No. C 462
September 2019

Estimating the potential of incremental behavioural changes to reduce Swedish emissions of NEC Directive air pollutants

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Report number C 462
ISBN 978-91-7883-097-8
Edition Only available as PDF for individual printing

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This report has been reviewed and approved in accordance with IVL's audited and approved management system.

Preface

This report constitutes the final deliverable of the project “Potential for behavioural changes to reduce air pollution in Sweden” (contract No 252-18-015), financed by the Swedish Environmental Protection Agency. The work leading to this report is co-financed by the research programme “Swedish Clean Air and Climate” (SCAC) programme (www.scac.se). The contact person at the Swedish Environmental Protection Agency has been Johan Genberg Safont. The project has been executed by Stefan Åström at the Swedish Environmental Research Institute (IVL) with support by Sonia Yeh at Chalmers University of Technology. Large parts of the data collection have been done by the Swedish SMED-consortium (www.smed.se). Thanks goes to Mohammad-Reza Yahya at IVL Swedish Environmental Research Institute and Annika Gerner and Carina Ortiz at Statistics Sweden for data related to emission scenarios, as well as to Anna Mellin at IVL for reviewing a draft version of this report. Thanks also to Johan Genberg Safont for active engagement in the project and patience with this delayed deliverable. Through the Swedish EPA’s approval of this report the project is hereby finalised. All potential errors are the authors’ responsibility.

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Summary

The revised EU National Emissions Ceilings Directive was agreed upon in December 2016. In this revision, targets are set for maximum allowed levels of national emissions of sulphur dioxide, nitrogen oxides, non-methane volatile organic compounds, ammonia, and fine particulate matter for all member states by 2030. For Sweden, this revision implies emission reductions of 22, 66, 36, 17, and 19% compared to 2005 levels for these pollutants. These ambition levels mainly imply that larger efforts to reduce emissions of nitrogen oxides are required. The revised Directive also mandates an establishment of a National air pollution control programme. In the current programme it is expected that the major part of these emission reductions will take place in the industrial sector. However, since the emission reduction requirements are ambitious and the time frame is short, there is a risk that some of the proposed efforts will not deliver the emission reductions in time. It is therefore useful to estimate the possibility to reduce emissions with other means, and this report presents an estimate of how large emission reductions could become through implementation of behavioural change measures.

The analysis was done in several steps. First an extensive literature overview of reported behavioural change measures was made. From this overview a number of measures were selected for further analysis based on data quality and suitability for Swedish circumstances. After this, the national behavioural change potential of the measures was estimated. Through a re-use of the data supporting the official Swedish emission projections, alternative emission scenarios could be calculated for the selected measures. All in all, this report presents potential emission effects of 10 available behavioural change measures: four in the personal mobility domain, three in the indoor climate control domain, and three in the dietary choice domain. All of which should be considered, incremental and not demanding a larger societal transition.

Currently, the data quality on behavioural change is inadequate, so the results are indicative and should be considered best available estimates. Further, there are more behavioural change measures available but currently unquantifiable. Given these caveats the analysis shows that the measures affecting emissions of nitrogen oxides could contribute with some 12-24% of the required additional emission reductions of nitrogen oxides in 2030. Further, the measures are multipollutant in their nature and will reduce emissions of both the air pollutants in focus of this study as well as greenhouse gases. As an example, if all 10 measures would be implemented emissions of carbon dioxide (biogenic and fossil) could be reduced by approximately 2-4 Mtonne in 2030.

There are, however, several issues that deserves more discussion. First, more data and knowledge are needed in order to enable a fair comparison of these measures with more conventional technical solutions. The extent to which behaviour is undergoing autonomous change needs to be clarified and there is a need for a proper framework to establish socio-economic costs of these measures. Also, given that these measures are aimed at individual or group behaviour, it is unclear what type of policy instruments that would provide an effective realisation of these measures. One important aspect highlighted in the academic literature on behavioural change is the importance of a strong perceived link between the measure and the effect on emissions. Unfortunately, many of the studied measures are currently only having weak links. It is also important to highlight that it is by no means clear that economic instruments will provide effective incentives to change behaviour. All in all, it can be concluded that the best estimate is that there is still in 2030 a potential to substantially reduce air pollution and greenhouse gas emissions in Sweden through behavioural change. Prior to taking action more knowledge and data is needed on environmental behavioural changes and how to implement them cost-efficiently.

Sammanfattning

I december 2016 kom EU:s medlemsländer överens om ett reviderat EU:s utsläppstaksdirektiv. Revideringen innebar att maximalt tillåtna nationella utsläppsnivåer av svaveldioxid, kväveoxider, flyktiga organiska kolväten, ammoniak, och partiklar sattes för år 2030. För Sverige innebär revisionen utsläppsminskningar på 22, 66, 36, 17 och 19 % jämfört med 2005 för de ovan nämnda utsläppen. Huvudsakligen innebär dessa ambitionsnivåer att utökade insatser för utsläppsminskning av kväveoxider kommer krävas. Det reviderade direktivet innefattar också krav på upprättande av ett nationellt luftkvalitetsprogram. I det nuvarande programmet för Sverige förväntas det att huvuddelen av insatserna kommer ske för att minska utsläpp från industrin. Men då ambitionsnivån är hög och tidsramen kort finns det viss risk att vissa av åtgärderna inte kommer leverera önskade utsläppsminskningar i tid till 2030. Det är därför motiverat att undersöka andra möjligheter att minska utsläppen, och i denna rapport presenteras en uppskattning av hur stora utsläppsminskningar som skulle kunna nås genom användande av beteendeförändrande åtgärder.

Analysen gjordes i flera steg. Först genomfördes en litteraturöversikt av den befintliga beteendeförändringslitteraturen. Från denna översikt valdes de åtgärder ut som var rapporterade med god datakvalitet och med gott överensstämmande med svenska förutsättningar. Efter detta steg uppskattades en nationell potential för beteendeförändring i Sverige. Genom en återanvändning av den data som används för att ta fram Sveriges officiella utsläppsprognoser kunde alternativa utsläppsscenarier beräknas för de utvalda åtgärderna. Denna rapport redovisar därigenom potentiell effekt på utsläpp från 10 tillgängliga beteendeförändrande åtgärder: fyra inom domänen 'individuell mobilitet', tre inom 'inomhusklimat', samt tre inom 'kost-val'. Alla dessa är inkrementella och kräver ingen större samhällsomställning.

För närvarande är datakvaliteten relaterat till beteendeförändringar bristfällig, så resultaten är indikativa och bör betraktas som bästa tillgängliga uppskattning. Dessutom finns det fler beteendeförändrande åtgärder som än så länge inte gått att kvantifiera. Givet dessa tillkortakommanden visar analysen att de åtgärder som påverkar utsläpp av kväveoxider skulle kunna bidra med cirka 12–24 % av kravet på utökade insatser till år 2030. Dessutom påverkar åtgärderna flera utsläpp samtidigt och kommer minska utsläpp av både luftföroreningar och växthusgaser. Som ett exempel kan nämnas att om alla 10 åtgärderna skulle implementeras fullt ut skulle utsläppen av koldioxid (både biogen och fossil) kunna minska med ca 2–4 Mton till 2030.

Det finns dock flera aspekter som förtjänar ytterligare diskussion. För det första behövs bättre data och kunskap kring beteendeförändrande åtgärder för att möjliggöra en rättvis jämförelse med konventionella utsläppsminskningar. Graden av autonom beteendeförändring till år 2030 behöver förtydligas, och det finns behov av ett ramverk för hur socio-ekonomiska kostnader av dessa åtgärder skall bedömas. Dessutom, givet att åtgärderna är riktade mot individ- eller gruppbeteenden, så är det oklart vilket av styrmedel som effektivt skulle kunna leda till ett förverkligande av åtgärderna. En aspekt som lyfts i den akademiska litteraturen om beteendeförändringar är vikten av en stark mental koppling mellan åtgärden och utsläppsändringen. Tyvärr är flera av åtgärderna karaktäriserade av svaga länkar, och det är inte självklart att ekonomiska styrmedel kan anses effektiva för dessa åtgärder. Den sammanfattande slutsatsen är att bästa uppskattningen ger vid handen att det fortfarande år 2030 kommer finnas en betydande potential för beteendeförändrande åtgärder för utsläppsminskning av luftföroreningar och växthusgaser. Innan man träder till handling behövs däremot mer kunskap och data kring miljörelaterade beteendeförändringar och hur de skall förverkligas för kostnadseffektiv policy.

Introduction

Although a larger problem in the past, European emissions of air pollutants are still today causing substantial human and environmental health problems. As an example, human exposure to fine atmospherically formed particulate matter with aerodynamic diameter <2.5 µm (PM2.5) was in 2012 attributable to some 380,000 deaths in the European Union (Lelieveld et al. 2015) and to some 4,700 attributable deaths in Sweden 2015 (Gustafsson et al. 2018). Another example is that 17% of Swedish water catchment areas are exposed to acid deposition exceeding critical loads for acidification (Fölster et al. 2014). Improvements are expected, but it has been recognised that more efforts are needed.

In December 2016 the EU agreed upon a revised National Emissions Ceiling (NEC) Directive (No 2016/2284/EU) which sets upper 2020 and 2030 limits for national emissions of PM2.5, sulphur dioxide (SO_2), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOC), as well as ammonia (NH_3). Through the revised NEC Directive and the revised EU climate and energy policies it is expected that attributable deaths from air pollution in 2030 will be 194,000 instead of the 260,000 estimated prior to the revised NEC (Ågren 2016, Amann et al. 2018).

For Sweden, the revised NEC Directive implies that Sweden needs to implement additional measures to reduce emissions of NO_x, and NH_3 (Table 1). The Directive also implies that a Swedish national air pollution control programme needs to be developed and revised. In the latest version of the control programme, emission abatement measures in three action areas aimed at the agricultural industry, large combustion plants, and transport are anticipated to deliver the necessary emission reductions required to meet the NEC Directive requirements for Sweden (Ministry of the Environment 2019).

Table 1: Swedish 2005 emissions of NEC Directive air pollutants (Swedish Environmental Protection Agency 2017) and emission reduction requirements to 2020 and 2030 (European Union 2016), excluding NO_x-emissions from agricultural soils.

	2005 (kilotonne)	NEC emission reduction requirement relative to 2005 (% by 2020)	(% by 2030)
SO_2	36	-22%	-22%
NO_x	172	-36%	-66%
NMVOC	182	-25%	-36%
NH_3	63	-15%	-17%
PM2.5	27	19%	-19%

However, there is a risk that some of the proposed measures will be difficult to implement (i.e. be expensive or subject to other barriers) or will underperform, which motivates analysis of complementary options. Another equally important, but more long-term, rationale for analysing complementary options is the fact that the current approach used when producing policy support analysis is cost-benefit analysis of marginal costs and benefits of different air quality levels. Such an approach, in which the 'optimal' air quality level is one where the marginal costs of reducing emissions is equal to the marginal benefits of reducing emissions, is dependent on which control measures that are included in the models used for the policy support analysis. An incomplete consideration of all the measures available risks rendering incomplete policy support. In a worst-case scenario, it can imply that the acclaimed 'optimal' future emission levels are too high. For these two reasons it is important to analyse other complementary options that can be relevant for Swedish emissions of NEC Directive pollutants.

One group of measures that is rarely analysed, and currently omitted from air pollution policy support analysis, are behavioural changes measures (BCM). BCM have long been suggested and mentioned as potentially potent ways of reducing emissions of both air pollution and greenhouse gases but most recent efforts to consider BCM have been for climate change mitigation (Sternhufvud and Åström 2006, European Commission 2011, Faber 2012, Williamson et al. 2018). However, when highlighted in the climate change policy support, BCM is often unsatisfactorily characterised (Faber 2012) and sometimes introduced only as means to solve the residual needed to reach emission targets (den Elzen et al. 2008, McKinsey & Company 2009, European Commission 2011). It is also often the case that BCM is excluded completely from the analysis (Amann et al. 2008, European Climate Foundation 2010, Amann et al. 2018). This unsatisfactory approach to BCM in policy support analysis is unfortunately natural, given the lack of fundamental knowledge on BCM. BCMs is an active research topic in the academic disciplines related to decision making, and the questions asked in the research are still the fundamental questions: What drives behaviour? What induces behavioural change? Under what circumstances does a behavioural change transforms into a new habit? Which incentives promotes behavioural change? What is the importance of individuals, influencers, groups, and the larger society? In contrast, the questions that needs to be answered for a satisfactory inclusion of BCM in policy support modelling are more practical: What is the future implementation potential of BCM? What are the costs of BCM? What is the effect of BCM on emissions?

The modelling research community, which can be considered a natural interim body between fundamental researchers and policy support modellers, are starting to harmonise approaches and models. As an example, Darnton (2008) presents principles for modelling behavioural change, whilst considering the plethora of different behaviours and desired endpoints. In the climate change research, the bridging of the gap between fundamental and applied research has started since a couple of years, mainly through merging engineering models with consumer choice models. As another example, Bunch et al. (2015) was able to merge the TIMES[1] energy system model with a discrete choice model of consumer behaviour. This enabled analysis of vehicle purchase decisions – considering some behaviour-relevant aspects such as consumer heterogeneity, inconvenience costs, and risk aversion – and consequential effects on the energy system in the state of California, U.S. Further, Giraudet et al. (2012) coupled a detailed household space heating energy use model with an economic computable general equilibrium model allowing consideration of behavioural aspects such as consumer heterogeneity, demand adaptations, rebound effects, intangible costs, and learning-by-doing.

All in all, the situation is that Swedish policy makers need additional information on behavioural change measures available to reduce emissions of air pollutants, policy support models does not yet provide such information, the fundamental research is under development, and the existing efforts to integrate the research-under-development with modelling has yet to extend their modelling to emission calculations and generalise the knowledge and modelling into a format suitable for the current European air pollution policy support modelling.

These remaining challenges are too large to be covered by one single project and report. But to motivate further research and work within this theme it is reasonable to start by estimating the potential effect on emissions if BCMs were to be implemented. In other words, to estimate whether BCMs, if implemented, would contribute to a large or small share of the solution to Swedish air pollution challenges.

[1] https://iea-etsap.org/index.php/etsap-tools/model-generators/times, accessed 2019-09-17

Based on the problem description above, the purpose of this project is to analyse the effect of BCMs aimed at reducing emissions of the Swedish NEC Directive pollutants of highest concern: NO_x and NH_3. The term 'effect' includes the three terms of highest relevance for policy support modelling: current and future implementation potential, effects on emissions, as well as socio-economic costs. Since the focus is on BCM, and the pollutants NO_x, NH_3 and to some extent PM2.5, the corresponding behavioural domains in focus are personal mobility, indoor climate control, and dietary choices. Given the policy-purpose, the project is limited to Swedish 2030 emissions, and takes a production perspective' on emissions, which is the perspective taken in international environmental agreements.

Method

In brief, the analysis in this project was made by identifying relevant measures through a literature inventory and using this information in combination with behavioural domain-specific data on emission drivers to calculate the effects of BCM in Sweden.

Inventory and review of the literature on behavioural change measures

The starting point for the estimation of implementation potential and socio-economic costs was a literature inventory conducted over the last five years within the SCAC[2] research programme. To identify which literature to review, several variations of search queries were used in several different databases for academic literature and other reports, inter alia Google Scholar, Scopus, and Web of Science. The specific search queries involved the terms behaviour change or non-technical measures and greenhouse gas and/or air pollution, sometimes with further extensions. The literature includes both theoretical discussions on behavioural change as well as domain-specific estimates of effects of behavioural change. From the approximately 300 papers and reports resulting from the queries, the sub-set that considered behavioural changes related to personal mobility, indoor climate control, and dietary choices were selected (Appendix 1).

When reading the BCM literature it became clear that there is no consensus on what constitutes a BCM. As has been discussed earlier (Sternhufvud and Åström 2006), the lack of definition obstructs the identification and discussion on BCM potentials, emission effects, and costs. It will also in the long run obstruct the possibility to introduce BCM into policy support modelling. Therefore, here a project-specific definition of BCM was utilised as basis for selecting which measures to consider for further analysis.

In this report, behavioural change measures are considered to have the following characteristics:

1. A BCM can be implemented by small groups or on an individual level of societal organization. A BCM is not – for implementation – dependent on the entire society transforming (transformative measures) or on direct governmental physical steering of behaviour.
    a. Hence, large society-wide macro trends and possibilities such as slow-growth societies, urbanisation, city planning, circular economy, and self-identity transformation are not considered BCMS in this report and are excluded from further analysis.
    b. Also, command-and-control measures, such as reducing the number of parking spaces next to dwelling areas, are excluded since implementation is dependent on third-party decisions.
2. A BCM does not require any financial investment by the group/individual implementing the measure. The only out-of-pocket expenses considered for BCM costs are operational- and maintenance costs occurring on an annual basis.
    a. I.e. a BCM relates to changes in the way an individual use technology, not which technology that is purchased. Hence:

[2] Swedish Clean air and Climate (www.scac.se)

      i. Vehicle shift to electric cars is not a BCM in this report.
      ii. Downsizing from a large to a small car is not BCM in this report since it often involves a large purchase decision (even though annual costs will be lower)
   b. However, modal shift from using car to using train to commute is considered a BCM, as well as telecommuting. The latter since Swedish households are almost fully computerized, software is available, and will be even more so in 2030.
3. Secondary/indirect impact on the individual/group implementing the BCM are considered when calculating overall effects. As an example, a BCM that reduce travel expenses can lead to increased travel demand, which risk cancelling out some of the effect of for example eco-driving. This phenomenon is called rebound effect and is well documented (Swedish Environmental Protection Agency 2006, Broberg 2011).
4. Potential secondary and/or system-wide impact on other agents than the individual implementing the BCM, such as upstream and downstream technology shifts, are considered effects of a BCM if these are driven by demand or supply changes caused directly by the BCM. The guiding principle here is the impact pathway approach (Bickel and Friedrich 2005) in which all direct techno-physical links between societal activity and emissions are considered.
   a. Changes in agricultural practices and NH_3 emissions are considered as effects of the final customer demand changes following a BCM such as a dietary shift.
   b. Production changes in the energy system are considered effects of electricity and heat demand changes following a BCM such as reduced indoor temperature.
5. Tertiary effects, such as indirect rebound effects are not considered an effect of BCM. In other words, the risk of increased emissions due to increased consumption on other commodities enabled by a cost-saving BCM is not considered when estimating effects of the BCM. A clear example of a tertiary effect comes from Dost and Maier (2018). In that study, a large part of the identified rebound effect associated with e-commerce is due to increased energy use in the residential sector, presumably because of "behavior shifts toward other energy-demanding activities in the time formerly spent shopping offline."

Given the characteristics above the BCMs discussed in this report should be considered as incremental BCMs. Alternatively, one can refer to this reports' characterisation of BCMs as changing habits.

Characteristic No 4 deserves some special mentioning. Swedish electricity and agricultural commodities are sold on an international market, which at least have some properties of an idealised market under perfect competition. Further, the policy instruments used to regulate emissions from these are often international (such as the EU CO_2 emissions trading system). It is thus not at all sure that there would be a Swedish supply response caused by a change in Swedish demand for electricity or agricultural commodities. The supply response might happen wherever production is least profitable (or gather least governmental support). Characteristic No 4 should therefore be considered a physically realistic assumption, but also an uncertain economic assumption. The effect of a zero domestic supply response is discussed later in this report.

Identified measures and their potential in Sweden

The literature highlights several relevant BCMs in behavioural domains related to personal mobility, indoor climate control, and dietary choices. Several studies focus on shifting the mode of transportation from car to public transport, from air to rail travel (Aamaas et al. 2013), or from car to bicycle (Buekers et al. 2015, Gössling and Choi 2015). These types of shifts are often denominated modal shifts. Other transport BCMs suggested includes changes in the way travel is conducted, like car or bike sharing (D'Elia et al. 2009, European Environment Agency 2016) or changes in travel distance (Aamaas et al. 2013). Also, energy efficient driving of cars is discussed (Faber 2012, Swedish Road Administration 2014).

The possibility to utilise BCMs to reduce energy use associated with indoor climate control is most often focusing on energy-efficient behaviour such as reducing the time technology is idle (UK Department of Energy and Climate Change 2008, European Environment Agency 2013), temporal shifts in energy use (UK Department of Energy and Climate Change 2008), and reduction in the demand through for example lower indoor temperature (Palmer et al. 2012). A more specific example comes from Kindbom et al. (2018) in which combustion behaviour in boilers and stoves is analysed.

With respect to the dietary choice domain the potential for reduced food waste is discussed where Sutton et al. (2013) presents the feasibility of European consumers reducing food waste by some 50% (corresponding to ~50 kg per capita annually) while others study effects of dietary shifts by replacing meat with other protein sources (Bryngelsson et al. 2013, Åström et al. 2013, Westhoek et al. 2014, Westhoek et al. 2015). While there is quite an abundance examples in the literature, the possibility to generalise the results into Swedish circumstances renders only a few studies directly suitable. The selection criteria for which studies to use as input to this study has been regional proximity to Sweden and possibility to estimate potentials in 2030. In some cases, it has however been necessary with assumptions based on literature with lower generalisability.

Personal mobility

The Swedish Road Administration (2014) summarises a large range of measures to reduce greenhouse gas emissions from the Swedish transport system by 2030 and 2050. Some of these measures are clearly identifiable as BCMs according to the definition in this report: *Car pools*, *E-commerce*, *Travel-free behaviour*, and changes in driving behaviour (*Eco-driving & speed limits*).

According to the estimate in Swedish Road Administration (2014), increased use of car pools could reduce the total distance travelled with light duty vehicles by some 3% compared to baseline estimates for 2030. These 3% corresponds to some 2.7 billion vehicle kilometres in 2030. An anticipated secondary effect of this is a shift to other modes of transport, out of which 2.4 billion person-kilometres is expected to require public transportation with buses, railways, subways, and trams. Although it is unknown how much of these 3% by 2030 that are on top of already established use of car pools in 2014 it is worth noting that a Trivector report (Indebetou and Börefelt 2014) estimate that the largest car pool in Sweden in 2014 induced travel demand savings corresponding to 0,3% (8.9 million vehicle-kilometres) of the 2030 potential estimated by of the Swedish Road Administration (2014). This estimate is based on self-reported survey answers by new customers, so the possibility to generalise these estimates are suboptimal. Another indication comes from a recent travel survey, which indicated that 1% of the respondents who use cars utilise car pools in 2018 (Teknikens Värld 2018). Due to lack of contrasting information, in this report it is assumed that the 2030 3% of total mileage potential estimated by the Swedish Road Administration in 2014 is still applicable for this study.

A shift in consumption travel patterns from physical transport to shopping centres to at-home shopping via internet and pick-up in local postal offices (*E-commerce*) could reduce the projected total distance travelled with light duty vehicles by some 3% in 2030 but without secondary effects on other transport. The possibility to work from home or teleconferencing (*Travel-free behaviour*) is by the Swedish Road Administration (2014) estimated to reduce projected travel with light duty vehicles with some 4% without secondary effects on other transport. Faber (2012) assumes 6-7% through work from home and 6% from teleconferencing, all in all 13% by 2030. When corrected for behavioural barriers these 13% is deflated to 10-11%.

The final BCM identified by the Swedish Road Administration (2014) is the effect on fuel efficiency from energy-efficient driving. Earlier estimates have shown that energy-efficient driving can lead to fuel savings of up to 10-15% provided training and follow-up repetition is catered for (Barkenbus 2010, Swedish Road Administration 2014). A 15% effect by 2030 is assumed in the calculations by the Swedish Road Administration (2014) while Faber (2012) assumes 7% with motivation that newer computerised cars should auto-regulate fuel consumption. Emissions of NO_x and PM2.5 from road transport is regulated per vehicle kilometre, so in principal a fuel efficiency measure should only have effect on CO_2 emissions. However, even before Dieselgate (Jonson et al. 2017) there were observations that both CO_2 and NO_x emissions in real driving were much higher than type-approval values. For diesel engines, fuel consumption and CO_2 emissions were up until the last measurement in 2016 14-42% higher for all tested cars with production year 2006-2016 (Transport & Environment 2018). And NO_x emissions for cars manufactured 2006-2012 had monitored real life driving values that were around a factor 4 higher than type-approval values (Chen and Borken-Kleefeld 2014). Given that the catalytic equipment installed to reduce emissions is expensive for the car manufacturer it is reasonable to hypothesise that the catalytic equipment is calibrated to pass the type approval tests. If this hypothesis is valid, and real-life driving implies higher fuel consumption and CO_2 emissions, it is reasonable to assume that some NO_x emissions will pass the catalytic equipment unabated. With basis in reasoning, in this report it was the hypothesises that fuel-efficient driving will have an effect also on NO_x emissions from diesel cars. Based on Transport & Environment (2018) and Chen and Borken-Kleefeld (2014) it was assumed that fuel efficiency improvements reduces surplus NO_x emissions proportionally to the size of the fuel efficiency improvement. Further, since the new WLTP[3] type approval emission test driving cycle acted into force on the 1st of September 2018 the analysis needed to consider the fact that much of the above-mentioned effect might be nullified in newer cars. Therefore, the calculations of the BCM *Eco-driving & Speed limits* were done for one case assuming that all diesel cars in 2030 would be affected, and for one case assuming only diesel cars older than 12 years would be affected. With an assumed average car life time of 15 years it was assumed that 3/15th of all Euro 6 diesel engines would be subject to this assumed effect.

Indoor climate control

In the indoor climate control domain three measures were identified. One option to reduce household emissions of mainly PM2.5 is to change practice when using fireplaces, wood-stoves, or boilers to provide heat and ambience. Best practice solutions when using these appliances involves ensuring low humidity in fuel and 'from-the-top' ignition during start-up (Swedish environmental Protection Agency 2009). Bodin (2018) evaluates the effectiveness of a 'from-the-top' information

[3] Worldwide Harmonized Light-Duty Vehicles Test Procedure

campaign. Although being a self-evaluation and using leading questions, Bodin (2018) gives a weak indication that such an information campaign changes combustion behaviour of some 50% of the households receiving information. It is however not clear how many of these that already practices good combustion behaviour. Kindbom et al. (2018) present a Nordic study of inter alia behavioural change during use of small-scale wood combustion appliances in 2030. By using best available estimates on current practices gathered by chimney sweepers, Kindbom et al. (2018) estimated that some 10% of users are not using the fuel and appliances optimally. Correspondingly, there is a behavioural change potential to reduce emissions from some 10% of all users. It is expected that these 10% will remain until 2030 if no initiatives are taken. However, the number is uncertain and Kindbom et al. (2018) therefore also calculated effects if 20% of the users acted sub-optimally. Further, the impact on behavioural change is affected by the age structure of the appliances 2030. In this report it is therefore assumed that the potential of behavioural change when using small scale wood combustion appliances applies to some 10-20% of all users. If this potential would be realised by 2030, then emissions of for example PM2.5 would decrease with some 15-40% (Kindbom et al. 2018).

Later sensitivity analyses based on trends from recent wood boiler purchase statistics gives smaller potential for behaviour change due to lower 2030 baseline emission levels. However, these purchase trends have not been noted for smaller stoves, which can be argued to have another main purpose than heating: i.e. 'hygge'. In contrast to wood combustion in boilers, it is reasonable to assume that some of the wood combusted in stoves is for ambiance reasons (in 2005 only 26% of all stoves were tiled heat accumulating stoves or kitchen stoves, indicating that <74% of the stoves should be used primarily for other reasons than cooking and heating). So, some of the emissions should be possible to reduce through some hitherto unknown type of ambiance shift or the like.

The effect of changed combustion behaviour in stoves should be highlighted. The analysis of the BCM *Wood combustion behaviour* is a disaggregation of the analysis made in Kindbom et al. (2018). However, as a speculation it can also be interesting to analyse the effect of a reduction in total fuel combusted in stoves. However, little is known on drivers of wood combustion in stoves, so this report has not been able to quantify any potential. But based on results from Kindbom et al. (2018) scenarios for Swedish emissions from wood combustion in stoves ranges around 1 kilotonne (ktonne) per year for PM2.5 and 0.8-1.7 ktonne per year for NMVOC (range due to assumed age structure of appliances). These emission estimates are based on an assumed wood consumption of 9 Petajoules (2.5 Terawatt hours) in 2030. If the wood consumption in stoves would be lower than expected, it is reasonable to assume that emissions would be reduced proportionally. In this report the effect of a 10% reduction in wood use in stoves is calculated in the BCM *Reduced wood combustion*.

A more classic BCM is a reduction in indoor temperature. Faber (2012) present that a 1° Celsius reduction in indoor temperature could reduce EUs 2030 CO_2 emissions with 19 Mtonne CO_2 while Palmer et al. (2012) presents that a 1° Celsius reduction would result in 10-13% reduction in heating energy demand. No Swedish estimates have been found, the closest estimate is the potential of smart metering of household electricity consumption (also including non-heating purposes) which has been shown to be some 15% (Fjellander et al. 2018). Since Palmer et al. (2012) is more transparent than Faber (2012) the potential indicated in Palmer is used when calculating the effect of the BCM *Reduced indoor temperature*. Further it is assumed that the share of residential electricity consumption used for indoor climate control is the same in 2030 as in 2016, when it was approximately 20% (Swedish Energy Agency 2019a).

Dietary choices

In the dietary choice domain, there are two BCMs that have gotten most attention in the reports: reduced food waste and dietary shifts. The Institution of Mechanical Engineers (2013) estimate that in the western world some 30-50% of the food purchased at supermarkets are thrown away by the final consumer, often due to non-rational reasons. Ventour (2008) report that some 6.7 million tonnes (108 kg/capita) of food was wasted by households in the United Kingdom 2008. Out of these, 61% (66 kg/cap, 20% of all food purchased) could be considered avoidable, and out of the avoidable fraction 44% was thrown away since it was left on the plate after eating or left over from cooking (34% and 10%). In Sweden, the total amount of household food waste was 97 kg per person and year in 2016 but the statistics does not contain information on avoidable vs. unavoidable food waste (Westöö and Jensen 2018). According to recently published survey results, Food & Friends (2019) report that 81% of the respondents use their leftovers, and only 1% of the respondents throw away left-overs, figures that contrast with the survey results from Ventour (2008) and the fact that the amount of Swedish food waste is on par with British estimates. In the Food & Friends survey results, some 35% of the respondents never bring lunch-boxes to work, whilst some 40% brings a lunch-box at least three times per week. Over the years the survey has been made the numbers lie relatively stable but varies between regions. Westhoek et al. (2015) also indicate that some 20% of all food purchased is thrown away although they are edible but does not specify effect of actions towards reduced food waste. In this report, the BCMs *More lunchboxes* and *Only-take-what-you-eat* are analysed, with basis in Ventour (2008).

When it comes to dietary shifts most Swedish assessments have been made with a limited focus on greenhouse gases (Bryngelsson et al. 2013, Åström et al. 2013) but Westhoek et al. (2014, 2015) calculate effects on reactive nitrogen emissions from several alternative diets. By using the concept of nitrogen footprints and the Common Agricultural Policy Regional Impact (CAPRI) model (Britz and Witzke 2014), Westhoek et al. (2015) calculate that agricultural emissions of reactive nitrogen (NH_3, and N_2O) in EU27 could be reduced by up to 40% and 25% respectively if current (2004) meat consumption would be reduced by 50%, a behavioural measure dubbed *Semi-vegetarian diets* in this report. Analysis was done, but not presented, for NO_x and for Sweden.

The measures considered for further analysis

To allow for best possible consideration of Swedish behaviours in 2030, the following BCMs were selected for further analysis:

Table 2: Behaviour change measures in focus for this report, ordered per behavioural domain

Personal mobility domain	Indoor climate control domain	Dietary choice domain
Car pools	*Wood combustion behaviour*	*More lunchboxes*
E-commerce	*Reduced wood combustion*	*Only-take-what-you-eat*
Travel-free behaviour	*Reduced indoor temperature*	*Semi-vegetarian diets*
Fuel-efficient driving & Abiding to speed limits (Eco-driving & Speed limits)		

Estimating 2030 emission reductions of behavioural change measures

Emissions were calculated separately for each BCM and corresponding baseline (*bsl*) scenarios without any BCM implemented. Emissions were calculated according to the following principle:

Equation 1: Generalised form equation for calculating emissions associated with behavioural changes within any domain, based on a simplification of Cofala et al. (2009)

$$Em = Ef * Ad * Af * M * (1 - \mu) * X$$

Where:
Em = Emissions,
Ef = Emission factor [ktonne emission / unit of polluting technology],
Ad = Activity data [units of polluting activity],
Af = Activity factor [unit of polluting technology / polluting activity].

The terms *M*, μ, and *X* represents different aspects of behavioural change. The intensity multiplier *M* represents macro-level changes over time of the main activity *Ad***Af* (personal mobility, indoor climate control, dietary choice). As an example, the space per new-built dwelling is in most EU countries projected to increase whilst the inhabitants per household decreases, both macro-trends that drives up the energy demand for indoor climate control (Capros et al. 2007, 2016). The BCM effect term μ represent the percentage reduction in either *Ef*, *Ad*, or *Af* (dependent on the domain, pollutant, and character of the BCM). As an example, as presented above the experiments on eco-driving shows a reduction in energy demand (*Af*) of 15% on an individual basis, which implies a μ value of 15% for CO_2. This individual effect represented by μ is then modified by the total potential uptake of the BCM, the implementation rate *X*. As is stated above, Faber (2012) assumes that the introduction of computerised cars will limit the BCM-potential of energy-efficient driving so that the total effect is 7%. With an μ at 15%, *X* for eco-driving becomes 47%. However, the literature and data supporting the calculation of emission effects does not contain disaggregated information on *M*, μ, or *X*. Therefore, in practice, the calculations were based on the aggregated joint term: M*(1-μ)*X, which can be abbreviated to *(1-Bp)*, where *Bp* stands for 'behaviour potential'.

When the BCM affects several technologies or an entire system (like the transport and energy system), the calculation of emissions associated with a BCM was done for all directly affected parts of the system. Equation 1 is then extended to Equation 2, here exemplified with the personal mobility domain calculation.

Equation 2: Indexed form of Equation 1

$$Em_{p,s} = \sum_{c,t,f} (Ef_{p,c,t,f} * Ad_{c,t,f} * Af_{c,t,f} * (1 - Bp_{p,c,s,t,f}))$$

Where:

p = pollutant,
s = scenario (baseline or any BCM),
c = vehicle class (light duty vehicle, city bus, long-distance bus, train, subway, tram),
t = vehicle emission technology (Euro-standard for road transport),
f = fuel (liquid or electricity for transport)

Finally, the emission reduction associated with a given BCM is just the result from subtracting total emissions in the BCM scenario from the total emissions in the *baseline* scenario (Equation 3).

Equation 3: Calculating emission reduction from any BCM

$$Em.Ch._{p,BCM} = Em_{p,bsl} - Em_{p,BCM}$$

Emission factors for electricity and heat

Emission factors for electricity and heat were calculated as exemplified for electricity (Equation 4).

Equation 4: Calculating emission factors for electricity

$$Ef_{p,ele} = \frac{\sum_f \left(Ef_{p,f,ele} * FC_{f,ele}\right)}{Prod_{ele}}$$

Where:
FC = Fuel consumption for electricity production
Prod = Production of electricity

This approach to emissions from electricity and heat implies that average emission factors, not marginal production emissions factors, were used when estimating effects of the BCMs.

Data used when calculating emissions

For the transport and indoor climate control domains, most of the *baseline* emission calculations were done based on the activity data and emission factor data used in the current official scenarios for emissions in 2030 (Ortiz 2019, Swedish energy Agency 2019b, Swedish Environmental Protection Agency 2019, Yahya 2019). For small scale wood combustion within the indoor climate control domain, baseline scenario data and calculations were taken from Kindbom et al. (2018), and for the dietary choice domain data was taken from Ventour (2008) and Westhoek et al. (2015). Aggregated *Ef*, *Ad*, and *Af* values from these sources are presented in Appendix 2.

There are unfortunately no robust estimates or data on how behaviour within the respective domains might autonomously change until 2030. Neither are there robust estimates on the maximum social potential of the BCM measures discussed here. As was presented above, much of the potential estimates are based on self-reported estimates of behaviour. But it is well established that we humans tend to misrepresent our actual behaviour when answering surveys. As an example, if only 1% of the Swedish population would throw away edible food (as self-reported estimates indicate), then the maximum implementation rate for the BCMs *More lunchboxes* and *Only-take-what-you-eat* would be 1%, which in turn would imply a very large effect μ of the BCMs for the numbers to add up (given that Swedes on average throw away 97 kg edible food per year). Given these data shortages the final potentials presented in the literature was used as values of *Bp* (behavioural potential) for the emission calculations.

BCM-specific adjustments and assumptions

Given the differences between the domains with respect to data availability, the data of relevance for the indoor climate control and dietary choice domains needed to be adjusted prior to the emission calculations. The following paragraphs presents the necessary adjustments and assumptions that were made prior to emission calculations.

Calculating emissions from BCMs in the indoor climate control domain

To estimate the effect of changing *Wood combustion behaviour* or *Reducing wood combustion* in stoves the results from Kindbom et al. (2018) were used without any recalculations.

To estimate the effect on emissions from *Reduced indoor temperature*, a couple of assumptions were necessary to get values for *Ad*. It was necessary to disaggregate the *baseline* scenario data from Swedish energy Agency (2019b) between households and commercial facilities and between fuel used for indoor climate control and other purposes. This disaggregation was done based on data for 2016 (Swedish Energy Agency 2019a) and an assumption that the relative energy demand in 2030 would be equal to that in 2030. In 2016 households needed 58.7 TWh energy for heating and hot water, whilst commercial facilities needed 21.9 TWh, altogether 80.5 TWh. No data was available to disaggregate between hot water and climate control energy needs. The total energy need for the same year were 146 TWh. In the calculations, the disaggregation was done per fuel type.

Calculating emissions from BCMs in the dietary choice domain

To estimate effect on Swedish emissions from reduced food waste (*More lunchboxes* & *Only-take-what-you-eat*) or dietary shifts (*Semi-vegetarian diets*) it was necessary to complement consumption estimates from Westhoek et al. (2015) with an estimate of how much of the consumption that is and will be produced in Sweden. Commodity-specific trade statistics were used to disaggregate the total consumption between Swedish and foreign origin (Swedish board of agriculture 2019a, b). Only Swedish production was included in the emission calculations.

Uncertainty analysis

Given the large uncertainties in the possible autonomous change in behaviour, and the inherent uncertainties of future scenarios, most emission calculations were done over a range of alternative *baseline* scenarios (values of *Ef*, *Ad*, or *Af*). For the personal mobility domain, the emission calculations were done with *Af* values from the Swedish Road Administration (2014) but with *Ad* values from either Yahya (2019) or the Swedish Road Administration (2014). The car vintages affected is uncertain for all travel demand BCMs. Therefore, in the analysis the calculations are done for two cases. One in which the BCM affect only the newest vehicles (Euro 6 & VI) and one in which the BCM affects the average car fleet. Correspondingly, *Ef*-values were taken for either only Euro 6/VI or for the average vehicle fleet (Yahya 2019) (with corresponding change in *Bp* for the light duty vehicles affected). For the BCM *Travel-free behaviour*, the calculations used two literature estimates of *Bp*: 0.96 and 0.88 (Faber 2012, Swedish Road Administration 2014). For the BCM *Eco-driving & Speed limits*, the calculations were done for the separate cases where the BCM affected all light duty vehicles with diesel engines, or only the light duty vehicles with diesel engines older than 12 years (all Euro 0, 1, 2, 3, 4, 5 and 3/15th of the Euro 6 vehicles). Further, two different values of Bp_{CO2} was analysed: 0,93 and 0,85 (Faber 2012, Swedish Road Administration 2014), with the corresponding values on Bp_{NOx} for diesel cars (0,985 and 0,926).

For the indoor climate control domain, the results varied with respect to the uncertain rate of rejuvenation for boilers and stove, as is already calculated in Kindbom et al. (2018). The BCM *Reduced indoor temperature* varied with respect to three different scenarios for household climate control demand (Swedish energy Agency 2019b) and value of *Bp*: 0,9 and 0,87 (Palmer et al. 2012).

For the dietary choice domain, the calculations varied with respect to assumed shares of Swedish production in the Swedish consumption: values for 2018 from the Swedish board of agriculture (2019a, b) and values for 2030 based on linear extrapolation of the 1996-2018 trend from the same source. 1996 was chosen as starting point since this was the year when Sweden joined the EU and thereby the Common Agricultural Policy. Since the consumption of food commodities varies much over time, with inter alia current distinct trends towards more consumption of chicken, also the *Ad*-values for the food items dairy, beef, poultry, pig, and sheep were varied using the same statistics and approach.

For all BCMs affecting electricity and/or heat consumption, the *Ef*-values for electricity and heat production were varied following the alternative scenarios in the Swedish energy Agency (2019b). For completeness and future reference, the calculations also included effects on emissions of Black Carbon (BC), Organic Carbon (OC), and other PM2.5-subfractions when the data availability allowed for this.

Quantified behaviour potential values of the measures

The values of *Bp* for each BCM was derived from the quantified information in the BCM-literature, the background scenario data, and the most important uncertainties. Table 3 present the *Bp*-values used for the emission calculations within the personal mobility domain and Table 4 the *Bp*-values for the indoor climate and dietary choice domains.

Table 3: Bp-values used in the personal mobility domain emission calculations

Scenario	**Uncertainty case**	***p***	***c***	***t***	***f***	***Bp***
Baseline	All	All	All	All	All	0
Car pools	Central-Euro 6/VII	All	Light duty	Euro 6	Liq.	0.035
				All	Ele.	0
			Buses	Euro VI	Liq.	-0.085
			Rail	All	Ele.	-0.085
	Central-Average	All	Light duty	All	All	0.03
			All other	All	All	-0.085
E-commerce	Central-Euro 6	All	Light duty	Euro 6	Liq.	0.035
				All	Ele.	0
	Central-Average	All	Light duty	All	All	0.03
Travel-free behaviour	Low-Euro 6/VI	All	Light duty	Euro 6	Liq.	0.047
				All	Ele.	0
	Low-Average	All	Light duty	All	All	0.04
	High-Euro 6	All	Light duty	Euro 6	Liq.	0.13
				All	Ele.	0
	High-Average	All	Light duty	All	All	0.11
Eco-driving & Speed limits	Low- >12year	NO_x	Light duty	All	Liq.	0.015
		CO_2	Light duty	All	Liq.	0.07
	High- All vintages	NO_x	Light duty	All	Liq.	0.074
		CO_2	Light duty	All	Liq.	0.15
All transport BCMs	Low-Euro 6/VI- >12year	NO_x	Light duty	Euro 6	Liq.	0.127
				All other	Liq.	0.095
		CO_2	Light duty	Euro 6	Liq.	0.175
				All other	Liq.	0.145
		All non- NO_x, non- CO_2	Light duty	Euro 6	Liq.	0.113
				All other	Liq.	0.081
		All	Light duty	All	Ele.	0
			All other	All	All	-0.085
	High-Average-All vintages	NO_x	Light duty	Euro 6	Liq.	0.224
				All other	Liq.	0.224
		CO_2	Light duty	Euro 6	Liq.	0.288
				All other	Liq.	0.288
		All non- NO_x, non- CO_2	Light duty	All	All	0.163
		All	All other	All	All	-0.085

Table 4: Bp-values for the indoor climate and dietary choice domains

Domain	Scenario	Uncertainty case	*p*	*t*	*Bp*
	Bls	All	All	All	0
Indoor climate control	*Wood combustion behaviour*	Low	CH_4	All	0.07
			NMVOC	All	0.12
			PM2.5	All	0.13
			BC	All	0.01
			OC	All	0.14
		High	CH_4	All	0.19
			NMVOC	All	0.22
			PM2.5	All	0.24
			BC	All	0.03
			OC	All	0.25
	Reduced wood combustion	Central	All	Stoves	0.1
	Reduced indoor temperature	Low	All	All	0.1
		High	All	All	0.13
Food	*More lunchboxes*	Central	All	All	0.1
	Only-take-what-you-eat	Central	All	All	0.34
	Semi-vegetarian diets	Central	All	Cereals	-0.63
				Vegetable	0
				Fruit & Vegetables	0
				Pulses	0
				Potatoes & other starchy roots	0
				Sugar	0
				Dairy	0.63
				Beef	0.61
				Poultry	0.34
				Pig meat	0.5
				Sheep and goat meat	0
				Eggs	0.45
				Fish and other seafood	0
				Others	0

Effects of behavioural change measures on emissions

The results from the emission calculations are presented as ranges, covering all variations in the central analysis and uncertainty cases presented above. The results are summed per pollutant in Table 5, Table 6, and Table 7, and per BCM in Appendix 3.

Some caveats are important to mention prior to reading the results. First, the data available did not allow for quantification of non-exhaust PM2.5 emissions from non-road transport (train, subways, trams), so the effect of *Car pools* (which implies modal shift from cars to trains etc.) on PM2.5 emissions is overstated. Second, the scenario data assumes no electrification of busses, which also implies an overstatement of effects on emissions if one believes in a large transition to electric busses by 2030. Third, the scenario data did not contain any estimates on OC emissions from electricity and heat production, nor effects on NO_x emissions from changes in small-scale wood combustion. Correspondingly, effects on OC was not calculated for *Reduced indoor temperature*, neither was effects on NO_x from *Wood combustion behaviour* and *Reduced wood combustion*. For *Wood combustion behaviour* the effect is unknown and for *Reduced wood combustion* the effect is an understated effect on NO_x. Fourth, the effect on CO_2 emissions from the BCM measures include bio-genic CO_2 emissions, and the net fossil CO_2 effect will depend on the level of biofuel mixing in the transport fuel sector and their implied life-cycle CO_2 emissions. Despite some data-gaps it was decided to present all available results for future reference.

In aggregation, the results show that the BCMs discussed in this report could accommodate some 12-24% of the Swedish NO_x emission reduction requirements by 2030. NH_3 emissions in 2030 could be reduced by approximately <1 ktonne (some <2% of projected national total in 2030), and NMVOC emissions by some 2-5 ktonne (<3% of national total in 2030). Further, SO_2 and PM2.5 emissions could be reduced with levels corresponding to some 1% and 5-15% of national total 2030 emissions respectively. Since the results for the personal mobility domain are calculated with basis in the data used for the most recent official Swedish emission projection, they are comparable with the latest official emission projection whilst accounting for known uncertainties. For the measures related to wood combustion the calculations should be comparable with future official emission projections once the PM2.5 emission factors in these have been updated. For the dietary choice domain the results are indicative for Sweden.

Table 5: Calculated NO_x, MNVOC, NH_3, and SO_2 emission reduction from the implementation of BCMs

BCM	NO_x	NMVOC	NH_3	SO_2	Unit
Car pools	0.12 - 0.16	0.16 - 0.21	0.05 - 0.06	0 – 0	ktonne/year
E-commerce	0.17 - 0.23	0.17 - 0.21	0.05 - 0.06	0 – 0	ktonne/year
Travel-free behaviour	0.23 - 0.83	0.22 - 0.79	0.06 - 0.22	0 - 0.01	ktonne/year
Eco-driving & Speed limits	0.1 - 0.56	0 - 0	0 – 0	0 – 0	ktonne/year
All personal mobility domain	0.7 - 1.62	0.62 - 1.07	0.17 - 0.29	0 – 0	ktonne/year
Wood combustion behaviour	n.e.	0.42 - 1.63	n.e.	n.e.	ktonne/year
Out of which stoves	n.e.	0.15 - 0.48	n.e.	n.e.	ktonne/year
Reduced wood combustion	n.e.	0.08 - 0.19	n.e.	n.e.	ktonne/year
Reduced indoor temperature	0.67 - 0.9	1.29 - 1.78	0.02 - 0.03	0.16 - 0.23	ktonne/year
More lunchboxes	0.04 - 0.05	n.e.	0.14 - 0.22	n.e.	ktonne/year
Only-take-what-you-eat	0.11 - 0.13	n.e.	0.11 - 0.13	n.e.	ktonne/year
Semi-vegetarian diets	0.16 - 0.48	n.e.	0.16 - 0.48	n.e.	ktonne/year
Sum of calculated effects	**1.68 - 3.18**	**2.41 - 4.67**	**0.06 – 1.15**	**0.16 - 0.24**	**ktonne/year**
Sum if excluding hypothetical NO_x effect of eco-driving	1.58 - 2.62				ktonne/year

Table 6: Calculated PM2.5, BC, OC, and other PM2.5 emission reduction from the implementation of BCMs

BCM	PM2.5	BC	OC	Other PM2.5**	Unit
Car pools	-0.21 - 0.08*	n.e.	n.e.	n.e.	ktonne/year
E-commerce	0.08 - 0.1	n.e.	n.e.	n.e.	ktonne/year
Travel-free behaviour	0.11 - 0.35	n.e.	n.e.	n.e.	ktonne/year
Eco-driving & Speed limits	0 – 0	n.e.	n.e.	n.e.	ktonne/year
All personal mobility domain	0.01 - 0.46*	n.e.	n.e.	n.e.	ktonne/year
Wood combustion behaviour	0.3 - 1.19	0 - 0.02	0.11 - 0.45	0.19 - 0.72	ktonne/year
Out of which stoves	0.16 - 0.33	0 - 0	0.08 - 0.16	0.08 - 0.17	ktonne/year
Reduced wood combustion	0.08 - 0.11	0.02 - 0.02	0.02 - 0.04	0.04 - 0.05	ktonne/year
Reduced indoor temperature	0.63 - 0.87	0.06 - 0.09	n.e.	0.57 - 0.79	ktonne/year
More lunchboxes	n.e.	n.e.	n.e.	n.e.	ktonne/year
Only-take-what-you-eat	n.e.	n.e.	n.e.	n.e.	ktonne/year
Semi-vegetarian diets	n.e.	n.e.	n.e.	n.e.	ktonne/year
Sum of calculated effects	**1.02 - 2.63**	**0.08 - 0.13**	**0.13 - 0.49**	**0.8 - 1.56**	**ktonne/year**

*Not considering non-exhaust PM2.5 emissions from rail transport
** Non-carbonaceous PM2.5-fractions

Table 7: Calculated CO_2, CH_4, and N_2O emission reduction as well as reduced N-leaching from the implementation of BCMs

BCM	CO_2*	CH_4	N_2O	N-leaching	Unit
Car pools	175 - 234	n.e.	n.e.	n.e.	ktonne/year
E-commerce	251 - 316	n.e.	n.e.	n.e.	ktonne/year
Travel-free behaviour	335 – 1 160	n.e.	n.e.	n.e.	ktonne/year
Eco-driving & Speed limits	583 – 1 485	n.e.	n.e.	n.e.	ktonne/year
All personal mobility domain	1 361 – 2 750	n.e.	n.e.	n.e.	ktonne/year
Wood combustion behaviour	n.e.	0.09 - 0.38	n.e.	n.e.	ktonne/year
Out of which stoves	n.e.	0.05 - 0.21	n.e.	n.e.	ktonne/year
Reduced wood combustion	n.e.	0.08 - 0.11	n.e.	n.e.	ktonne/year
Reduced indoor temperature	859 – 1 163	1.09 - 1.51	n.e.	n.e.	ktonne/year
More lunchboxes	n.e.	n.e.	0.07 - 0.11	0.08 - 0.09	ktonne/year
Only-take-what-you-eat	n.e.	n.e.	0.11 - 0.13	0.77 - 1.18	ktonne/year
Semi-vegetarian diets	n.e.	n.e.	0.16 - 0.48	7.75 - 14.17	ktonne/year
Sum of calculated effects	**2 220 – 3 913**	**1.26 - 2**	**0.34 - 0.72**	**8.6 - 15.44**	**ktonne/year**

*Including biogenic CO_2 emissions

Discussion and conclusions

The results in this report indicate that a successful implementation of 10 selected BCMs could contribute significantly to the achievement of Swedish NO_x emission ambition levels in 2030, with most of the opportunity belonging to measures in the personal mobility domain. There are also co-benefits with the other pollutants regulated in the EU National Emission Ceilings Directive and the Gothenburg protocol of the Air Convention[4] . The only BCM at risk of implying trade-off between pollutants is *Car pools*, which might lead to some increase in PM2.5 emissions.

There are however gaps in the analysis, both with respect to the limited number of measures studied, and with respect to the data available to support the analysis. Correspondingly, the presented quantitative results can only be considered as indicative. Furthermore, with respect to the original project plan there are gaps in the results with respect to implementation costs of the measures. Despite an extensive literature collection, it has not been possible to get any raw data or other input suitable for further analysis of the costs of these 10 behavioural change measures.

This chapter starts with presenting some of the domain-specific issues of concern (including a discussion on omitted measures), which is followed by more general discussions on the lack of data and background scenarios, how to estimate the costs for society of BCMs, and how BCMs can be implemented via policy instruments. The discussion ends with proposing next steps for future analysis and present some balanced conclusions.

Domain-specific concerns

Personal mobility domain

In this report it is estimated that BCM can contribute substantially to reducing emissions of air pollutants from the transport sector. There are some major caveats that needs to be considered though. First, it has not been possible to estimate the extent to which the BCMs will be implemented already in the newer versions of the baseline scenario. An aggravating observation is that in the BCM source material (Swedish Road Administration 2014) the estimated 2030 baseline transport demand for light duty vehicles was some 89 Gigavehicle-kilometers (Gvehkm), whilst in the newer estimates (Yahya 2019), baseline transport demand for light duty vehicles is estimated to be 75 Gvehkm. Due to the way in which these transport demand estimations are produced it is not possible to allocate how much of the difference (15 Gvehkm) that is due to assumed implementation of BCMs in the newer estimates. However, since the data from Yahya (2019) is used in the latest official Swedish emission projections, the results for the personal mobility domain are directly comparable.

Indoor climate control domain

The *baseline* scenario is also in the indoor climate control domain important for the effect of the BCMs studied. Recent statistics shows that the number of installed wood boilers is declining, which contrasts with the assumed future increase in wood boiler use in the estimates delivered by the Swedish Energy Agency. In a short PM submitted from IVL to the Swedish Environmental

[4] Official name: Convention on Long-Range Transboundary Air Pollution

Protection Agency, an assumed linear continuation of this observed trend would decrease estimated 2 035 emissions of benzopyrene (BaP) from biofuel combustion in households from 1.2 tonne to 0.8 tonne, a 34% decrease (Gustafsson 2019). If the current trend of decreasing number of installed wood boilers would continue it is reasonable to assume similar differences for the pollutants discussed in this report. This would in turn imply smaller effect of the BCMs in the indoor climate control domain. The results for the BCM *Reduced indoor temperature* is compatible with current official national emission projections. And given the expected update of emission factors in coming official Swedish emission projections, the results for *Wood combustion behaviour* and *Reduced wood combustion* should be compatible with future national emission projections.

Dietary choice domain

In contrast to the approach in the other domains, the BCM-calculations in the dietary choice domain are using *Ef*-values based on EU-average values for the year 2004, and *Ad*-values based on the Swedish situation in 2004 (Westhoek et al. 2015). This is obviously a shortcoming of the analysis, but as of today no Swedish corresponding numbers are available. EU-average *Ad* and *Ef*-values can also be estimated as reasonable approximations of the Swedish situation, given that little substantial efforts to reduce nitrogen emissions from agriculture are foreseen. There is however an ongoing research project at Chalmers University of Technology financed by FORMAS[5] (Food Nitrogen Footprints in Sweden, registration number 2017-01118), which when finalised should enable a future replacement of EU-average *Ef*-values when calculating effects of dietary choice domain BCMs.

It is also important to stress the difference in the nature of the *Ef*-values used in the dietary choice domain from the *Ef*-values used in the other domains. Whilst, energy- and transport-related *Ef*-values are easily estimated by measurements in tail pipes and chimneys, emissions from food consumption requires a footprint approach, which in principal implies a (more or less) advanced system approach and allocation of emissions between different food items. The choice of footprint approach, and thereby of system boundaries and allocation principles used, does influence the corresponding *Ef*-values, and with that comes an implicit subjective dimension when using *Ef*-values within the dietary choice domain (Einarsson and Cederberg 2019).

The 2030 *Ad*-values where for some of the analysis derived by adjusting the 2004 values with trendlines of food consumption. These extended trendlines then implies that meat consumption per capita would increase slightly between 2004 and 2030 in some of the *baseline* scenarios. But there are indications that the past trend is changing. For the two most recent years, meat consumption is decreasing, and a recent report from Martin&Servera (2019) present that many restaurants are currently increasing their number of vegetarian options on their menus.

In contrast to the summed effect of BCMs in the personal mobility domain, the sum of BCMs in the dietary choice domain are assumed to be simply additive. This could be problematic since the type of food wasted is affect by the type of food eaten. However, the estimates of food types wasted gives at hand that ~90% of the 'avoidable food waste' is other food items than dairy and meat (Ventour 2008), so an additive approach does not lead to large errors in the results. Due to the use of EU-average data and assumptions, the effects on emissions of the dietary choice domain BCMs are not directly compatible with the official national emission projections. However, there are no identified reasons to assume large discrepancies from official projections.

[5] The Swedish Research Council for Sustainable Development

Without system-wide effects

The calculations presented here have assumed that demand changes for electricity, heat, and food will imply domestic production changes corresponding the average production mix envisaged for 2030. However, these indirect effects are due to the economic market functionality in no way certain. It is feasible that the actual electricity and heat production affected will be the most polluting, implying larger emission effects than calculated here. But it is also feasible that the production response will occur outside Swedish boarders, reducing the effect on Swedish heat, electricity, and food production to zero. In this project it has not been possible to estimate effects if the most polluting sources would reduce production, but the net-effect of a 'zero-domestic' production impact is that NO_x emissions would be reduced by 1-2 ktonne (compared to 1.7-3.2 in the main analysis), and that NH_3 emissions would be reduced with <0.3 ktonne (compared to 0.6-1-2). The other emissions would not be affected as much.

Omitted measures

The calculations presented in this report are only made for a limited number of BCMs. There are however several other measures that could be considered as BCMs according to the criteria of this report. For the personal mobility domain, there is the opportunity for modal shifts from cars to bicycles or walking. Such shifts are often brought forward as important measures with beneficial socio-economic effects (Buekers et al. 2015, Gössling and Choi 2015), but the available estimates are too aggregated for them to be included in this report. Other BCMs omitted from the calculations are ride sharing and eco-driving in trucks and buses. For the indoor climate control domain, the main measure omitted is demand side management (changing when apparatus such as washing machines are used). For the dietary choice domain, there are various degrees of vegetarianism that could be included as measures, as well as healthy food consumption choices. Common for all domains is the omittance of 'status quo' behaviour: i.e. avoiding autonomous behavioural shifts. Examples could be: keeping indoor temperatures constant, keeping living areas constant, freezing food choice behaviour to current or past mixes. Common for all these omitted measures is the lack of literature estimates of their impact on the activities driving emissions. Another group of commonly mentioned options relates to advancing the technology purchase behaviour of individuals and corporations. There is literature in the climate research for several such measures, and these show substantial effects of such measures on greenhouse gas emissions (Faber 2012, Williamson et al. 2018). But since most of these are considered 'technical measures' in the air pollution modelling context it has not been considered suitable to quantify these in this report.

Transformative changes

The criteria for BCMs used in this report disqualifies another large group of behavioural change option discussed in the literature, a group that can be dubbed transformative changes. These types of options are often mentioned and presented as a large change in the entire social system and our ways of life. In the literature one can note differences in perspectives on transformation, which might be differentiated through the amount of change strived for. Geels et al. (2014) discuss the differences in perspectives on sustainable consumption research and practice and differentiates between reformist approaches (promoting eco-innovations etc.), revolutionary approaches (with emphasis on critique against capitalism, materialism, economic growth, consumerism and the like) whilst advocating a third approach: transition approach. This latter one is distinctive from the other two foremost through the focus on 'multi-level perspective' and systems perspective.

Most focus have been on implementing transformative changes to reduce climate change. Webb (2013) argues that policies aimed at individuals never will achieve enough transformative drive to enable a transition to a low-carbon society in time. Rather, policies should be aimed at societal change by treating society as a social system and addressing values and norms in society. A similar line of thought can be seen in Eyre et al. (2018) who discuss the necessity of a transforming four interacting categories of the electricity system (physical infrastructure, consumers, energy business models, institutions and governance) in order to rapidly transform the electricity system to contribute to reaching the 1.5-degree Paris target. In Eyre et al. (2018), behavioural change is a piece of the puzzle in a lager societal transformation. Some other examples of transformative behavioural changes are the discussions around and proposals for a societal development with low or zero economic growth (Meadows et al. 2004, Jackson 2009, Malmaeus 2011, OECD 2011), or 'low-energy lifestyles' (albeit with a flavour of low economic growth as well) (Statens Offentliga Utredningar 2005, The Worldwatch Institute 2010).

Given the calculated climate benefits of such transformative changes it is reasonable to assume co-benefits with air pollution, but no quantifications on national scales have been done yet. And given that this report adheres to an EU Directive that acts within the current paradigm of economic growth, as well as market and social liberalism, such a quantification has not been prioritised in this report.

The challenge of estimating future potential with insufficient data

One purpose of the project was to also calculate estimates of the implementation potential for future behavioural change. However, due to lack of both statistics and theory this has not been feasible within the frame of this project. As has been noted the aggregated term behavioural potential (Bp) has been used to estimate the emission effect of the BCMs. But for both policy and modelling purposes it would be necessary to have a separate grasp of unit effect per measure (μ) and implementation potential (X). From a physical perspective such data would be constituted of current knowledge and projections on for example: Number of miles currently driven in car pools, number of current hours with work-from-home and telecommuting, the amount of wood use and combustion behaviour, indoor temperatures etc. Here a larger data collection exercise and theory development is needed.

But for BCMs the term implementation potential also has a social dimension, which is rarely considered when discussing measures to reduce air pollution emissions. Ajzen (1991) in his theory of planned behaviour presents a theory of human behaviour that has a good explanatory capacity of at least some types of behaviour. In order to predict behaviour (and thereby behavioural change) Ajzen stress the need for assessing attitudes towards the behaviour, the social norms surrounding the behaviour, perceived behavioural control, as well as correctness of the self-assessed 'perceived behavioural control'.

Costs for society?

The costs of the 10 BCMs has not been possible to estimate within this project, partly due to lack of cost estimates in the source material, and partly due to lack of knowledge about the non-tangible welfare effects of the measures. Granted, some of the relevant cost items are relatively easy to estimate. As examples, Ventour (2008) estimate that the market value of British food waste corresponds to an annual £10.2 billion per year, Åström et al. (2013) indicate that vegetarian diets has costs (estimated based on retail store prices) of -3 to -7 SEK/kg CO_{2eq} avoided (i.e. a benefit for the consumer wallet). Further, fuel cost savings from fuel efficiency improvements can be relatively easy calculated and the Swedish Road Administration (2016) presents that a transport energy efficiency measure has a cost of -1.4 – 1.2 SEK/kg CO_{2eq} avoided when implemented through increased driving costs.

But in contrast to technical measures, BCMs can have a substantial part of their socioeconomic cost belonging to non-tangible cost items as introduced above. As a principle, Verhallen and Pieters (1984) express that behavioural costs (price) is determined by the time, psychic effort, and physical effort required to perform the behaviour. Expressed in relation to the 10 BCMs studied in this report, these cost items can for example relate to time spent travelling, experienced comfort and convenience of travelling, experienced comfort of a certain indoor temperature, experienced pleasure of lighting a fire etc. As a personal example from testing the measure *Wood combustion behaviour* I can state that it takes longer time for the cosy fire to establish itself: but what is the value of waiting for a cosy fire to get established? On the other end there is also a possibility for intangible benefit items, such as improved health from more exercise associated with some modal shifts.

Promisingly, there are examples valuations of these intangible costs. Gössling and Choi (2015) quantify the net socio-economic costs of bicycling in Copenhagen to 0.08 €/km and of car driving to 0.5 €/km. Bunch et al. (2015) utilise inconvenience costs when modelling market penetration of electric vehicles and Wardman (2014) presents the rule-of-thumb values for transport-related inconvenience used in different countries. Further, the Swedish Road Administration (2015a, b) present different values of time, contingent on what the time is spent on (driving, waiting, etc.) and what the context is (mode of transport, and mode of surrounding). In other words, there are examples of separate cost items that could serve as a starting point for further analysis of BCM costs, but more research efforts would be needed. However, there is still no established thinking on which cost items that should be included when estimating costs of BCMs.

Finally, when estimating cost it is important to acknowledge the risk of rebound effects. The European Environment Agency (2013), Swedish Environmental Protection Agency (2006), Broberg (2011), and Haas and Biermayr (2000) all present substantial rebound effects related to indoor climate control. And as examples from the transport sector, Coroamă and Mattern (2019) and Dost and Maier (2018) identify rebound effects related to digitalisation (including e-commerce). However – although the rebound effect must be considered – since it is driven by changes in relative prices/income it is reasonable to assume that the size of the effect is dependent on the instrument chosen to implement the BCM.

Which instruments will be effective when implementing these measures?

The policy instruments suitable for realisation of the measures discussed in this report deserves a special discussion. The literature pertaining to how to change behaviour is now vast but with little apparent consensus, at least as identifiable within the framework of this project. Different models of behaviour are advocated by different researchers and disciplines, and it appears as the models are suitable for different types of behavioural changes. So, this chapter makes no aspiration to be complete in its discussion of how to implement the studied BCMs. Williamson et al. (2018) presents several different mental models for explaining behaviour and behavioural change: education models, extrinsic motivation models, intrinsic motivation models, information-processing models, and social models. Further, Axsen and Kurani (2012) with a focus on diffusion of new technology present a diffusion of innovation model, social network analysis, and social norm theory as helpful to explain behavioural change. All with requiring the recognition that behavioural models of new-technology consumption must account for a dynamic development of how the consumer might perceive a commodity with respect to its functional, symbolic, private, and social attributes. Common for most examples is that there are clear individual as well as social dynamics of behavioural change and that one most account for intentional and unintentional behaviour (Faber 2012). The difference between intentional and unintentional behaviour can be problematic, at least for behavioural change within the personal mobility domain. Avineri (2012) argues that behavioural change principles based on behavioural economics might have unintended effects on transport emissions since 'nudging' (Thaler et al. 2012) is primarily directed towards the 'automatic' decision making system, whilst transport emissions are also the consequence of a 'reflective' decision making system. Nudging might be better used to speed up the behaviour change induced by other policy instruments.

With respect to the BCMs presented in this report it is yet unclear which behavioural model that best fits the bill for policy needs, but some general aspects still can be highlighted. Most of the behaviours that would be changed are non-market in their nature. In other words, these are not behaviours involving any direct purchase behaviour/economic transactions. The economic transactions related to these behaviours occur before or after the behaviour that is intended to change. The economic transaction related to emissions from the transport sector origins from the purchase of a vehicle and the purchase of fuel, none of which occur at the same time as the travel-free behaviour or fuel-efficient driving. The fuel-efficient driver of a car is not directly financially rewarded for saving fuel, neither is the dweller that reduce indoor temperatures, or the food consumer that decreases food waste. Psychological research has shown how the tempus of payment can lead to differences in emotional response to the use of the purchase. The concept of mental accounting is proposed by Prelec and Loewenstein (1998) and implies that consumer choices are affected by decision phenomena such as prospective accounting, debt aversion, and uncertainty aversion. Prospective accounting implies that already payed for items feels as if they are for free when used, debt aversion implies that we prefer to pay before using, and uncertainty aversion implies that we prefer fixed rates to pay-as-you-go. As some support of the importance of non-economic instruments, Eker et al. (2019) present that the main drivers of modelled dietary choice changes are social norm effects and feelings of self-efficacy.

However, the use of car pools would be qualitatively different from the other measures since it does involve a shift in timing of economic transactions. Having used car pool services, myself I know the 'up-front' cost is made salient when ordering a car pool car online, in contrast to the monthly payment of a car loan or monthly payment of gasoline through credit card bills. Currently a car-pool user can feel the cost of using a car to a much higher degree than the owner of a car. Considering the possibility that individuals engage in prospective accounting I theorise that a car and fuel is a good example of already purchased items, and at least from my part I rarely consider the wear-and-tear cost of each mile when I take my own car out for a drive, apparently a common bias (Laine et al. 2018). But I did when I used a car pool car.

Following the discussion above it can be argued that these behavioural change measures need to be implemented through other than economic instruments or via economic instruments that ensures that the financial costs of the behaviour that is to be changed becomes directly coupled to the behaviour. And with respect to most of the BCMs in the indoor climate control and dietary choice domains it needs to be recognised that these are non-economic habits and that the introduction of money into the minds of people might change their motivation for changing behaviour. Past research has shown that making people aware of money, or making them expect monetary rewards, might shift their motivation for behaving the way they do, with sometimes unwanted outcomes (Gneezy and Rustichini 2000, Vohs et al. 2006, Rohrer et al. 2015, Vohs 2015).

Another important aspect, which varies over the measures, is the perceived behavioural control over the emission effect of the measure. Ajzen (1991), when presenting his theory of planned behaviour, stress the importance of perceived behavioural control for a behaviour to establish itself. But the BCMs affecting electricity and agriculture are subject to low "perceived behavioural control" over emissions, and should thus, given the current weak links between domestic consumption and domestic production, be more difficult to realise. If the approach proposed by Ajzen is valid for the BCMs in this report, it proposes that *Wood combustion behaviour* (which has clear visual effects on the amount of smoke from the chimney) and the personal mobility domain measures should be easiest to implement.

How to become effective…

A cautionary tale that needs to be mentioned here in the discussion is the fact in order to be effective, it is reasonable to assume that an instrument needs to consider the heterogeneity among individuals and social groups. This would require even more data gathering than discussed above. And one group of applied researchers and practitioners that were very effective in promoting behavioural change was Cambridge Analytica, the firm that allegedly helped swing the British Brexit referendum in 2016. In fact, in their sales material to prospective customers, Cambridge Analytica presented their business idea as "Behavioural psychology + Big Data + Targeted Engagement = Behavioural change" (Amer and Moujaim 2019). It is important that the strive for BCM instrument effectiveness does not repeat the approach used in the United Kingdom 2016.

Quick implementation

To end the discussion on a more positive note it is noteworthy that behavioural change measures, at least in the domain of personal health, can give rapid effects. In other words, the value of X should be possible to undergo a quick transition. Charness and Gneezy (2009) presents that a monetary intervention was able to increase exercise routines already after some five weeks, with corresponding impact on weight, waist size etc. If lessons learned from the personal health domain can be extended to more environmentally related domains, it would imply that BCMs could be considered a quick response if the conventional solutions underperform. Whether this five-week intervention is enough for a new habit to form is however subject to current research in for example the Behavioural Change for Good Initiative.[6]

Next steps

As has been stressed in this report many times, this area of study needs improvement in several areas. First, there is a need for an expanded inventory of available BCMs, including consideration to which degree they can be combined. Second, better data and theory is needed to enable estimates of the measure unit effect (μ) and implementation potential (X) in a baseline and maximum scenario on a national level (including data on social acceptability: i.e. attitudes, norms, and perceived control related to the measures). Third, more research to clarify which cost items that should be included when calculating BCM costs is to the extent of my knowledge desirable.

[6] https://bcfg.wharton.upenn.edu/, accessed 2019-08-21

And finally, efforts should be made to link lessons learned from the existing behavioural change research with the BCMs of relevance for air pollution control.

Balanced conclusions for policy makers

Based on the results and the discussion above, the following conclusions for policy makers are proposed:

- The best available quantitative estimate of emission effects from 10 behavioural change measures indicates that Swedish 2030 emissions of NO_x can be reduced with approximately1.3-3 ktonne, which corresponds to some 12-24% of the Swedish 2030 NEC Directive emission reduction requirements.
- Emissions of NMVOC, NH_3, SO_2, PM2.5, CO_2, and CH_4 could also be reduced by the 10 measures, most notably NMVOC, NH_3, PM2.5 and CO_2 for which the indicative calculations show emission reductions of up to 5, 1, 3 and 4000 ktonne respectively.
- The data supporting the calculations is currently inadequate. For most measures it has not been possible to estimate the 2030 implementation potential since there is little or no statistics on current trends and/or no models to predict future projections of autonomous behavioural changes. Further, it has not been possible to present a sufficiently complete estimate of the socio-economic costs of implementing these measures, partly due to constraints in the project resources. But also, partly since the measures would be associated with non-tangible effects on welfare such as loss of convenience, for which there is no coherent method or socio-economic data available.
- Since the measures are mostly aimed at non-market behaviour it can be questioned whether economic instruments are suitable as means to achieve the emission reduction potentials. Other means of affecting behaviour, such as education, nudging, information, or even advertisements, should also be considered equally seriously for implementation of policies aimed at these BCMs.
- Since some measures have positive environmental effects mainly due to indirect system effects, and Ajzen (1991) and others argues for the importance of direct feedback to get behavioural change to stick, it can be argued that the measure *Wood combustion behaviour* and to some extent measures in the personal mobility domain should be easiest to implement out of the 10 measures studied.

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Appendix 1: Literature identified in the literature overview

Table A 1: Literature identified as relevant for the project

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Black, A policy agenda for changing our relationship with consumption	2017
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Cerasoli et al., Performance, incentives, and needs for autonomy, competence, and relatedness: a meta-analysis	2016
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Manski, Economic Analysis Of Social Interactions	2000
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Appendix 2: Ef, Ad, and Af values used in the calculations

Personal mobility domain

Table A 2: Emission factors for liquid fuel vehicles

TRP system	Energy system	p	c	t	f	Ef (ktonne/Gveh-km)
All	All	CO2(total)	Light duty vehicles	Euro 0	liq	231.961
All	All	CO2(total)	Long-distance bus	Euro 0	liq	671.398
All	All	CO2(total)	City Bus	Euro 0	liq	924.335
All	All	CO2(total)	Light duty vehicles	Euro 1	liq	223.51
All	All	CO2(total)	Long-distance bus	Euro I	liq	573.316
All	All	CO2(total)	City Bus	Euro I	liq	1230.978
All	All	CO2(total)	Light duty vehicles	Euro 2	liq	215.173
All	All	CO2(total)	Long-distance bus	Euro II	liq	677.167
All	All	CO2(total)	City Bus	Euro II	liq	715.483
All	All	CO2(total)	Light duty vehicles	Euro 3	liq	205.454
All	All	CO2(total)	Long-distance bus	Euro III	liq	704.333
All	All	CO2(total)	City Bus	Euro III	liq	851.264
All	All	CO2(total)	Light duty vehicles	Euro 4	liq	227.468
All	All	CO2(total)	Long-distance bus	Euro IV	liq	650.77
All	All	CO2(total)	City Bus	Euro IV	liq	439.561
All	All	CO2(total)	Light duty vehicles	Euro 5	liq	154.49
All	All	CO2(total)	Long-distance bus	Euro V	liq	693.776
All	All	CO2(total)	City Bus	Euro V	liq	1032.17
All	All	CO2(total)	Light duty vehicles	Euro 6	liq	118.687
All	All	CO2(total)	Long-distance bus	Euro VI	liq	693.377
All	All	CO2(total)	City Bus	Euro VI	liq	1023.455
All	All	NH3	Light duty vehicles	Euro 0	liq	0.047
All	All	NH3	Long-distance bus	Euro 0	liq	0.003
All	All	NH3	City Bus	Euro 0	liq	0.003
All	All	NH3	Light duty vehicles	Euro 1	liq	0.102
All	All	NH3	Long-distance bus	Euro I	liq	0.003
All	All	NH3	City Bus	Euro I	liq	0.003
All	All	NH3	Light duty vehicles	Euro 2	liq	0.12
All	All	NH3	Long-distance bus	Euro II	liq	0.003
All	All	NH3	City Bus	Euro II	liq	0.003
All	All	NH3	Light duty vehicles	Euro 3	liq	0.039
All	All	NH3	Long-distance bus	Euro III	liq	0.003
All	All	NH3	City Bus	Euro III	liq	0.003
All	All	NH3	Light duty vehicles	Euro 4	liq	0.019
All	All	NH3	Long-distance bus	Euro IV	liq	0.003

TRP system	Energy system	p	c	t	f	Ef (ktonne/Gveh-km)
All	All	NH3	City Bus	Euro IV	liq	0.003
All	All	NH3	Light duty vehicles	Euro 5	liq	0.019
All	All	NH3	Long-distance bus	Euro V	liq	0.003
All	All	NH3	City Bus	Euro V	liq	0.003
All	All	NH3	Light duty vehicles	Euro 6	liq	0.022
All	All	NH3	Long-distance bus	Euro VI	liq	0.003
All	All	NH3	City Bus	Euro VI	liq	0.003
All	All	NMHC	Light duty vehicles	Euro 0	liq	1.537
All	All	NMHC	Long-distance bus	Euro 0	liq	0.639
All	All	NMHC	City Bus	Euro 0	liq	2.794
All	All	NMHC	Light duty vehicles	Euro 1	liq	0.488
All	All	NMHC	Long-distance bus	Euro I	liq	0.423
All	All	NMHC	City Bus	Euro I	liq	0.759
All	All	NMHC	Light duty vehicles	Euro 2	liq	0.341
All	All	NMHC	Long-distance bus	Euro II	liq	0.326
All	All	NMHC	City Bus	Euro II	liq	0.378
All	All	NMHC	Light duty vehicles	Euro 3	liq	0.18
All	All	NMHC	Long-distance bus	Euro III	liq	0.32
All	All	NMHC	City Bus	Euro III	liq	0.296
All	All	NMHC	Light duty vehicles	Euro 4	liq	0.08
All	All	NMHC	Long-distance bus	Euro IV	liq	0.032
All	All	NMHC	City Bus	Euro IV	liq	0.016
All	All	NMHC	Light duty vehicles	Euro 5	liq	0.075
All	All	NMHC	Long-distance bus	Euro V	liq	0.033
All	All	NMHC	City Bus	Euro V	liq	0.026
All	All	NMHC	Light duty vehicles	Euro 6	liq	0.08
All	All	NMHC	Long-distance bus	Euro VI	liq	0.03
All	All	NMHC	City Bus	Euro VI	liq	0.035
All	All	NOx	Light duty vehicles	Euro 0	liq	1.303
All	All	NOx	Long-distance bus	Euro 0	liq	7.764
All	All	NOx	City Bus	Euro 0	liq	10.208
All	All	NOx	Light duty vehicles	Euro 1	liq	0.757
All	All	NOx	Long-distance bus	Euro I	liq	5.856
All	All	NOx	City Bus	Euro I	liq	12.407
All	All	NOx	Light duty vehicles	Euro 2	liq	0.352
All	All	NOx	Long-distance bus	Euro II	liq	7.766
All	All	NOx	City Bus	Euro II	liq	8.107
All	All	NOx	Light duty vehicles	Euro 3	liq	0.141
All	All	NOx	Long-distance bus	Euro III	liq	6.173
All	All	NOx	City Bus	Euro III	liq	8.136
All	All	NOx	Light duty vehicles	Euro 4	liq	0.141
All	All	NOx	Long-distance bus	Euro IV	liq	4.067
All	All	NOx	City Bus	Euro IV	liq	5.406

TRP system	Energy system	p	c	t	f	Ef (ktonne/Gveh-km)
All	All	NOx	Light duty vehicles	Euro 5	liq	0.415
All	All	NOx	Long-distance bus	Euro V	liq	3.066
All	All	NOx	City Bus	Euro V	liq	4.151
All	All	NOx	Light duty vehicles	Euro 6	liq	0.077
All	All	NOx	Long-distance bus	Euro VI	liq	0.272
All	All	NOx	City Bus	Euro VI	liq	0.981
All	All	PM	Light duty vehicles	Euro 0	liq	0.007
All	All	PM	Long-distance bus	Euro 0	liq	0.345
All	All	PM	City Bus	Euro 0	liq	0.824
All	All	PM	Light duty vehicles	Euro 1	liq	0.006
All	All	PM	Long-distance bus	Euro I	liq	0.219
All	All	PM	City Bus	Euro I	liq	0.504
All	All	PM	Light duty vehicles	Euro 2	liq	0.007
All	All	PM	Long-distance bus	Euro II	liq	0.143
All	All	PM	City Bus	Euro II	liq	0.148
All	All	PM	Light duty vehicles	Euro 3	liq	0.007
All	All	PM	Long-distance bus	Euro III	liq	0.139
All	All	PM	City Bus	Euro III	liq	0.168
All	All	PM	Light duty vehicles	Euro 4	liq	0.003
All	All	PM	Long-distance bus	Euro IV	liq	0.034
All	All	PM	City Bus	Euro IV	liq	0.039
All	All	PM	Light duty vehicles	Euro 5	liq	0.002
All	All	PM	Long-distance bus	Euro V	liq	0.041
All	All	PM	City Bus	Euro V	liq	0.026
All	All	PM	Light duty vehicles	Euro 6	liq	0.002
All	All	PM	Long-distance bus	Euro VI	liq	0.004
All	All	PM	City Bus	Euro VI	liq	0.007
All	All	PM (non-exhaust)	Light duty vehicles	Euro 0	liq	0.035
All	All	PM (non-exhaust)	Long-distance bus	Euro 0	liq	0.115
All	All	PM (non-exhaust)	City Bus	Euro 0	liq	0.193
All	All	PM (non-exhaust)	Light duty vehicles	Euro 1	liq	0.035
All	All	PM (non-exhaust)	Long-distance bus	Euro I	liq	0.115
All	All	PM (non-exhaust)	City Bus	Euro I	liq	0.193
All	All	PM (non-exhaust)	Light duty vehicles	Euro 2	liq	0.035
All	All	PM (non-exhaust)	Long-distance bus	Euro II	liq	0.115
All	All	PM (non-exhaust)	City Bus	Euro II	liq	0.193

TRP system	Energy system	p	c	t	f	Ef (ktonne/Gveh-km)
All	All	PM (non-exhaust)	Light duty vehicles	Euro 3	liq	0.035
All	All	PM (non-exhaust)	Long-distance bus	Euro III	liq	0.115
All	All	PM (non-exhaust)	City Bus	Euro III	liq	0.193
All	All	PM (non-exhaust)	Light duty vehicles	Euro 4	liq	0.035
All	All	PM (non-exhaust)	Long-distance bus	Euro IV	liq	0.115
All	All	PM (non-exhaust)	City Bus	Euro IV	liq	0.193
All	All	PM (non-exhaust)	Light duty vehicles	Euro 5	liq	0.035
All	All	PM (non-exhaust)	Long-distance bus	Euro V	liq	0.115
All	All	PM (non-exhaust)	City Bus	Euro V	liq	0.193
All	All	PM (non-exhaust)	Light duty vehicles	Euro 6	liq	0.035
All	All	PM (non-exhaust)	Long-distance bus	Euro VI	liq	0.115
All	All	PM (non-exhaust)	City Bus	Euro VI	liq	0.193
All	All	SO2	Light duty vehicles	Euro 0	liq	0.001
All	All	SO2	Long-distance bus	Euro 0	liq	0.001
All	All	SO2	City Bus	Euro 0	liq	0.001
All	All	SO2	Light duty vehicles	Euro 1	liq	0.001
All	All	SO2	Long-distance bus	Euro I	liq	0.001
All	All	SO2	City Bus	Euro I	liq	0.002
All	All	SO2	Light duty vehicles	Euro 2	liq	0.001
All	All	SO2	Long-distance bus	Euro II	liq	0.001
All	All	SO2	City Bus	Euro II	liq	0.001
All	All	SO2	Light duty vehicles	Euro 3	liq	0.001
All	All	SO2	Long-distance bus	Euro III	liq	0.001
All	All	SO2	City Bus	Euro III	liq	0.001
All	All	SO2	Light duty vehicles	Euro 4	liq	0.001
All	All	SO2	Long-distance bus	Euro IV	liq	0.001
All	All	SO2	City Bus	Euro IV	liq	0
All	All	SO2	Light duty vehicles	Euro 5	liq	0.001
All	All	SO2	Long-distance bus	Euro V	liq	0.001
All	All	SO2	City Bus	Euro V	liq	0
All	All	SO2	Light duty vehicles	Euro 6	liq	0
All	All	SO2	Long-distance bus	Euro VI	liq	0.001
All	All	SO2	City Bus	Euro VI	liq	0.001

Table A 3: Emission factor data for electric vehicles

TRP system	Energy system	p	c	t	f	Ef (ktonne/TWh)
All	REFERENS EU	CO2(total)	All	Euro-el	ele	48.261
All	REFERENS EU	NH3	All	Euro-el	ele	0.001
All	REFERENS EU	NMHC	All	Euro-el	ele	0.008
All	REFERENS EU	NOx	All	Euro-el	ele	0.027
All	REFERENS EU	PM	All	Euro-el	ele	0.002
All	REFERENS EU	SO2	All	Euro-el	ele	0.008
All	Högre elektrifiering	CO2(total)	All	Euro-el	ele	46.354
All	Högre elektrifiering	NH3	All	Euro-el	ele	0.001
All	Högre elektrifiering	NMHC	All	Euro-el	ele	0.007
All	Högre elektrifiering	NOx	All	Euro-el	ele	0.026
All	Högre elektrifiering	PM	All	Euro-el	ele	0.002
All	Högre elektrifiering	SO2	All	Euro-el	ele	0.008
All	Varmare klimat	CO2(total)	All	Euro-el	ele	47.938
All	Varmare klimat	NH3	All	Euro-el	ele	0.001
All	Varmare klimat	NMHC	All	Euro-el	ele	0.008
All	Varmare klimat	NOx	All	Euro-el	ele	0.027
All	Varmare klimat	PM	All	Euro-el	ele	0.002
All	Varmare klimat	SO2	All	Euro-el	ele	0.008
All	All	PM (non-exhaust)	Light duty vehicles	Euro-el	ele	0.035*
All	All	PM (non-exhaust)	Long-distance bus	Euro-el	ele	n.a.
All	All	PM (non-exhaust)	City Bus	Euro-el	ele	0.193*
All	All	PM (non-exhaust)	Railroad	Rail	ele	n.a.
All	All	PM (non-exhaust)	Subway	Sub	ele	n.a.
All	All	PM (non-exhaust)	Tram	Tram	ele	n.a.

Table A 4: Emission factor data for electricity production

		Swedish Energy Agency (2019) scenario			
		REFERENS EU	**Högre elektrifiering**	**Varmare klimat**	
Group	**Name**	**Value**	**Value**	**Value**	**Unit**
NEC priority pollutants	NO_x	0.02745	0.02648	0.02723	ktonne/TWh/yr
	$PM_{2.5}$	0.00229	0.002	0.00227	ktonne/TWh/yr
	NMVOC	0.00804	0.00739	0.00796	ktonne/TWh/yr
Other pollutants	BC	0.00008	0.00007	0.00008	ktonne/TWh/yr
	OC	n.e.	n.e.	n.e.	
	$PM_{2.5\text{-}oth}$	0.00221	0.00193	0.00219	ktonne/TWh/yr
	NH_3	0.00054	0.00057	0.00054	ktonne/TWh/yr
	SO_2	0.00796	0.00819	0.00795	ktonne/TWh/yr
Greenhouse gases	CO_2	48.2607	46.35411	47.9385	ktonne/TWh/yr
	CH_4	0.00433	0.00389	0.0043	ktonne/TWh/yr

Table A 5: Emission factor data for district heat production

		Swedish Energy Agency (2019) scenario			
		REFERENS EU	**Högre elektrifiering**	**Varmare klimat**	
Group	**Name**	**Value**	**Value**	**Value**	**Unit**
NEC priority pollutants	NO_x	0.0954	0.1137	0.0969	ktonne/TWh/yr
	$PM_{2.5}$	0.0042	0.0048	0.0043	ktonne/TWh/yr
	NMVOC	0.0143	0.0181	0.0146	ktonne/TWh/yr
Other pollutants	BC	0.0002	0.0003	0.0002	ktonne/TWh/yr
	OC	n.e.	n.e.	n.e.	
	$PM_{2.5\text{-}oth}$	0.004	0.0045	0.0041	ktonne/TWh/yr
	NH_3	0.0024	0.0028	0.0024	ktonne/TWh/yr
	SO_2	0.0354	0.0438	0.0359	ktonne/TWh/yr
Greenhouse gases	CO_2	124.4028	148.4285	126.3775	ktonne/TWh/yr

	CH_4	0.02	0.0225	0.0203	ktonne/TWh/yr

Table A 6: Activity data for liquid fuel vehicles (FFF = Fossilfrihetsutredningen: SOU 2013:84)

TRP system	Energy system	p	c	t	f	Ad (10^9 person-km)	Af (Gveh-km / 10^9 pers-km)
FFF	All	All	Light duty vehicles	Euro 0	liq	0.134	0.653
FFF	All	All	Long-distance bus	Euro 0	liq	0	0.109
FFF	All	All	City Bus	Euro 0	liq	0	0.109
FFF	All	All	Light duty vehicles	Euro 1	liq	0.055	0.653
FFF	All	All	Long-distance bus	Euro I	liq	0	0.109
FFF	All	All	City Bus	Euro I	liq	0	0.109
FFF	All	All	Light duty vehicles	Euro 2	liq	0.153	0.653
FFF	All	All	Long-distance bus	Euro II	liq	0	0.109
FFF	All	All	City Bus	Euro II	liq	0	0.109
FFF	All	All	Light duty vehicles	Euro 3	liq	0.106	0.653
FFF	All	All	Long-distance bus	Euro III	liq	0.001	0.109
FFF	All	All	City Bus	Euro III	liq	0.001	0.109
FFF	All	All	Light duty vehicles	Euro 4	liq	2.14	0.653
FFF	All	All	Long-distance bus	Euro IV	liq	0.001	0.109
FFF	All	All	City Bus	Euro IV	liq	0.004	0.109
FFF	All	All	Light duty vehicles	Euro 5	liq	4.876	0.653
FFF	All	All	Long-distance bus	Euro V	liq	0.021	0.109
FFF	All	All	City Bus	Euro V	liq	0.086	0.109
FFF	All	All	Light duty vehicles	Euro 6	liq	115.485	0.653
FFF	All	All	Long-distance bus	Euro VI	liq	4.261	0.109
FFF	All	All	City Bus	Euro VI	liq	4.716	0.109
HBEFA3.3	All	All	Light duty vehicles	Euro 0	liq	0.114	0.653
HBEFA3.3	All	All	Long-distance bus	Euro 0	liq	0	0.109
HBEFA3.3	All	All	City Bus	Euro 0	liq	0	0.109
HBEFA3.3	All	All	Light duty vehicles	Euro 1	liq	0.047	0.653
HBEFA3.3	All	All	Long-distance bus	Euro I	liq	0	0.109
HBEFA3.3	All	All	City Bus	Euro I	liq	0	0.109
HBEFA3.3	All	All	Light duty vehicles	Euro 2	liq	0.13	0.653
HBEFA3.3	All	All	Long-distance bus	Euro II	liq	0	0.109
HBEFA3.3	All	All	City Bus	Euro II	liq	0	0.109
HBEFA3.3	All	All	Light duty vehicles	Euro 3	liq	0.09	0.653
HBEFA3.3	All	All	Long-distance bus	Euro III	liq	0.001	0.109
HBEFA3.3	All	All	City Bus	Euro III	liq	0.001	0.109
HBEFA3.3	All	All	Light duty vehicles	Euro 4	liq	1.814	0.653
HBEFA3.3	All	All	Long-distance bus	Euro IV	liq	0.001	0.109
HBEFA3.3	All	All	City Bus	Euro IV	liq	0.004	0.109
HBEFA3.3	All	All	Light duty vehicles	Euro 5	liq	4.132	0.653

TRP system	Energy system	p	c	t	f	Ad (10^9 person-km)	Af (Gveh-km / 10^9 pers-km)
HBEFA3.3	All	All	Long-distance bus	Euro V	liq	0.021	0.109
HBEFA3.3	All	All	City Bus	Euro V	liq	0.078	0.109
HBEFA3.3	All	All	Light duty vehicles	Euro 6	liq	97.864	0.653
HBEFA3.3	All	All	Long-distance bus	Euro VI	liq	4.17	0.109
HBEFA3.3	All	All	City Bus	Euro VI	liq	4.247	0.109

Table A 7: Activity data for electric vehicles (FFF = Fossilfrihetsutredningen: SOU 2013:84)

TRP system	Energy system	p	c	t	f	Ad (10^9 person-km)	Af (TWh / 10^9 pers-km)
FFF	All	All	Light duty vehicles	Euro-el	ele	13.067	0.103
FFF	All	All	Long-distance bus	Euro-el	ele	n.a.	n.a.
FFF	All	All	City Bus	Euro-el	ele	0.324	0.158
FFF	All	All	Railroad	Rail	ele	16.604	0.126
FFF	All	All	Subway	Sub	ele	2.226	0.12
FFF	All	All	Tram	Tram	ele	0.705	0.222
HBEFA3.3	All	All	Light duty vehicles	Euro-el	ele	11.074	0.103
HBEFA3.3	All	All	Long-distance bus	Euro-el	ele	n.a.	n.a.
HBEFA3.3	All	All	City Bus	Euro-el	ele	0.202	0.158
HBEFA3.3	All	All	Railroad	Rail	ele	14.071	0.126
HBEFA3.3	All	All	Subway	Sub	ele	1.887	0.12
HBEFA3.3	All	All	Tram	Tram	ele	0.597	0.222

Indoor climate control domain

See Kindbom et al. (2018) for wood combustion-related CBMs

Table A 8: Activity data for household and service sector energy use (TWh)

	2030		
	REFERENS EU	**Högre elektrifiering**	**Varmare klimat**
Biofuels (non-transport)	12.13	11.37	11.37
Fuel oil class 1	0.22	0.22	0.22
Gas	0.03	0.08	0.03
District heat	30.8	27.59	30.16
Electricity	16.58	18.24	16.34

Dietary choice domain

Table A 9: Emission factor data for the dietary choice domain

Food item	g NH3/kg prod	g Nox / kg produkt	g N2O / kg produkt	g N leaching / kg product
Cereals	0.13	0.03	0.06	0.3
Vegetable	0.12	0.2	0.06	0.3
Fruit & Vegetables	0.15	0.49	0.16	0.3
Pulses	0.02	0.04	0.03	0.3
Potatoes & other starchy roots	0.15	0.08	0.13	0.3
Sugar	0.18	0.05	0.24	0.3
Dairy	1.82	0.27	0.79	0.3
Beef	3.64	1.36	3.14	0.3
Poultry	0.91	0.27	0.31	0.3
Pig meat	1.82	0.41	0.47	0.3
Sheep and goat meat	3.34	1.36	3.14	0.3
Eggs	0.97	0.27	0.31	0.3
Fish and other seafood	0	0	0	0.3
Others	0	0	0	0.3

Table A 10: 2030 *Ad* data for the dietary choice domain

	Ad (kg food/cap/year)			
Food item	Baseline alt 1	Baseline alt 2	Baseline alt 3	Baseline alt 4
Cereals	312.3	312.3	312.3	312.3
Vegetable	40.8	40.8	40.8	40.8
Fruit & Vegetables	357.7	357.7	357.7	357.7
Pulses	4.8	4.8	4.8	4.8
Potatoes & other starchy roots	93.4	93.4	93.4	93.4
Sugar	109.1	109.1	109.1	109.1
Dairy	910.1	910.1	1 015.2	1 015.2
Beef	38.4	38.4	47.3	47.3
Poultry	26.7	26.7	38.1	38.1
Pig meat	61.6	61.6	63.1	63.1
Sheep and goat meat	2.3	2.3	3.2	3.2
Eggs	28.1	28.1	28.1	28.1
Fish and other seafood	64	64	64	64
Others	178.8	178.8	178.8	178.8

Table A 11: 2030 *Af* and share domestically produced for the Dietary choice domain

	Af (food waste %)	Share domesticly produced			
	All	Baseline alt 1	Baseline alt 2	Baseline alt 3	Baseline alt 4
Cereals	35	1	1	1	1
Vegetable	24	0.5	0.5	0.5	0.5
Fruit & Vegetables	22	0.2	0.2	0.2	0.2
Pulses	17	0.1	0.1	0.1	0.1
Potatoes & other starchy roots	24	0.9	0.9	0.9	0.9
Sugar	23	0.9	0.9	0.9	0.9
Dairy	11	0.7	0.5	0.7	0.5
Beef	14	0.6	0.3	0.6	0.3
Poultry	14	0.7	0.4	0.7	0.4
Pig meat	14	0.8	0.5	0.8	0.5
Sheep and goat meat	14	0.3	0.1	0.3	0.1
Eggs	11	0.9	0.9	0.9	0.9
Fish and other seafood	14	0	0	0	0
Others	20	0	0	0	0

Appendix 3: Results per behavioural change measure

Personal mobility domain

Table A 12: Estimated reduction of 2030 baseline emissions from increased use of *Car pools*

Group	Name	Value	Unit
NEC priority pollutants	NO_x	0.12 - 0.16	ktonne/year
	PM2.5*	-0.21 - 0.08	ktonne/year
	NMVOC	0.16 - 0.21	ktonne/year
Other pollutants	BC	n.e.	
	OC	n.e.	
	Other PM2.5-fractions	n.e.	
	NH_3	0.05 - 0.06	ktonne/year
	SO_2	0 - 0	ktonne/year
Greenhouse gases	CO_2	174.85 - 233.94	ktonne/year
	CH_4	n.e.	

*Not including non-exhaust PM2.5 emissions from rail transport

Table A 13: Estimated reduction of 2030 baseline emissions from larger use of *E-commerce*

Group	Name	Value	Unit
NEC priority pollutants	NO_x	0.17 - 0.23	ktonne/year
	PM2.5*	0.08 - 0.1	ktonne/year
	NMVOC	0.17 - 0.21	ktonne/year
Other pollutants	BC	n.e.	
	OC	n.e.	
	Other PM2.5-fractions	n.e.	
	NH_3	0.05 - 0.06	ktonne/year
	SO_2	0 - 0	ktonne/year
Greenhouse gases	CO_2	251.46 - 316.4	ktonne/year
	CH_4	n.e.	

*Not including non-exhaust PM2.5 emissions from rail transport

Table A 14: Estimated reduction of 2030 baseline emissions from more *Travel-free behaviour*

	Name	Value	Unit
NEC priority pollutants	NO_x	0.23 - 0.83	ktonne/year
	PM2.5	0.11 - 0.35	ktonne/year
	NMVOC	0.22 - 0.79	ktonne/year
Other pollutants	BC	n.e.	
	OC	n.e.	
	Other PM2.5-fractions	n.e.	
	NH_3	0.06 - 0.22	ktonne/year
	SO_2	0 - 0.01	ktonne/year
Greenhouse gases	CO_2	334.76 - 1160.14	ktonne/year
	CH_4	n.e.	

Table A 15: Estimated reduction of 2030 baseline emissions from *Eco-driving & speed limits*

Group	Name	Value	Unit
NEC priority pollutants	NO_x	0.1 - 0.56	ktonne/year
	PM2.5	0 - 0.05	ktonne/year
	NMVOC	0 - 0	ktonne/year
Other pollutants	BC	n.e.	
	OC	n.e.	
	Other PM2.5-fractions	n.e.	
	NH_3	0 - 0	
	SO_2	0 - 0	ktonne/year
Greenhouse gases	CO_2	583.05 - 1484.89	ktonne/year
	CH_4	n.e.	

Table A 16: Estimated reduction of 2030 baseline emissions from joint implementation of all BCMs (assuming overlapping effects)

Group	Name	Value	Unit
NEC priority pollutants	NO_x	0.7 - 1.62	ktonne/year
	PM2.5	0.01 - 0.46	ktonne/year
	NMVOC	0.62 - 1.07	ktonne/year
Other pollutants	BC	n.e.	
	OC	n.e.	
	Other PM2.5-fractions	n.e.	
	NH_3	0.17 - 0.29	ktonne/year
	SO_2	0 - 0	ktonne/year
	CO_2	1361.34 - 2749.79	ktonne/year

Greenhouse gases	CH_4	n.e.	

Indoor climate control domain

Table A 17: Estimated reduction of 2030 baseline emissions from *Wood combustion behaviour* in Sweden (Kindbom et al. 2018)

Group	Name	Value	Unit
NEC priority pollutants	NO_x	n.e.	
	PM2.5	0.3 - 1.19	ktonne/year
	NMVOC	0.42 - 1.63	ktonne/year
Other pollutants	BC	0 - 0.02	ktonne/year
	OC	0.11 - 0.45	ktonne/year
	Other PM2.5-fractions	0.19 - 0.72	ktonne/year
	NH_3	n.e.	
	SO_2	n.e.	
Greenhouse gases	CO_2	n.e.	
	CH_4	0.09 - 0.38	ktonne/year

Table A 18: Estimated reduction of 2030 baseline emissions from *Wood combustion behaviour* in stoves (Kindbom et al. 2018)

Group	Name	Value	Unit
NEC priority pollutants	NO_x	n.e.	
	PM2.5	0.16 - 0.33	ktonne/year
	NMVOC	0.15 - 0.48	ktonne/year
Other pollutants	BC	0 - 0	ktonne/year
	OC	0.08 - 0.16	ktonne/year
	Other PM2.5-fractions	0.08 - 0.17	ktonne/year
	NH_3	n.e.	
	SO_2	n.e.	
Greenhouse gases	CO_2	n.e.	
	CH_4	0.05 - 0.21	ktonne/year

Table A 19: Estimated reduction of 2030 baseline emissions from *Reduced wood combustion*. Based on Kindbom et al. (2018)

Group	Name	Value	Unit
NEC priority pollutants	NO_x	n.e.	
	PM2.5	0.08 - 0.11	ktonne/year
	NMVOC	0.08 - 0.19	ktonne/year
Other pollutants	BC	0.02 - 0.02	ktonne/year
	OC	0.02 - 0.04	ktonne/year

	Other PM2.5-fractions	0.04 - 0.05	ktonne/year
	NH_3	n.e.	
	SO_2	n.e.	
Greenhouse gases	CO_2	n.e.	
	CH_4	0.08 - 0.11	ktonne/year

Table A 20: Estimated reduction of 2030 baseline emissions from *Reduced indoor temperature*

Group	Name	Value	Unit
NEC priority pollutants	NO_x	0.67 - 0.9	ktonne/year
	PM2.5	0.63 - 0.87	ktonne/year
	NMVOC	1.29 - 1.78	ktonne/year
Other pollutants	BC	0.06 - 0.09*	ktonne/year
	OC	n.e.	
	Other PM2.5-fractions	0.57 - 0.79*	ktonne/year
	NH_3	0.02 - 0.03	ktonne/year
	SO_2	0.16 - 0.23	ktonne/year
Greenhouse gases	CO_2	858.92 - 1163.06	ktonne/year
	CH_4	1.09 - 1.51	ktonne/year

*Only estimated for household wood combustion

Dietary choice domain

Table A 21: Estimated reduction of 2030 baseline emissions from *More lunchboxes*

Group	Name	Value	Unit
NEC priority pollutants	NO_x	0.01 - 0.02	ktonne/year
	$PM_{2.5}$	n.e.	
	NMVOC	n.e.	
Other pollutants	BC	n.e.	
	OC	n.e.	
	Other PM2.5-fractions	n.e.	
	NH_3	0.05 - 0.08	ktonne/year
	SO_2	n.e.	
Greenhouse gases	CO_2	n.e.	
	N_2O	0.02 - 0.04	ktonne/year
N-leaching		0.08 - 0.13	ktonne/year

Table A 22: Estimated reduction of 2030 baseline emissions from *Only-take-what-you-can-eat* behaviour

Group	Name	Value	Unit
NEC priority pollutants	NO_x	0.04 - 0.06	ktonne/year
	$PM_{2.5}$	n.e.	
	NMVOC	n.e.	
Other pollutants	BC	n.e.	
	OC	n.e.	
	$PM_{2.5\text{-oth}}$	n.e.	
	NH_3	0.17 - 0.28	ktonne/year
	SO_2	n.e.	
Greenhouse gases	CO_2	n.e.	
	ktonne/year	0.08 - 0.13	ktonne/year
N-leaching		0.28 - 0.43	ktonne/year

Table A 23: Estimated reduction of 2030 baseline emissions from *Semi-vegetarian diets*

Group	Name	Value	Unit
NEC priority pollutants	NO_x	0.35 - 0.63	ktonne/year
	$PM_{2.5}$	n.e.	
	NMVOC	n.e.	
Other pollutants	BC	n.e.	
	OC	n.e.	
	$PM_{2.5\text{-oth}}$	n.e.	
	NH_3	2.11 - 3.76	ktonne/year
	SO_2	n.e.	
Greenhouse gases	CO_2	n.e.	
	N_2O	0.93 - 1.68	ktonne/year
N-leaching		2.83 - 5.17	ktonne/year

References in Appendix

Kindbom, K., et al. (2018). Potentials for reducing the health and climate impacts of residential biomass combustion in the Nordic countries. TemaNord. N. C. o. Ministers http://dx.doi.org/10.6027/TN2018-530.

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