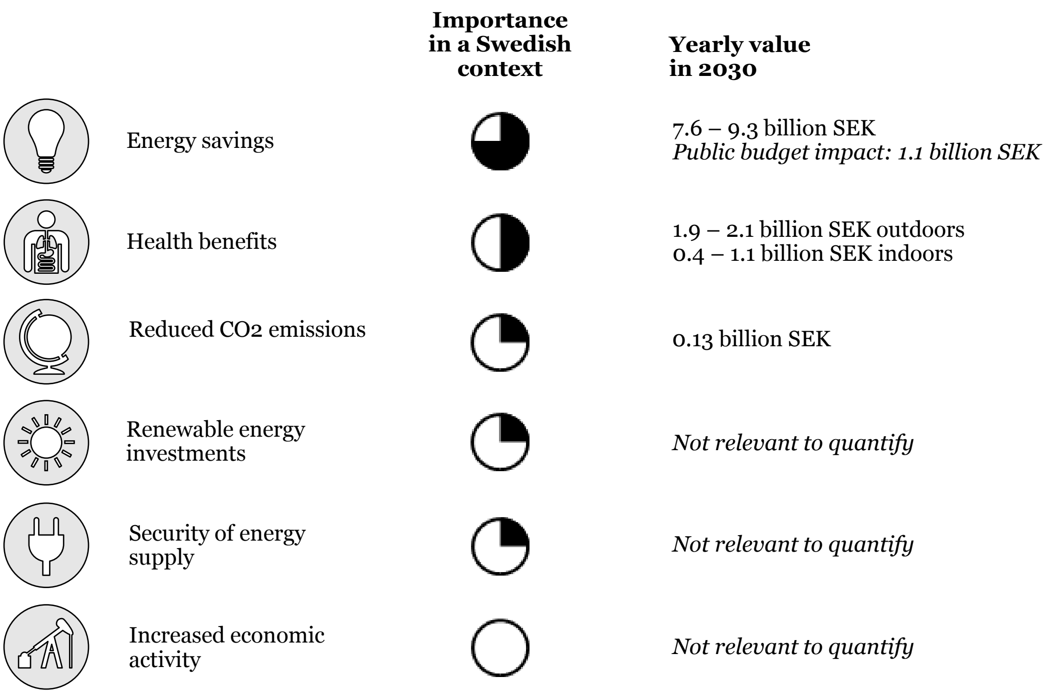
Compared to other European countries, we find that multiple benefits in Sweden are relatively small. For example, a reduced need for investment in renewable energy, outdoor air pollution from NO_x and SO_2, strategic energy security and increased economic impact are less important in Sweden than in other EU countries. This has several explanations:

- Sweden's legally adopted target of using at least 50 per cent renewable energy as a share of total energy use by the year 2020 is already reached. Therefore, there are no longer binding for decisions towards 2020, which reduces the benefit from renewable energy investments. Sweden and four other EU countries have already reached the target, but for the 23 who have not this can constitute a significant benefit.
- The energy system, especially electricity production, is to a large degree renewable, or with low emission e.g. from nuclear, which means emissions of CO_2 are low. Some impact from NO_x and SO_2 and $PM_{2.5}$ are still relevant, especially from biomass used for producing district heating. Reduced $PM_{2.5}$ emissions from local biomass use is also a

potentially large benefit: almost 30 per cent of Sweden total emission of $PM_{2.5}$ came from stationary biomass combustion and biomass combustion in the residential sector in 2014.

- A large share of renewable energy in the energy system also means that Sweden does not obtain many of the benefits related to security of energy supply, which are typically linked to reduced oil and natural gas consumption. For countries dependent on these fuels, energy efficiency renovations reducing this dependency constitutes a larger benefit.
- Swedish GDP is currently above its structural level and is expected to stay there in the foreseeable future, which implies that a stimulus effect driven by energy renovation initiatives should not be considered a benefit in this period. For EU countries in an economic recession, this can be ascribed as a benefit.
- Finally, while improving indoor air quality in Sweden can potentially have a large impact, this is also likely more important in other EU countries. For example, in countries with where indoor air temperatures are 'too low' thereby causing significant health costs, improved energy efficiency is likely to be lead to larger benefits.

Figure 16 Looking across the multiple benefits



Source: Copenhagen Economics.

Three things are especially worth noting here:

Firstly, we have estimated benefits of a maximum energy savings scenario, where buildings are assumed to be subject to a state-of-the-art-renovation which yields up to 50 per cent energy savings, at various rates given type of the building. If a less ambitious scenario is investigated, the impact is not likely to be the same. Benefits can be expected to be linear in ambition for some elements such as energy savings, but not necessarily for some other categories. For example, a strategy that does not include the ventilation measures required to gain the identified indoor air quality improvement will reduce overall benefits.

Secondly, it is very important to also remember the cost side of the analysis. There are not only benefits from reducing energy use in buildings and thereby reducing energy demand. Costs naturally include the costs of installing the measures, but will also include more subtle costs such as time spent and inconvenience for households and firms in carrying out the energy efficiency project. Moreover, reduced consumption may reduce the utilisation of existing capital infrastructure such as existing electricity and heat plants, and perhaps spur stranded assets.

Finally, when the cost of energy is reduced (e.g. through increased energy efficiency), consumption of energy is likely to increase in response. This *rebound effect* tends to reduce the total amount of energy saved, in exchange for improving consumer welfare. Indeed, the efforts of reducing, e.g., fuel poverty in some countries is intended to increase energy use in these households.

Multiple benefits can have a more or less extensive effect on the benefits in a cost-benefit analysis of a given renovation project or programme. It is, however, very important to also remember the cost side of the analysis, and assess this carefully. In energy savings alone can drive the business case when taking into all relevant costs including transaction costs such as the value of time and hassle, renovations should just be undertaken. When the business case built on just energy savings is less clear, including multiple benefits becomes more important.

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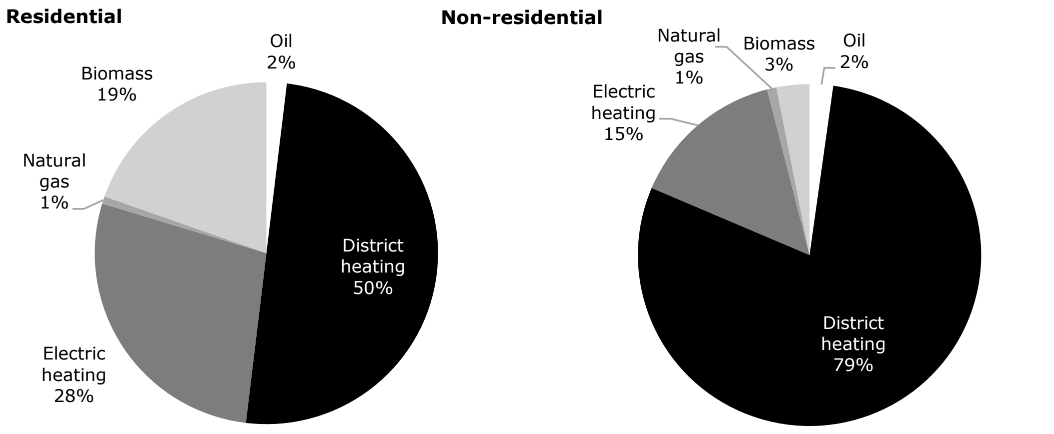
Appendix

A.1 Energy savings

The economic impact of energy-efficient renovations depends on the distribution of fuels in the energy system. Today, almost 80 per cent of energy consumption for heating and hot water in non-residential buildings in Sweden is produced using district heating, while the corresponding number for residential buildings is 50 per cent. The second largest category for both types of buildings is electric heating, followed by biomass. A small share is made up by oil and natural gas, cf. Figure A.1.

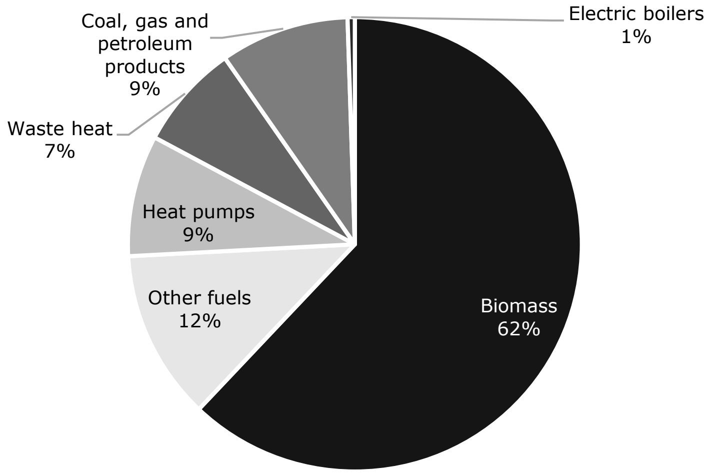
Figure A.1 Energy use for heating and hot water in buildings, 2013



Source: The Swedish Energy Agency, (2016) *Energy in Sweden.*

District heating and electricity are in turn produced using a variety of fuels. The share of input energy in district heating is shown in Figure A.2, and the share of input energy in electricity is shown in Figure A.3.

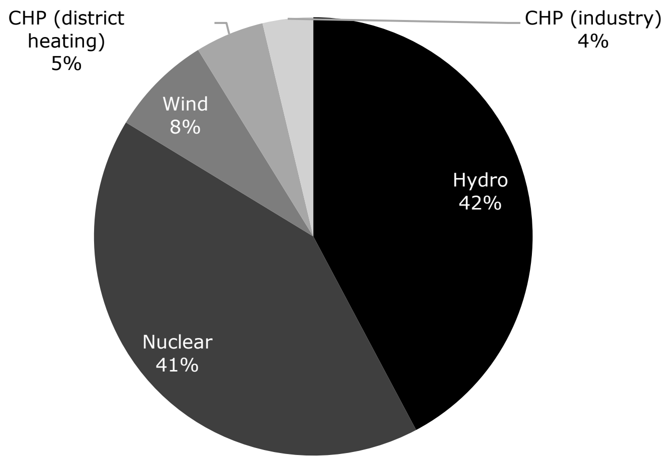
Figure A.2 Input energy used in the production of district heating, 2014



Note: 'Others' consist of coal (including coke oven and blast furnace gases), petroleum products and electric boilers.

Source: The Swedish Energy Agency, (2016) *Energy in Sweden.*

Figure A.3 Input energy used in electricity production, 2014



Note: Production for own use is not included.

Source: The Swedish Energy Agency, (2016) *Energy in Sweden.*

The economic impact of energy savings also depends on the price of energy in the current system, and in the future. The prices generally used for the estimations are listed in Table A.1. For district heating, we use the consumer end price per municipality, cf. Table A.2 for a selection. When no district heating price per municipality is available, we use the average price for Sweden.

Available prices include energy, CO_2 and the value added taxes (the first half of Table A.1). These are deducted to arrive at a price without tax (bottom half of Table A.1).

Table A.1 Prices used for calculations of value of energy savings

	2015	*2020*	*2030*
Price (SEK/MWh) with tax			
District heating	920	960	1 030
Electricity	1 250	1 330	1 550
Electricity North of Sweden	1 250	1 330	1 550
Biomass	560	590	700
Oil	1 180	1 270	1 460
Natural gas	1 080	1 080	1 150
	2015	*2020*	*2030*
Price (SEK/MWh) without tax			
District heating average	892	932	1 002
Electricity	885	965	1 185
Electricity North of Sweden	1 009	1 089	1 309
Biomass	560	590	700
Oil	671	761	951
Natural gas	699	699	769

Note: Prices without tax are calculated by multiplying taxes for the respective fuel source from the last column of Table A.16 with 25 per cent VAT, and deducting this value from pre-tax prices.

Source: The Swedish Energy Agency (2016), *Energiindikatorer*, and unpublished data from the Swedish Energy Agency.

Table A.2 Price district heating (SEK/MWh) without tax

Municipality	2015	2020	2030
Ale	728	760	815
Alingsås	821	857	919
Alvesta	768	802	860
Aneby	852	889	954
Arboga	760	793	851
Arjeplog	892	931	999
Arvidsjaur	781	815	874
Arvika	830	867	930
Askersund	832	868	932
Etc.	…	…	…

Note: Average 2015 prices for small multi-dwelling buildings, large multi-dwelling buildings, and single-dwelling buildings. Growth rate is based on projections for average district heating price from the Swedish Energy Agency (Table A.1).

Source: The Swedish District Heating Association, District heating prices (2015-2016).

Calculations

Calculations of the value of energy savings are based on the total energy consumption estimation by Profu, CIT and WSP in the maximum renovations and business as usual scenarios, as well as certain assumptions about the evolution of the fuel input mix over time.

We assume that the shares of district heating, electricity and natural gas in total consumptions are constant going forward. This means that we use their 2014 shares of total consumption from the Swedish Energy Agency.[57] Furthermore, we assume that the share of oil in the energy mix is halved by 2020 and that oil is completely eliminated from heating by 2030, based on historic trends. For biomass we assume 1 per cent yearly growth for non-residential buildings, 4 percent yearly growth for multi-dwelling buildings and no annual growth for the single-dwelling buildings.

For geographic segmentation of energy savings in multi-dwelling buildings we rely on a separate analysis by the Swedish Energy Agency on potential energy savings in the Swedish building stock. For the geographical distribution in single-dwelling and non-residential buildings we assume the share of energy savings to be proportional to the number of apartments of each type per municipality in 2015, using data from Statistics Sweden.

A.2 Health benefits

Outdoor air pollution

By reducing energy consumption, and consequently power and heat production, air pollution that arise from plants can also be reduced. District heating plants and local heating generate air pollutants such as NO_x, SO_2, which can cause morbidity or even death among the already very ill, if too concentrated in the air.[58] Small particles ($PM_{2.5}$ and PM_{10})[59] that form in the atmosphere as a result of emissions of SO_2 and NO_x can cause short-term health effects such as eye, nose, throat and lung irritation, decrease lung function and worsen medical conditions such as asthma and heart disease. Emissions create economic costs due to required treatment, hospitalisation and reduced worker productivity, as well as impacts on individuals' well-being. By reducing energy consumption, these emissions can be reduced, thus creating socioeconomic benefits.

To calculate the benefits of reduced emissions in the maximum energy efficiency scenario, we go through three steps.

57 Energy in Sweden 2016.

58 Thomson, Hilary, et al. "Housing improvements for health and associated socio-economic outcomes." *Cochrane Database Syst Rev* 2 (2013).

59 PM_{10} are inhalable particles, with diameters that are generally 10 micrometres and smaller and $PM_{2.5}$ are fine inhalable particles with diameters of 2.5 micrometres and smaller. Particles less than 10 micrometres in diameter pose the greatest problems since they can travel deeply into the respiratory tract, reaching the lungs and even the bloodstream. These are also the ones hardest to measure.

Firstly, the economic cost of emissions depends on where they occur. We therefore calculate energy savings per area, divided into five categories: metropolitan areas, suburban municipalities, larger cities, other urban areas and rural areas, cf. Table A.3. Energy is assumed to be produced in the same area where it is consumed.

Table A.3 Energy savings per area (produced)

TWh	2020	2030
Oil		
Metropolitan areas	0.0	0.0
Suburban municipalities	0.0	0.0
Larger cities	0.0	0.0
Other urban areas	0.0	0.0
Rural areas	0.0	0.0
District heating		
Metropolitan areas	1.1	2.5
Suburban municipalities	0.7	1.5
Larger cities	1.5	3.3
Other urban areas	1.3	2.8
Rural areas	0.2	0.5
Electricity		
Metropolitan areas	0.2	0.4
Suburban municipalities	0.3	0.7
Larger cities	0.6	1.3
Other urban areas	0.8	1.8
Rural areas	0.1	0.3
Natural gas		
Metropolitan areas	0.0	0.0
Suburban municipalities	0.0	0.0
Larger cities	0.0	0.0
Other urban areas	0.0	0.1
Rural areas	0.0	0.0
Biomass		
Metropolitan areas	0.1	0.2
Suburban municipalities	0.2	0.4
Larger cities	0.3	0.8
Other urban areas	0.5	1.1
Rural areas	0.1	0.2
Total	**8.1**	**18.0**

Note: Metropolitan areas include inner Stockholm, Gothenburg and Malmö.

Source: Calculations based on HEFTIG scenarios from Profu, CIT and WSP, data delivered from the Swedish Energy Agency (2015 for single-dwelling and 2016 for multi-dwelling and non-residential buildings), Swedish Association of Local Authorities and Regions municipal division, and fuel shares from the Swedish Energy Agency (2016), *Energy in Sweden*.

Secondly, we assess the volume of emissions per produced unit of energy. The Swedish Environmental Protection Agency publishes the report "Emisssion Factors and Heating Values" every year, which includes national average emission factors and heating values for different fuel combustion activities. Emission factors are listed for each year from 1990 and onwards. We include SO_2, NO_x and $PM_{2.5}$ emission factors for 2014, cf. Table A.4. Emissions for each municipality group are then calculated using the values from Table A.3 and Table A.4.

Table A.4 Emission factors oil, natural gas and biomass, 2014

Tonnes/TWh	NO_x	SO_2	$PM_{2.5}$
Heating oil	180	90	11
Natural gas	180	540	1
Biomass	277	36	379

Source: The Swedish Environmental Protection Agency, (2016) *Emission Factors and Heating Values 2016.*

Table A.5 Emission factors district heating, 2014

Tonnes/TWh	Share	NO_x	SO_2	$PM_{2.5}$
Biomass	62%	225	80	75
Coal	4%	288	360	60
Heating oil	2%	720	180	7
Natural gas	3%	180	540	2
Other fuels	12%	NA	NA	NA
Electric boilers, heat pumps, waste heat	17%	0	0	0
Weighted average	**100%**	**170**	**85**	**50**

Note: Shares are based on the input of the respective fuels in district heating.

Source: The Swedish Environmental Protection Agency, (2016) *Emission Factors and Heating Values 2016.*

Table A.6 Emission factors electricity

Tonnes/TWh	Share	NO_x	SO_2	$PM_{2.5}$
Nuclear power	50%	0	0	0
Thermal power (DH used)	50%	170	85	50
Weighted average	**100%**	**85**	**43**	**25**

Note: Shares are based on the estimated share of savings for the respective type of electricity production.

Source: The Swedish Environmental Protection Agency, (2016) *Emission Factors and Heating Values 2016.*

Thirdly, the reduced emissions were valued using the Swedish Transport Authority data on cost of emissions, cf. Tables A.7 and A.8. Data on local cost of emissions from the Swedish Transport Administration for the closest comparable sample municipality was used for each municipality group. The Swedish Transport Administration provides both regional and local socioeconomic costs of air pollution. Local costs include only health impacts, while regional costs include both health impacts and certain environmental impacts, such as eutrophication and acidification. This means that what we call 'health benefits' are not strictly limited to health, but comprise certain effects on other parameters. These should still be seen as a socioeconomic value stemming from reduced energy consumption.

The Swedish Transport Administration recommends that emissions in rural areas should be valued at the regional value, while cost of air pollution in urban environments should be valued at the sum of the regional and local values of air pollution. Values for 2020 and 2030 are adjusted based on the Administrations projections for 2040.

The costs are based on individuals' willingness to pay, which increase with increased real income. Costs account for both increased mortality as well as morbidity that typically arises from emissions of these pollutants. The economic value of mortality is calculated based on an estimate of the expected Value of a Lost Life Year (VOLL), and the economic value of increased morbidity is calculated as a flat rate proportional to increase in the valuation of mortality.[60]

Furthermore, time preferences are of general interest when evaluating health effects. In economic valuation, estimates time preferences are considered by introducing a discount rate, thereby reducing the value of future events. For comparability we discount with a 4 per cent discount rate, which is a common rate used in valuation of health effects related to air pollution.[61]

Table A.7 Regional value of emissions

SEK/kg	2015	2020	2030
SO_2	29	32	38
NO_x	86	90	100

Note: 2015 values.

Source: The Swedish Transport Administration, (2016) *Analysmetod och samhällsekonomiska kalkylvärden för transportsektorn: ASEK 6.0. Kapitel 11 Kostnad för luftföroreningar.*

[60] The Swedish Transport Administration (2016) *Analysmetod och samhällsekonomiska kalkylvärden för transportsektorn: ASEK 6.0.*

[61] IVL, (2014) *Quantification of population exposure to NO_2, $PM_{2.5}$ and PM_{10} and estimated health impacts in Sweden 2010.*

Table A.8 Local value of emissions

SEK/kg	2015	2020	2030
SO_2			
Metropolitan areas	379	413	487
Suburban municipalities	103	112	132
Larger cities	172	187	221
Other urban areas	85	93	109
Rural areas	0	0	0
NO_x			
Metropolitan areas	41	45	52
Suburban municipalities	41	45	52
Larger cities	20	22	26
Other urban areas	9	10	11
Rural areas	0	0	0

Note: 2015 values. Metropolitan areas include inner Stockholm, Gothenburg and Malmö.

Source: The Swedish Transport Administration, (2016) *Analysmetod och samhällsekonomiska kalkylvärden för transportsektorn: ASEK 6.0. Kapitel 11 Kostnad för luftföroreningar.*

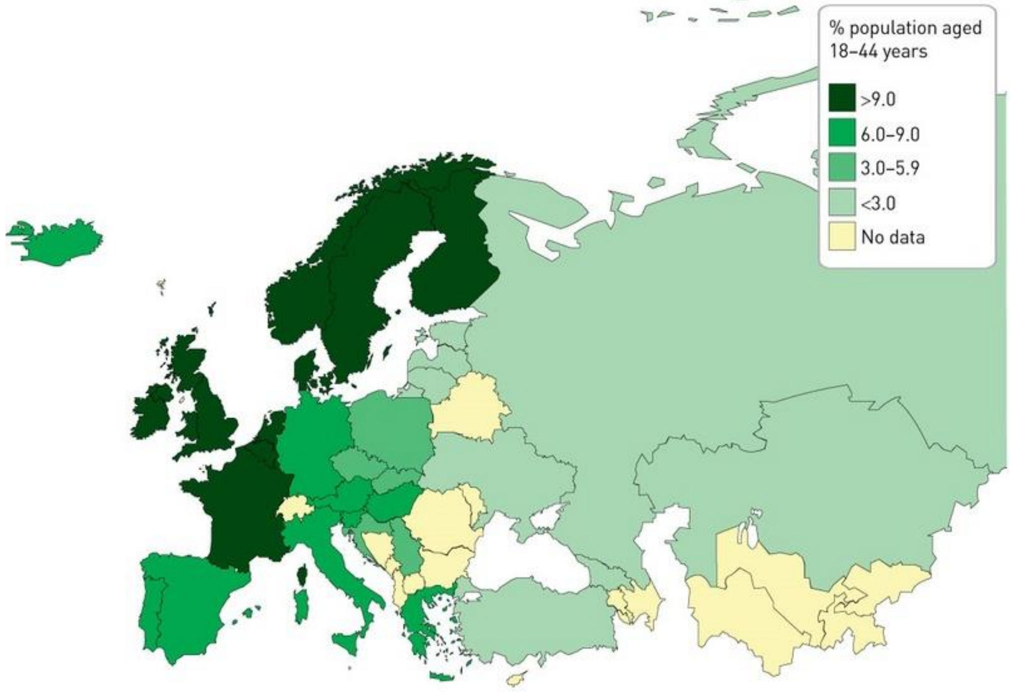
Valuation of reduced emissions of $PM_{2.5}$ is highly uncertain, and treated separately. See section 2.3 in the report.

Indoor air pollution

Reduced prevalence of mould and damp induced asthma
Allergic and asthmatic diseases have doubled in the industrialised countries over the past two decades.[62] They comprise one of the main contemporary problems for public health, with large costs for medicine, treatment and absenteeism. Sweden is one of the countries with the highest prevalence of asthma among adults in Europe, with over 9 per cent of the population suffering from the disease, cf. Figure A.4. The total societal cost of asthma in Sweden is estimated by Jansson et al. to be between 3.4 and 8.6 billion SEK annually.[63]

62 European Lung Foundation (u.d.) *Adult Asthma.*
63 In 2015 prices. Jansson et al., (2007) *Okänt hur mycket astma och allergier kostar samhället.*

Figure A.4 Prevalence of adult asthma in Europe



Source: European Lung Foundation, webpage. Link: http://www.europeanlung.org/lung-disease-and-information/lung-diseases/adult-asthma.

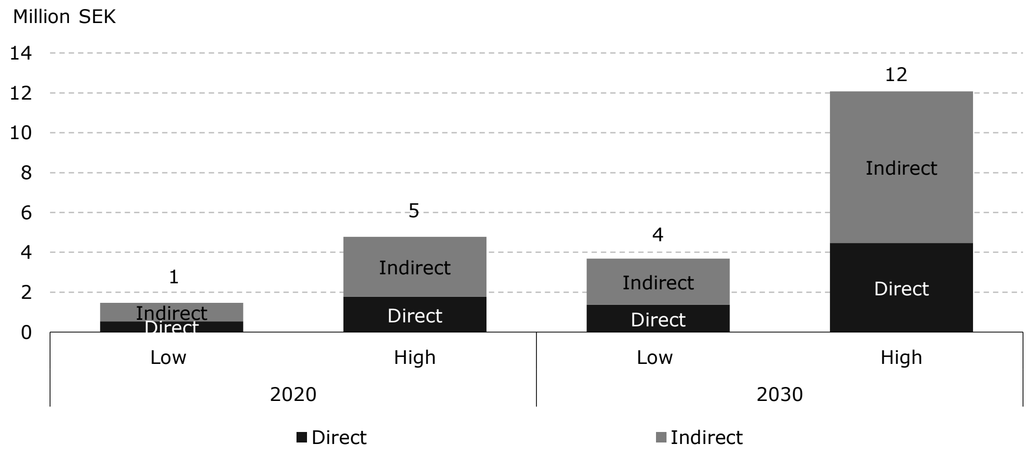
Damp and mould in buildings is one of the causes of asthma symptoms and other respiratory diseases. The Swedish National Board of Health and Welfare estimates that approximately 36 per cent of the Swedish building stock is subject to mould and damp problems and that as a result 25 000 people or about 3 per cent of the estimated 970 000 asthma cases in Sweden stem from mould and damp problems indoors, and just over 300 of asthma cases diagnosed annually depend in damp and mould indoors.[64,65] The majority of affected buildings are older single and two family residential buildings.

In the maximum energy renovations scenario, we estimate that circa 470 mould and damp related asthma cases in Sweden can be avoided by 2020, and that the corresponding number is 1 280 cases by 2030. This would create an annual value of between 2 and 6 million SEK per year in 2020 and an annual value of between 4 and 12 million SEK in 2030, cf. Figure A.5. The values stem from saved costs of outpatient care, drugs and hospital admissions (40 per cent) and from reduced to productivity loss, costs of sick leave, early retirement and premature death (60 per cent).[66,67] Benefits mainly accrue to individuals, but can also affect public budgets.

64 The National Board of Health and Welfare, (2009) *Miljöhälsorapport*.
65 Astma- och Allergiförbundet, (2016) *Allergifakta*.
66 The values do not include transfers, such as sickness benefits and early retirement pensions.
67 See appendix for an in-depth description of input data and calculations.

The severity of asthma among already ill people is also likely affected positively by the renovations. Even though this is another important health benefit, the extent of it is more uncertain and hence we do not assess its economic value here.

Figure A.5 Annual value of avoided new asthma cases



Note: Annual discount rate of 4 per cent based on National Board of Housing, Buildings and Planning. 2015 prices.

Source: Copenhagen Economics based on National Board of Housing, Building and Planning (2010) *God bebyggd miljö – förslag till nytt delmål för fukt och mögel*; asthma prevalence in Sweden from Astma och Allergiförbundet and cost of asthma from Folkesundhedsrapporten 2007, Ehlers et al. (2014) and Mossing & Nielsen (2003).

Calculations of the value of avoided incidence of asthma follow 4 steps.

First we estimate the share of mould and damp problems that can be addressed by the renovations. Our estimations rely on the data from the National Board of Housing, Buildings and Planning BETSI project[68] on the spread of mould and damp problems in the Swedish building stock and the rollout rate of renovations in the maximum scenario. We take into account that the distribution of these problems in the Swedish housing stock vary by age and type of the buildings. Based on this data we conclude that 30 per cent of the mould and damp problems can be addressed by the planned renovations until 2020 and that 72 per cent can be addressed until 2030.

In the next step we calculate the current annual number of new asthma cases that depend on mould and damp problems. Here we rely on the estimates of the current extent of asthma problems in Sweden as assessed by the Swedish Asthma and Allergy Association[69] and the estimate of mould and damp caused asthma cases in Sweden by the National Board of Housing, Buildings and Planning. Based on these and the average life expectancy in Sweden we estimate the annual incidence of new asthma cases due to mouldy and damp indoor environment to be around 300.

68 National Board of Housing, Building and Planning, (2010) *God bebyggd miljö – förslag till nytt delmål för fukt och mögel. Resultat om byggnaders fuktskador från projektet BETSI.*

69 Astma och Allergiförbundet, (2016) *Allergifakta.*

Finally, we calculate the annual savings in asthma spending on avoided asthma cases, as a result of the renovations. These are based on the cost estimations of asthma treatment per person and year. The total cost of asthma consists of both direct cost of medical care and indirect cost to the society in form of reduced productivity. These are characterised in more detail in Figure A.6. To calculate the total annual benefit we multiply the cost per individual by the estimated number of avoided asthma cases per year in 2020 and 2030 to illustrate the annual savings due to avoided asthma cases, cf. Table A.9.

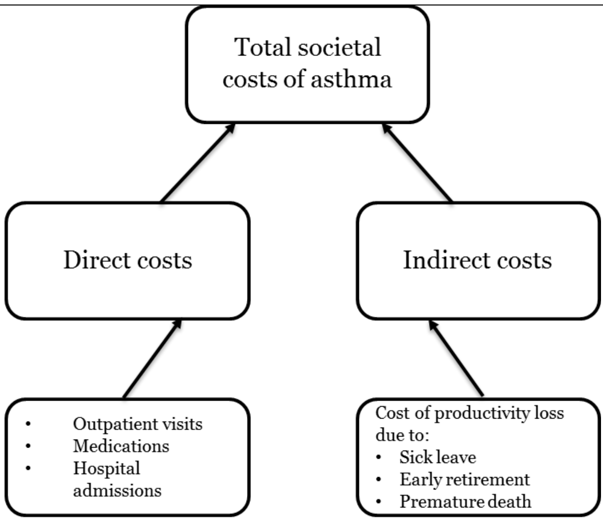
Table A.9 Annual benefit from reduced asthma

	Annual costs, SEK			Avoided asthma cases	Benefits, MSEK		
	Direct	Indirect	Total		Direct	Indirect	Total
2020 LOW	3 990	6 784	10 774	465	2	3	5
2020 HIGH	8 188	13 919	22 107	465	4	6	10
2030 LOW	3 990	6 784	10 774	1 275	5	9	14
2030 HIGH	8 188	13 919	22 107	1 275	10	18	28

Note: 2015 prices.

Source: Copenhagen Economics based on Jansson et al. (2007), Folkesundhedsrapporten 2007, Ehlers et al. (2014), Mossing & Nielsen (2003).

Figure A.6 Socioeconomic costs of asthma



Source: Copenhagen Economics based on Jansson et al. (2007) *Okänt hur mycket asthma och allergier kostar samhället*.

Sick building syndrome

Calculations of the value of improved productivity as a result of avoided sick buildings syndrome (SBS) follow 3 steps.

We value the reduction in the prevalence of sick buildings syndrome among the office workers at average increase in labour productivity of the cured workers. Swedish guidelines recommend the use of the traditional human capital (HC) method, which values lost or gained productivity in terms of gross earnings.[70] As a simplification, we use gross domestic product (GDP) per hour worked from the National Institute of Economic Research (NIER), which was 478 SEK in Sweden in 2015, and the corresponding forecasted value for 2020 is 506 SEK. 71 Our own forecasted value of hourly GDP for 2030 is 589 SEK and is based on the average growth rate of the NIER estimate for period between 2015 and 2025.

Based on the abovementioned hourly productivity estimations, a productivity increase of 5 to 10 per cent per worked hour implies a 25 to 51 SEK increase per hour in 2020 and a 29 to 59 SEK increase per hour in 2030.

For the estimations of the number of office workers that are currently affected by the sick buildings syndrome, we rely on a national health survey carried out by the National Board of Health and Welfare[72] that estimates the share of people that suffer from at least one sick buildings syndrome related symptom at school or workplace to be 14 per cent of the total population between 18 and 80 years old. We estimate that 5.4 million of these are students or workers and that furthermore circa 1.9 million of these are office workers. We assume the same occurrence of sick building symptoms among office workers as among the entire working population, i.e. 19 per cent. This means that 362 thousand office workers are estimated to be affected by at least one of the SBS symptoms.

Furthermore, the sick building syndrome is typically characterised by the presence of at least two symptoms, we assume that out of 362 thousand people who have one of the sick building syndrome between one third and half also have another. The share of sick building cases that are addressed by renovations is assumed to be proportional to the share of non-residential buildings renovated until that year, i.e. 15 per cent in 2020 and 34 per cent in 2030.

Based on number of people affected by sick buildings syndrome and the renovation rate we estimate that between 23 and 35 thousand sick building syndrome cases can be addressed until 2020 and an additional 18 to 27 thousand cases can be addressed between 2020 and 2030.

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70 Tandvårds-och Läkemedelsförmånsverket, (32) General guidelines for economic evaluations from the Pharmaceutical Benefits Board (LFNAR 2003:2) 2003. Available from: http://www.tlv.se/Upload/English/ENG-lfnar-2003-2.pdf. Accessed Niverber 11, 2016

71 National Institute of Economic Research, (2016)*Produktion per arbetad timme, fasta priser, referensår 2015, kalenderkorrigerade värden, baspris.*

72 The National Board of Health and Welfare, (2009) *Miljöhälsorapporten.*

Finally, we quantify the annual productivity increase resulting from the renovations. Based on the number of cases that can potentially be addressed, the hourly GDP and an estimate of average annual working hours (1621) we calculate the value of increased productivity to be between 0.2 and 0.6 billion in 2020 and 0.4 and 1.1 billion in 2030. According to the human capital approach values should be discounted, and we use the same rate as for other health impacts (4 per cent).

A.3 CO_2 benefit

To quantify the value of the reduced CO_2 emissions we use the Thomson Reuters reference scenario forecast of emissions allowance price for EU ETS 2030, i.e. 309 SEK per tonne. [73]. Given the high volatility of prices – the average EU ETS auction price has fallen from 72 SEK in 2015 to 50 SEK to date in 2016 – the forecast should be interpreted with some caution. However, given that European Commission has taken several measures to address the oversupply problem and that the market cap of CO_2 emissions is reduced by 1.74 per cent annually and that in 2021 the pace of reduction will increase to 2.2 per cent, the prices are very likely to increase significantly.

Table A.10 CO_2 emission factors, 2014

Tonnes/TWh	
Oil	269 507
District heating	73 975
Electricity	42 813
Natural Gas	205 178
Biomass	0

Note: Emission factor for district heating is calculated based on the average fuel inputs weighted by the emission factor of each input. For electricity, 50 per cent of reduction is assumed to be in nuclear power and 50 per cent from CHP power.

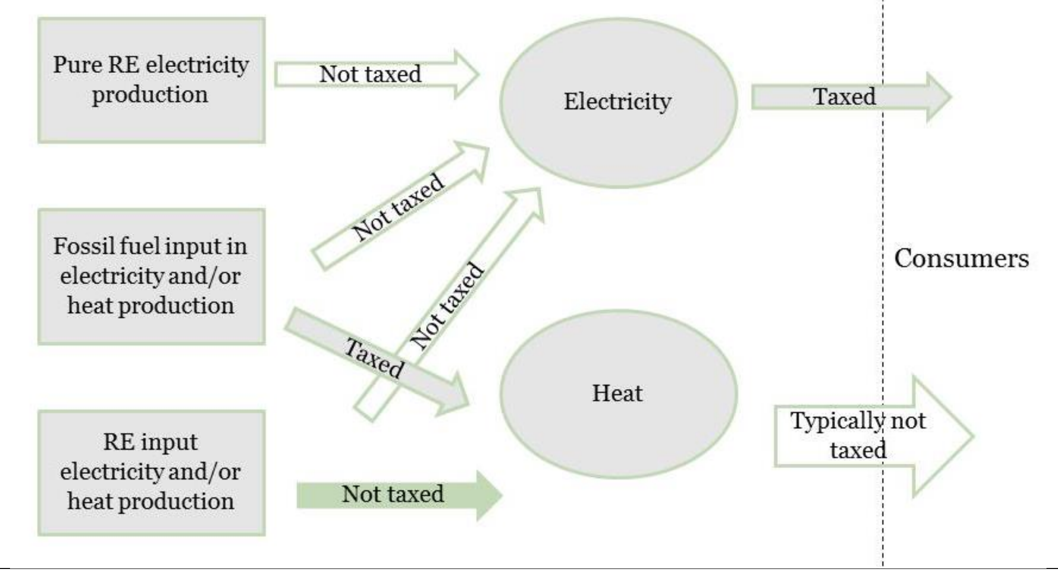
Source: Swedish Environmental Protection Agency, (2016) *Emission Factors and Heating Values 2016* and Swedish Energy Agency (2016), *Energy in Sweden.*

A.4 Reduced tax income

To estimate the impact on state revenue from reduced energy and CO_2 taxes, we use the calculated energy savings per fuel source, as well as data on the current level of excise duties for energy and CO_2, cf. Table A.11 and Table A.12. We also take into account the type of buildings in which the savings occur. Savings in the privately owned building stock will benefit the private owners or the tenants of the buildings and reduce the budget income, however, savings that occur in the publically owned building stock will not have an effect on the public budgets as a whole.

73 Thomson Reuters, (2014) *Thomson Reuters Point Carbon.*

Figure A.7 Energy taxation system



Source: Copenhagen Economics.

Table A.11 Fuel taxation

	1 - Heating values				2 - Energy tax			
Fuel type	Heating value		Converting heating value so that is has the same base as the taxes		Energy tax		SEK/GJ	SEK/MWh (Energy tax)
Natural gas	39	GJ/1000m3	0.04	GJ/m3	0.94	SEK/m3	24	85
Coal	30	GJ/ton	0.03	GJ/kg	0.64	SEK/kg	22	78
Heating oil	36	GJ/m3	0.04	GJ/m3	0.85	SEK/m3	24	85

Source: Copenhagen economics based on tax rates from the Swedish Tax Agency and heating values from the Swedish Energy Agency.

Table A.12 Fuel taxation cont.

	3 - CO_2 tax				4 - Sum of energy- and CO_2 tax			
Fuel type	CO_2 tax		SEK/GJ	SEK/MWh (CO2 tax)	Total		SEK/GJ	SEK/MWh
Natural gas	2.4	SEK/m3	61	219	3.33	SEK/m3	85	305
Coal	2.8	SEK/kg	94	338	3.43	SEK/kg	116	416
Heating oil	3 204	SEK/m3	90	322	4,050	SEK/m3	113	407

Source: Copenhagen economics based on tax rates from the Swedish Tax Agency and heating values from the Swedish Energy Agency.

Energy losses in the district heating of 12 per cent are taken into account. For calculations of tax impact from reduced electricity, energy losses are irrelevant since taxes are levied on consumption.

Calculations

To calculate the tax reduction in the maximum energy efficiency scenario, we have made the following assumptions.

Tax rates for each fuel are calculated as a sum of energy and CO_2 tax. We assume that there is no change in taxation of the different fuels until 2030. The fuel input mix in district heating is also assumed to be constant over time.

Biomass is assumed to continue to be fully exempt of both energy and CO_2 tax.[74]

Tax on district heating is calculated as a weighted average between tax on fuel input in combined heat and power plants (CHP) and fuel input in other district heating plants. The share of each of these types of power plants in district heating production is assumed to be 40 per cent CHP and 60 per cent other district heating plants, i.e. remain the same as in 2014.[75] This distinction is made due to different energy tax levels levied on the two types of district heating plants, cf Table A.13. CHP plants pay 30 per cent of energy tax while the other district heating plants pay full amount of the energy tax.[76] Furthermore, all CHP plants in district heating are part of the EU emissions trading system and hence fully exempt from the CO_2 tax.[77,78]

Table A.13 Per cent of the regular tax rate paid on input fuels

	Energy tax	CO_2 tax
CHP plants	30%	0%
Non-CHP plants	100%	100%

Source: Swedish Tax Agency.

When calculating the tax reduction from lower electricity consumption we distinguish between the North of Sweden, where the tax rate is subsidised by the government and hence lower and the rest of Sweden where the full tax is paid by the consumers. We also take into account the proposed electricity tax changes in the Swedish Government's budget for 2017.[79]

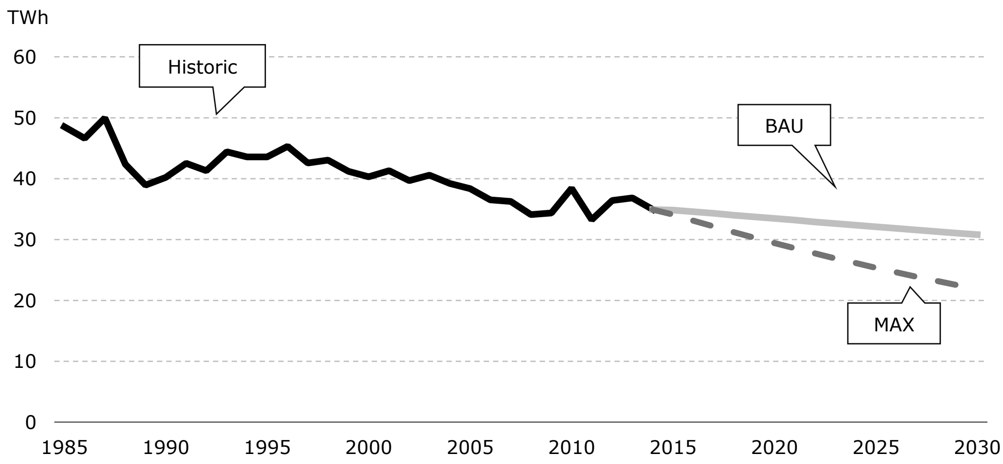
As mentioned above, the tax reduction only affects the public budgets if it stems from energy consumption in privately owned buildings or in publically owned buildings where the tenants are from the private sector.

74 Swedish Tax Agency, (2016) *Biogas och vegetabiliska oljor m.m. som förbrukas för uppvärmning.*
75 Statistics Sweden and the Swedish Energy Agency, (2015) *Combined heat and power generation, 1983–2014.*
76 Swedish Tax Agency, (2016) *Kraftvärme.*
77 Swedish Tax Agency, (2016)*Utsläpsrätter.*
78 Statistics Sweden, Phone conversation with Barbro Olsson, Statistics Sweden to confirm that practically all CHP district heating plants are within EU ETS system.
79 Regeringskansliet (2016), *Förändringar på skatteområdet i budgetpropositionen för 2017.*

To calculate the benefits from the maximum energy efficiency scenario, we go through the following steps. First the energy tax levied on a fuel (expressed in SEK per gigajoule) is divided by the heating value of that fuel (expressed in gigajoule per volume of fuel, typically in tonnes or cubic meters) to calculate the tax in SEK per gigajoule. Then we convert the tax rate to SEK per MWh in order to multiply this with the expected energy savings per fuel. Same steps are repeated for the CO_2 tax. Second the total tax rate per fuel (i.e. the sum of the energy and CO_2 tax) is multiplied with the expected savings from that fuel in 2020 and 2030 respectively.

A.5 Scenario: Maximum savings excluding single dwelling buildings

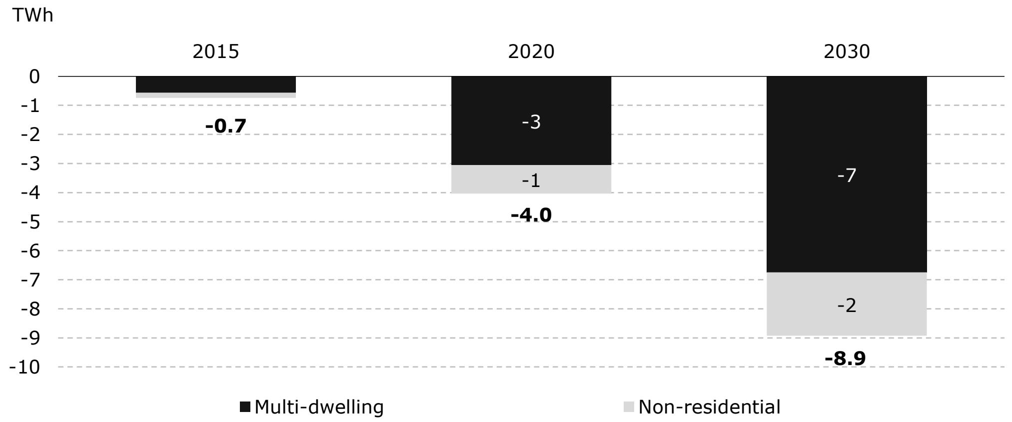
Figure A.8 Energy consumption for heating with and without energy savings measures based on scenarios



Note: The figure includes energy consumption for heating and hot water in multi-dwelling as well as office and school buildings. The figure does not include other non-residential buildings such as churches, hotels, restaurants, shops, warehouses, and sports facilities, due to lack of data for energy saving potential in these. In 2014, these other non-residential buildings used approximately 10 TW hours of energy for heating and hot water. As historic values and projections come from different sources, they are not fully comparable. For example, historic values which are based on the Swedish Energy Agency's statistics over Energy in Sweden 2016 are not subject to temperature correction, in contrast to projected values.

Source: Scenarios from Profu, CIT and WSP study HEFTIG (2016 for Multi-dwelling and non-residential buildings) and historic consumption from the Swedish Energy Agency (Energy in Sweden 2016).

Figure A.9 Energy savings per building type



Note: The figure shows the energy savings potential for the maximum savings scenario compared to the business as usual scenario. Figures may not add up to sum due to rounding.

Source: Copenhagen Economics based on scenarios from Profu, CIT and WSP study HEFTIG (2016 for multi-dwelling and non-residential buildings), historic consumption by the Swedish Energy Agency (2016), *Energy in Sweden*; and statistics on dwelling stock by Statistics Sweden (2015).

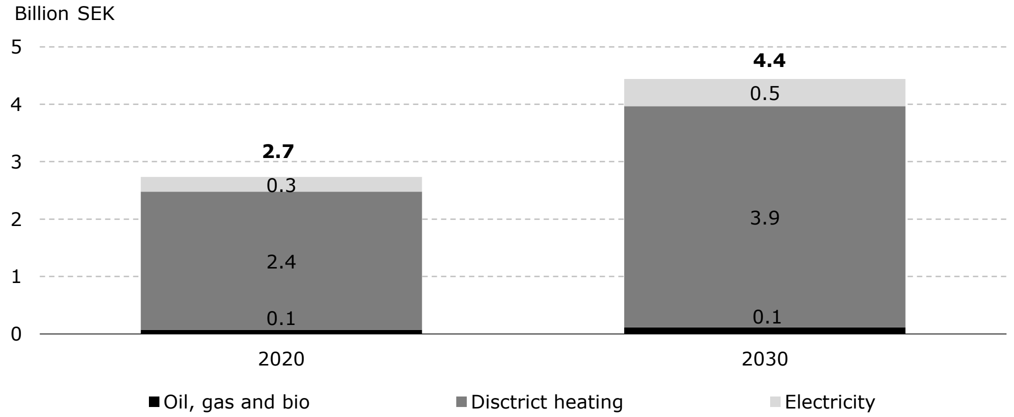
Table A.14 Energy savings per production source

TWh	2015	2020	2030
Oil and gas	0.0	0.1	0.1
Biomass	0.0	0.1	0.2
District heating	0.7	3.6	7.9
of which:			
Biomass	*0.4*	*2.2*	*4.9*
Other fuels	*0.1*	*0.4*	*1.0*
Heat pumps	*0.1*	*0.3*	*0.7*
Waste heat	*0.0*	*0.3*	*0.6*
Coal, gas and petroleum products	*0.1*	*0.3*	*0.7*
Electric boilers	*0.0*	*0.0*	*0.0*
Electricity	0.1	0.3	0.7
of which:			
Hydropower	*0.0*	*0.0*	*0.0*
Nuclear power	*0.0*	*0.2*	*0.4*
Windpower	*0.0*	*0.0*	*0.0*
Thermal power	*0.0*	*0.2*	*0.4*
Total	**0.7**	**4.0**	**8.9**

Note: The table shows the energy savings potential for the maximum savings scenario compared to the business as usual scenario. Figures may not add up to sum due to rounding.

Source: Copenhagen Economics based on scenarios from Profu, CIT and WSP study HEFTIG (2016 for Multi-dwelling and non-residential buildings and 2015 for Single dwelling buildings) and historic consumption from the Swedish Energy Agency (2016), *Energy in Sweden*; and statistics on dwelling stock by Statistics Sweden (2015).

Figure A.10 Value of energy savings until 2030 in maximum scenario excluding single-dwelling buildings, annual



Note: Value of energy savings is discounted using annual discount rate of 4 per cent based on the National Board of Housing, Buildings and Planning. 2015 prices. Figures may not add up to sum due to rounding.

Source: Copenhagen Economics bassed on *Fallstudier till HEFTIG* (2015) and *Renoveringsnivåer för flerbostadshus, skolor och kontor, en intervjustudie och analys i HEFTIG* (2016) by CIT Energy Management, WSP Sverige AB, Profu; Energy in Sweden 2016 by Swedish Energy Agency and statistics on dwelling stock by Statistics Sweden. For energy prices cf. Table A.1 and Table A.2.

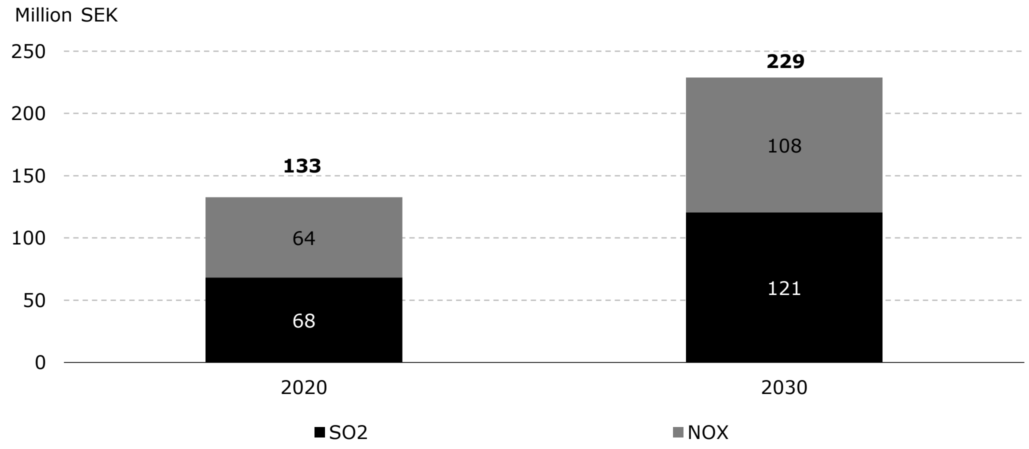
Table A.15 Reduced production, annual

TWh	2020	2030
Oil and gas	0.1	0.1
Biomass	0.1	0.2
District heating	4.1	9.0
of which:		
Biomass	*2.5*	*5.6*
Other fuels	*0.5*	*1.1*
Heat pumps	*0.4*	*0.8*
Waste heat	*0.3*	*0.7*
Coal, gas and petroleum products	*0.4*	*0.8*
Electric boilers	*0.0*	*0.0*
Electricity	0.3	0.8
of which:		
Nuclear power	*0.2*	*0.4*
Thermal power	*0.2*	*0.4*
Total	**4.5**	**10.1**

Note: Reduction in production is calculated based on energy savings per fuel (cf. Table A.14) and losses occurring in district heating (12%) and electricity production (7%).

Source: Copenhagen Economics based on scenarios from Profu, CIT and WSP study HEFTIG (2016 for multi-dwelling and non-residential buildings) and historic consumption from the Swedish Energy Agency (Energy in Sweden 2016); and statistics on dwelling stock by Statistics Sweden (2015).

Figure A.11 Value of reduced air pollution, annual

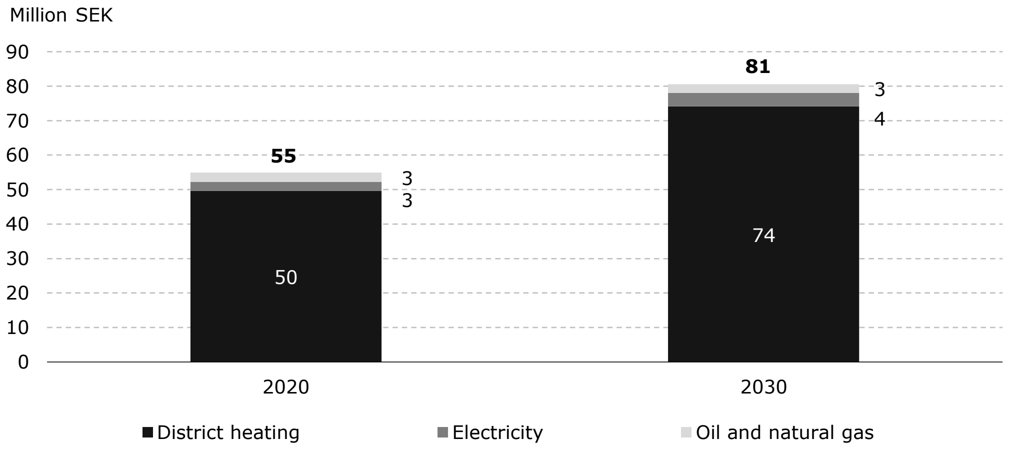


Note: Annual discount rate of 4 per cent, and 2015 prices. Calculations are based on the local and regional/global socio-economic cost of air pollution as valued by the Swedish Transport Agency. The local valuation includes impact on mortality and morbidity, while the regional costs includes health impacts and some environmental impacts, such as eutrophication and acidification. This means that what we call 'health benefits' are not strictly limited to health, but contains some impacts on other parameters. These should still be seen as a socioeconomic value stemming from reduced energy consumption. Figures may not add up to sum due to rounding.

Source: Copenhagen Economics, based on Swedish Transport Agency, (2016), *Kostnad för luftföroreningar,* Swedish Environment Protection Agency (2016), *Emission Factors and Heating Values,* historic consumption from the Swedish Energy Agency, (2016) *Energy in Sweden*; and Statistics Sweden (2015) *Dwelling Stock*.

Based on the IVL study of health impacts of $PM_{2.5}$ in Sweden, i.e. using their estimates of the total costs of $PM_{2.5}$ and the total emissions of $PM_{2.5}$ in 2010, and the estimate in their sensitivity analysis based on European Commission data, the maximum scenario excluding single-dwelling buildings would yield a span of 234 to 275 million in benefits in 2020, and from 427 to 503 million in 2030.

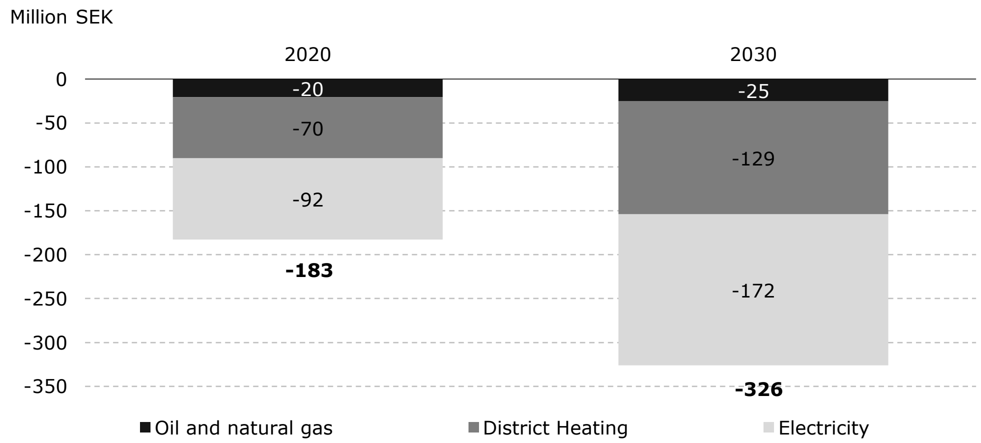
Figure A.12 Annual value of reduction in CO_2 emissions



Note: Based on Thomson-Reuters Point Carbon (2016) forecast of CO_2 emission price of 24 EUR (228 SEK) within EU ETS in 2030. 2015 prices. Figures may not add up to sum due to rounding.

Source: Copenhagen Economics based on price forecast from Thomson Reuters Point Carbon (2016), CO_2 emission factors from Swedish Environmental Protection Agency (2016) *Emission factors and heating values,* fuel shares from Swedish Energy Agency (2016), *Energy in Sweden.*

Figure A.13 Reduced tax income from maximum energy savings, annual



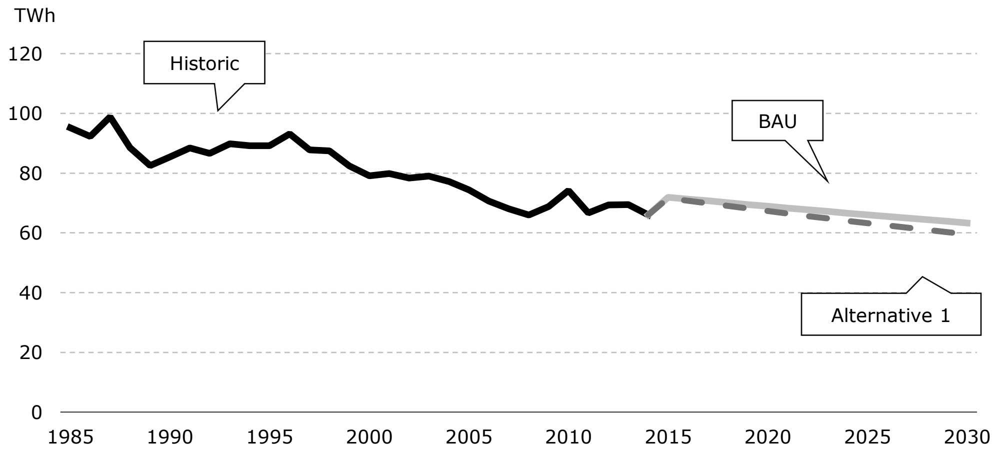
Note: Annual discount rate of 4 per cent based on National Board of Housing, Buildings and Planning. 2015 prices. Figures may not add up to sum due to rounding.

Source: Copenhagen Economics based on current energy tax rates from Swedish Tax Agency, future changes in tax rates as decided by the Swedish Government (2016), historical fuel input from Swedish Energy Agency (2016), *Energy in Sweden,* heating values from Swedish Energy Agency (2016), *Värmevärden från Energimyndighetens datalager (DW),* Statistics Sweden and the Swedish Energy Agency (2015), *Combined heat and power generation, 1983–2014* and Statistics Sweden (2015), *Dwelling Stock.*

A.6 Scenario: Alternative 1

The Alternative 1 scenario is based on standard improvements ("level 2") of energy efficiency from the HEFTIG (2016)[80] study for multi-dwelling and non-residential buildings, and energy savings scenario from the HEFTIG (2015)[81] study for single-dwelling buildings. It is compared to business as usual scenario.

Figure A.14 Energy consumption for heating with and without energy savings measures based on scenarios



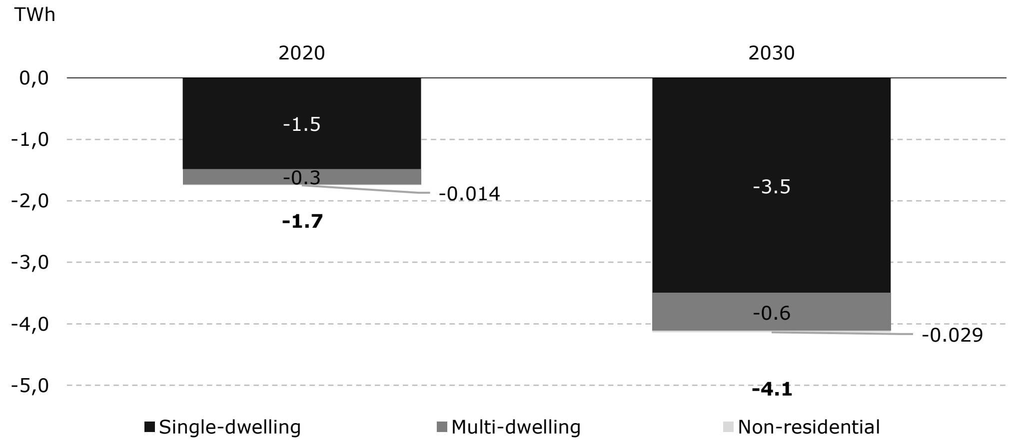
Note: The figure includes energy consumption for heating and hot water in multi- and single-dwelling as well as office and school buildings. The figure does not include other non-residential buildings such as churches, hotels, restaurants, shops, warehouses, and sports facilities, due to lack of data for energy saving potential in these. In 2014, these other non-residential buildings used approximately 10 TW hours of energy for heating and hot water. As historic values and projections come from different sources, they are not fully comparable. For example, historic values which are based on the Swedish Energy Agency's statistics over Energy in Sweden 2016 are not subject to temperature correction, in contrast to projected values.

Source: Scenarios from Profu, CIT and WSP study HEFTIG (2016 for Multi-dwelling and non-residential buildings and 2015 for Single dwelling buildings) and historic consumption from the Swedish Energy Agency (Energy in Sweden 2016).

80 CIT Energy Management, WSP Sverige AB, Profu, (2016) *Renoveringsnivåer för flerbostadshus, skolor och kontor. En intervjustudie och analys i HEFTIG.*

81 CIT Energy Management, WSP Sverige AB, Profu, (2015) *Fallstudier till HEFTIG.*

Figure A.15 Energy savings per building type



Note: The figure shows the energy savings potential for the Alternative 1 scenario compared to the business as usual scenario. Savings are net values of the decrease from savings for heating and increase from installing energy saving measures. Figures may not add up to sum due to rounding.

Source: Copenhagen Economics based on scenarios from Profu, CIT and WSP study HEFTIG (2016 for multi-dwelling and non-residential buildings and 2015 for single-dwelling buildings), historic consumption by the Swedish Energy Agency (2016), *Energy in Sweden*; and statistics on dwelling stock by Statistics Sweden (2015).

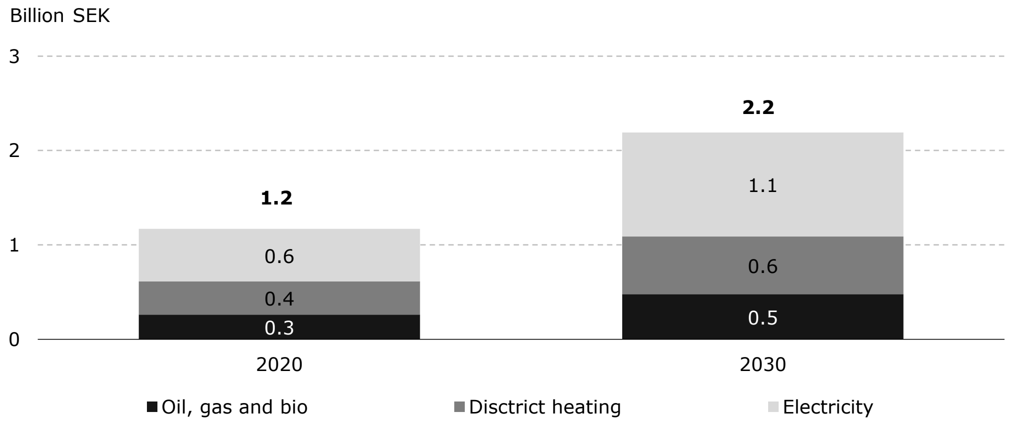
Table A.16 Energy savings per production source

TWh	2020	2030
Oil and gas	0.0	0.0
Biomass	0.5	1.2
District heating	0.5	1.3
of which:		
Biomass	*0.3*	*0.8*
Other fuels	*0.1*	*0.2*
Heat pumps	*0.0*	*0.1*
Waste heat	*0.0*	*0.1*
Coal, gas and petroleum products	*0.0*	*0.1*
Electric boilers	*0.0*	*0.0*
Electricity	0.7	1.7
of which:		
Hydropower	*0.0*	*0.0*
Nuclear power	*0.3*	*0.8*
Windpower	*0.0*	*0.0*
Thermal power	*0.3*	*0.8*
Total	**1.7**	**4.1**

Note: The table shows the energy savings potential for the Alternative 1 scenario compared to the business as usual scenario. Savings are net values of the decrease from savings for heating and increase from installing energy saving measures. Figures may not add up to sum due to rounding.

Source: Copenhagen Economics based on scenarios from Profu, CIT and WSP study HEFTIG (2016 for Multi-dwelling and non-residential buildings and 2015 for Single dwelling buildings) and historic consumption from the Swedish Energy Agency (2016), *Energy in Sweden*; and statistics on dwelling stock by Statistics Sweden (2015).

Figure A.16 Value of energy savings until 2030 in Alternative 1 scenario, annual



Note: Value of energy savings is discounted using annual discount rate of 4 per cent based on the National Board of Housing, Building and Planning. 2015 prices.

Source: Copenhagen Economics based on *Fallstudier till HEFTIG* (2015) and *Renoveringsnivåer för flerbostadshus, skolor och kontor, en intervjustudie och analys i HEFTIG* (2016) by CIT Energy Management, WSP Sverige AB, Profu; Energy in Sweden 2016 by Swedish Energy Agency and statistics on dwelling stock by Statistics Sweden. For energy prices cf. Table A.1 and Table A.2.

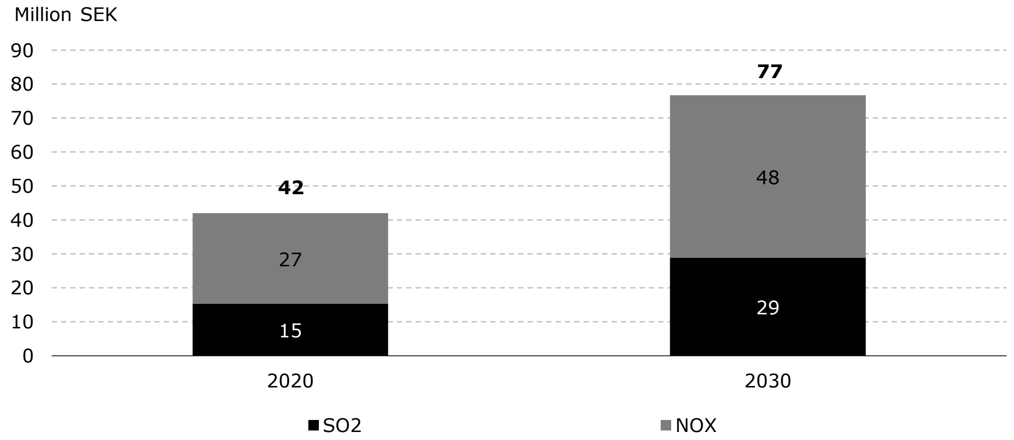
Table A.17 Reduced production, annual

TWh	2020	2030
Oil and gas	0.0	0.0
Biomass	0.5	1.2
District heating	0.6	1.4
of which:		
Biomass	*0.4*	*0.9*
Other fuels	*0.1*	*0.2*
Heat pumps	*0.1*	*0.1*
Waste heat	*0.0*	*0.1*
Coal, gas and petroleum products	*0.1*	*0.1*
Electric boilers	*0.0*	*0.0*
Electricity	0.7	1.8
of which:		
Nuclear power	*0.4*	*0.9*
Thermal power	*0.4*	*0.9*
Total	**1.9**	**4.4**

Note: Reduction in production is calculated based on energy savings per fuel (cf. Table A.16) and losses occurring in district heating (12%) and electricity production (7%). Figures may not add up to sum due to rounding.

Source: Copenhagen Economics based on scenarios from Profu, CIT and WSP study HEFTIG (2016 for multi-dwelling and non-residential buildings and 2015 for single-dwelling buildings) and historic consumption from the Swedish Energy Agency (Energy in Sweden 2016); and statistics on dwelling stock by Statistics Sweden (2015).

Figure A.17 Value of reduced outdoor air pollution, annual



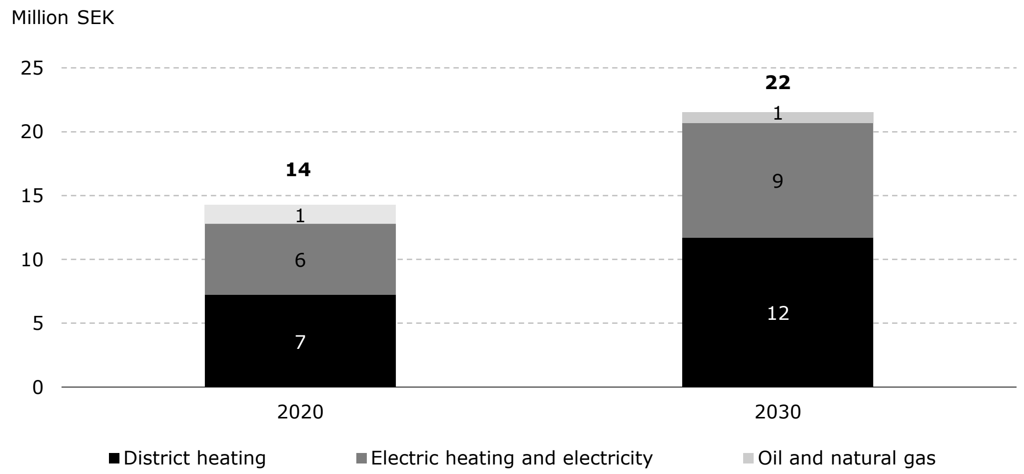
Note: Annual discount rate of 4 per cent, and 2015 prices. Calculations are based on the local and regional/global socio-economic cost of air pollution as valued by the Swedish Transport Agency. The local valuation includes impact on mortality and morbidity, while the regional costs includes health impacts and some environmental impacts, such as eutrophication and acidification. This means that what we call 'health benefits' are not strictly limited to health, but contains some impacts on other parameters. These should still be seen as a socioeconomic value stemming from reduced energy consumption. Figures may not add up to sum due to rounding.

Source: Copenhagen Economics, based on Swedish Transport Agency, (2016), *Kostnad för luftföroreningar,* Swedish Environment Protection Agency (2016), *Emission Factors and Heating Values,* historic consumption from the Swedish Energy Agency, (2016) *Energy in Sweden*; and Statistics Sweden (2015) *Dwelling Stock*.

Based on the IVL study of health impacts of $PM_{2.5}$ in Sweden, i.e. using their estimates of the total costs of $PM_{2.5}$ and the total emissions of $PM_{2.5}$ in 2010, and the estimate in their sensitivity analysis based on European Commission data, Alternative 1 scenario would yield a span of 258 to 304 million in benefits in 2020, and from 492 to 579 million in 2030.

We estimate that the annual productivity gain resulting from reduction in sick building syndrome in the Alternative 1 scenario is equal to that in the maximum savings scenario, i.e. between 200 and 600 million SEK in 2020 and between 400 million and 1.1 billion SEK in 2030, cf. Figure 7. The estimated effect on the indoor air quality does not change compared to the maximum scenario because measures that are crucial for improving indoor environment, e.g. better ventilation and indoor temperature control, are included in both maximum savings and Alternative 1 scenario.

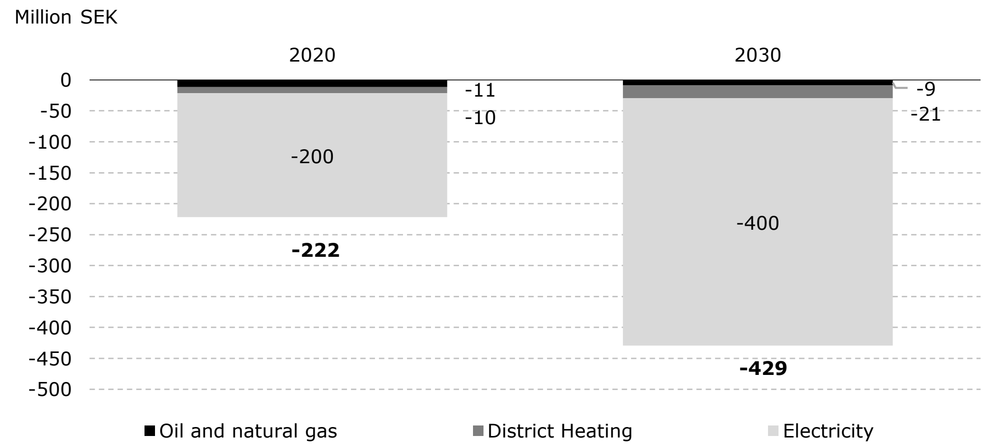
Figure A.18 Annual value of reduction in CO_2 emissions



Note: Based on Thomson-Reuters Point Carbon (2016) forecast of CO_2 emission price of 24 EUR (228 SEK) within EU ETS in 2030. 2015 prices.

Source: Copenhagen Economics based on price forecast from Thomson Reuters Point Carbon (2016), CO_2 emission factors from Swedish Environmental Protection Agency (2016) *Emission factors and heating values,* fuel shares from Swedish Energy Agency (2016), *Energy in Sweden.*

Figure A.19 Reduced tax income from maximum energy savings, annual



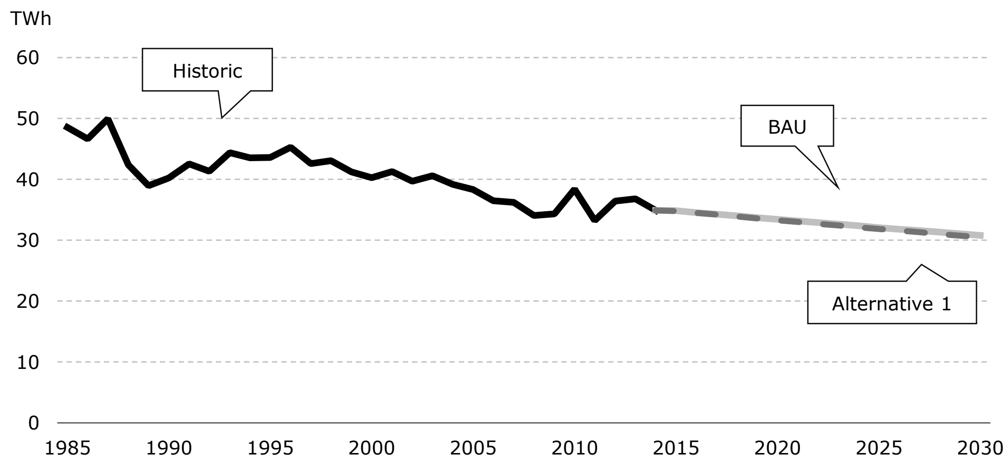
Note: Annual discount rate of 4 per cent based on National Board of Housing, Buildings and Planning. 2015 prices. Figures may not add up to sum due to rounding.

Source: Copenhagen Economics based on current energy tax rates from Swedish Tax Agency, future changes in tax rates as decided by the Swedish Government (2016), historical fuel input from Swedish Energy Agency (2016), *Energy in Sweden,* heating values from Swedish Energy Agency (2016), *Värmevärden från Energimyndighetens datalager (DW),* Statistics Sweden and the Swedish Energy Agency (2015), *Combined heat and power generation, 1983–2014* and Statistics Sweden (2015), *Dwelling Stock.*

A.7 Scenario: Alternative 1 excluding single-dwelling buildings

The Alternative 1 scenario excluding single-dwelling buildings is based on standard improvements ("level 2") of energy efficiency from the HEFTIG (2016)[82] study for multi-dwelling and non-residential buildings, and does not include savings for single-dwelling buildings. It is compared to a business as usual scenario.

Figure A.20 Energy consumption for heating with and without energy savings measures based on scenarios

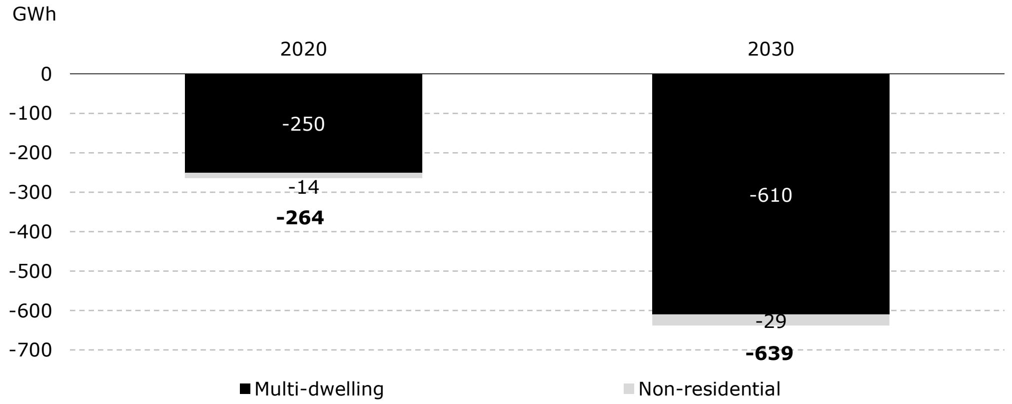


Note: The figure includes energy consumption for heating and hot water in multi-dwelling as well as office and school buildings. The figure does not include other non-residential buildings such as churches, hotels, restaurants, shops, warehouses, and sports facilities, due to lack of data for energy saving potential in these. In 2014, these other non-residential buildings used approximately 10 TW hours of energy for heating and hot water. As historic values and projections come from different sources, they are not fully comparable. For example, historic values which are based on the Swedish Energy Agency's statistics over Energy in Sweden 2016 are not subject to temperature correction, in contrast to projected values.

Source: Scenarios from Profu, CIT and WSP study HEFTIG (2016 for Multi-dwelling and non-residential buildings and 2015 for Single dwelling buildings) and historic consumption from the Swedish Energy Agency (Energy in Sweden 2016).

[82] CIT Energy Management, WSP Sverige AB, Profu, (2016) *Renoveringsnivåer för flerbostadshus, skolor och kontor. En intervjustudie och analys i HEFTIG.*

Figure A.21 Energy savings per building type



Note: The figure shows the energy savings potential for the Alternative 1 savings scenario compared to the business as usual scenario for multi-dwelling and non-residential buildings. Figures may not add up to sum due to rounding.

Source: Copenhagen Economics based on scenarios from Profu, CIT and WSP study HEFTIG (2016), historic consumption by the Swedish Energy Agency (2016), *Energy in Sweden*; and statistics on dwelling stock by Statistics Sweden (2015).

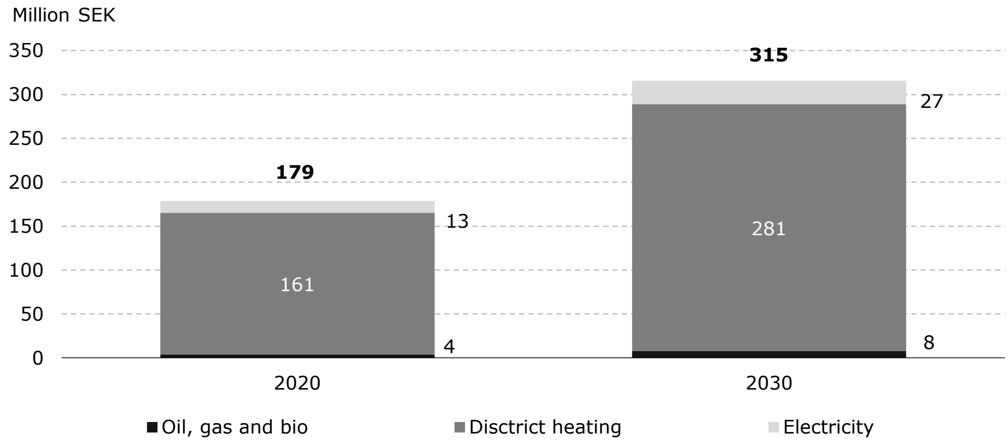
Table A.18 Energy savings per production source

GWh	2020	2030
Oil and gas	3	6
Biomass	4	13
District heating	240	579
of which:		
Biomass	*149*	*360*
Other fuels	*29*	*70*
Heat pumps	*21*	*50*
Waste heat	*18*	*43*
Coal, gas and petroleum products	*22*	*53*
Electric boilers	*1*	*3*
Electricity	17	40
of which:		
Hydropower	*0*	*0*
Nuclear power	*8*	*20*
Windpower	*0*	*0*
Thermal power	*8*	*20*
Total	**264**	**639**

Note: The table shows the energy savings potential for the Alternative 1 scenario compared to the business as usual scenario. Figures may not add up to sum due to rounding.

Source: Copenhagen Economics based on scenarios from Profu, CIT and WSP study HEFTIG (2016 for Multi-dwelling and non-residential buildings and 2015 for Single dwelling buildings) and historic consumption from the Swedish Energy Agency (2016), *Energy in Sweden*; and statistics on dwelling stock by Statistics Sweden (2015).

Figure A.22 Value of energy savings until 2030 in Alternative 1 scenario excluding single-dwelling buildings, annual



Note: Value of energy savings is discounted using annual discount rate of 4 per cent based on the National Board of Housing, Building and Planning. 2015 prices.

Source: Copenhagen Economics based on *Fallstudier till HEFTIG* (2015) and *Renoveringsnivåer för flerbostadshus, skolor och kontor, en intervjustudie och analys i HEFTIG* (2016) by CIT Energy Management, WSP Sverige AB, Profu; Energy in Sweden 2016 by Swedish Energy Agency and statistics on dwelling stock by Statistics Sweden. For energy prices cf. Table A.1 and Table A.2.

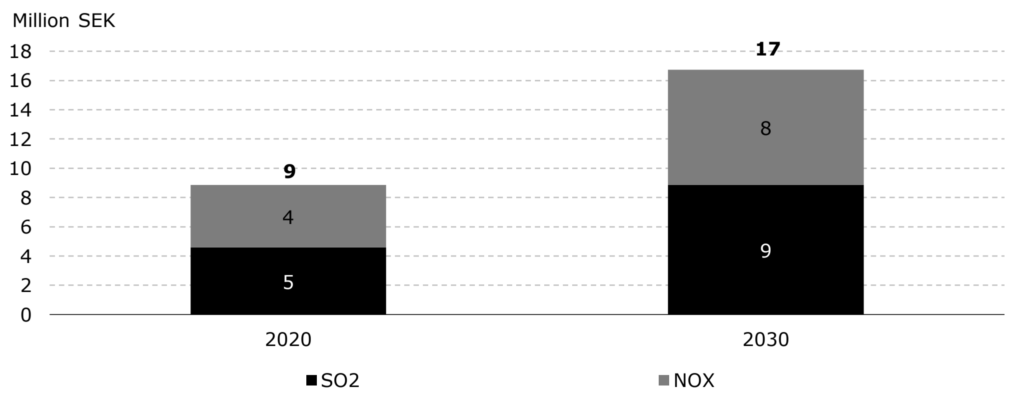
Table A.19 Reduced production, annual

GWh	2020	2030
Oil and gas	3	6
Biomass	4	13
District heating	273	657
of which:		
Biomass	*169*	*408*
Other fuels	*33*	*80*
Heat pumps	*24*	*57*
Waste heat	*20*	*49*
Coal, gas and petroleum products	*25*	*60*
Electric boilers	*1*	*3*
Electricity	18	43
of which:		
Nuclear power	*9*	*22*
Thermal power	*9*	*22*
Total	**298**	**720**

Note: Reduction in production is calculated based on energy savings per fuel (cf. Table 1) and losses occurring in district heating (12%) and electricity production (7%).

Source: Copenhagen Economics based on scenarios from Profu, CIT and WSP study HEFTIG (2016) and historic consumption from the Swedish Energy Agency (Energy in Sweden 2016); and statistics on dwelling stock by Statistics Sweden (2015).

Figure A.23 Value of reduced outdoor air pollution, annual

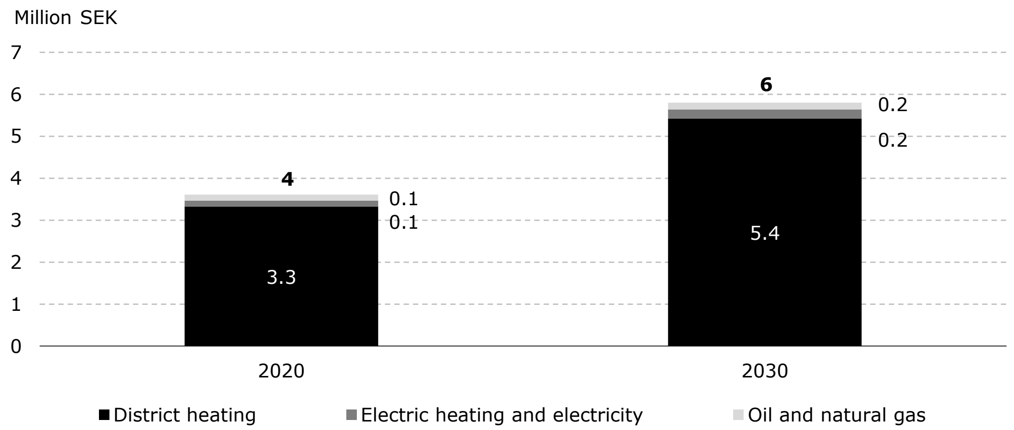


Note: Reduction in production is calculated based on energy savings per fuel (cf. Table 1) and losses occurring in district heating (12%) and electricity production (7%).

Source: Copenhagen Economics based on scenarios from Profu, CIT and WSP study HEFTIG (2016 for multi-dwelling and non-residential buildings and 2015 for single-dwelling buildings) and historic consumption from the Swedish Energy Agency (Energy in Sweden 2016); and statistics on dwelling stock by Statistics Sweden (2015).

Based on the IVL study of health impacts of $PM_{2.5}$ in Sweden, i.e. using their estimates of the total costs of $PM_{2.5}$ and the total emissions of $PM_{2.5}$ in 2010, and the estimate in their sensitivity analysis based on European Commission data, Alternative 1 scenario with the single dwelling buildings excluded would yield a span of 20 to 24 million in benefits in 2020, and from 40 to 47 million in 2030.

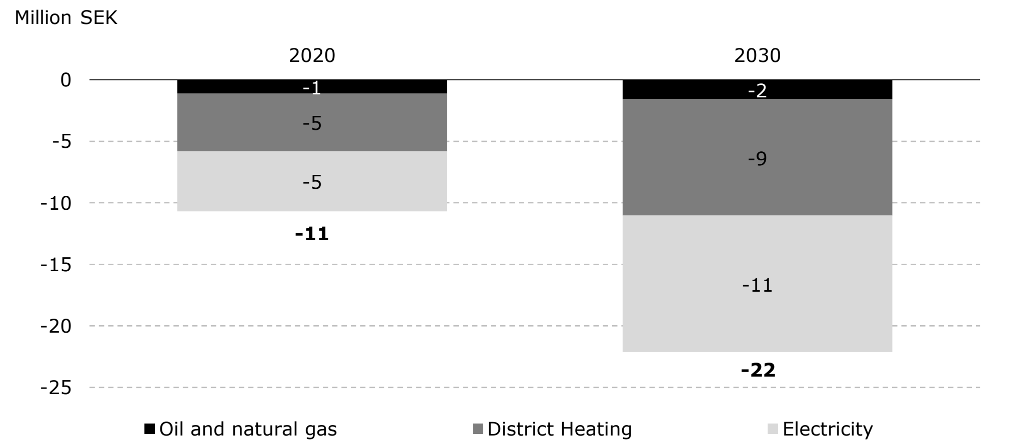
Figure A.24 Annual value of reduction in CO_2 emissions



Note: Based on Thomson-Reuters Point Carbon (2016) forecast of CO_2 emission price of 24 EUR (228 SEK) within EU ETS in 2030. 2015 prices. Figures may not add up to sum due to rounding.

Source: Copenhagen Economics based on price forecast from Thomson Reuters Point Carbon (2016), CO_2 emission factors from Swedish Environmental Protection Agency (2016) *Emission factors and heating values,* fuel shares from Swedish Energy Agency (2016), *Energy in Sweden.*

Figure A.25 Reduced tax income from energy savings, annual



Note: Annual discount rate of 4 per cent based on National Board of Housing, Buildings and Planning. 2015 prices. Figures may not add up to sum due to rounding.

Source: Copenhagen Economics based on current energy tax rates from Swedish Tax Agency, future changes in tax rates as decided by the Swedish Government (2016), historical fuel input from Swedish Energy Agency (2016), *Energy in Sweden,* heating values from Swedish Energy Agency (2016), *Värmevärden från Energimyndighetens datalager (DW),* Statistics Sweden and the Swedish Energy Agency (2015), *Combined heat and power generation, 1983–2014* and Statistics Sweden (2015), *Dwelling Stock.*

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