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Transforming the energy system in Västra Götaland and Halland

– linking short term actions to long term goals

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Jan Kjärstad[*] (main author)

Mattias Bisaillon**

Simon Harvey*

Filip Johnsson*

John Johnsson**

Ebba Löfblad**

Erika Mata*

Emil Nyholm*

Johan Rootzén*

Håkan Sköldberg**

Henrik Thunman*

Thomas Unger[**]

Modelling of the European electricity generation sector in Chapter 6.5 was performed by Mikael Odenberger and Lisa Göransson, Department of Energy and Environment at Chalmers University of Technology.

* Department of Energy and Environment, Chalmers University of Technology, S-412 96 Göteborg

** Profu AB, Götaforsliden 13, S-431 34 Mölndal

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EXECUTIVE SUMMARY

This study analyzes pathways to meet EU, national and regional targets for CO_2 emissions, energy efficiency and penetration of renewable energy in the Swedish part of the Kattegat-Skagerrak region (KASK-SE), i.e. more specifically in the counties of Västra Götaland (VGR) and Halland. Special focus is placed on four areas: The potential for energy savings in the building sector, energy savings and fuel shifting in the energy intensive industry, large-scale deployment of renewables in the electricity generation sector and greenhouse gas emission reductions in the transport sector. The energy savings are through the implementation of different energy efficiency measures.

Based on a description of the existing energy system and the four focus areas of the study, we make an overall analysis of the possibilities to transform the energy system of the region and from this we provide a pathway which can meet energy and climate targets in the short (Year 2020), medium (Year 2030) and long term (Year 2050). The aim of the pathway is not to predict the future but to identify challenges and possibilities in transforming the energy system of the region. As for emissions we focus on CO_2 emissions emitted within the geographical boundary of the KASK-SE region, i.e. so-called production based emissions. Additional details of the analysis in this study can be found in the technical reports listed on page 9.

The following is concluded from the study:

1. It is possible to meet long term climate targets for the region but not without significant challenges. Also, a successful transformation of the energy system will require coordinated actions where a concerted planning for the transformation must be initiated immediately.
2. The region is likely to meet its target for energy efficiency improvements, but this is primarily due to the fact that this target is relative to the gross regional product (i.e. meeting the target does not necessarily require a reduction in energy use in absolute numbers).
3. The transport sector can reach zero CO_2 emissions in 2050 but only with immediate and concerted local, regional and international action.
4. Zero CO_2-emissions from the region in 2050 is likely to require utilization of all mitigation options investigated in this work.
5. Up to 10 GW onshore wind capacity may be installed in the region at competitive cost when excluding areas of conflict and not exceeding the population density of present wind power installations. Thus, there are significant possibilities to expand wind power without the need to use the more costly offshore wind power.
6. The final energy use in the buildings (currently 29 TWh) can be reduced by more than 15 TWh with a techno-economic (profitable) reduction potential of almost 6 TWh.
7. Large scale penetration of variable (“intermittent”) power will have modest impact on *local* CO_2-emissions. This, since the power sector in the region already has a relatively modest consumption of fossil fuels, mainly natural gas.
8. Large scale penetration of variable electricity generation combined with phase-out of nuclear and fossil based power is likely to lead to increasing import requirements and

create significant challenges for the electricity grid in the region. Such expansion will also lead to increasing need for balancing the high share of intermittent energy such as from load following thermal plants (e.g. biomass based combined heat and power plants) or other balancing options such as energy storage technologies and demand side management.

9. All sectors investigated (electricity, transport, industry and heating) can use biomass as a measure to reduce CO2 emissions but biomass is a limited resource. In order to put less stress on biomass and to obtain a high efficiency in the biomass conversion, electricity should play a large role in the transport sector.
10. Up to 6 TWh additional biomass can be produced in the region up to 2030 assuming a strong Nordic forest industry and high climate ambitions.
11. Assuming that the region should reach zero CO2-emissions in 2050 we see the following options for the refineries in the region;
    a. Transformation to bio-refinery at current activity levels, but this will require substantial volumes of biomass – some 120 TWh in spite of that significant vehicle efficiency gains have been assumed. Total biomass use for energy in Sweden is currently around 130 TWh.
    b. Transformation to bio-refinery and significantly reduced activity level.
    c. Continued use of fossil feedstock, but this will require carbon capture and storage (CCS) to eliminate process related emissions. If the fossil fuels are used within the Swedish transport sector it will also require CCS applied to biogenic emissions (BECCS) to neutralize these fossil emissions. Yet, this option opposes the Swedish goal to achieve a "transport sector independent from fossil fuels" by 2030 (proposition 2008/09:162). However, the fossil fuels can also be exported, for instance to take additional market shares on the international market with export of low sulphur diesel fuels.
    d. Combinations of options a to c.
12. It is likely that fuel demand in the transport sector must be covered by a combination of biomass and electricity in the long term (not at least with respect to point 11a). Also, hydrogen may play a role although this has not been investigated in this work.
13. A robust and cost efficient "bio-solution" for the chemical cluster in Stenungsund would be to keep existing process equipment and purchase bio-based raw material from the refineries. Yet, this will obviously require "greening" of the refineries.

An overall assessment of the challenges associated with meeting the long term (Year 2050) climate targets set up by the region shows that a substantial part of the measures required will impose very significant challenges. Many of these challenges can only be overcome by investments in energy infrastructures for which there are only one or a few investment cycles left until Year 2050. Yet, there are also a significant amount of measures to be taken which should be of a less a challenge to implement. Taken together, we conclude that if any chance to meet the long term targets, *there is an immediate need to develop a framework which can ensure that short term actions can be linked to long term goals*. If not, there is a risk that targets required on the long term remain visions. Thus, we conclude that establishment of a pathway to meet climate and renewable targets in the region – such as the one shown in this report - requires politicians, industries and other key actors to collaborate at an early stage to develop an overall energy master plan for the region.

The work presented in this report is by no means complete in the sense that it answers what actions are to be taken and what is the capacity to act of different organizations and stakeholders within the region. Social dimensions and lifestyle issues have also been outside the scope of this work. More work is obviously required to develop a concrete strategy with action points for the region at the same time as many of the actions required depend on policy measures on national and EU levels, as well as development of global markets of export products such as transportation fuels, chemicals and vehicle technologies. Hence, if the Halland and VGR regions are to have high ambitions in the area of sustainable development (e.g., as expressed in “Regionala Miljömål för Västra Götaland”), there is a need to further develop and analyze concrete actions with respect to what is needed to link short term actions with the long term targets. This so that the region is prepared for the future development of national and international policy measures as well as in order to take local initiatives, which are sustainable from an environmental, economic and social point of view.

Sammanfattning

Denna studie har analyserad möjliga utvecklingsvägar för att möta nationella och regionala mål samt EU mål för CO2-utsläpp, energieffektivitet och förnybar energi i den svenska Kattegatt-Skagerrak regionen (KASK-SE), dvs i Västra Götaland och Hallands län. Speciellt läggs fokus på fyra områden; potential för energibesparing i byggnadssektorn, energibesparing och byte av bränslen i den energiintensiva industrin, storskalig integration av förnybar elproduktion och minskning av växthusgasutsläpp i transportsektorn. Energibesparingen sker genom att en rad olika åtgärder implementeras för att höja energieffektiviteten.

Baserad på en beskrivning av det existerande energisystemet och de fyra fokusområdena görs en övergripande analys av möjligheterna för att ställa om regionens energisystem och utifrån detta formulera en utvecklingsväg som kan möta energi- och klimatrelaterade mål på kort (2020), medellång (2030) och lång (2050) sikt. Avsikten med den formulerade utvecklingsvägen är inte att försöka förutsäga framtiden utan att identifiera utmaningar och möjligheter vid en omställning av regionens energisystem. När det gäller utsläpp så är fokus på CO2-utsläpp innanför den geografiska regionen som utgörs av Västra Götaland och Hallands län, dvs så kallade produktionsbaserade emissioner.

Sammanfattningsvis visar arbetet följande:

1. Det är möjligt att nå regionens långsiktiga klimatmål men detta kräver att ett kraftfullt och koordinerat omställningsarbete påbörjas snarast.
2. Regionen kommer troligtvis uppnå målet för energieffektivisering, men detta beror till stor del på att energieffektiviseringsmålet är relaterat till bruttoregionalprodukten och därför inte nödvändigtvis kräver en minskning av energianvändningen i absoluta tal.
3. Transportsektorn kan nå noll utsläpp till år 2050 men detta kräver kraftfulla åtgärder på såväl lokal som regional och internationell nivå.
4. För att uppnå noll CO2-utsläpp i regionen till år 2050 pekar resultaten på att samtliga tekniker och metoder som analyserats i detta arbete måste implementeras.
5. Uppemot 10 GW landbaserad vindkraft kan installeras inom regionen till konkurrenskraftig kostnad, även om man exkluderar konfliktområden och upprätthåller liknande nivå för befolkningstäthet som för nuvarande vindkraftsanläggningar. Det finns därför betydande möjligheter för ytterligare expansion av vindkraft utan att havsbaserad vindkraft behöver tas i anspråk – den senare uppvisar betydligt höger kostnader.
6. För slutanvändning av energi i byggnadssektorn (för närvarande ca 29 TWh) finns en teknisk potential för minskad energianvändning på mer än 15 TWh och en teknisk-ekonomisk (lönsam) potential på nästan 6 TWh.
7. Expansion av variabel (”intermittent”) elproduktion kommer ge liten påverkan på lokala CO2 utsläpp eftersom kraftsektorn i regionen endast använder små mängder fossila bränslen, i huvudsak naturgas.
8. Storskalig expansion av variabel förnybar elproduktion i kombination med utfasning av kärnkraften och fossilbaserad elproduktion kommer leda till ökat importbehov av el och ge betydande utmaningar båda för elnätet i regionen och för balansering av

elproduktionssystemet. Detta kommer troligtvis också leda till ökat behov av variationshantering som bio-baserad kraftproduktion (i tex kraftvärmeverk), lagring av energi och åtgärder på användarsidan ("Demand Side Management").

9. Flera sektorer kommer göra anspråk på att använda biomassa – transportsektorn, industrin, uppvärmning – samtidigt som biomassa är en begränsad resurs. För att minska trycket på biomassa så bör el få en betydande roll i omställningen av transportsektorn så att transportsektorns behov av biomassa begränsas.

10. Under antagande av en stark Nordisk skogsindustri och höga klimatambitioner bör regionen kunna öka sin produktion av biomassa med upp till 6 TWh år 2030.

11. Om det antas att regionen skall nå noll utsläpp av CO2 till 2050 utan användning av de flexibla mekanismerna så ser vi följande möjligheter för raffinaderierna i regionen;

    a. Omställning till bio-raffinaderier med nuvarande aktivitetsnivå men detta kräver mycket stora mängder biomassa – ca 120 TWh trots att det har antagits betydligt mer effektiva bilar än i dag. Totala användningen av biomassa i hela Sverige är för närvarande ca 130 TWh.

    b. Omställning till bio-raffinaderier med betydligt lägre aktivitetsnivå.

    c. Fortsatt användning av fossila råvaror men detta måste då kombineras med avskiljning och lagring av koldioxid (så kallas CCS teknik) för att eliminera processbaserade utsläpp. Om de fossila bränslena används inom Sverige kommer skulle dessa behöva kompenseras i andra sektorer t ex genom att tillämpa CCS på biogena utsläpp (så kallad BECCS teknik). Det senare är dock inte i linje med Sveriges mål (Proposition 2008/09:162) om en transportsektor oberoende av fossila bränslen år 2030. Emellertid kan man också tänka sig att all fossilbaserad produktion exporteras, tills exempel för att höja marknadsandelen för lågsvavlig diesel på internationella marknader, där i så fall utsläppen sker utanför Sveriges gränser.

    d. Olika kombinationer av a-c ovan.

12. En trolig utveckling i transportsektorn är att bränslebehovet på längre sikt kommer att täckas av en kombination av biomassa och el (inte minst med tanke på punkten 11a ovan). Även vätgas kan komma att spela en roll men har inte undersökts i detta arbete.

13. En robust och kostnadseffektiv bio-baserad lösning för kemiklustret i Stenungssund är att behålla existerande processutrustning och använda bio-baserade råmaterial från raffinaderier (inom eller utanför regionen).

En samlad bedömning av de utmaningar som är förknippade med att möta de långsiktiga (år 2050) klimatmål som ställts upp av regionen visar att en betydande del av de åtgärder som krävs kommer att innebära mycket stora utmaningar. Flera av dessa utmaningar kan bara mötas genom investeringar i energiinfrastruktur för vilka det endast är en eller ett fåtal investeringscykler kvar till år 2050. Det finns dock också åtgärder som bör kunna genomföras med enklare medel och vilka kommer att vara lönsamma tidigare.

En övergripande slutsats från detta arbete är att om regionen överhuvudtaget skall ha någon chans att nå de långsiktiga klimatmålen *så krävs att det omedelbart kommer till stånd ett ramverk som kan säkerställa att kortsiktiga åtgärder kan kopplas till de långsiktiga målen*.

Om inte, finns det en risk att de på lång sikt uppställda målen endast förblir visioner. Vi drar därför slutsatsen att politiker, industrier och andra nyckelaktörer bör samarbeta kring upprättande av en färdplan för regionen mot år 2050, vilken når klimatmålen och målen för förnybar energi i regionen. En sådan färdplan kan vara lik den som presenteras i denna rapport, det vill säga baserad på att de över tid nödvändiga förändringarna kvantifieras.

Arbetet som presenteras i denna rapport är ingalunda fullständigt i den mening att det ger exakta svar på vilka åtgärder som ska vidtas och vilken rådighet olika organisationer och aktörer har inom regionen. Det är också viktigt att understryka att denna rapport inte tar upp sociala dimensioner och livsstilsfrågor relaterad till de åtgärder som föreslås och diskuteras i rapporten. Fortsatt arbete kommer självklart krävas för att utveckla en konkret strategi med åtgärdspunkter för regionen samtidigt som många av de åtgärder som krävs beror på politiska åtgärder på nationell nivå och EU-nivå, samt på utvecklingen av globala marknader för exportprodukter såsom drivmedel, kemikalier och fordonsteknik. Om Halland och VGR (inklusive Göteborgs stad) önskar upprätthålla höga ambitioner när det gäller hållbar utveckling (t.ex., uttryckt i "Regionala miljömål för Västra Götaland"), så finns det ett behov av att vidareutveckla och analysera konkreta åtgärder med avseende på vad som behövs för att koppla beslut på kort sikt med de långsiktiga målen. Detta så att regionen är förberedd för den framtida utvecklingen av nationella och internationella politiska åtgärder så att dessa kan länkas samman till regionens initiativ för att uppnå en miljömässigt, ekonomiskt och socialt hållbar omställning av regionens energisystem.

Technical reports:

Johnsson J., Löfblad E., 2014. ”Transforming the energy system in Västra Götaland and Halland – The Reference Energy System for Year 2010”.

Harvey S., Andersson E., Franck P-Å., Fatnes A.M., Aas K., 2014. “Energy efficiency in industry”. Chalmers-Tel-Tek 2014-12-19.

Mata E., Fraitely U., 2014. “Transforming the energy system in Västra Götaland and Halland - the potential for energy savings and CO2 emissions reductions in the building sector”.

Unger T., Nilsson K., Göransson L., 2014a. ”Transforming the energy system in West Sweden and South Norway – an assessment of wind power potential”.

Unger T., Odenberger M., Göransson L., 2014b. ”Transforming the energy system in West Sweden and South Norway – Assessment of electricity generation towards 2050”.

Bisaillon M., Nilsson K., 2014a. ”Transforming the energy system in West Sweden and South Norway – an assessment of biomass production potential”.

Bisaillon M., Holmström D., 2014b. “Transforming the energy system in West Sweden and South Norway – future power production from biomass and waste”.

Sköldberg H., Löfblad E., 2014. ”Möjligheter till omställning av transportsektorn i Västra Götaland och Halland – analys och jämförelse med nationella utredningar”.

The technical reports can be obtained from Department of Energy and Environment, Division of Energy Technology, Chalmers University of Technology;

Jan Kjärstad, kjan@chalmers.se, 031 772 1454

Filip Johnsson, filip.johnsson@chalmers.se , 031 772 1449

CONTENTS

1 Introduction

The three main pillars of EU's energy policy are competitiveness, supply security and sustainability. With regard to climate policy the overall aim is to ascertain that the global temperature increase is limited to 2 degrees Celsius. Implementation of policies which can transform the energy system to fulfill this aim will be a great challenge, not at least politically. Such policies and efforts must not only be carried out on an international, EU and national level but also on a local level. The local level is of importance since many *decisions* are taken on this level and the results of these have direct implications on aggregated national results. The local level is also where the policies will have direct impact on the general public.

This report discusses and analyses pathways towards meeting targets for CO2-emission reductions, renewable energy and energy efficiency in the Västra Götaland (VGR) and Halland counties which belong to the Kattegat Skagerrak region – the KASK region as shown in Figure 1.1 (the entire KASK region comprising parts of Denmark, Norway and Sweden indicated in dark blue).

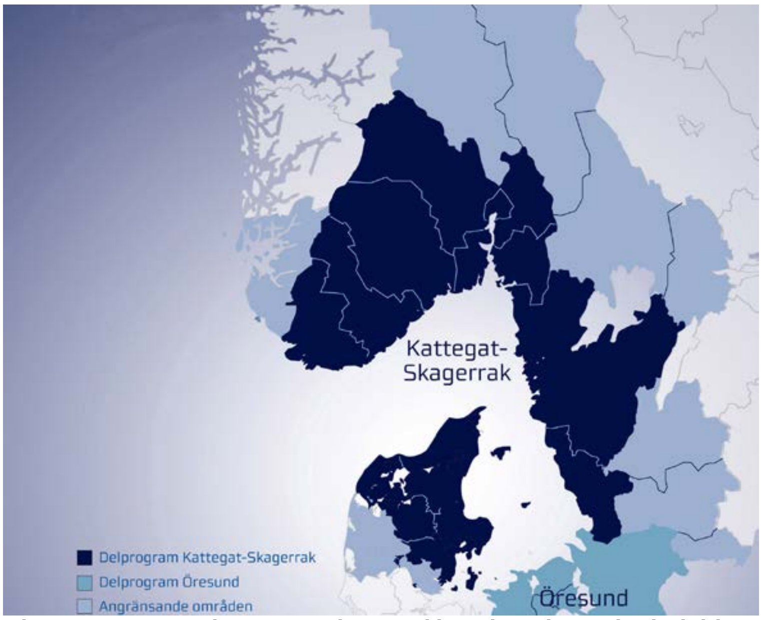

Figure 1.1: KASK (Kattegat-Skagerrak) region shown in dark blue.

The work takes into consideration local, regional, national and EU based targets and plans for improved energy efficiency, increased deployment of renewables and reduction of production-based CO2-emissions (emissions that arise within the geographical boundary of Västra Götaland and Halland counties). A special focus is placed on energy efficiency savings potential in the building sector and in the energy intensive industry in the region as well as on large-scale deployment of renewables in the electricity generation sector which is a fully integrated part of the European electricity sector. It should be mentioned that we provide no detailed analysis with respect to how the *capacity to act* is divided between the different organizations involved in the local decision making (on the level of municipalities and the VGR and Halland counties). As for the transportation system it is obvious that the politicians in the two counties have little influence on the development of car technology since this is mainly governed by international and global markets.

The aim of this report is also to discuss the different aspects of the work required to transform the regional energy system of the VGR and Halland counties, i.e. the Swedish KASK-region (in the following we use the notation Swedish KASK region – KASK-SE - to represent the VGR and Halland counties). The report follows to some extent a framework developed in a previous EU project (PATH-TO-RES) which outlines a methodology to define Pathways which can link short term actions with long term visions (Lodén et al., 2009a). The methodology applied starts with a detailed description of the present system (energy statistics, energy infrastructure as well as decision makers and stakeholders) and, based on this, a number of steps are defined with the aim to serve as check points to ensure that one or more Pathways can be formulated which describe how the local energy system can be transformed to comply with goals and targets. The energy system of the region is described by energy and emission statistics and by a Reference Energy System (RES), from which the structure (i.e. components, flows and connections) and energy balance of the energy system is determined.

Working processes for municipal/local energy planning are carried out in many European countries. If such processes are successful they can be a powerful tool for transforming local energy systems in desired directions. Several studies have shown that system boundaries for energy planning have widened over recent decades in certain European countries (see Lodén, et al. 2009a and references therein). Thus, Local Energy Planning (LEP) processes have developed from simply being administrated by the municipality, to being a cross functional process including different fields and actors, all of which have a strong dependence on the local energy situation. Consequently, the need for alignment between individual projects and long-term energy strategies for entire municipally administered areas has been recognised.

Currently most municipalities within the EU have strategies or are developing strategies that aim at fulfilling long term national and international goals such as those contained in the EU climate change and energy package, i.e. the 20-20-20 targets in 2020, described above. There are also several municipalities, mainly within the EU, that have signed up to the Covenant of Mayors and thereby committed their municipalities and cities to go further than the EU 20-20-20 goals (Covenant of Mayors, 2014). It is worth noting that during the last years there has been a strong increase in the number of municipalities who have signed the Covenant of Mayors (with currently – January 2015, almost 6,200 signatories). This shows that there is a strong regional local interest to develop society towards a more sustainable one. In line with this it seems to be rather common for regions and municipalities to establish visions on what would be the future, including long term energy and climate goals. Yet, these are often visions rather than concrete action plans since the region often has limited capacity to act and besides, a long term vision is usually considered to be “politically safe” (new politicians by then).

In this work we combine the results of the present project of the KASK region with some insights gained from previous work (Lodén et al., 2009b). As indicated above the Swedish KASK region is divided into two counties; Västra Götaland county (VGR) and Halland county with 49 and 6 municipalities, respectively. The political power (the capacity to act) is mainly with the municipalities, i.e. the municipalities have so-called local self-government while the counties mostly have an administrative function and provides a link between the government and the municipalities. The municipalities are often large property owners and also usually own the main energy utility company in the municipality. It is often considered that such municipality owned infrastructure could be subject to early adoption of actions to transform the energy systems (e.g. energy efficient renovations of buildings and renewable fuels and waste fuels in district heating systems).

As indicated, the point of departure of the work presented in this report is the present energy system. The work combines an analysis of the entire energy system with a more detailed analysis on:

- Energy efficiency in selected key industries
- Large scale integration of intermittent electricity generation
- Energy savings potential in the existing building stock
- Greenhouse-gas (GHG) emission reductions in the transport sector

The overall analysis was refined during the course of the work by using results from the detailed analysis as input. The four chosen areas of the energy system outlined above have been selected since they constitute an important part of the energy system in the region responsible for large CO2-emissions and/or high energy consumption.

As mentioned above focus in this work is placed on reduction of production based CO2-emissions, reduced energy consumption and large-scale deployment of intermittent renewables. Thus, non-CO2 GHG emissions arising foremost from the agricultural sector and mitigation in the form of increased uptake of CO2 from the biosphere have been outside the scope of the work. The work reported in this report does not address the social dimensions and lifestyle issues related to the actions that have been proposed since this has been studied in other reports, see for instance Andersson, D. et al., (2014) and Larsson et al., (2015).

According to Elforsk (2013), the production potential of both hydro- and wind based power may increase as a consequence of climate change, the former in the north of Sweden while it may decline in the southern parts. Also, increased production potential within forestry and agriculture may lead to increased production potential of bioenergy depending on prices and how we choose to use the increased production potential within the forestry and agriculture sectors. A warmer climate will reduce demand for heat while at the same time increase demand for cooling during the summer but future use of heat and cooling will also depend on many other factors, such as implementation of energy efficiency measures in the building stock and population growth. Thus, the combined effects from climate change are difficult to project, at least quantitatively, and therefore in this work no considerations have been taken with regard to the effect on energy supply and energy use in KASK-SE from climate change.

The methodology used in this work starts with a detailed description of the present system (energy and emission statistics and energy infrastructure as well as decision makers and stakeholders) and, based on this, a number of steps are defined with the aim to serve as check points to ensure that one or more Pathways can be formulated which describe how the local energy system can be transformed to comply with goals and targets. Starting with “trend lines” based on the past (up to 2010) CO2 emissions and energy consumption and officially announced targets on CO2 emission reductions, energy conservation and renewable energy in each of the counties involved, the project proposes CO2 reduction and energy conservation technologies as well as inclusion of renewables by sector.

Most of the work in this project is reported in individual technical reports which are discussed and summarised in Chapters 4 to 7. Chapter 8 discusses overall results for the energy system in the region with regard to targets for energy efficiency, renewables and CO2 emissions while Chapter 9 discusses the challenges that the region is likely to face in meeting zero or near-to-zero CO2 emissions towards Year 2050. Main conclusions are highlighted in Chapter 10 while Chapter 11 suggests further work.

2 Energy Overview

This chapter provides a brief description of the energy system in KASK Sweden and in Göteborg including large-scale energy- and emission intensive sources, existing and under development, and electricity production plants and statistics on energy consumption and emissions. Göteborg is described separately since it is by far the largest municipality in the Swedish KASK-region and it is the second largest city in Sweden with a population of around 533,000 at end 2013. By 2025, the population is expected to increase to 612,000.

As mentioned above, the Swedish KASK region consists of two counties, VGR and Halland, which in turn are divided into 49 and 6 municipalities, respectively. Each county has a County Administrative Board (CAB), a government authority basically providing a link between the municipalities and the government. With regard to Energy and climate change, the main role of the county administrative board is to coordinate regional goals so that they align with the national goals. Much of the political power and therefore also the ability to change the energy system lies within the municipalities, they have a district council with a rather extensive governance independent of the national government although there is a strong connection between the district council and the national government. All municipalities in Sweden are required by national law to have an energy plan (The law on municipal energy planning - 1977: 439) which often includes a climate plan. As of February 2015 fifty of the fifty-five municipalities in the region also have a wind power plan allocating preferred areas for location of wind parks.

Table 2.1 provides some key characteristics of VGR and Halland with regard to size, energy consumption and GHG emissions.

Table 2.1: Basic characteristics of the counties of Västra Götaland and Halland.

	VGR	Halland	Total
Population (end 2012)	1,612,144	305,986	1,918,130
Approximate area [km²]	23,942	5,719	29,661
Population density [/km²] - end 2012	67.3	56.1	65.3
Number of municipalities	49	6	55
Primary energy supply [TWh/year - 2008]	69.6	63.1	132.9
Regional share of national primary energy supply, %	12.7	11.5	24.2
Final Energy Consumption (FEC) [TWh/year] - 2010	66.1	13.9	80.0
FEC /capita [MWh/year] - 2010	41.0	45.5	41.7
FEC/capita *(national level)* [MWh/year] - 2010	43.7		
GHG emissions, Mt CO2e - 2010	12.4	1.9	14.3
GHG emissions/capita, tCO2e - 2010	7.7	6.2	7.5
Largest emitting municipality, (Mt CO2e – 2010)	Göteborg (3.0)	Halmstad (0.6)	Göteborg (3.0)

As can be seen from Table 2.1, VGR is considerably larger than Halland in most respects. The population in VGR is expected to increase to 1.74 million by 2025 (VGR 2012a) while the population in Halland is projected to increase to around 340,000 by 2030 (Region Halland 2014).

The VGR region is characterized by a high degree of industrialization with major clusters of large industries in Göteborg and Stenungsund plus Sweden's largest oil refinery outside Lysekil. In fact, three refineries and a chemical plant in VGR combined emit some 3.4 Mt CO2e annually, corresponding to almost 24% of all GHG emissions in the Swedish KASK region. The Halland region contains the site of a major nuclear power plant generating around

24 TWh electricity annually of which the bulk are exported out of Halland. The largest single CO2-source in Halland used to be Pilkington (glass production) which emitted around 150 kton CO2 annually but it was shut down in 2013 (Averfalk et al., 2014). A pulp and paper plant located in the Halland region emits around 1 Mt biogenic CO2 per year and the same plant is preparing for a substantial expansion possibly raising emissions in the future, although biogenic.

It should be emphasized that data on energy use given in this report has not been temperature corrected[1]. Large and/or sudden differences in energy use between years can be a combined effect of differences in year-average temperature and activity level due to variations in the state of the economy, where the former mainly influence the heating sector and the latter the industry sectors. Both the Years 2009 and 2010 were cold years indicating higher than normal use of district heat in these two years.

Figure 2.1 shows the Reference Energy System (RES) for the KASK-SE region in Year 2010. A more detailed RES for each county and for the individual sectors can be found in Johnsson J., et al. (2014). The RES shows the flow of energy (in GWh) within the region from primary energy going into the system through conversion and transport to final consumption by end-users.

Primary energy into the KASK-SE region is dominated by uranium (nuclear power production) and crude oil. Most of the oil is being refined within the VGR county and

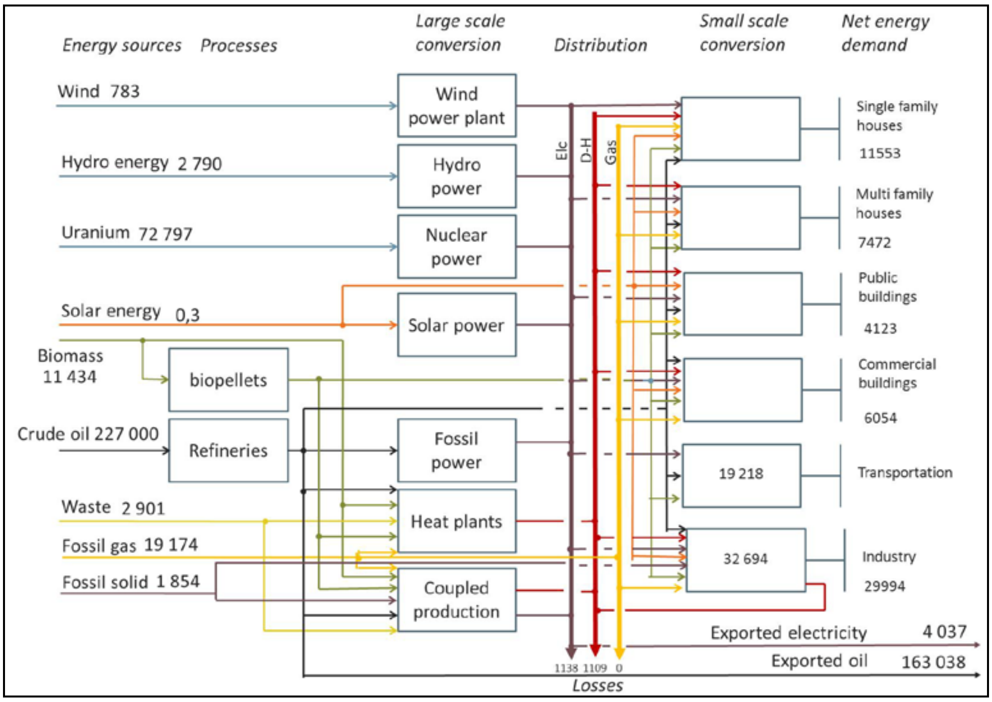

Figure 2.1. The Reference Energy System for the KASK-SE region in Year 2010, figures are in GWh, source: Johnsson J., et al., (2014).

[1] There can for instance be many causes to annual variations in production and use of district heat. Besides the temperature, the price difference between different fuels and electricity may play a role as well as the availability of the production facilities.

exported out of Sweden while most of the generated nuclear power is exported from Halland county to Göteborg county, i.e. the electricity is being consumed within the region. There is also a considerable amount of fossil gases going into the system, mostly natural gas being used for power and heat generation in the industry as well as for generation of District Heat (DH). In fact, it can be stated that most of the CO2-emissions in the region originate from 1) natural gas based heat generation, 2) natural gas based industrial heat generation and 3) fossil consumption in the transport sector. Yet, overall CO2 emissions from the heating sector is low in Sweden and also for the region since the major part of heating is provided by biomass fuelled DH.

Electricity is generated mainly by hydro, nuclear and biomass, the latter mostly in combined heat and power plants. In total the region burnt 4.2 TWh fossil fuels to produce mainly heat (0.2 TWh for electricity generation) in 2010 (industry not included) of which 3.2 TWh natural gas. Most of the fossil fuels used to generate heat (plus some electricity) was used in the VGR region, some 4.0 TWh. As evidenced by the large CO2-emissions mentioned above, the industry is a large consumer of fossil energy; 19.2 TWh in 2010 of which almost 16 TWh in the form of gas (natural gas, city gas, kerosene, LPG).

The contribution from non-hydro renewables (wind, bio, waste) in power and heat production is increasing rapidly and VGR and Halland showed the highest and sixth highest installed wind power capacity in Sweden, respectively, at the end of 2013. In VGR 696 MW wind power was installed at end 2013 generating almost 1.6 TWh power while corresponding figures in Halland were 327 MW and 0.65 TWh respectively (Swedish Energy Agency 2014a).

The main reason for the rapid increase in non-hydro renewables is the joint "green certificate" system agreed between Norway and Sweden targeting 26.4 TWh additional renewable power generation in the two countries between 2012 and 2020[2]. The certificate system has so far resulted in a boom in wind power in Sweden and in hydro power in Norway.

Figure 2.2 shows total Final Energy Consumption (FEC) and FEC per sector in KASK-SE between 1990 and 2012. Note that the year 2005 is not shown and that only three sectors and total consumption (dashed black line) are shown after 2009 due to incomplete statistics for these years. The data have been taken from Statistics Sweden (2014a).

[2] In March 2015, Sweden suggested that the target should be raised to 28.4 TWh. The new proposed target will be discussed in the Norwegian Government during the spring of 2015 (Norwegian Government 2015).

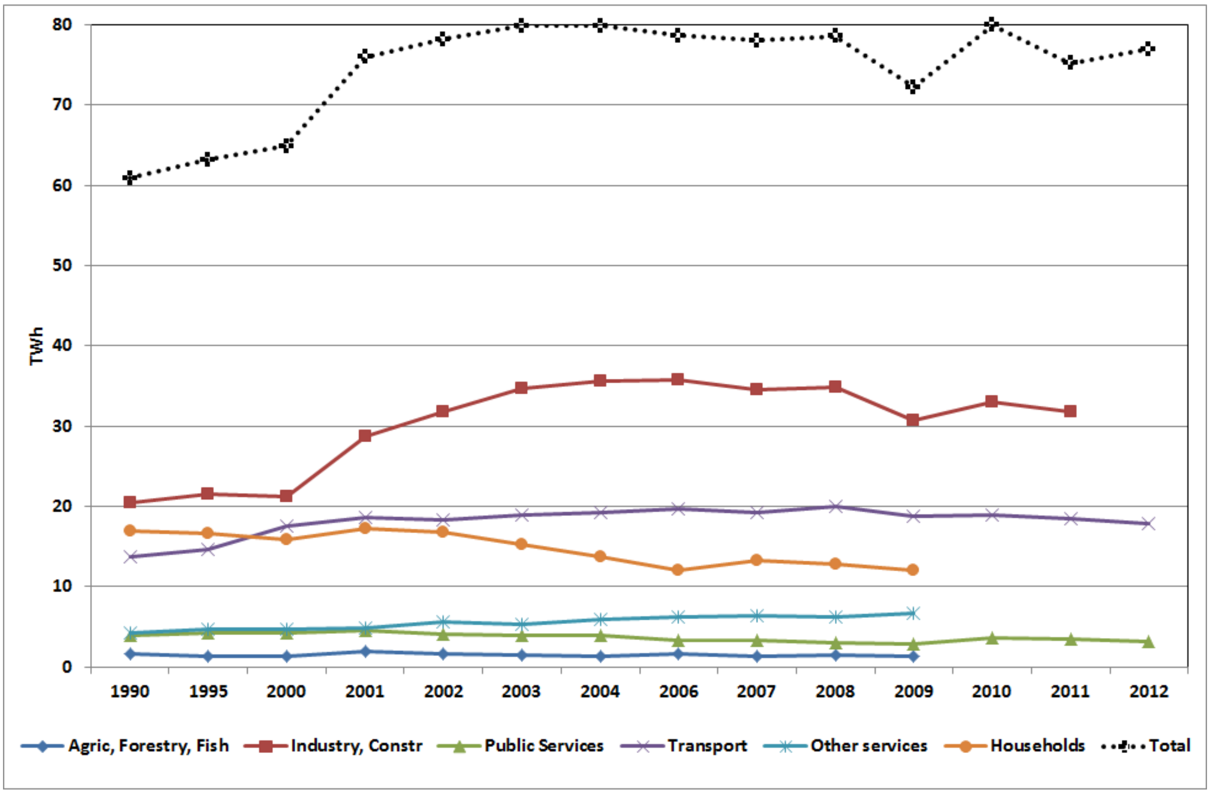

Figure 2.2: Final Energy Consumption (FEC) by Sector in KASK-SE between 1990 and 2012, TWh. The year 2005 is not shown and only three sectors and total FEC are shown after 2009. Source: Statistics Sweden (2014a).

Three sectors account for around 85% of FEC throughout the period; industry, transport and households. As can be seen from Figure 2.2, while energy consumption in the households has gone down by almost 30% between 1990 and 2009, consumption has increased in the transport and industry sectors. Between 1990 and 2012, the industry's energy consumption has increased by 55% while energy consumption in the transport sector has increased by 29%. Total consumption has increased by 26% between 1990 and 2009 reaching a peak of 80.0 TWh in 2010. It should also be noted that there is a large increase in total consumption between 2000 and 2001 and that consumption has been relatively constant since 2002 at around 80 TWh apart from a dip to 72 TWh in 2009. This is, as can be seen from Figure 2.2 almost entirely caused by increased consumption in the industry and the dip down in 2009 was of course caused by the decline in the global economy in that year. The industry increased its annual energy consumption from around 21 TWh in 2000 to between 35 and 36 TWh between 2003 and 2008 and its share in total consumption increased from 33% in 2000 to 45% in 2004 and 2006. The data in Figure 2.2 emphasizes the strong role of energy intensive industry in the region. VGR accounts for more than 80% of FEC in the region and for almost 85% of the industry's energy consumption.

Figures 2.3 and 2.4 show total GHG emissions (in CO2 equivalents), total GHG emissions excluding agriculture and GHG emissions from agriculture, total CO2 emissions and CO2 emissions by sector in 1990, 2000 and between 2005 and 2012 for VGR and Halland, respectively.

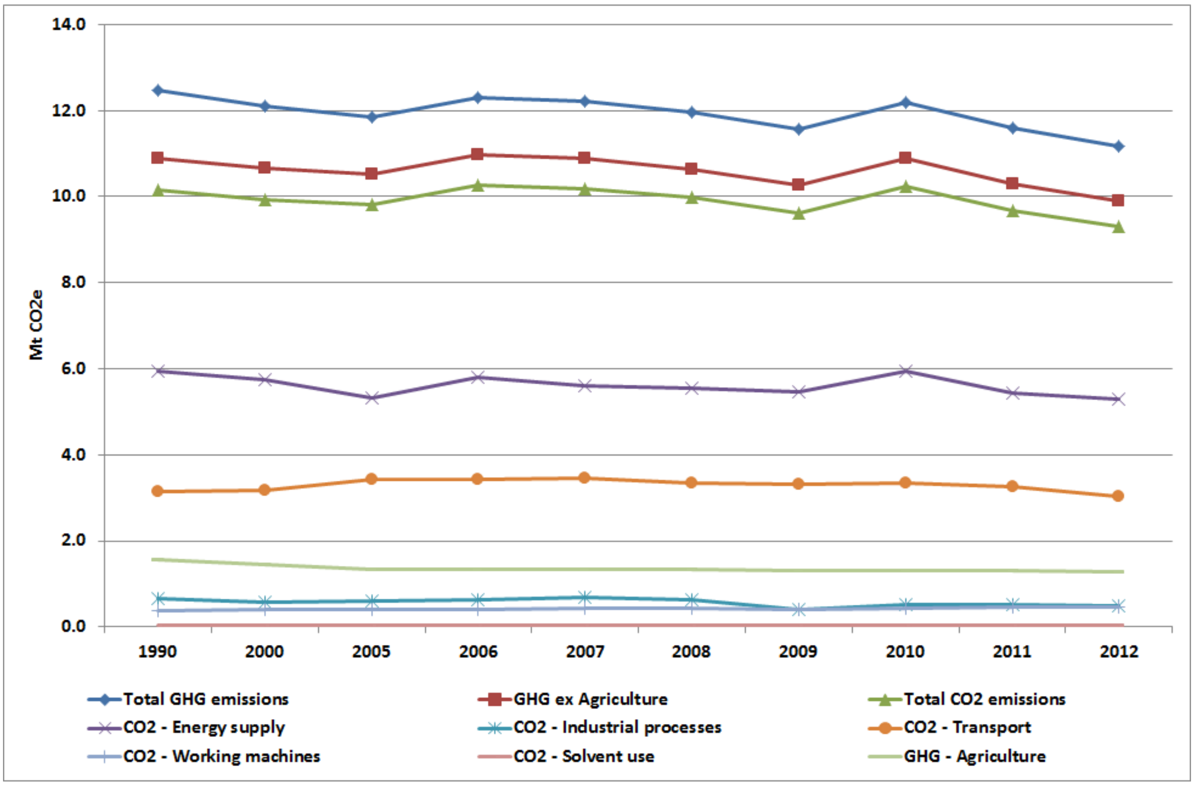

Figure 2.3: Total GHG emissions (in CO2e), total GHG emissions ex agriculture, GHG emissions agriculture, total CO2 emissions and CO2 emissions by sector for VGR 1990, 2000 and between 2005 and 2012. Source: Länsstyrelserna 2014.

In VGR county GHG emissions have declined by 10% since 1990, from 12.5 Mt to 11.2 Mt, mostly due to an 11% decline in CO2 emissions from energy supply and a 25% decline in emissions from industry processes. Transport related emissions have remained almost constant over the period accounting for 27% of total GHG emissions in the VGR county in 2012 and for 33% of total CO2 emissions. Combined, energy supply and transport account for 74% of the GHG emissions in the county and for almost 90% of CO2 emissions (2012). Agriculture is the third largest sector with respect to GHG emissions accounting for more than 11% of total GHG emissions (2012) but, as mentioned above, emissions from the agriculture sector has not been analyzed in this report.

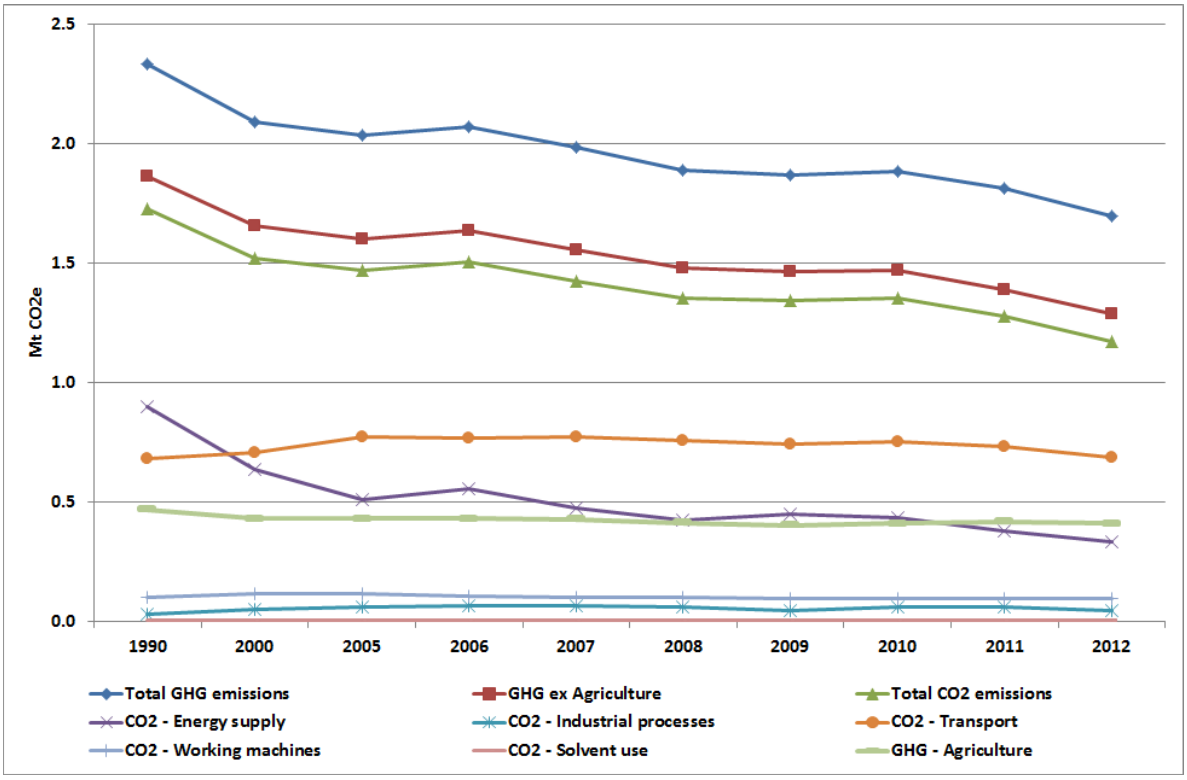

Figure 2.4: Total GHG emissions (in CO2e), total GHG emissions ex agriculture, GHG emissions agriculture, total CO2 emissions and CO2 emissions by sector for Halland 1990, 2000 and between 2005 and 2012. Source: Länsstyrelserna 2014.

In Halland county GHG emissions have declined by some 27% since 1990, from 2.3 to 1.7 Mt. CO2 emissions have declined even more, by 32% and as can be seen from Figure 2.4 this is primarily due to reduced emissions from energy supply which have gone down by more than 60%, from 900 ktons in 1990 to 333 ktons in 2012. A closer examination reveals that it is foremost energy supply within the industry and on-site generation of heat that has reduced emissions, the latter due to a switch to DH. CO2 accounts for nearly 70% of total GHG emissions. Combined, the two sectors energy supply and transport account for roughly 60% of total GHG emissions and for 87% of total CO2 emissions in the region.

In 2012, the two regions emitted 12.9 Mt GHG (CO2e) together, corresponding to 23% of total GHG emissions in Sweden of which 20 percentage points in VGR alone. Some 81% of total GHG emissions in the region are CO2-emissions. Emissions from energy supply and transport account for 44 and 29% of total GHG emissions respectively (and 54 and 36% of CO2 emissions). While CO2 emissions from energy supply have gone down by 18% since 1990, emissions have gone down by only 2% in the transport sector. Since 1990 there has been a 13% reduction in GHG emissions in KASK SE excluding net changes in LULUCF (Land Use, Land Use Change and Forestry) while corresponding reduction in CO2 emissions is 12%.

Göteborg has the largest Total Final Energy Consumption (TFEC) among the municipalities in the Swedish KASK-region, around 20 TWh in 2010 corresponding to around 40 MWh per capita which is fairly close to the national average of ca 43 MWh but far below FEC/capita in the two KASK municipalities of Lysekil and Stenungsund at 505 and 251 MWh/capita respectively (2009) (Swedish Energy Agency 2013, Statistics Sweden 2014a). The large per capita consumption in Lysekil and Stenungsund is due to the oil refinery in Lysekil and the chemical cluster located in Stenungsund and these two industry plants are analysed in Section 4.

TFEC in Göteborg has grown by 69% since 1990 and by 27% since 2000. Energy consumption in the industry sector has grown by almost 200% since 1990 and by 84% since 2000 accounting for almost a third of TFEC in Göteborg. Energy consumption in the transport sector has grown by 42% since 1990 but has actually gone down by slightly more than 10% since 2000. Energy consumption in the transport sector accounts for 27% of TFEC in Göteborg. The third largest energy consuming sector, households, have reduced energy consumption by 26% relative 1990 and by 22% relative 2000. Finally, the fourth largest sector accounting for 17% of TFEC, other services, has increased its consumption by 94% since 1990 and by 87% since 2000.

In 2012 Göteborg accounted for 23% of GHG emissions and 26% of CO2 emissions in VGR, CO2 alone contributed to 94% of total GHG emissions. Figure 2.5 shows total and agriculture GHG emissions and CO2 emissions in total and by sector in Göteborg from 1990 to 2012.

As can be seen from Figure 2.5 GHG emissions in the City of Göteborg have remained more or less constant since 1990, with the only significant changes due to the above mentioned effects from the cold years 2009 and 2010 (mainly in energy supply). In total there has been a marginal increase since 1990 by ca 50 kton of which two thirds are CO2 emissions. CO2 emissions from transport have only decreased by ca 28 kton in spite of that the average car should be significantly more fuel efficient today than 25 years ago. Thus, increased transportation work has offset most of improved fuel efficiency. CO2 emissions from transport and energy supply account for 88% of total GHG emissions and for 94% of total CO2 emissions in 2012 while CO2 emissions from industry processes and working machines combined accounted for 5% of both GHG and CO2 emissions that year.

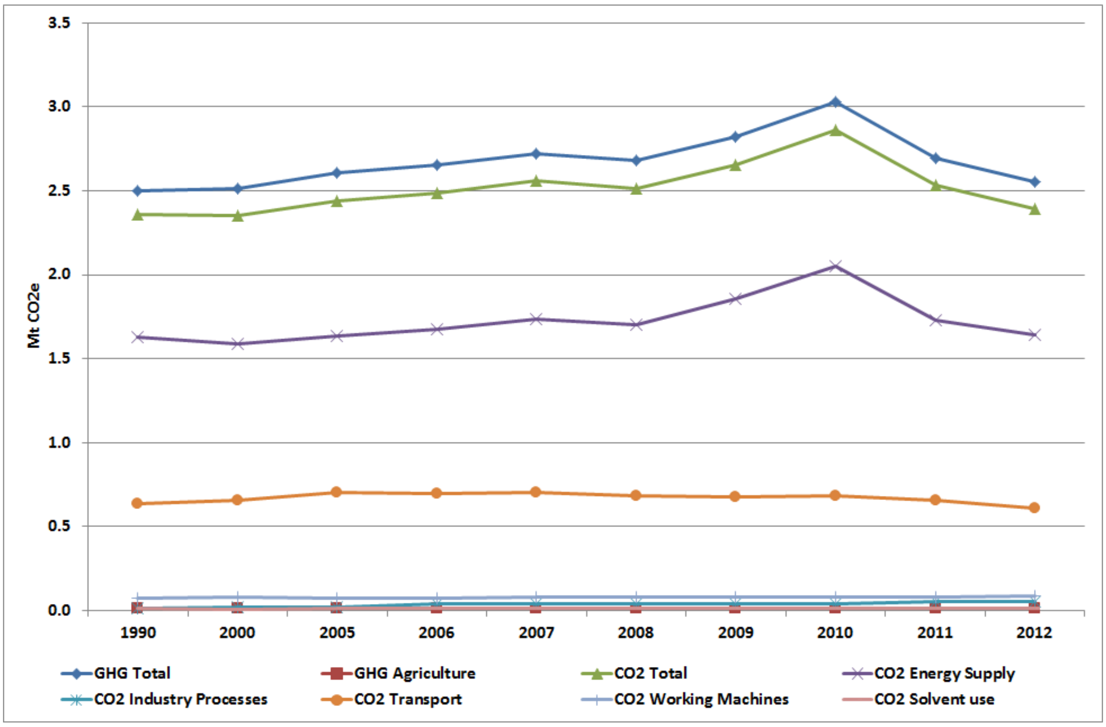

Figure 2.5: GHG and CO2 emissions by sector in the City of Göteborg 1990, 2000 and 2005-12, source: Länstyrelserna 2014.

Obviously, as stated above climate change will have an effect both on energy supply and demand for energy in the region but, as mentioned in Section 1, this has not been analyzed in this report.

It can be concluded that the energy intensive industry plays a large role in the region accounting for a substantial share of the regions final energy consumption, particularly in the county of VGR. The bulk of CO_2 emissions, 90%, originate from two sectors; transport and energy supply, the latter mostly as a consequence of the energy intensive industry located in VGR. The CO_2 emissions in the KASK-SE region have declined by 12% between 1990 and 2012, mostly due to increasing consumption of renewable energy for generation of DH and heat/steam to the industry.

3 Energy and Climate goals

This chapter outlines EU, national and regional (i.e. by county) goals with respect to emissions of GHG's, deployment of renewables and energy efficiency. In addition to goals on national and county levels, each municipality also have individual goals. Therefore this section also includes some of the corresponding goals for City of Göteborg, which, as mentioned, is by far the largest municipality in the region in most respects.

EUs climate targets are defined to comply with emission reductions required to limit global warming to 2 degrees Celsius. To meet this, the EU has defined the so called 20-20-20 targets to Year 2020, i.e. to achieve by 2020 a 20% reduction in GHG emissions relative to 1990, 20% share of renewables in energy consumption and 20% energy savings in consumption relative to a baseline projection for 2020. In the longer term, by 2050, the goal is to achieve 80 to 95% GHG emission reductions relative to 1990. In October 2014, the EU also agreed on intermediate targets to be reached by Year 2030; a 40% reduction in GHG emissions (again relative to 1990 emissions), an increase in the share of renewables to 27% of energy consumption and an indicative target of 27% savings in energy consumption, relative to projected energy consumption for 2020. Typically, national and regional targets relate to the EU targets, i.e. are similar or, in the case of Sweden, typically more ambitious than the EU targets.

3.1 Greenhouse Gas Emission goals

In 2011 the Swedish Environmental Protection Agency (EPA, NVV in Swedish) was commissioned by the Swedish Government to suggest a roadmap for how Sweden could achieve its goal of zero net GHG emissions in 2050 (NVV 2012). The Swedish EPA suggested two indicative scenarios of which the most ambitious with respect to absolute reduction is shown in Figure 3.1, the so-called "Target scenario 1".

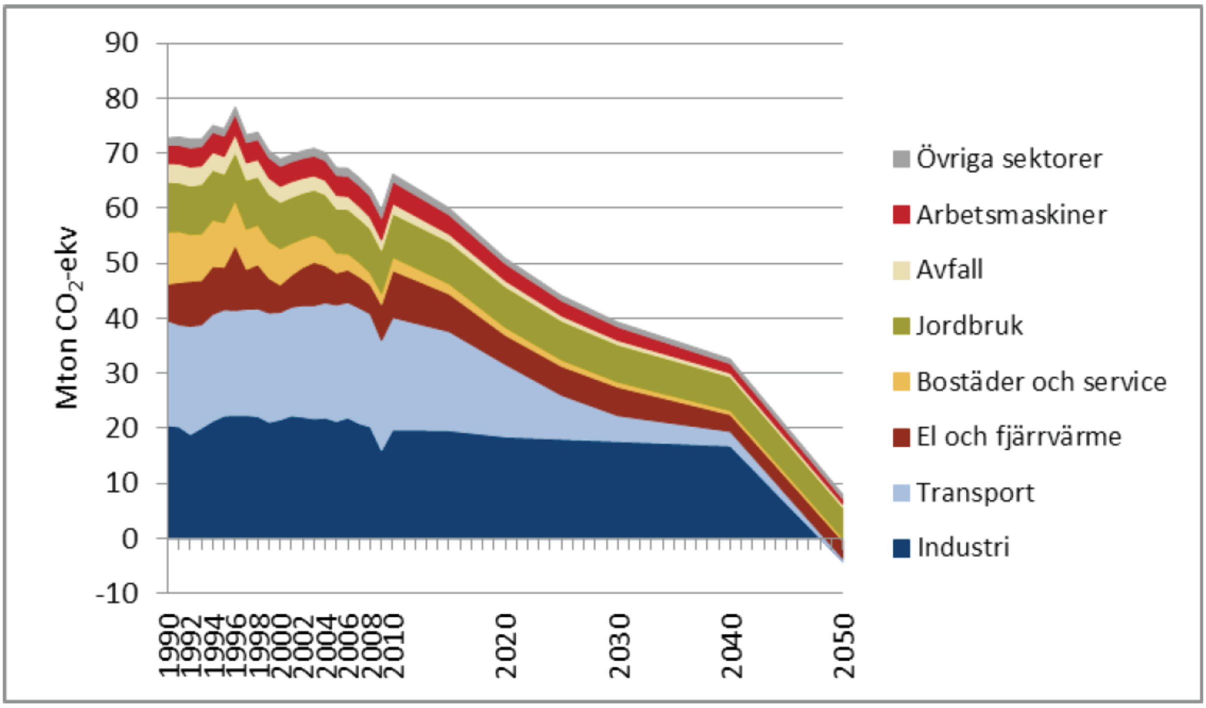

Figure 3.1: Indicative GHG emission reduction scenario (the so-called "Target scenario 1") provided by the Swedish Environmental Protection Agency in its "Basis for a Roadmap 2050" commissioned by the Swedish Government. The negative emissions are provided through biogenic CCS (Carbon Capture and Storage). Source: NVV (2012).

In the scenario depicted in Figure 3.1, emissions are reduced to ca 10 Mt CO2e in 2050. More than 20 Mt CO2 is captured and stored in the industry in 2050 using Carbon Capture and Storage (CCS) which is assumed to be applied at a large scale from 2040. Around 10 Mt CO2 is assumed to be captured from bio-based combustion (NVV 2012). In a second scenario ("Target scenario 2"), emissions are reduced to approximately 20 Mt in 2050 without the use of CCS. To reach zero net emissions the Swedish EPA suggests use of two more flexible mechanisms; increased uptake of CO2 from the forestry and land use sector and/or utilization of international carbon credits (NVV, 2012).

In January 2015, the new national Government (elected in late 2014) commissioned "Miljömålsberedningen" (i.e. a parliamentary committee) to develop a political framework for a long-term climate policy. The aim of the framework is to specify the rate at which Sweden will reduce its emissions, create clear incentives for the transformation to a climate friendly society and create a stable and predictable investment climate for business. Both Halland and VGR county follow the current national plan with regard to targets for GHG emission reductions, i.e.;

- 40% reduction of GHG emissions in 2020 relative to 1990 from sectors not included in the European Emission Trading Scheme (ETS)[3]. Additionally, the County Administrative Board in VGR (VGR 2014) has proposed 80% reduction by 2030, again relative to 1990 emissions.

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[3] According to Averfalk et al. (2014), the national plan envisions that one third of the targeted national emission reduction to 2020 could be taken through purchase of external emission credits suggesting that Halland only needs to reduce emissions by a further seven percentage points (140 kton) between 2012 and 2020 in order to reach the 2020 target. This is also proposed by the Swedish Environmental Protection Agency in its "Roadmap 2050" (NVV 2012) although not explicitly given as an option already in 2020.

- Sectors that are included in the ETS shall reduce their emissions by 21% in 2020 and by 43% in 2030, in both cases relative to year 2005 emissions (EC 2014)
- Net GHG emissions should be zero by the middle of this century. In order to reach this target, the Swedish Government has released proposition 2008/09:162 which states that Sweden will prioritize to achieve a "transport sector independent from fossil fuels" by 2030 (see Footnote 38).

More specifically and additionally, the CAB in VGR has proposed the following with respect to GHG emissions (VGR 2014);

- An economy not dependent on fossil fuels by 2030. This target has not been quantified.
- Road traffic: 40% reduction by 2020 and 80% by 2030
- Agriculture (excluding machines): 15% reduction by 2015 and by 2030.
- Energy supply and Industry processes should reduce their emissions by 25% by 2020 and by 80% in 2030.
- Machines: 25% reduction by 2020 and 80% by 2030.

The CAB in VGR (2014) has also proposed reduction targets related to consumption based emissions[4] suggesting that these emissions should be reduced from roughly 10 ton CO2e per capita and year (Swedish average 2003, NVV 2008) to less than 6 ton in 2020 and further to 2 ton and to between 0.5 - 1.0 ton in 2030 and 2050, respectively.

With respect to Halland county, Averfalk et al., (2014) claim that emission reductions beyond 2020 will be very hard to implement since these emission reductions will have to occur foremost within the transport and agriculture sectors and that the county therefore should build up a regional competence centre for these sectors. It is fair to assume that the challenge is similar also in other regions such as VGR.

Also in Göteborg, the main target up to 2020 is in line with the national target, i.e. emissions from sectors not included in the EU Emission Trading Scheme (ETS) should be reduced by 40% in 2020 relative to emissions in 1990. The required emission reductions include emissions from combustion of waste since these facilities were not included in the ETS when the target was decided. In 2012, emissions from sectors not included in the ETS had declined by 20% relative to 1990, from around 1.7 Mt to 1.3 Mt (City of Göteborg 2014a, b). However, as stated by City of Göteborg (2014a, b), such emissions are dependent both on weather and economic cycles and may therefore change significantly from year to year. Further emission targets announced by the City of Göteborg is for instance that in Year 2035, production and consumption based (see Footnote 4) emissions per capita should be reduced to a maximum of 2 and 3.5 ton CO2e per capita, respectively. This may be compared to today's corresponding emissions of ca 5 and 8 ton CO2e per capita. Finally, Göteborg has announced that they aim to reduce CO2 emissions from road and sea transport by at least 80% and 20% respectively in 2030 relative to 2010 (City of Göteborg 2014a, b). A few additional measures have been announced but these will have a relatively modest impact on total emissions.

3.2 Goals for renewable energy

The Swedish Government is aiming for that at least half the energy consumption in 2020 should be from renewables and at least a 10% share of renewable fuels in the transport sector. In 2012 renewable energy accounted for 51% of total energy consumption in Sweden while

[4] Consumption based emissions refer to emissions in VGR plus emissions outside VGR but caused by consumption in the region (VGR 2014).

the share of renewable fuels in the transport sector reached 12.6%[5]. Thus, Sweden has already reached the 2020 targets for renewable energy (The Swedish Government 2013). The Swedish target is part of the EU's common target of 20% renewables by 2020. In October 2014 the EU Council endorsed a binding target (on EU level) of 27% renewable energy by 2030. However, the Swedish Government has not, at the time of writing this report, announced a specific target for renewable energy beyond 2020. Both VGR and Halland have endorsed the national target for renewable energy in 2020 (County Administrative Board Halland 2012, VGR 2014). However, VGR is also proposing more ambitious targets aiming for a share of renewable energy in total energy consumption of at least 60% in 2020 and 80% in 2030, the latter as a consequence of the county's target of an economy independent from fossil fuels in 2030. Reaching a 60% share for renewables in 2020 is likely to be a great challenge since the share was only 41% in 2012 (VGR 2014). It should be emphasized however, that the more ambitious targets have not yet been decided as of early December 2014. VGR has also set several more specific RES targets such as the target of 5 TWh wind based power generation in 2020, up from 1.4 TWh in 2012.

Göteborg city is aiming for that all district heat (DH) should be produced from renewables, waste and industrial waste heat by 2030 and that Göteborg will produce at least 500 GWh renewable electricity and 1,200 GWh biogas, also in 2030 (City of Göteborg 2014a, b). According to City of Göteborg (2014b) this implies that DH produced by natural gas should be phased out and partly replaced by the above mentioned fuels and partly through energy efficiency measures leading to lower demand for heat. In 2012, the share of natural gas based DH generation in Göteborg was 29%, down from 47% in 2010. DH production in the City of Göteborg was 3.8 TWh in 2010, 3.1 TWh in 2011 and 2.9 TWh in 2012 but as mentioned in Section 2, the Year 2010 was a cold year (as was also 2009).

3.3. Energy efficiency goals

Both Halland and VGR county follow the national plan with regard to targets for energy consumption (County Administrative Board Halland 2012, VGR 2012b, 2014), i.e. 20% more efficient energy consumption in 2020 than in 2008 (measured as energy intensity, i.e. gross energy consumption divided by Gross Regional Product in 2008 prices).

Göteborg has an ambition that total annual primary energy consumption for generation of electricity and heat should be below 31 MWh/capita in 2030 representing a reduction of ca 10% relative to 2011. More specifically, primary fuel supply for heat production should be reduced by 17% from 6.3 TWh in 2011 while primary fuel supply for generation of electricity should be reduced by 6.4% from 4.4 TWh in 2011 (in both cases primary consumption corrected to normal year consumption).

4 Energy efficiency in energy-intensive industries

As mentioned above, the Swedish KASK region hosts a number of energy intensive industries. A mechanical pulp mill (for newspaper production), a Kraft pulp mill (producing market pulp, but not paper) and a large sawmill are located in Halland. In Göteborg there are two refineries, each with a capacity of slightly below 5 Mton/yr of crude oil. On the VGR coast, in Lysekil, there is a large refinery with a capacity of around 10 Mton/yr of crude oil.

[5] In fact, preliminary figures indicate that the share of renewable fuels in the transport sector in 2013 increased by another 3 percentage points from 2012 to 15.6% (The Swedish Government 2014).

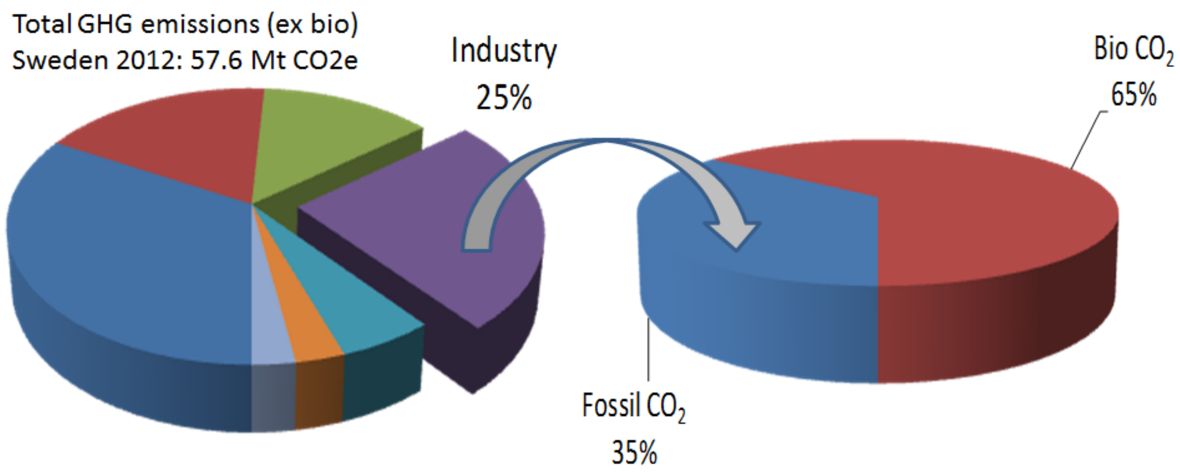


Figure 4.1: Total GHG emissions in Sweden in 2012 to the left (ex biogenic emissions) and to the right the share of fossil and biogenic GHG emissions in total Swedish industry emissions in 2012, source: Swedish Environmental Protection Agency.

There is also a cluster of chemical industries in Stenungsund where chemicals and polymers are produced.

The energy intensive industries have a key role to play regarding reduction of GHG emissions. In the Swedish KASK region, 4 industrial plants accounted for 30% of the fossil based CO2 emissions in 2010. The forest industry sector uses large amounts of energy mainly supplied from biomass and, thus, yielding biogenic CO2 emissions. In Figure 4.1 the right-hand graph shows that the forest-based sector (saw mills, pulp & paper mills) is a large part of the Swedish industry sector with biogenic CO2 emissions amounting to almost twice the amount of the fossil CO2 emissions from this sector.

Final energy usage in the Swedish industry in 2010 corresponded to approximately 36% of the Swedish total while energy usage in KASK-SE amounted to 20 % of the total energy used in Swedish industry of which 80% in VGR and the remaining 20% in Halland.

Industry can contribute in many ways to increasing energy efficiency and decreasing GHG emissions. Some of the most important measures that can be implemented include:

- Energy Management Systems.
- Best Available Technologies (BAT).
- Enhancement of internal process heat recovery.
- Combined Heat and Power (CHP).
- Exporting excess process heat to nearby district heating networks.
- Using excess process heat on-site for e.g. biomass drying, electricity generation, CCS or other energy-intensive processes.
- Switching to low carbon fuels/energy carriers/feedstocks.
- On-site integrated polygeneration concepts (e.g. biorefinery processes) CO2 separation for storage or reuse.

It is beyond the scope of this study to discuss possible options for key industries in the KASK region with respect to all of the above. The work has focused on energy efficiency options based on enhanced internal process heat recovery that could be achieved in the short to medium term. In the long term a mix of the measures listed above will be necessary in order to meet regional and national energy efficiency and GHG emission reduction targets. However, there is currently a lack of knowledge about which mixes of measures are most cost

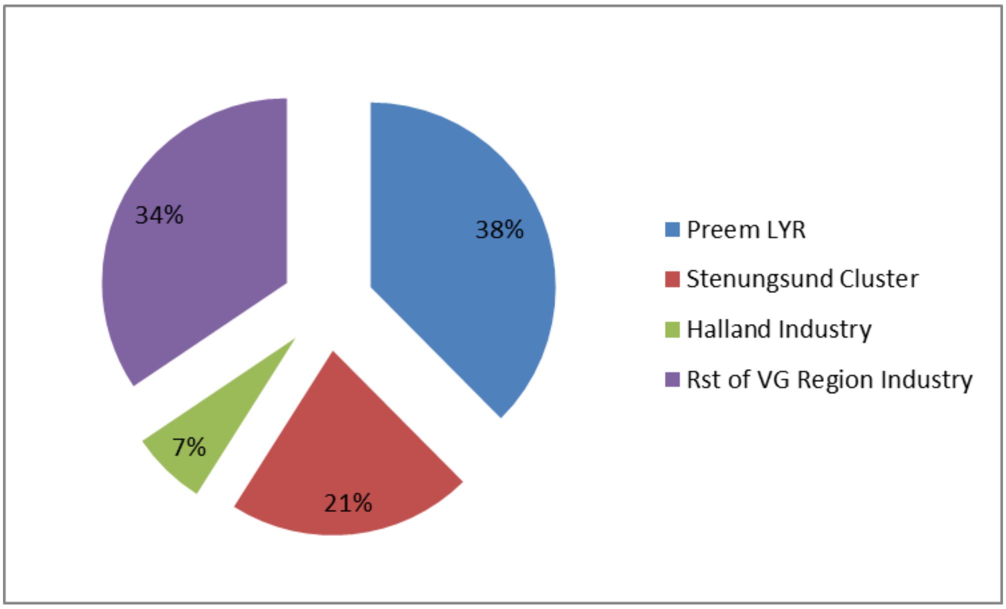


Figure 4.2: Fossil GHG emissions (2010) from the industry sector of the KASK Sweden region, source: Länsstyrelserna 2014.

efficient and likely to be implemented under given energy and climate policy conditions. It is beyond the scope of the current project to generate such complex roadmap visions. Hence, this part of the report focuses only on possible developments for the short term (2020) and the medium term (2030). However, it is likely that in order to reach emission reductions required in the longer term, i.e. to 2050, CCS or a complete or partial transformation to bio-refinery (or a combination of CCS and bio-refinery) will be required and this is discussed in Sections 8 and 9.

Figure 4.2 shows the contribution from industry to fossil GHG emissions in the KASK region from the industries in Halland, from the Preem refinery in Lysekil (Preem LYR), from the chemical cluster in Stenungsund and from the rest of the industries in the VGR county.

As can be seen from Figure 4.2 a large part of the emissions from the industry sector in the region are primarily from the industries in Stenungsund and from Preem's refinery in Lysekil. Thus these two sites were chosen for deeper analysis of possible energy efficiency measures. The two plants were studied using Pinch Analysis (PA) and Total Site Analysis (TSA). TSA represents an extension of the PA method and is applied to industrial sites to analyze increased energy efficiency via a common utility system (for a more detailed description of the study, see Harvey et al. 2014). By using these tools it is possible to analyze both the potential for saving energy and reducing emissions.

4.1. The Preem refinery in Lysekil

The Lysekil Refinery (LYR) is owned and operated by Preem and is the largest and most modern of the three refineries in VGR. It was built in 1975 but has since then been subject to a number of modernizations. Preem has started to initiate partial shift from fossil to biomass feedstock, primarily tall oil. However, this shift has so far been implemented in Preem's refinery in Göteborg and not in the Lysekil operations. Figure 4.3 shows that the processed oil at Preem LYR accounts for more than 50 % of the total processed oil in the three refineries in VGR in 2011. The fraction of the raw materials used for energy purposes in the refinery processes is only 5 %. However, due to the high throughput, this is still a large fuel

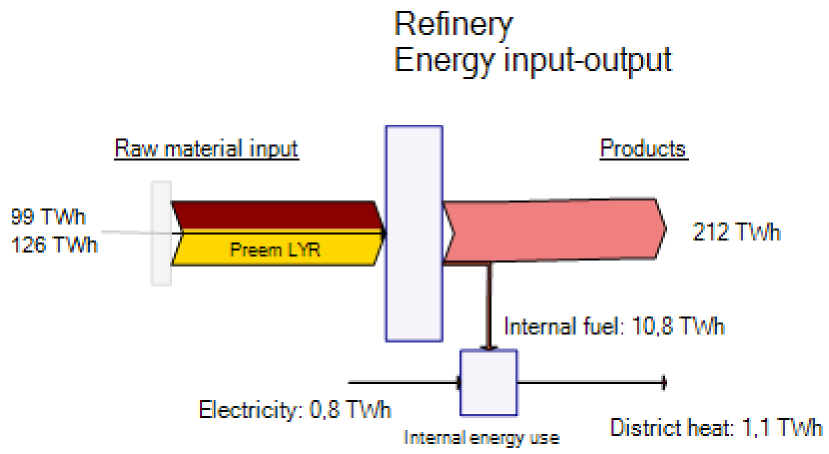


Figure 4.3: Annual energy flows at the three refineries in VGR including the energy embedded in the raw material and products. (Data from 2011).

consumption in absolute numbers for the three refineries in the region, 10.8 TWh in 2011 (see Figure 4.3) yielding corresponding CO_2 emissions of 2.7 Mt which account for 4% of total emissions in Sweden. CO_2 emissions for the Preem LYR refinery were 1.7 Mton in 2011.

At the refinery, the crude oil is separated into different fractions and transformed into desired products. A significant fraction of the internal energy usage is related to separation processes. Separation is carried out in distillation column units where heat is supplied to the column re-boilers and removed in the column condensers. A number of process streams are heated in furnaces and fired heaters. Excess process heat is mainly removed by air coolers. In addition there are a large number of heat exchangers to transfer heat between process streams.

Andersson et al., (2013) conducted an energy inventory and pinch analysis of the Preem refinery in Lysekil. The pinch analysis was used to calculate the theoretical energy savings potential for the refinery and to identify possible modifications required in order to decrease utility usage. Energy related data as well as process stream data were collected for all streams included in the process flow diagrams for all 18 refinery process units. The time point for process data collection corresponded to representative process conditions.

The results of the energy saving analysis reported in Andersson et al., (2013) depend on the constraints considered when conducting the analysis. To reduce the energy demand and approach the minimum heat demand, new heat exchangers must be installed to recover heat between process streams. However, there are often process or cost-related issues that hinder availability of streams for heat exchanging. Examples of such constraints include i) long distances between process streams that can result in prohibitively expensive piping and pumping costs; ii) operability issues if streams from different refinery process units exchange heat, particularly during start-up, shut-down and other types of transient operation and iii) risks associated with direct contact between process streams if leakage occurs in heat exchangers. Three different levels of constraints were considered when conducting the pinch analysis and the energy targets were established for the following cases:

A. No restriction for heat exchanging between streams within or between different process units. It is important to note that the necessary rearrangements in the heat exchanger networks will be substantial, and achieving this target is not feasible in practice.

B. No restriction for heat exchanging between streams within a process unit, but exchange of heat *between* process units is not allowed. The necessary rearrangements in the heat exchanger networks may be considerable.
C. Heat exchange is only allowed between streams heated or cooled by utility. However, this type of heat exchanging may occur between process units (heat must however be transferred indirectly using a heating media or utility) or within process units directly. All existing process to process heat exchangers are assumed to remain unchanged. The rearrangements in the heat exchanger networks should therefore be limited.

One way to find possible modifications to reduce energy demand is to identify heat exchangers that are not used in the most efficient way. Hot streams that need to be cooled should deliver their heat to a stream with a heat demand at as high temperature as possible. Pinch analysis can identify heat exchangers that are not delivering heat as efficiently as possible (hereafter referred to as *pinch violations*) and pinch analysis can also be used as a guiding tool to identify improved heat exchanger configurations.

4.1.1 Energy savings potential for Preem Lysekil

The total energy use in the refinery process units is 409 MW heat (3,580 GWh/yr assuming 8,500 h/yr of operation), supplied to process streams in heaters fired with fuel gas. Steam generated while cooling the process is used in part to heat streams elsewhere at the process site and in part for other purposes including co-generation of shaft power to run compressors and pumps.

Case A (unrestricted heat exchange between all process streams) results in a theoretical savings potential of 210 MW (1,785 GWh/yr). However, as discussed above, this is a highly theoretical energy saving target which cannot be achieved in practice.

For Case B heat exchanging is only allowed between process streams within the same process unit. This requires that the minimum heat demand must be calculated separately for each process unit. Since the heat exchange is restricted, the total minimum heat demand for the refinery process units is higher and the energy savings target is lower, 146 MW (1,240 GWh/yr).

For Case B, the refinery process units were also analyzed separately and it was thus possible to identify the process units with the largest energy savings potentials. Two units (Isocracker unit and Mild Hydrocracker unit) were selected for further analysis. The total combined external heat demand for the two units is 71 MW (604 GWh/yr). The results of the detailed analysis are described by Åsblad et al., (2014). The specific measures investigated could save at least 20 MW (170 GWh/yr) and, with extensive modifications of the heat exchanger network, up to 50 MW (425 GWh/yr). Revamp of existing units is associated with large investment costs, thus further investigation is required to identify the energy savings measures that are profitable. The proposed modifications include new heat exchanger units to recover usable excess process heat that is currently discharged in air coolers.

For Case C, heat exchange between process units is allowed for those streams which are currently heat exchanged with utility, based on the principles of Total Site Analysis (TSA, see Dhole et al., 1993 and Raissi 1994). Further amounts of excess heat can be recovered from streams currently cooled by utility and used to heat process streams presently heated with utility. In this analysis, only the five largest process units were considered. The combined current utility demand of these five process units is 363 MW (approx. 90 % of the total heat demand). This demand could be reduced to 306 MW, corresponding to an energy savings target for Case C of 57 MW (485 GWh/yr).

The savings potential stated above are all heat savings. Most of the heat demand in these process units is supplied by fired heaters and furnaces, and a reduced utility heat demand could thus reduce fuel gas usage in these units. Assuming a boiler efficiency of 80 % for fired heaters and furnaces, the corresponding fuel gas savings are between 212 and 531 GWh/yr.

Possible energy savings opportunities for Preem Lysekil that could be implemented in the short term include the suggested heat recovery measures in the isocracker and mild hydrocracker units or to increase heat integration between the different process units by implementing heat exchange through the site utility system (Case C). It is unlikely that the full savings potential for these units can be achieved in the short term. We therefore suggest that utility heat energy savings of 200 GWh/yr (5.6 % of the total heat supply to the process units) could be achieved by 2020, corresponding to 62 kton CO2eq/yr of reduced emissions, assuming natural gas as marginal fuel. Costs for implementing these measures were not available.

For the medium term (2030) it is reasonable to assume implementation of further measures to eliminate other pinch violations. Further study is necessary to identify specific additional heat integration opportunities between process units. We therefore suggest that 50 % of the theoretical heat savings potential for Case B could be achieved by 2030, i.e. 620 GWh/yr (17 % of the total utility heat energy supply to process units), corresponding to 192 kton CO2eq/yr of reduced emissions, again assuming natural gas as marginal fuel. Costs for implementing these measures were not available.

Long term opportunities to reduce CO2 emissions could include a bio-refinery plant unit for production of biofuels integrated with the present refinery or a CCS (carbon capture and storage) plant using excess heat from the refinery as heat source (see Sections 8.2 and 8.3). A previous investigation of CCS opportunities for the Preem LYR refinery indicated that there is a potential to capture 1,480 kton/yr of CO2 with an emissions avoidance cost in the range 50-53 €/ton of CO2 (Chalmers-Tel-Tek 2012).

The oil refinery in Lysekil has a large amount of excess process heat. Currently, only a small fraction of this heat (47 GWh/yr in 2008) are collected and delivered to the local district heating network in the nearby community in Lysekil. The community is small, and there are therefore no further opportunities to increase such deliveries. However, the potential for additional recovery of excess heat for district heating is substantial. Recent studies have estimated that up to 800 GWh/yr of excess heat are available at the refinery site at levels that are suitable for district heating purposes. This amount of heat is sufficient to satisfy the combined space heating demands of the cities of Uddevalla, Trollhättan and Vänersborg. The costs for collecting this heat within the refinery have been estimated at around 300 MSEK, and the costs for constructing a pipeline to the city of Uddevalla have been estimated at around 700 MSEK (Preem 2014). For a variety of reasons, there are no current plans to proceed with implementation of this opportunity.

4.2 Stenungsund Chemical cluster

The Stenungsund chemical cluster was established in the 1960’s. The companies involved and their main products are AGA Gas AB producing industrial gases, Akzo Nobel Sverige AB producing amines and surfactants, Borealis AB producing ethylene and polyethylene (PE),

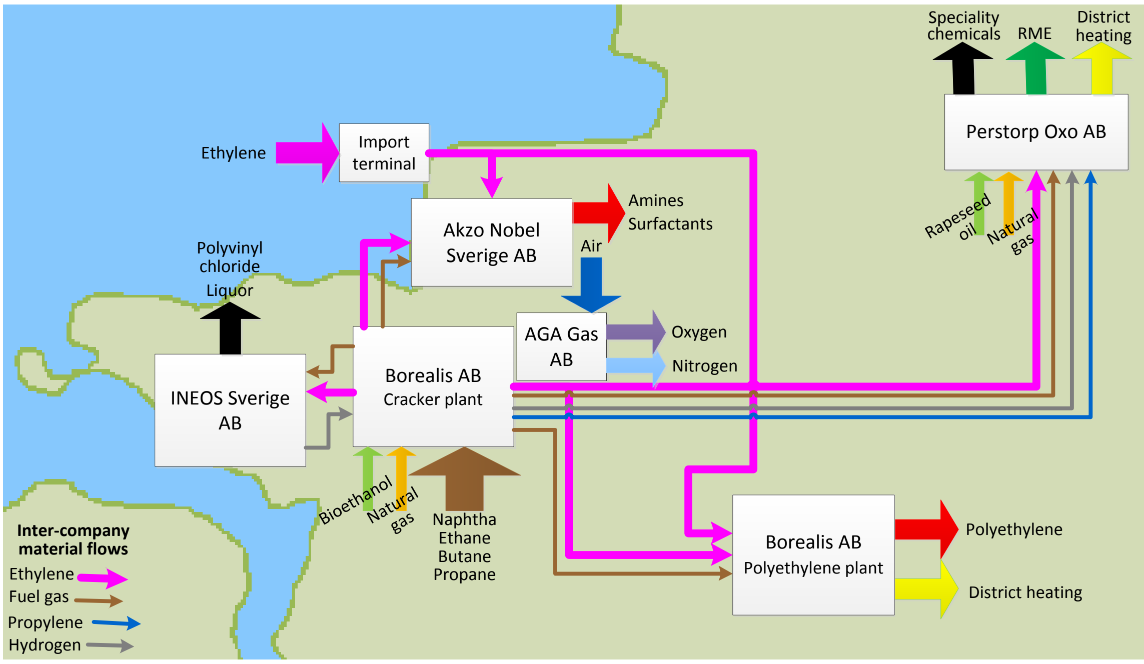


Figure 4.4: Overview of the chemical cluster in Stenungsund. For each company major inputs and outputs are shown (arrows), as are the material exchanges within the cluster. The nitrogen and oxygen produced by AGA Gas AB are used by the other plants in the cluster as well as exported.

INEOS Sverige AB producing polyvinyl chloride (PVC) and Perstorp Oxo AB producing specialty chemicals.

The process plants included in the cluster are profiled towards different business segments, thereby avoiding direct competition with each other, which facilitates cooperation and knowledge transfer. However, the plants are all owned by larger international groups which compete in some market segments. The cluster in Stenungsund is rather small by international standards. However, the cluster is strategically located within reach of the port of Göteborg (Sweden’s largest freight port), the natural gas grid (to which increasing amounts of biogas are fed), the oil refineries in Lysekil and Göteborg (producing the majority of Sweden’s transport fuels) and local district heating grids (to which excess process heat is currently delivered in small amounts). Furthermore, both pulp and paper industries and heat and power producers with ongoing ambitious projects regarding possible implementation of biomass gasification for production of energy carriers (heat, electric power and gas) and materials are located within the cluster’s reach. An overview of the cluster is provided in Figure 4.4.

The largest plant and the heart of the cluster is a steam cracker plant. It delivers both feedstock (mostly ethylene and propylene) and fuel gas to the surrounding plants. 23 % of the oil and gas fed to the cluster are used to satisfy the cluster’s internal energy demand. This generates 950 kton CO2e, 1.5 % of the Swedish national fossil CO2e emissions (2011). Figure 4.5 provides an overview of the main flows entering and leaving the cluster.

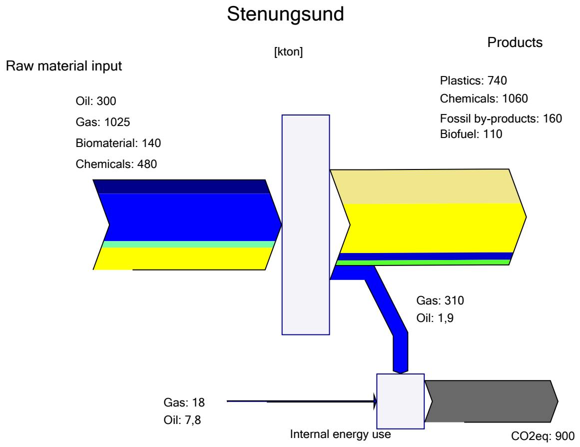


Figure 4.5: Annual mass flows (kton)within the chemical cluster in Stenungsund including raw material, product output, internal use, import of fuel and CO2 emissions. (Data from 2011).

The cluster consumes large amounts of electricity, 1.7 TWh/yr corresponding to 1.2 % of the electricity used in Sweden in 2011, compared to the three refineries in VGR that consume 0.8 TWh/yr. The fuel requirements for heat and power production within the cluster exceeds the amounts of process off-gases generated by the cluster processes, and some external fuels (oil and gas) must be purchased to satisfy the cluster requirements. District heat is delivered to the local community's district heating system.

An extensive amount of process data was extracted from the different plants in order to analyze energy flows within the cluster and to establish targets for energy savings (Harvey et al., 2014). The cluster's current consumption of external utility for process heating is approximately 129 MW (1,096 GWh/yr assuming 8,500 hours of operation). Total Site Analysis (TSA) was used to establish targets for the minimum heating and cooling demand of the overall cluster if it is assumed that excess heating and cooling capacity can be transferred from one plant to another via a common utility system. As no common utility systems exist at the chemical cluster in Stenungsund, TSA was also used to determine suitable common utility levels that could enable recovery of the maximum amount of process heat. TSA also provides insights necessary to make specific changes to the site's utility systems in order to reach the targets identified for the minimum heating and cooling demands.

4.2.1 Energy savings potential for the chemical cluster in Stenungsund

Pinch Analysis was first used to determine the energy savings potential for each individual process plant within the cluster. The sum of the individual process plant energy savings potential was estimated at 57 MW (484 GWh/yr).

TSA was then used to determine the energy savings potential for site-wide energy efficiency measures involving unrestricted heat exchange between the cluster plants. The results indicate energy savings potential of up to 140 MW (1,190 GWh/yr), i.e. more than twice the savings which could be achieved without energy collaboration between the companies (57 MW, as discussed previously). This result indicates that it is theoretically possible to eliminate the cluster's demand for hot utility produced in site boilers fired with purchased fuel. In order to achieve the energy savings for site-wide energy efficiency measures, the following measures are required:

- Implementation of a site-wide hot water circuit to distribute excess heat across the cluster

- Increased recovery of low pressure (LP) steam
- Changes in several coolers to enable steam generation at higher pressure
- Changes in several process heaters in order to operate with steam at lower pressure

In order to realize the 140 MW savings potential, extensive retrofitting of process heaters and coolers is required throughout the cluster site, as well as implementation of a complex utility network allowing exchange of hot water, steam and off-gas fuel streams between the different process plants and the harmonization of existing steam utility pressure levels throughout the cluster. In the short and medium term this was deemed infeasible.

A roadmap for heat recovery investments was formulated in order to identify a chain of investments that can achieve a significant fraction of the site-wide heat recovery potential in the long term. Five different promising systems were identified that can save between 20.7 MW (176 GWh/yr) and 54 MW (459 GWh/yr) of hot utility. The estimated payback period (PBP) of these systems lies between 3.2 and 4.2 years.

One of the five systems investigated, “System 20” enables utility savings of 20.7 MW (176 GWh/yr) and can be seen as a short term measure (i.e. by 2020) that also can be pre-fitted for future expansion resulting in a medium term solution (i.e. by 2030), e.g. System 50 (50 MW/425 GWh/yr of utility savings). Further energy savings beyond those achieved with System 50 are still possible in the long term, but were not investigated further in this work. CO2 emission savings were calculated assuming that increased heat recovery leads to decreased firing of natural gas in utility boilers. The estimated CO2 emissions reduction is 56 kton/yr for System 20 and 138 kton/yr for System 50 (see Harvey et al., 2014).

System 20 involves only two of the five companies, namely Borealis and Perstorp. In this system the Perstorp plant serves as a sink for excess Low Pressure (LP) steam from Borealis, while recovered excess process heat is delivered from Borealis PE to Borealis Cracker. System 20 only achieves a minor share of the total energy savings potential and it is thus considered as a first step towards more significant changes to the Stenungsund site.

Three companies, Borealis, Perstorp and INEOS are involved in the System 50 retrofit. Borealis PE and Perstorp mainly deliver excess process heat to Borealis Cracker, while INEOS serves as a sink for excess steam from Borealis Cracker. As mentioned above it is possible to extend System 20 towards System 50 if minor preparatory investments are taken.

A recent research project was conducted by Chalmers, SP and IVL in collaboration with the West Sweden chemical cluster (Berntsson 2015). The major focus of the study was investigation of the technical, economical and environmental consequences of building a heat collection system to collect excess process heat from the process plants in Stenungsund, and building a hot water pipeline to deliver this heat to Kungälv and Göteborg. More specifically, the overall main objectives of the project were:

- to analyze a possible future pipeline connecting the chemical cluster in Stenungsund to the district heating system in Göteborg and Kungälv, in terms of economic performance, climate consequences, general sustainability aspects and market design model consequences.
- to make an assessment of a corresponding pipeline from Värö to the Göteborg area.
- to assess different opportunities for using excess heat available at Preem’s refinery in Lysekil (this part is still ongoing, thus no results are currently available).
- to investigate the importance of different types of policy instruments on excess heat usage.

Costs were estimated for collecting up to 170 MW of excess process heat within the chemical cluster in Stenungsund. This information was used as input in a model of the complete energy system of West Sweden. The system cost reduction achieved by implementation of a hot water pipeline from Stenungsund was shown to vary considerably with different scenarios and assumptions. In some cases, there is no cost reduction. However, with very favourable assumptions of main parameters, especially regarding biomass prices, pipeline cost and investment interest rate levels, this cost reduction was shown as potentially being up to 130 million Euros over the studied time period, 2020-2050.

4.3 Summary of key results

Major measures are necessary if industry is to reach the GHG emission reduction targets set out by the EU for year 2030. In this report, we have investigated energy efficiency opportunities, as well as corresponding reduction of GHG emissions, for two key industrial plants located in the KASK region in Sweden. Key results from the study are summarized in Tables 4.1 and 4.2.

Table 4.1: Summary of Energy Savings Opportunities for the Industrial Plants in KASK-SE.

	Energy Use 2012, GWh	Savings Potential 2020, GWh	Savings Potential 2030, GWh
Preem Lysekil	3,580	200	620
Stenungsund	1,096	176	425
Total	**4,676**	**376**	**1,045**
Fuel savings 80% boiler efficiency		**470**	**1306**

Table 4.2: GHG emission reduction potential (kton) key Industries KASK-SE.

	GHG emissions 2009	Estimated Reduction Potential 2020	Estimated Reduction Potential 2030
Preem Lysekil	1,700	62	192
Stenungsund	950	56	138
Total	**2,650**	**118**	**330**

In the short term (i.e. by 2020), the EU target is to reduce GHG emissions by 20%, compared to 1990 levels.

The emission reduction potentials for Preems refinery in Lysekil and the chemical cluster in Stenungsund are in the range of 4% to 6% (emissions for Year 2020 compared to emission levels in 2009).

In the medium term, EU targets call for emission reductions of 40% by 2030 (compared to 1990 levels). As shown in Tables 4.1 and 4.2, the potential energy efficiency savings described in this report are clearly insufficient to enable the selected industrial plants to comply with this target. Furthermore, it is important to note that the measures required to reach the levels of enhanced energy efficiency discussed in this report are complex and require substantial investments. We conclude that enhanced heat recovery within the selected process plants is not sufficient to reach the EU emission reduction targets, and that reaching these targets will require combinations of energy efficiency measures and other measures such as:

- Complex heat recovery projects including several process plants and delivery of excess heat to integrated regional district heating networks

- New and more efficient process technology
- Fuel switching in utility boilers and process furnaces
- Increased use of bioenergy and biocarbon feedstock
- Application of CCS

In the long-term, industry must aim for radical change, including switching to biomass feedstock (within the limits of availability), adopting new process technology and implmenting ambitious programmes for maximizing process energy efficiency. Where possible, CCS should be implemented.

Finally, it should be noted that a number of projects in line with the proposed measures listed above are ongoing in energy-intensive process plants in the KASK-SE region. For example, Preem Lysekil has recently switched to LNG as feedstock for the refinery's main hydrogen unit. This measure is expected to decrease emissions by 130 ktons/yr. The ST1 refinery in Göteborg is in the process of constructing a new plant for production of ethanol from organic residuals streams. The plant (capacity 5 millions litres/yr) is expected to be operational by 2015. Assuming that the bio-ethanol produced in this plant has similar well-to-wheel emissions as conventionally produced bio-ethanol, the estimated GHG emissions reduction will be 5.2 ktons/yr, assuming that the ethanol replaces oil-based gasoline and that the biomass feedstock can be assumed to be climate neutral. The chemical cluster in Stenungsund has adopted an ambitious vision for 2030, which implies complete switch from fossil feedstock to biogenic feedstock. However, at this point there are no specific large-scale projects ongoing which will contribute to achieving this vision.

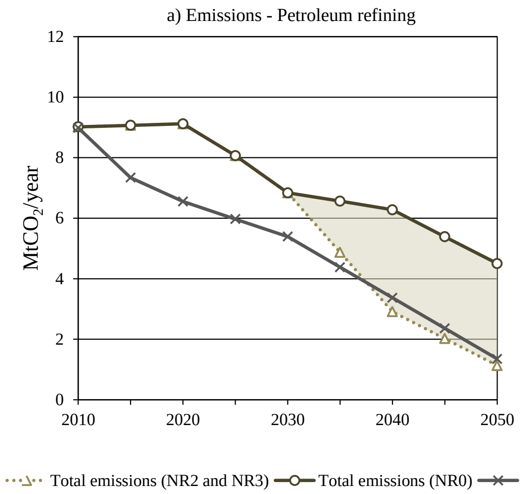
4.4 Discussion

Johansson et al., (2012) assessed strategies for CO2 abatement in the European petroleum refining industry and Rootzén et al., (2013, 2015) have explored long-term (up to year 2050) opportunities for CO2 emissions abatement in three Nordic and European industry sectors; the petroleum refining, iron and steel as well as cement production sectors. Rootzén et al. (2013) assessed the prospects for achieving regional and EU level targets for CO2 emissions, with a focus on short term (2020), medium term (2030) and long term (2050) perspectives.

Johansson et al. (2012) and Rootzén et al. (2013) highlight three trends with implications for the refineries in the KASK-SE region: (1) For the refinery industry policies aimed at transforming the transport sector will, obviously, be crucial for defining the scope for action. While the actual policy measures are yet to emerge, policymakers in both Sweden and Norway have repeatedly proclaimed their commitment to promoting a transport sector that is independent of fossil-fuel consumption, which in the case of KASK-SE is planned for as early as Year 2030.; (2) Within the transportation fuel segment, the market for middle distillates (i.e., diesel and aviation fuel) is assumed to continue to expand at the expense of lighter distillates (i.e., gasoline); (3) Simultaneously, the regulations governing product quality and environmental specifications (e.g., sulfur content and aromatics) are assumed to be progressively tightened . Both the two latter trends would involve increased processing intensity and consequently, increased energy use.

In the KASK-SE region there is one cement plant. The plant is located in Skövde and emits around 360 kt CO2 per year. However, the Skövde plant may be forced to close down after March 2017 since the environmental district court in Vänersborg in May 2014 rejected continued operation at the limestone quarry associated with the cement plant at the site. Assuming that the cement plant in Skövde will continue to operate beyond 2017, there are currently three main options for reducing CO2 emissions associated with cement manufacturing; continued improvements of thermal and electric efficiencies, increased use of biomass based fuels to replace coal and pet-coke and continued reduction of the share of cement clinker in the finished cement. Rootzén et al., (2015) estimates that an ambitious implementation of these measures could potentially half the specific emissions (t CO2/t cement) from the Nordic cement industry. However, the study also emphasizes that to achieve more far reaching CO2 emission reductions CCS will need to be introduced.

Johansson et al. (2012) and Rootzén et al. (2013) conclude that presently available technologies are sufficient for refineries and cement plants to achieve short term emission reduction targets, but that novel low-carbon technologies (including Carbon Capture and Storage) and production processes will be necessary to meet more stringent medium and long term reduction targets. Rootzén et al. (2015) assess the prospects for Nordic carbon-intensive industries to achieve significant reductions in direct CO2 emissions in the period 2010 to 2050. Their results indicate that an ambitious deployment of CCS could result in emissions reductions that are in line with stringent emission reduction targets required to the year 2050. However, large-scale introduction of CCS would come at a significant price in terms of energy use and the suggested flows of captured CO2 would place high requirements on timely planning of infrastructure for the transportation and storage of CO2. More specifically, for the petroleum refining sector, Rootzén et al (2015) assume the following: (1) a steady decline in output from the Nordic refinery industry; (2) the most complex refineries, which are more capable of adapting to changing markets, endure the longest; and (3) the internal fuel mix remains largely unchanged throughout the studied period. They also assume that the Nordic refineries with the least flexibility will be phased out and that increased processing intensity will offset the effects from energy conservation measures and result in an increase in specific energy usage (GJ/t throughput) in all cases. Figure 4.6 shows the results obtained for the Nordic refinery industry with respect to emission reductions (a) and energy usage (b).



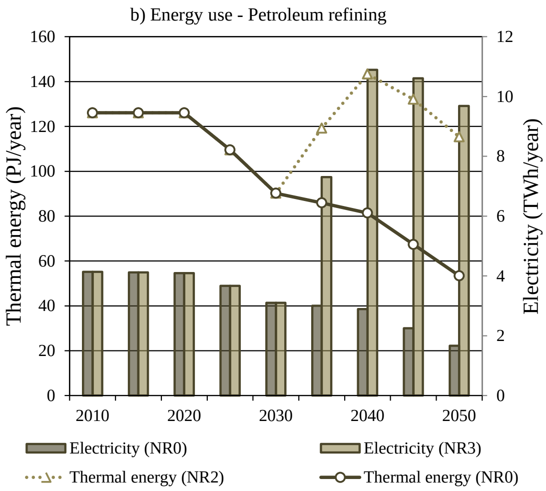


Figure 4.6. Estimated levels of CO2 emissions and energy usage from the Nordic petroleum refining industry in the period 2010–2050, as obtained in Rootzén et al., (2015). The base case (NR0) assumes a steady decline in output from the Nordic refinery industry without any deployment of CCS. Cases NR2 (post-combustion) and NR3 (oxyfuel combustion), in addition to the abatement measures in the base case, assume the deployment of CO2 capture from Year 2030. (a) Estimated CO2 emissions from Nordic refineries in the period 2010–2050, with (dashed line) or without (solid line) the introduction of CCS. The emission cap for the period 2010–2050 (crossed solid line) corresponds to the total number of emission allowances allocated to Nordic refineries for the period 2010–2020 and the proposed reduction targets for Year 2030 and Year 2050. (b) Estimated development of thermal (solid/dashed lines) and electrical (bars) energy usage with (light brown) or without (brown) the introduction of CCS. From Rootzèn et al. (2015).

Thus, there is a high complexity in the numerous factors that drive energy usage and CO2 emissions in industry and hence it is difficult to perform long-term extrapolation from results obtained from bottom-up studies conducted for individual industrial process plants.

5 Energy savings potential in buildings

In this section a bottom-up modelling approach has been applied to assess energy savings potential in the building stock in KASK-SE. This has been done by calculating the energy consumption of a representative number of individual building types and extrapolating the results to represent the region. Section 5.1 explains the applied methodology in brief. A more extensive description is found in the technical paper associated with this work (Mata et al., 2014). Section 5.2 describes the results which are then being discussed in Section 5.3 while main conclusions are highlighted in Section 5.4.

5.1. Methodology

The building stock of KASK-SE has been divided into 414 different representative buildings based on a national dataset representing the entire building stock in Sweden (Mata et al., 2013a; Grundsell, 2013); 183 single-family dwellings (SFDs), 119 multifamily dwellings (MFDs) and 112 non-residential (NR) buildings. The number of representative buildings is determined by a combination of building types, construction periods and climate zones. The national dataset is downscaled by updating the weighting coefficients with respect to the number of buildings (given in Statistics Sweden 2014b) and heated floor areas in the KASK-SE region (the latter is not available at regional level and has been obtained from the national dataset by assuming direct proportion to the population of the region given in RegionFakta, 2011). To characterize the buildings the physical properties of the buildings and their energy use (for hot water, lighting and appliances) are assumed to be the same as in the national dataset due to lack of information of data representative for the region. As mentioned above a more comprehensive description of the applied methodology is provided in Mata et al., (2014).

In KASK-SE electricity is generated mainly by hydro, nuclear and biomass, the latter mostly in combined heat and power plants producing both electricity and district heat (DH). In addition DH is mostly produced from biomass and waste combustion (59%), heat pumps (12%), and waste heat (11%). Single-family dwellings are mostly heated by electricity or biomass, while over 90% of multifamily dwellings use DH. DH is also the dominating heating carrier (over 70%) for non-residential buildings. The Final Energy Consumption (FEC) by type of buildings and type of energy carrier is simulated with a building-stock model (ECCABS – Energy, Carbon and Cost Assessment of Building Stocks; Mata et al., 2013b). The FEC has been validated by comparison to available statistics for residential and non-residential buildings. While the modelled FEC for non-residential buildings agrees rather well with the literature (-6% deviation from the data in Swedish Energy Agency 2012a), for SFDs and MFDs the modelled FEC is 20% higher and 22% lower than statistics (Swedish Energy Agency 2012b, c). These deviations within the subtypes could be caused by deviations in the above-mentioned estimated distribution of heated floor areas within the representative buildings in the KASK region or by the fact that the buildings chosen within the Swedish KASK region are not representative of all buildings in the region (in spite of being representative of a particular segment of all Swedish buildings). Regarding the distribution of FEC per end-use and fuel type, a direct comparison to statistics is not possible; thus, the modelled values have been compared to corresponding values for the building sector estimated in the Reference Energy System (Johnsson J., et al., 2014). Such a comparison results in relatively large differences, which can be explained by uncertainties both in the RES source data and in the source data for the bottom-up analysis used in this section (see for instance Footnote 7). All uncertainties are listed and discussed in the technical report by Mata et al., 2014).

The FEC obtained from the modeling should be seen as an estimate. Yet, these data have been used as basis for an estimation of the CO2 emissions and quantification of potential reduction in energy use from application of energy conservation measures (ECMs). For the latter, the ECCABS model (Mata et al., 2013b) is used to assess a portfolio of ECMs (Energy Conservation Measures) yielding the technical potential for savings in energy demand from the building sector in the region.

Table 5.1 shows the estimated current FEC in the building sector of the two counties as obtained from the ECCABS simulations.

From the analysis presented in this section, Table 5.1 gives that FEC in the building stocks in VGR and Halland amounts to 23.6 and 4.5 TWh, respectively. The residential buildings take up most of the demand, with SFDs using in total around twice the amount of final energy

Table 5.1. Final energy consumption (TWh/yr) in year 2010 by building type and in total as estimated from the ECCABS model. It should be noted that the values are subject to the uncertainties in the input data used. Observe that sums may not add up due to rounding.

Final Energy Consumption	**Västra Götaland**				**Halland**			
TWh/yr	**SFD**	**MFD**	**NR**	**All**	**SFD**	**MFD**	**NR**	**All**
FEC								
Space Heating	8.7	2.6	4.7	16.0	1.7	0.5	0.9	3.1
Hot Water	0.8	0.5	0.7	2.0	0.2	0.1	0.1	0.4
Electricity	1.4	0.9	3.2	5.5	0.3	0.2	0.6	1.0
Total	**10.9**	**4.0**	**8.7**	**23.6**	**2.1**	**0.8**	**1.6**	**4.5**
FEC by fuels								
El (heating)	3.5	0.2	0.4	4.0	0.3	0.2	0.5	1.0
El (non-heating)	1.4	0.9	3.2	5.5	0.7	0.0	0.1	0.9
El (all purposes)	**4.8**	**1.1**	**3.6**	**9.5**	**1.0**	**0.2**	**0.7**	**1.9**
Oil	0.1	0.1	0.2	0.3	0.0	0.0	0.0	0.0
Gas	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.1
Biomass	4.3	0.0	0.1	4.4	0.8	0.0	0.0	0.9
Coal	-	-	-	-	-	-	-	-
District Heating	0.8	2.5	4.1	7.5	0.1	0.4	0.8	1.3
Other	0.8	0.3	0.7	1.9	0.2	0.1	0.1	0.4
Total	**10.9**	**4.0**	**8.7**	**23.6**	**2.1**	**0.8**	**1.6**	**4.5**
Energy need								
Space Heating	8.7	2.4	4.3	15.5	1.7	0.5	0.8	2.9
Hot Water	0.7	0.5	0.7	1.9	0.1	0.1	0.1	0.4
Electricity	1.4	0.9	3.3	5.6	0.3	0.2	0.6	1.1
Total	**10.8**	**3.9**	**8.3**	**23.0**	**2.1**	**0.7**	**1.5**	**4.4**

compared to MFDs. Together, the residential buildings account for 63% of FEC compared to 37% for non-residential.

The majority of energy is used for space heating. For SFDs, electricity is the dominant heating source in most of the dwellings followed by biomass. For MFDs, DH is by far the most common heating source in most of the dwellings followed by electricity, i.e. similar to the general pattern in Sweden with DH covering a large part of heating in the cities and in densely populated areas (where MFDs are in majority). For non-residential buildings the main heating sources is DH followed by electricity. For all building types, other fuels represent around 10% of demand.

In Sweden both electricity and heat is generally associated with low CO2 emissions. Electricity is mainly generated from hydropower and nuclear and with increasing amount from renewables, mostly wind and biomass and waste fired combined heat and power plants. The two latter still only generates somewhat more than 10% of the national electricity supply (160 TWh). For heat, most is generated by renewables in district heating (a bit more than 40 TWh nationally) and with additional heat generation from biomass and peat (15 TWh) and from oil products (15 TWh). In addition, significant amount of electricity (around 20 TWh) is also used for heating (heat pumps and direct heaters/electric boilers). It is obviously not straight forward to determine which CO2 emissions should be associated with the different energy carriers. Electricity is for example traded on a common Nordic market whereas heat is typically produced in local markets such as in district heating systems or in domestic boilers. A reduction in electricity use will therefore have implications outside the region, possibly leading to that electricity generated from fossil fuels in continental Europe can be reduced whereas a reduction in demand for district heating reduce the use of fuel in the district heating system. These “fuels” can, as is the case in the City of Göteborg, to a large extent be in the form of waste heat and a reduction in the use of such heat will typically not be straightforward to use elsewhere. If on the other hand there is less renewable fuel burnt for heating, these can be used elsewhere and, thus, possibly replacing fossil fuels somewhere else. In summary, it is not obvious what will the effect be on CO2 emissions from a reduction in the use of district heating due to reduced energy needs in buildings. Yet, in this work, CO2 emissions were calculated based on the emission factors given by the Swedish Environmental Protection Agency (NVV, 2014). For electricity and district heating these factors are based on the average production mix for electricity and DH respectively in Sweden. The choice of applying these emission factors is based on that, as indicated previously, this work only looks at the direct emissions from the region. For electricity and district heating the national production mix yields slightly different emission factors than the regional ones and this is discussed in Section 5.3. Table 5.2 shows the emissions by consumption, when applying the emission factors to the simulation results of the fuel use in the buildings of the KASK-SE region.

Table 5.2. Annual CO2 emissions (ktCO2e) per building type in year 2010, obtained from the simulations in this work. It should be noted that the values are subject to the uncertainties in the input data used and that the sums may not add up due to rounding.

Annual emissions	VGR				Halland			
(kton CO2e)	SFD	MFD	NR	All	SFD	MFD	NR	All
El (heating)	51.9	3.6	3.6	59.0	11.0	0.7	0.6	12.3
El (non-heating)	20.0	13.4	49.2	82.6	3.8	2.5	9.1	15.3
El (all purposes)	**71.9**	**17.0**	**52.7**	**141.6**	**14.7**	**3.2**	**9.7**	**27.7**
Oil	27.4	21.8	47.9	97.2	5.0	0.0	8.7	13.7
Gas	5.0	0.0	6.8	11.8	0.8	13.8	1.2	15.9
Biomass	42.5	0.1	1.1	43.7	8.4	0.0	0.2	8.6
District Heating	57.8	175.8	288.5	522.1	7.6	28.4	52.9	88.9
Other	98.1	34.3	84.9	217.3	18.3	9.4	15.6	43.3
Total	**302.7**	**249.1**	**482.0**	**1033.7**	**54.9**	**54.9**	**88.3**	**198.1**

Average CO2-emissions for a SFD is 1.0 tCO2e/yr in VGR and 0.8 tCO2e/yr in Halland. For MFDs average emissions amount to 0.7 and 1.2 tCO2e per year and dwelling for VGR and Halland respectively. DH accounts for 50% of total building related emissions in VGR and for 45% of corresponding emissions in Halland. Corresponding shares for electricity is 14% in both counties.

A portfolio of ECMs (Energy Conservation Measures) is analyzed to assess the technical potential for savings in energy demand from the building sector in the region. The assessment is done with the above mentioned building-stock model ECCABS (Mata et al., 2013b). The ECMs have been investigated at national level within the so-called BETSI program (Swedish national board of housing, building and planning, 2009). Table 5.3 lists each separate ECM that has been applied in this work (for a more detailed description see Mata et al., 2014).

Table 5.3. ECMs that have been applied to the building stock in this work.

ECM	**Description**
1	Change in U-value of cellar/basement
2	Change in U-value of facades/external walls
3	Change in U-value of attics/roofs
4	Replacement of windows
5	Upgrade of ventilation systems with heat recovery
6	Reduction of power for lighting
7	Reduction of power for appliances
8	Replacement of hydro pumps with more efficient ones
9	Reduction in power used for the production of hot water
10	Lowering of indoor air temperature

ECMs 1 to 4 assume an improvement of the building envelope, i.e. a lower mean U-value of the building by adding insulation to, respectively, the cellar, wall, roof and/or windows. For residential buildings, the assessments of the optimal level of insulation have been done for each building by the Swedish National Board of housing (2009). The additional layers of insulation material are therefore different for the various buildings. For non-residential buildings, an additional insulation layer of 300mm is assumed. When replacing the windows

(ECM 4) it is assumed that the new window will have a U-value of 1.1 W/m^2K, both for residential and non-residential buildings.

ECM 5 – For residential buildings, ventilation systems with heat recovery are installed with an efficiency of 75% and specific fan power (SFP) values of 1.5 kW/m^3s. For non-residential buildings, the new system is expected to have an efficiency of 85%. The SFP is set to 1.5 kW/m^3s, and heat losses from the fan of 20% are expected.

ECMs 6 and 7 – For residential buildings, a decrease by 50% in the electricity consumption for lighting and appliances is assumed. For non-residential buildings, the lighting load is expected to decrease by 25%.

ECM 8 – It is expected that new circulation pumps are 25% more efficient than the current ones.

ECM 9 – By installing aerator taps, the power demand for hot water production is expected to decrease to 0.80 W/m^2 for SFDs and 1.10 W/m^2 for MFDs. For non-residential buildings, it is assumed that the how water demand can be reduced by 30%.

ECM 10 – Lowering of indoor air temperature to 20 °C from the current indoor temperature of 21.1°C in SFDs and 22.3°C in MFDs. This is normally not considered an energy efficiency measure but an energy saving measure.

All ten ECMs listed in Table 5.3 may be applied to all non-residential buildings. For residential buildings, the Swedish National Board of Housing (2009) has assessed to what extent each of the ECMs can be applied and this is listed in Table 5.4[6]. The listed share is based on heated floor area.

Table 5.4 Share of heated floor area in the residential building stock where each of the ECMs is assumed to be implemented.

ECM	Building Envelope				Ventilation	Electricity			Hot Water	Indoor temp.
	1	2	3	4	5	6	7	8	9	10
Share of building stock affected	59%	52%	49%	60%	88%	100%	100%	43%	100%	100%

Several measures may be applied at the same time in order to achieve larger energy savings while also saving time and costs. Three different "packages" of measures have therefore been investigated in this work:

- ECM package 1 - insulation of the full building envelope (ECM 1-4)
- ECM package 2 - reduce power demand for lighting, appliances and pumps (ECM 6-8)
- ECM package 3 - all ten measures, i.e. the maximum potential for the 10 ECMs listed in Table 5.3.

[6] The Swedish National Board of Housing (2009) does not provide an explanation to how they have derived the shares of the residential buildings given in Table 5.4.

5.2. Results

Figure 5.1 shows the technical potential in reductions in FEC for each county for the residential and non-residential sector divided between ECMs (Nos. 1 to 10) and packages of ECMs (Packages 1 to 3).

From Figure 5.1 it is clear that the largest potential for reductions in FEC can be realized by upgrading the ventilation systems (ECM 5), followed by reducing the indoor temperature (ECM 10) and improving the U-value of the building envelope (ECM 2-4). For the NR buildings, Figure 5.1 indicates that an upgrade of the ventilation systems (ECM 5) will lead to large energy savings. However, heat recovery has not been included in the baseline assumptions which may lead to higher energy demand for the ventilation than what has been calculated here. In case heat recovery is underestimated, the potential savings would be lower than the ones shown here.

The measures targeting electricity consumption show lower savings potentials. ECMs 6 and 7 (lighting and appliances respectively) yield savings of around 10% and 30% respectively in electricity demand for residential buildings and 9% to 12% for non-residential buildings. However, due to the increased heating demand that will come with the saved electricity (see Tables 5.5 and 5.6), the savings in total demand are only in the order of 0% to 2%. The expected savings from upgrading the hydronic pumps (ECM 8) are small (less than 3% of electricity demand).

The maximum technical savings potential corresponding to ECM package number 3 (some 15 TWh as can be seen in Figure 5.1) distributed by county and by fuel/source is shown in Figure 5.2.

Tables 5.5 and 5.6 show calculated savings in net and final energy demand for the three packages of measures, i.e. package number 1 to 3 for residential and non-residential buildings respectively.

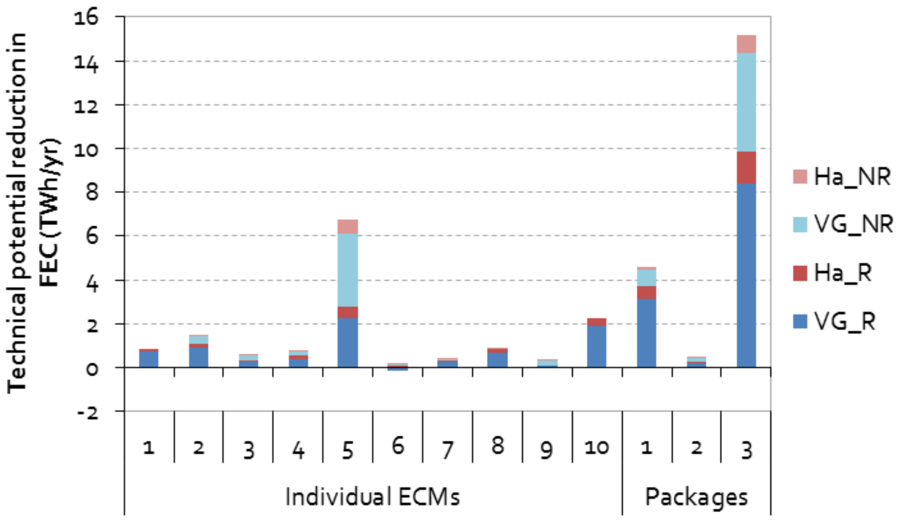


Figure 5.1. Technical potential for reductions in Final Energy Consumption (TWh/yr) for VGR (VG) and Halland (Ha) for residential (R) and non-residential (NR) buildings for each ECM (numbered 1 to 10) applied individually as well for application of the three packages of ECMs (numbered 1 to 3).

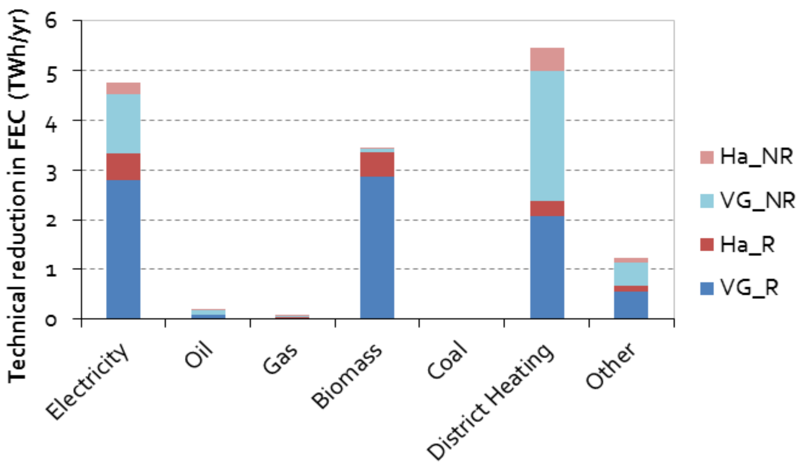


Figure 5.2. Maximum technical potential for reductions in Final Energy Consumption (TWh/yr, ECM package number 3) by county and by fuel/source.

Table 5.5. Annual potential energy savings for the packages of measures when applied to residential buildings. It should be noted that sums may not add up due to rounding and that the values are subject to the uncertainties in the input data used.

Annual Energy Savings	**Västra Götaland**						**Halland**					
(TWh/yr and %)	**Package 1**		**Package 2**		**Package 3**		**Package 1**		**Package 2**		**Package 3**	
Net Energy	**TWh/yr**	**%**	**TWh/yr**	**%**	**TWh/yr**	**%**	**TWh/yr**	**%**	**TWh/yr**	**%**	**TWh/yr**	**%**
SpaceHeating	3.5	26	-0.9	-7	7.3	55	0.6	26	-0.1	-7	1.2	54
HotWater	0.0	0	0.0	0	0.8	52	0	0	0.0	0	0.1	52
Electricity	0.0	0	1.2	43	1.1	40	0	0	0.2	43	0.2	38
Total	**3.5**	**20**	**0.3**	**2**	**9.2**	**52**	**0.6**	**20**	**0.0**	**2**	**1.5**	**51**
Final Energy												
El (all purposes)	0.6	10	0.8	13	2.7	46	0.1	11	0.2	13	0.5	44
Oil	0.0	14	0.0	-8	0.1	44	0.0	6	0.0	-11	0.0	28
Gas	0.0	0	0.0	-8	0.0	38	0.0	23	0.0	-7	0.0	62
Biomass	1.7	39	-0.1	-3	2.5	58	0.3	37	0.0	-3	0.5	57
District Heating	0.7	20	-0.3	-9	2.0	61	0.1	21	0.0	-9	0.3	59
Other	0.0	1	-0.1	-9	0.6	49	0.0	5	0.0	-9	0.1	52
Total	**3.0**	**20**	**0.2**	**2**	**7.9**	**53**	**0.6**	**20**	**0.0**	**2**	**1.5**	**51**

Table 5.6. Annual potential energy savings for the packages of measures when applied to non-residential buildings. It should be noted that sums may not add up due to rounding and that the values are subject to the uncertainties in the input data used.

Annual Energy Savings	Västra Götaland						Halland					
(TWh/yr and %)	Package 1		Package 2		Package 3		Package 1		Package 2		Package 3	
Net Energy	TWh/yr	%	TWh/yr	%	TWh/yr	%	TWh/yr	%	TWh/yr	%	TWh/yr	%
Space Heating	0.8	15	-0.6	-11	3.5	64	0.1	14	-0.1	-11	0.5	63
Hot Water	0.0	0	0.0	0	0.2	28	0.0	0	0.0	0	0.0	27
Electricity	0.0	0	0.9	23	1.3	33	0.0	0	0.1	23	0.2	33
Total	**0.8**	**8**	**0.3**	**3**	**5.0**	**49**	**0.1**	**8**	**0.0**	**3**	**0.8**	**49**
Final Energy												
El (all purposes)	0.0	1	0.8	20	1.4	34	0.0	1	0.1	20	0.2	34
Oil	0.0	13	0.0	-9	0.1	63	0.0	6	0.0	-6	0.0	58
Gas	0.0	6	0.0	-5	0.0	61	0.0	0	0.0	0	0.0	33
Biomass	0.0	12	0.0	-8	0.1	66	0.0	10	0.0	-5	0.0	57
District Heating	0.7	14	-0.5	-10	3.1	64	0.1	13	-0.1	-10	0.5	64
Other	0.1	14	-0.1	10	0.6	64	0.0	13	0.0	-10	0.1	64
Total	**0.9**	**9**	**0.2**	**2**	**5.3**	**52**	**0.1**	**8**	**0.0**	**2**	**0.8**	**52**

ECM package 3, implying that all ten ECMs are implemented, indicates FEC savings potential of 13.2 TWh in VGR and 2.3 TWh in Halland combined for residential and non-residential buildings. Corresponding annual savings potential for ECM 11 is 0.9 and 0.1 TWh in VGR and Halland respectively while for ECM package 2 it is 218 and 34 GWh respectively. Thus, it can be concluded that while the potential savings are modest with regard to package 1 and 2, the potential is significant for package 3.

As can also be seen from Tables 5.5 and 5.6 potential savings in total net energy demand from the measures related to upgrading the building envelope (ECM package 1) are 20% for residential buildings but only 8% for non-residential buildings. When it comes to ECM package 2, i.e. the measures targeting electricity demand, the potential savings are also larger for the residential buildings compared to the non-residential buildings. One reason for this is that the assumed decrease in electricity demand for appliances has been set to 50% in residential buildings but to only 25% in non-residential buildings assuming that equipment for lighting and appliances is already more efficient and better managed and controlled in NR buildings than in residential buildings.

Table 5.7 shows calculated CO2 emission reduction potentials per ECM and ECM package and by county for residential and non-residential buildings and corresponding to the energy savings potentials defined above. As mentioned above, the emission reduction potential is based on application of national average emission factors for coal, gas and oil and for production of electricity and heat given by NVV (2014). The emission factors are given by Mata et al., (2014). As mentioned above, this work only concerns direct emissions from the region and therefore we do not consider the overall system effect of CO2 emissions from a change in fuel, i.e. as obtained from a reduction in fuel use due to application of the energy conservation measures.

Table 5.7: Calculated emission reductions in absolute values (kton CO2e/yr) and relative to the baseline. It should be noted that the values are subject to the uncertainties in the input data used.

		VGR				Halland			
		Residential		Non-residential		Residential		Non-residential	
ECM	ECM #	kton CO2e	%	kton CO2e	%	kton CO2e	%	kton CO2e	%
Building envelope	1	32.7	5.1	-	-	5.4	4.9	-	-
	2	36.0	5.6	32.4	5.7	5.7	5.2	4.2	3.9
	3	13.2	2.1	20.9	3.7	2.2	2.0	2.3	2.1
	4	2.7	0.4	16.3	2.9	7.2	6.5	1.7	1.6
Ventilation	5	123.9	19.4	289.6	50.6	29.4	26.9	41.3	37.7
Electricity	6	-21.4	-3.4	-14.4	-2.5	2.2	2.0	-1.4	-1.3
	7	-13.8	-2.2	-19.9	-3.5	-3.0	-2.7	-2.2	-2.0
	8	3.7	0.6	0.5	0.1	0.5	0.5	0.1	0.1
Hot water	9	41.4	6.5	18.6	3.3	7.1	6.5	2.2	2.0
Indoor temp	10	92.5	14.5	-	-	15.6	14.2	-	-
Packages	1	17.0	15.5	69.7	12.2	17.0	15.5	8.7	7.9
	2	-28.0	-4.4	-36.1	-6.3	-4.2	-3.9	-4.0	-3.7
	3	343.7	53.7	343.3	59.9	57.8	52.7	48.6	44.4

As can be seen from Table 5.7, applying all ten measures (ECM package 3) may reduce emissions by almost 690 ktons in VGR (i.e. 344 + 343 kt) and by more than 100 ktons in Halland (i.e. 58 + 49 ktons) which combined correspond to 7.5% of total CO2 emissions in the region. Installation of ventilation with heat recovery (i.e. ECM 5) is the single most efficient measure with regard to reduction potential, emissions may be reduced by almost 485 kt if applied to both residential and non-residential buildings in VGR and Halland (124 + 290 + 29 + 41 kt), thus alone representing more than 60% of the entire emission reduction potential if all measures are being implemented.

Some of the measures actually lead to an increase in emissions (ECM 6 and 7 and ECM package 2) since the reduction in demand for electricity lead to an increase in demand for space heating which in turn yields the higher emissions, when applying the emission factors used in this work.

5.3 Discussion

As explained above, both VGR and Halland are targeting a 20% reduction in primary energy demand by 2020.The results of this work show that it is technically possible to reach this target in the building sector.

Figure 5.3 illustrates the estimated range in technical, techno-economical and market potential for energy savings in the building sector in KASK-SE. The technical potential refers to Package 3 derived in Section 5.2 while the techno-economical potential refers to ECMs where the cost of implementing the ECMs is lower than the cost of the corresponding energy consumption that is saved. Market potentials are taken to represent the potentials that are expected to be implemented if the consumers react as historically observed when making decisions on home energy retrofitting, and are estimated by using higher interest rates, i.e. so-called implicit discount rates as obtained from the literature [18%–308% in Newlon et al.

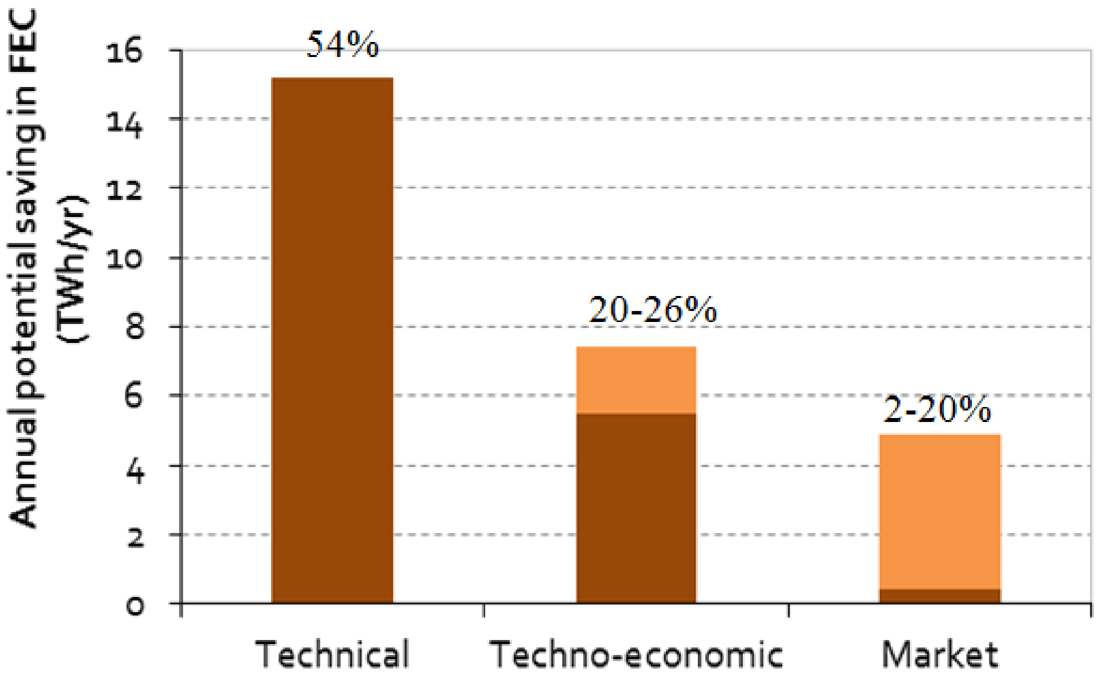


Figure 5.3 Total technical, techno-economical and market potential (TWh/yr) for reductions in final energy consumption as obtained in this work for the building sector of the Swedish KASK region. The ranges given in percentages refer to energy savings potential relative to estimated FEC in the Year 2010 (28.1 TWh). The market potential is an indirect estimate using different implicit interest rates derived in literature.

(1991); 50%–80% in Bailie et al. (1996); 20%–65% in ERG (1998); and 35% in Jaccard (2009)]. Therefore, the market potentials have been approximated with a sensitivity analysis using discount rates up to 80% (disregarding the large value of 308% which refers to installation of thermostats only).

For the 15.2 TWh/yr identified as technical potential in Section 5.2 (ECM package 3), only 5.5 – 7.4 TWh/yr is identified as a techno-economical energy saving potential. The market potentials are significantly lower and the indirect estimate made in this work yields a range of 0.4 to 5.8 TWh/yr. This indicates that other policy actions than what has previously been in place are necessary to accelerate the implementation of energy saving measures, if the technical and techno-economical potentials identified in this work should be reached. The corresponding CO2 emission reduction potential is of course also reduced drastically, from the 790 kt CO2e derived in Section 5.2 to between some 330 and 440 kt in the techno-economic case and to between only a few tens of kilotons to almost 300 kt in the market case.

The actual implementation of the measures will of course depend on the technical and physical characteristics of each single building. For instance considering retrofitting of the facades and other parts of the building envelope, Boverket has described how 39% of the non-residential buildings at national level have cultural/historical features which, to some degree, will hinder the possibilities for upgrades of the facade (Swedish National Board of Housing, 2010).

CO2 emission reduction potential for electricity production has, in this study, been based on the national average production mix. Applying instead the regional production mix, emissions should be slightly higher in VGR (higher share of natural gas and oil than the national average) and slightly lower in Halland (higher share of nuclear and biomass generation than the national average) compared to the national mix. Yet, electricity is generated and traded on the Nordic market (Nordpool) which is also connected to the European electricity system with the main policy governing the emissions being the Swedish-Norwegian Green certificate market and the EU emission trading scheme (EU-ETS). Thus, the resulting emissions and how these should be accounted for depend on the development of the Nordic and European electricity markets.

Regarding the goal for the region to become independent of fossil fuels by 2030, the results also give some insights. Electricity and DH represent 71% of the final energy demand for all buildings and there is a substantial production of natural gas based generation of electricity and DH in VGR. The remaining part is covered by biomass and oil. Reducing demand for electricity and DH will of course lead to that less fossil fuels will need to be burnt within the region but more important will be to replace the fossil fuels burnt to generate electricity and DH as well as replacement of the oil burners in SFDs. This is analyzed in Section 8.

5.4 Conclusions

A description of the building stock in the KASK region of Sweden has been established together with a first validation of this description. The validation has been done by comparing final energy consumption obtained from the modelling in this work (using ECCABS building-stock model) with available statistics, as described in Section 5.1. A validation of the number of buildings and heated floor areas at the regional level has only been possible by assuming, in the statistical data, the same share in the number of buildings and floor areas as for Sweden, i.e. scaling these numbers proportional to population (i.e. KASK-SE is 17% of Swedish population). Although it has been possible to apply the existing methodology for modelling of the building sector in the KASK-SE region, the lack of regional statistics disaggregated per building type and energy carrier, results in an uncertainty in the input values for the modelling work. Therefore, there is a need for improved and detailed statistics on the building sector of the region, in particular with respect to the number of buildings, their heated floor areas, technical characteristics and fuel use. Such statistics would facilitate an increased understanding of the existing building stock and its link to the energy system which in turn would constitute a better base for an analysis of how the building sector in the region can be transformed. Nevertheless, using the modeling of this work, the final energy consumption in the building stock in KASK-SE has been estimated to 28 TWh[7], 68% of which is used for heating, 9% for hot water and 23% as household electricity. SFDs account for 44% of total final energy demand while MFDs account for 20% and non-residential buildings for 36%.

10 different ECMs were investigated, individually and as applied in packages. The modeling identified that the largest potential for energy savings is related to installation of new ventilation systems with heat recovery, followed by improvements in the building envelope and lowering of the indoor temperature. With regard to building type, the largest potentials for energy savings are of course found in the building categories representing the larger shares of the building stock, which are the SFDs.

The three packages of measures investigated; overall improvement of the building envelope (ECM package 1), decrease in power for lighting and appliances (ECM package 2) and

[7] This can be compared to “actual” energy demand in the building stock in 2010 as given by the Reference Energy System, i.e. 29 TWh (Johnsson J., 2014).

implementation of all ten ECMs (ECM package 3) yield a final energy savings potential ranging from 0.25 TWh (Package 2) to 15.5 TWh (Package 3).

Assessing the economic feasibility of the potential energy savings identified in ECM package 3, the technical potential of 15.5 TWh was reduced to between 5.5 and 7.4 TWh when considering the techno-economic case while an indirect estimate gives a market potential between 0.4 and 5.8 TWh.

6 Large-scale integration of renewable electricity generation

In this section we analyze the potential for large-scale integration of renewables in the power sector. Sections 6.1 to 6.4 analyze and discuss the potential for hydro, wind, bio/waste and solar from a "bottom-up" perspective and in a local context while Section 6.5 applies Chalmers Electricity Investment Model (ELIN) from a European "top-down" perspective to analyze the prospects and possibilities for renewables in the power generation sector in KASK-SE in a European context. Analyzing integration of renewables in a European context follows from the fact that the North European power sector is more or less fully integrated meaning for instance that raising renewable capacity in KASK-SE may reduce coal based generation in northern Germany. In addition, there is a common Nordic market for electricity (Nordpool) and Sweden and Norway have a common market for Green certificates, further enhancing the integration of the electricity market.

6.1 Hydro

As of end 2013, there is some 16.5 GW hydropower installed in Sweden. A small part of this is installed in the KASK region, some 512 MW in VGR and 211 MW in Halland (Kjärstad et al., 2007, Swedish Energy Agency 2014b). In 2010, 1,972 GWh hydro based electricity was generated in VGR and 818 GWh in Halland while some 67 TWh hydro based electricity was generated in Sweden as a whole. These values will vary significantly depending on yearly precipitation (wet, normal or dry year) and normal year production in Sweden is estimated to around 65 TWh. Yet, there is a significant technical potential for expansion of hydro power in Sweden, at least some 10 TWh on an annual basis according to the Royal Swedish Academy of Sciences (2009) while according to Vattenkraftmiljö (2003) there is a techno-economic potential of up to 90 TWh total hydro power generation in Sweden, i.e. some 25 TWh additional production capacity. However at least for the moment, the bulk of the sites that can be expanded are protected by the Swedish Environmental Code (Royal Swedish Academy of Sciences 2009). Finally, there is a potential through upgrading of existing hydro plants, estimated to between 3 and 5% of normal years production by for instance Länsstyrelsen Dalarna (2013). Most of the expandable potential is located in Northern Sweden and a few smaller projects are under development but not in the Swedish KASK region as of late 2014, at least to the knowledge of the authors of this report. Thus, expansion of hydropower is not considered in the analysis for the Swedish part of the KASK region.

6.2 Wind

Wind power has been booming in the KASK-SE region over the last few years with for instance VGR being the county in Sweden having the largest installed wind power capacity among all counties at the end of 2013 at almost 700 MW. However, existing wind turbines are all installed onshore in spite of that the KASK-SE region has good conditions for offshore wind power. Apart from more wind, offshore sites will usually also provide more evenly distributed wind conditions over time than onshore sites, i.e. resulting in lower variations in the aggregated generation.

At the end of 2013, there was a total of 6.6 GW offshore wind capacity installed in the EU, of which 92% or 6 GW in four countries; Belgium, Denmark, Germany and UK. However, offshore wind capacity constituted only 6% of total wind capacity in the EU at end 2013. At the time of writing this report there are no offshore wind farms in the KASK-SE region while at the same time plans to build two large-scale offshore wind farms have recently been rejected by the region’s Land and Environmental court, namely Kattegat and Vindplats Göteborg offshore wind farms. In the former case, the court rejected the wind farm due to environmental concerns and poor project economics (Sveriges Radio 2014). In the latter case the risk of spread of contaminated dredged material, impact on outdoor activities and possible future widening of the marine fairway to Göteborg was quoted as reasons for rejecting the project. Both decisions have been appealed. According to the Swedish Energy Agency’s latest update of areas recognized as being of national interest for wind farms, two offshore areas in the region have been identified as interesting; namely Skottarev and Stora Middelgrund, both located off the coast of Halland. Strangely enough, the Kattegat offshore wind farm which was recently rejected by the region’s Land and Environmental court is located at Skottarev.

Due to that the costs for offshore wind power is significantly higher than onshore (see for instance Elforsk 2014 and Swedish Energy Agency 2014c) and the siting is governed by different parameters in a rather complex way (e.g. influence of the marine environment, sea depth and acceptance by the public and other organizations) offshore wind is not included in the analysis. Nevertheless, it should be recognized that the Government in December 2014 commissioned the Swedish Energy Agency to set up proposals on how support for offshore wind should be designed to create conditions for the expansion of offshore wind power (Ministry of the Environment and Energy, 2014).

The prospects for onshore wind power in the KASK-SE region has been analyzed in two ways; a “top-down” approach as part of the modelling of the European power sector (see Section 6.5) and a “bottom-up” approach through mapping and analyzing of available land surface and local wind-power resources as reported in this section. The first approach estimates the efficient expansion of wind power in KASK-SE depending on different European energy and climate policy setups, while the second approach aims at estimating the potential for wind power in the region by taking a detailed look at geographical conditions of the region. The outcome of the second approach, thus, determines the limits of the outcome of the first approach, i.e. the calculated and cost-efficient expansion of wind power within the region may not exceed the estimated potential.

To estimate the available land surface and, thereby, the potential for onshore wind power in the region, a number of conflict areas were identified. The lion share of this assessment is based on a GIS-methodology using the ArcInfo software. The conflict areas are defined as areas where wind-power installations are considered as not being possible or feasible for different reasons. In total, more than 30 different conflict areas were analyzed in the present analysis. These areas include lakes and seas, densely populated areas, roads, environmental and cultural protection areas, airports, and recreational areas. Buffer zones or safety distances, i.e., minimum distances to, for example, roads or densely populated areas, have been added to several conflict areas, thereby further reducing the available land surface (Unger et al., 2014a).

It is important to point out that we have defined, a priori, the conflict areas as “no-go” areas for onshore wind-power installations. In some cases, this is obvious, while in other cases it may not be as obvious. For example, in the case of areas that are linked to tourism, one might argue that there could be room for wind power, at least to a limited extent. In particular, the conflict area termed “densely populated area” is highly uncertain. For what population density is it reasonable to assume that wind-power installations are unlikely? We know that we have to establish some limit, since conflicts with near-by inhabitants are common in cases of wind-power installations. In our analysis, we have investigated population densities of 10 persons/km^2 and 50 persons/km^2. This means that for population densities of more than 10 or more than 50 persons per km^2, respectively, wind power installations are assumed to be unfeasible. Following this definition, “10 persons/km^2” represents a larger conflict area than “50 persons/km^2”.

To check the validity of the defined conflict areas, we took a closer look at existing wind-power turbines and at planned wind-power turbines in the Swedish part of the KASK region. The aim was to identify the number of single turbines that were placed in our conflict areas. For a high number, one might suspect that our choice of conflict area is less appropriate or, in fact, that certain “conflicts” are inevitable when expanding the number of wind turbines in a given region. In VGR there are currently (Autumn 2013) 471 operating turbines and 1,567 turbines under development. Thus, the numbers seem sufficiently high to produce a fair quality check. In Figure 6.1, we present the share of all existing wind power turbines that are placed in a conflict area according to the defined conflict areas. Each conflict area is denoted on the x-axis.

Executing the same exercise with planned wind turbines it can be stated that, in general, <10% of existing and planned turbines are placed, or are planned for placement, in a conflict

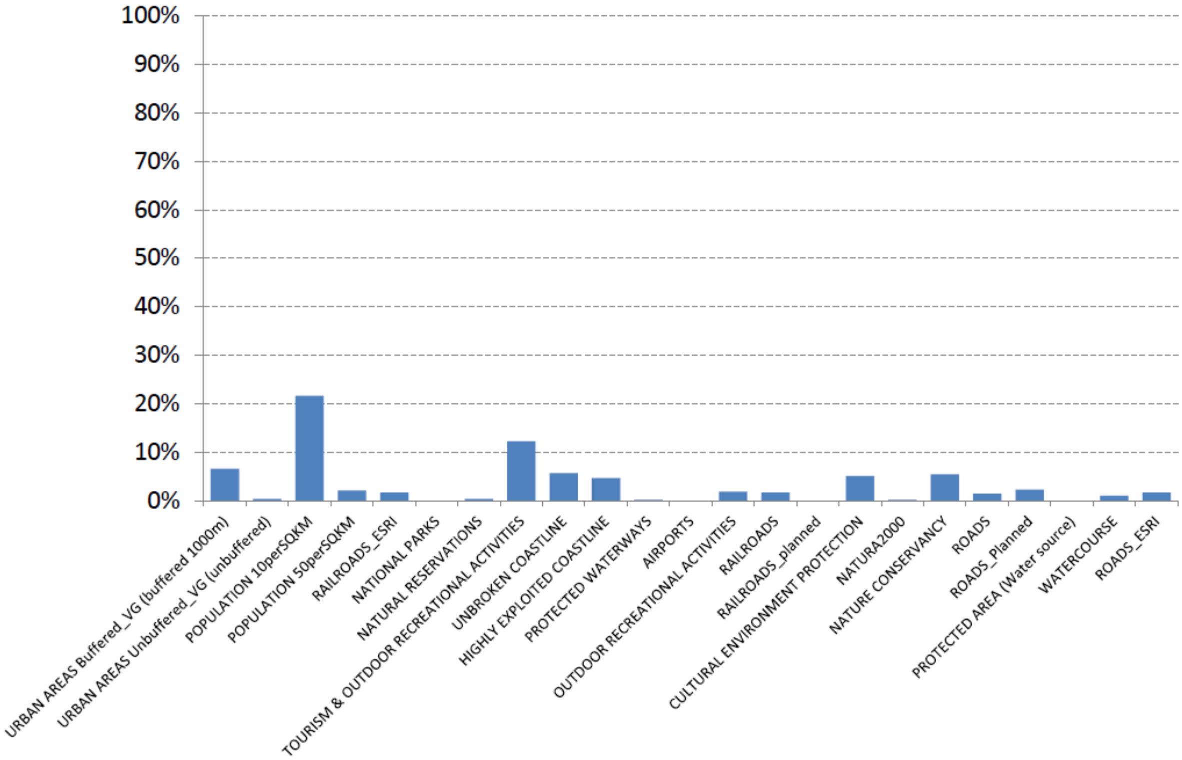


Figure 6.1: The shares of number of total existing wind turbines in VGR that are in conflict with the conflict areas indicated on the x-axis.

area that accords with our definition. This gives us reason to believe that our choice of conflict areas is appropriate. However, the dataset may also be interpreted as exhibiting some “true conflicts”, since our conflict areas are not entirely free of wind turbines. Furthermore, the numbers of the wind turbines placed in some conflict areas exceed the “threshold” of 10% of the total installed number. This applies especially when the population density of 10 persons/km^2 is chosen as a conflict area; in such a case, around 20% of the existing turbines are in conflict with other interests (in this case urban areas). In contrast, choosing areas with a population density higher than 50 persons/km^2 as conflict areas yields very few “conflicts” (approximately 1%).Therefore, in the final analysis, we chose the intermediate density of 30 persons/km^2 as the limit for a densely populated area that is not suitable for wind-power installations.

Based on these findings, it may be concluded that there are fewer conflicts for planned wind turbines than for existing turbines. This indicates that the process of choosing a site for wind power has improved or attained greater importance, at least if we consider our definition of conflict areas. Another part explanation could be that alternative land use has emerged some time after the installation of a wind turbine or a wind farm. Thus, existing turbines are ”in conflict areas” even though they originally were not. The quality check described above was also performed for the Swedish county of Halland. Although there are fewer wind turbines in Halland than in VGR, the results for Halland follow a similar pattern albeit with even fewer conflicts being identified (Unger et al., 2014a). Nevertheless, in reality some of our defined conflict areas, e.g. areas linked to tourism and cultural protection, are associated with wind power installations, both existing and planned. Other conflict areas are entirely free of wind power installations such as national parks. To what extent a certain area may be considered as a conflict area or not, varies significantly between areas and, thus, adds to the uncertainty of the analysis. However, our analysis clearly shows the impact of ruling out certain areas and including other areas as potential sites for wind power installations. Thereby, we may estimate available land surface and, thus, the potential for onshore wind power given the, in some cases, large uncertainty concerning alternative land use.

The GIS modelling shows that approximately 43% of the original geographical area of the Swedish part of the KASK region remains as potentially available after the surface reductions mentioned above. These results take into account the buffer zones surrounding the conflict areas, so as to reflect safety and publicly acceptable distances from wind-power installations, as discussed above. The results are reported in Table 6.1 (here we assume that our “final estimate” of >30 persons/km^2 as the conflict area defines conflicts with densely populated areas).

The GIS modelling of available land area has then been correlated with mapping of wind resource availability compiled at Chalmers. This latter data set allocates wind availability to a very large number of grid cells (single spatial cells of 200-700 km^2) covering the entire EU,

Table 6.1. Estimated potentially available land surface for installation of wind turbines in KASK-SE applying the conflict areas defined in this work (30 persons/km^2 and omitting conflict areas such as roads, rivers, cities etc).

	Total land area km^2	land area available for wind, km^2	land area available for wind, % of total
County of Halland	6 044	3 143	52%
County of Västra Götaland	28 269	11 483	41%
KASK SE	34 313	14 626	43%

Norway and Switzerland. The data originates from the wind-speed database managed by ECMWF (European Centre for Medium-Range Weather Forecasts). Data is valid for hub height of around 100 meters.

Combining wind availability and available land surface area for wind-power installations in each grid cell reveals the extent of possible and profitable wind-power investments in the region. In Figure 6.2, the full-load hours for each grid cell are arranged in decreasing order. Full-load hours are defined as the number of hours that a typical wind farm would have to generate at rated capacity in order to reach total actual annual production[8]. The corresponding available land surface (after subtraction of the assumed conflict areas) is indicated on the x-axis of the figure. If the numbers of full-load hours are known, it is possible to do a simple profitability check. Total costs of wind power are determined by full-load hours and assumptions regarding investment costs and operation and maintenance (O&M) costs. Based on default assumptions, a wind-power installation with 2,500 full-load hours per annum typically costs around 55 €/MWh. We assume only moderate grid-integration costs. If the number of full-load hours is decreased to 1,500 hours, i.e., by choosing a significantly less appropriate site, the total generation costs increase to around 100 €/MWh. Three such estimated production costs are included in Figure 6.2 and placed adjacent to the corresponding full-load hours. Modelling the development of the Nordic electricity market gives projected wholesale electricity prices of typically 40–45 €/MWh for the coming years. The prices of electricity certificates in the common Swedish-Norwegian electricity certificate market have in recent years been around 20 €/MWh. If that price level prevails the total income for new wind-power investments may reach 60–70 €/MWh i.e. well exceeding the wholesale electricity prices estimated from the modeling.

Based on the information shown in Figure 6.3, around 1,000 km^2 in the Swedish part of the KASK region would in that case be profitable. This is less than 10% of the entire land surface estimated as being available for onshore wind power. However, if we assume that this surface is available for entire wind farms with a power density of typically 10 MW/km^2, then the installed capacity could reach an impressive 10 GW (1000 km^2 × 10 MW/km^2). This figure may be compared to the total installed capacity including all power-generating plants and units in the whole of Sweden, which is around 35 GW. In conclusion, it is clear that land availability should not be a limitation for fulfilling large ambitions on wind power expansion. Since typical cost for offshore wind power exceeds € 100/MWh (Swedish Energy Agency, 2014c) it can be concluded that unless the cost of offshore wind power is significantly reduced, there is no need for such in the KASK-SE region.

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[8] Full-load hours is a typical indicator for assessing the annual average electricity cost of a wind turbine or a wind farm. Depending on choice of wind-availability data, typical hub height, geographical resolution, wind turbine design and power function (which converts wind speed to wind-power production), full-load hours can differ significantly when estimating the expected power output from a potential installation in a specific investigated site. Furthermore, the annual production from a given wind turbine is known to slowly degrade over time due to wear and tear. This argues for a more conservative approach in the choice of e.g. power function. Thus, the concept of full-load hours should be used somewhat carefully. In our study, we use wind-speed data from ECMWF, which are averaged over 5 minutes every third hour and valid for hub heights of 100 meters. The power function is taken from the Tradewind project (Van Hulle 2009) for a, at that time, “future” wind turbine design.

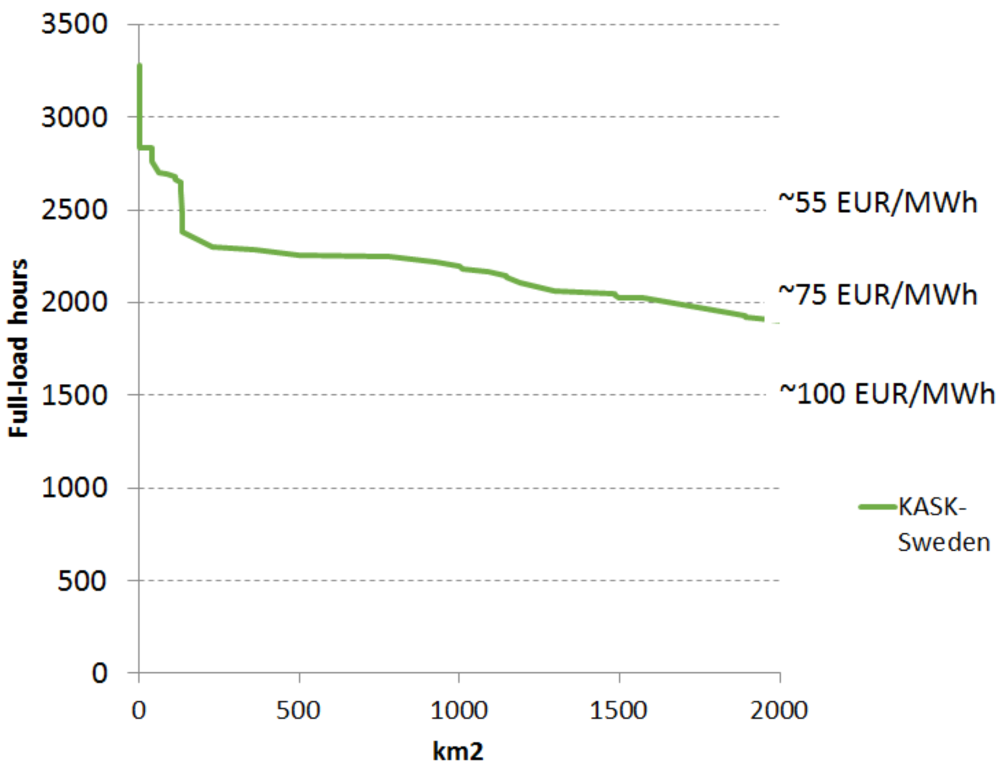


Figure 6.3: Full-load hours for on-land wind power in the KASK-SE region, arranged in decreasing order. The figure includes estimates of levelised costs of electricity for wind power for three different full-load hours (assuming investment cost of 1330 €/kW, O&M cost of 25 €/kW, and a real discount rate of 7%).

As mentioned in Section 2, Swedish municipalities are obliged, by law, to present energy plans that cover the geographical boundaries of their communities. However, as there are no major requirements as to the actual contents of such plans, they may be regarded as relatively flexible in terms of scope and detail. Nevertheless, a broad assessment and environmental aspects should be included. In parallel with these energy plans, many Swedish municipalities have prepared specific wind-power plans. These give valuable insights into the ways that different communities value the role of wind power and to which extent they estimate available land surfaces for such installations. When looking into these plans for the six communities of Halland County, we conclude that they, generally, have a more limited view of the availability of land surface than the availability which we have applied in our analysis. The factors that the municipalities include, besides the ones analyzed in this study, are more politically or strategically motivated, perhaps reflecting the different ambitions of the municipalities. One such example is how the municipalities in some cases include significantly larger buffer zones around densely populated areas, with the justification that they expect (or hope) that their cities will grow and they want to reduce the possibility of future conflicts over wind-power installations. Furthermore, municipalities tend to be more restrictive in terms of wind-power installations if they consider that these could be in conflict with tourism objectives. Thus, in some cases competing land use tends to be assigned a higher value in these plans than what we have estimated here. However, one might argue that areas that are currently considered as unlikely sites for wind power installations may be considered more likely as potential sites in the future, assuming that the threat from climate change will become all the more evident. This further underlines the difficulties associated with estimating available land use and potentials for onshore wind power. In reality, each wind-power installation is treated as a unique project with unique conditions. Nevertheless, estimations of the potentials of wind power are necessary when assessing strategies and options to increase the penetration of renewables in line with what is required in the longer term in a society complying with a 2°C warming target. When doing so, we must be aware of the fact that wind power siting can be controversial and that onshore wind-power installations in many cases have to compete with alternative forms of land use.

To summarize; the analysis on available land area has shown a large potential for onshore wind power in the KASK-SE region, up to some 1,000 km^2 land could be utilized at reasonable cost yielding an estimated wind power capacity of 10 GW with an estimated production potential of between 20 to 25 TWh. Thus, since offshore wind power is considerably more costly than onshore wind power, focus should, at least for the time being, be placed on utilization of onshore sites. New support schemes dedicated to support of offshore wind power could however reverse this situation.

6.3 Biomass and waste

It is obvious that biomass applied for energy purposes will become increasingly important in the future, not only in Sweden but also throughout Europe and also globally. Hence, both the potential for future production of biomass within the region as well as import possibilities are analyzed and discussed in this work. The analysis of biomass and waste resources has been carried out in two parts. The first part makes an analysis of the prospects for future production of biomass within Swedish and Norwegian KASK region (Bisaillon et al., 2014a) while the second part provides an analysis of the prospects for enhanced bio- and waste based power production within the same region (Bisaillon et al., 2014b). In this report, only the part of the analysis covering the Swedish KASK-region is reported.

6.3.1 Prospects for future production of biomass in the Swedish KASK region

The analysis in this part of the study includes fuel wood (whole trees and large tree parts from clearing and thinning), byproducts such as wood chips, wood dust and bark, tops and branches (so-called GROT), stumps, straw and energy forest (salix). Furthermore, the analysis in the first part starts by the identification of production and use of the selected solid biomass types in the year 2010. Next, it was studied how this solid biomass production can be developed to 2020 and to 2030.

In 2010, total solid biomass production in the Swedish part of the KASK region amounted to 5.7 TWh of which 95% was fuel wood, byproducts and GROT. The region used 7.5 TWh in 2010 with the deficit, 1.8 TWh, being imported from other regions in Sweden. The imbalance between production and use is fairly typical for a region with a relatively large number of residents and well-developed district heating networks but with relatively limited forest area such as in Västra Götaland County. Table 6.2 shows consumption by sector in 2010[9].

[9] Wood burnt in domestic boilers in SFDs is not covered well by official statistics and that is the main reason to the discrepancy between the use of solid biomass in SFDs given in Table 6.2 and the estimated value given in Table 5.1. Also, Table 6.2 shows only unprocessed solid biomass, i.e. pellets are not included.

Table 6.2 Selected use of unprocessed solid biomass (i.e. not including pellets) for energy purposes in KASK-SE in 2010.

Sector	Use 2010 (TWh)
Single-family houses	1.9
Industry	1.2
District heating (including CHP)	3.6
Biopellets production	0.8
TOTAL	**7.5**

The assessment of future potential production of the selected solid biomass types have been performed in a two-step process.

1. Literature survey for identifying solid biomass potential studies
2. Establishment of two scenarios for the solid biomass potential in 2020 and 2030

Many factors will affect the development of solid biomass production potentials. Therefore it was chosen to evaluate the 2020 and 2030 situation in the form of two possible scenarios, which have been termed "LOW" and “HIGH” respectively. Their purpose is to find a reasonable sample space of potentials for 2020 and 2030. To facilitate this, a number of factors were put together that contributes to a low and a high potential respectively. It should be noted that the scenario descriptions are qualitative. The scenario descriptions are used for selecting solid biomass potentials from the literature studies in point 1 above which fits into the given descriptions.

Scenario LOW suggests a limited supply of solid biomass due to an anticipated slow growth in the economy. The competitiveness of Nordic forestry industry (sawmill industry and pulp and paper industry) is weakened on the global market and demand for forestry products is relatively low. Furthermore, new policy instruments are introduced that limit the area of productive forest. A low climate ambition leads to a limited harvesting of bioenergy from forests and agriculture.

Scenario HIGH suggests large supply of solid biomass. The competitiveness of Nordic forestry industry (sawmill industry and pulp and paper industry) is strengthened on the global market. A general global pressure for reducing greenhouse gas emissions improves the competitiveness as the Nordic production uses comparatively low amounts of fossil energy. Also increased labour costs in developing economies in e.g. South America and Asia contributes to improve the competitiveness of the Nordic forestry industry.

The total area of KASK-SE is ca 30,000 km^2 (see Table 2.1) of which ca 17% is forest land and 19% agricultural land. Figure 6.4 shows that the solid biomass production potential for energy purposes in the Swedish KASK region can amount to 10 TWh in 2020 and just over 12 TWh in 2030 in Scenario HIGH. The potential in 2030 is relatively evenly divided between fuel wood, tops and branches (GROT), byproducts and agricultural fuels (straw and energy forest). In the LOW scenario, the driving forces for using fuels like straw, energy forest and stumps are limited and the potential for energy purposes is assumed to decline, albeit marginally from 5.7 TWh in 2010 to 5.5 TWh in 2020 after which the potential is assumed to remain constant. The potential in the LOW scenario mainly consists of fuel wood, tops and branches (GROT) and by-products.

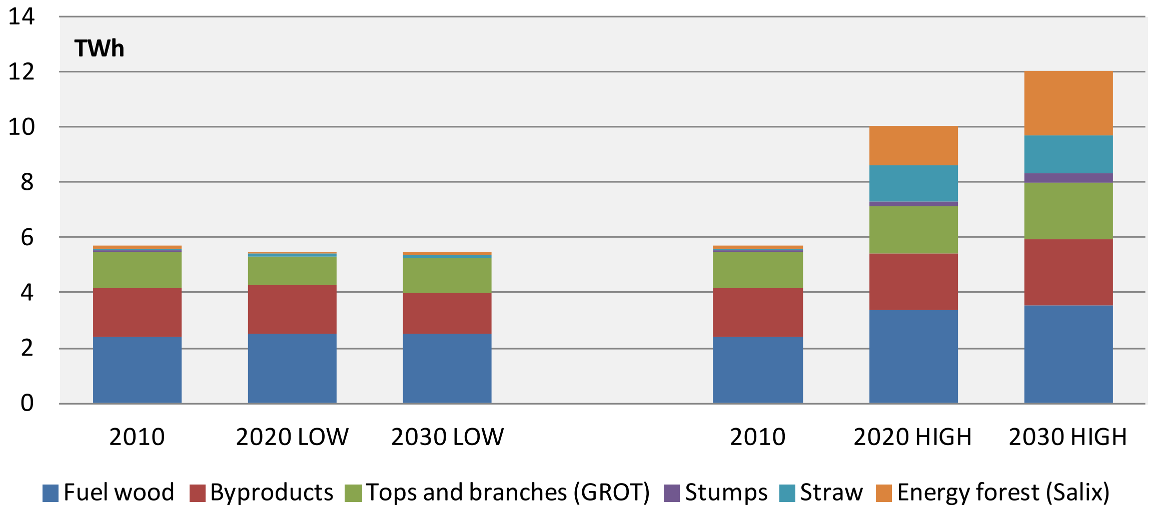


Figure 6.4: Estimated solid biomass production (TWH) for energy purposes within the Swedish KASK region in 2010 compared to estimated potentials for 2020 and 2030 in the LOW and HIGH scenario.

The forest industry, including both the sawmill industry and the pulp and paper industry, plays a crucial role in realizing increased solid biomass production in the KASK region, since the major part of the potential originates from the forest. In the scenario analysis, the HIGH potential is reached under the assumption that the competitiveness of the Nordic forestry industry is strengthened on the global market and consequently production increases. The HIGH potentials implicitly also demand higher solid biomass prices than today to be realized. In the Swedish KASK region, the current price level is in the range 18-23 euro/MWh delivered at district heating plants and ready to use (Profu 2013a).

Import of biomass to the KASK region could come from other regions in Sweden or from other countries. In Sweden, there is a current flow of solid biomass by railway and boat from the forest-rich northern part of the country (i.e. counties north of Dalarna and Gävleborg) to the southern part where the Swedish KASK region is located. These flows can be increased if the demand and the paying ability increase in e.g. the KASK region. For Sweden as a whole (including the Swedish KASK region), Profu (2013a) estimated the production and use in Year 2012 of the different studied solid biomass types included in this study to 50 TWh and 53 TWh respectively. The difference between production and use was met by a net import of around 3 TWh. Börjesson et al (2013) present a long list of studies estimating additional potentials for Sweden as whole. Depending on time perspective and limitations (technological, economical, ecological etc), these studies indicate an additional potential of 53 – 93 TWh of the solid biomass types.

Looking outside the Swedish borders, there is a current international trade of wood chips for energy purposes (originating either from fuel wood, tops and branches or by-products from the sawmill industry) for energy purposes. According to IEA (2012a), the global trade of wood chips can be estimated at around 5 TWh and the main trade is to and within Europe. Today, pellets are the dominating solid biomass fuel being traded over long distances. The import to Europe from other world regions (mainly North America and Russia) has increased steadily and was estimated to some 20 TWh in 2012 (Teir 2013). Up to 2020 the European import from other world regions might increase up to 70-140 TWh according to Faaij (2013). After 2020, IEA (2012b) has indicated that global trade in refined biomass (pyrolysis oil, torrefied wood and pellets) probably will “grow rapidly to supply large bioenergy power and/or heat plants in regions with limited feedstock availability”.

Thus, as shown above the first part of this study indicates that production of solid biomass within KASK-SE may be raised to twice the current capacity, i.e. to 12 TWh per year and that there is a large additional production potential in the rest of Sweden of which parts may be imported to the KASK region. Additionally, there is of course the possibility of imports of for instance pellets from as far away as North and South America.

6.3.2 Prospects for enhanced bio- and waste based power production in the Swedish KASK region

As mentioned above the second part of this study assessed the prospects for development of renewable power generation from solid biomass and waste fuels in the Swedish and Norwegian part of the KASK region (see Bisaillon et al 2014b). The renewable electricity production can for example occur in the form of CHP in district heating systems or in the form of back-pressure production in industries. Throughout the study it has been assumed that 50 % of the power production from waste fuels could be considered as of renewable origin.

First, the amount of renewable power production from solid biomass and waste fuels in the region in the year 2010 was identified. Next, it was assessed how this renewable electricity generation can be developed to 2020 and to 2030. The assessment for 2020 was mainly based on expansion and phase out plans and other changes (e.g., closure of industries) that have an impact on the renewable power production from solid biomass and waste fuels. For the 2030 assesment, the expected situation in 2020 was used as a starting point. A scenario analysis was then used to evaluate a HIGH and a LOW scenario for 2030.

Data for 2010 was collected and compiled using several different data sources and the same sources were also used to evaluate the development up to 2020:

- The Profu biomass database on existing CHP plants and heat plants using solid biomass and waste fuels (Profu 2014).
- Literature survey
- Coordination with the Chalmers Power Plant Database – 2014 edition (Kjärstad et al., 2007)

In the Swedish district heating sector, the first decade of the 2000s was characterized by a large expansion of solid biomass CHP and waste fuel CHP. Two important drivers were (and still are) the electricity certificate system and landfilling taxes/landfilling bans (Profu 2013a, b). As of 2010, 208 MWe capacity burning solid biomass and 39 MWe capacity burning waste fuels was installed in KASK-SE. Corresponding electricity generation in 2010 amounted to 1,031 and 211 GWh respectively. The two Swedish counties differ in their type of production. Västra Götaland is characterized by mainly power production through CHP in district heating systems, and 27 % of this type of power production comes from waste fuel CHP. Halland, on the contrary, gets most of its production from industrial back-pressure using solid biomass at two large pulp and paper industries.

However, there appears to be much less plans for new production units in the district heating sector in the period 2011-2020 than in the preceeding decade. For the Swedish KASK region, 39 MW additional electricity production capacity has been identified (of which some already has been installed) yielding an estimated additional production of 178 GWh per year.

Back-pressure production at pulp and paper industries is dependent on the expansion and phase out of plants. The pulp and paper industry competes on a global market, e.g. in 2013 some 90 % of the Swedish paper production was exported (Skogsindustrierna 2014). During the last 5-10 years, this sector has also been under growing competition from electronic media. Thus, the project identified 37 MWe additional power production capacity up to 2020 of which some already has been installed. Estimated production capacity of the expected new installations is roughly 260 GWh per year.

Therefore, adding the identified capacity additions up to 2020 for both the district heating sector and for back-pressure production from the industry, it is expected that total electricity generation capacity from solid biomass and waste increases from around 245 MWe in 2010 to 320 MWe in 2020 yielding an estimated annual production increase of 440 GWh (from 1242 GWh in 2010 to 1680 GWh in 2020).

Up to 2030 many factors, which are further described below, will affect the development. These factors can work in the direction of increasing or decreasing this type of renewable power production in the region. Therefore it has been chosen to evaluate the 2030 situation in in line with the above mentioned LOW and HIGH scenarios (which both use the expected situation in 2020 described above as a starting point). Scenario HIGH means a development where factors influencing the renewable power production from solid biomass and waste fuels are supporting a strong but possible development. The opposite goes for scenario LOW. The following factors have been considered:

- The supply and price of solid biomass
- Waste policy
- Electricity and TEP (Tradable Emission Permits) prices
- Electricity certificate prices
- The competitiveness of the Nordic pulp and paper industry

In scenario HIGH all the factors stated above support an overall development where solid biomass CHP is economically favoured over waste fuel CHP. Furthermore, back-pressure production in the region’s pulp and paper industry can be increased. The opposite goes for scenario LOW. In the assessment, a technical evaluation was performed of how the overall development in each scenario could affect the renewable power production from solid biomass and waste fuels in the KASK region by 2030. Based on the overall development in scenario HIGH, the following assumptions are made for 2030 compared to the estimated situation in 2020:

- 50 % of the district heat production from waste incineration is closed down and replaced by solid biomass CHP delivering the same district heat amount. In KASK-SE this means that only waste fuel CHP plants close down, since all waste incineration plants are CHP plants.
- Following the assumed waste policy (Bisaillon et al., 2014b), material recycling of plastics is strongly increased, leading to a renewable share in waste fuels of 75 %.
- Pulp and paper production increases by 25 % over 2020 levels, leading to a corresponding increase in back-pressure production.

Based on the overall development in scenario LOW, the following assumptions are made for 2030 compared to the expected situation in 2020:

- Waste incineration capacity and district heat production through waste fuel CHP increases slightly and replaces solid biomass CHP.
- Following the waste policy (Bisaillon et al., 2014b), the renewable share of waste fuels are 50 %.

- Pulp and paper production decrease by 25 % compared to 2020 levels, leading to a corresponding decrease in back-pressure production.

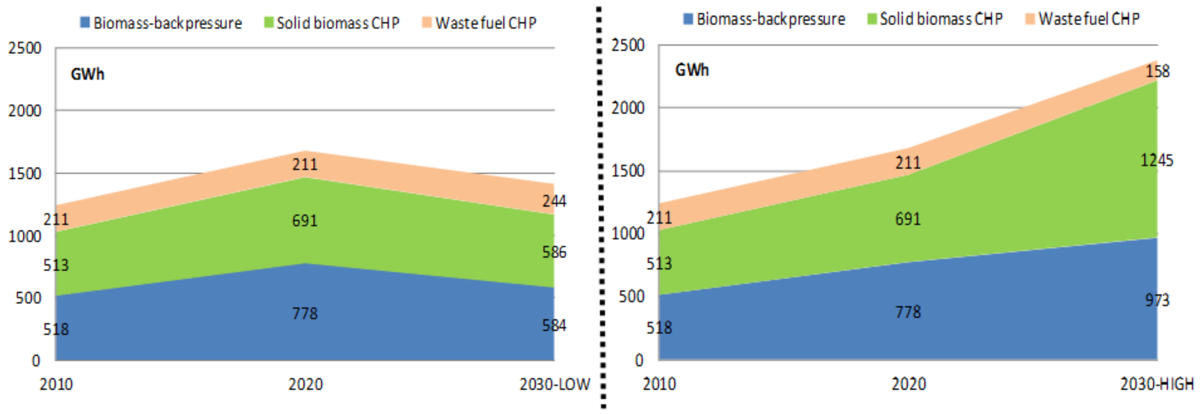


Figure 6.5: Assessment of future electricity production potential for solid biomass and waste in KASK-SE in scenario LOW (to the left) and scenario HIGH (to the right).

In Figure 6.5, the development of renewable power production from solid biomass and waste fuels in KASK-SE are illustrated for the HIGH and LOW scenarios.

As can be seen from Figure 6.5, estimated generation increases from some 1240 GWh per year in 2010 to 1,680 GWh in 2020 after which it declines to 1,415 GWh in 2030 in the LOW scenario and increases to almost 2,380 GWh in the HIGH scenario. In the HIGH scenario there is a relatively high increase both in biomass backpressure and biomass CHP electricity generation while wastefuel CHP declines. In the LOW scenario production capacity increases for all three categories up to 2020 after which however both biomass backpressure and biomass CHP declines while waste CHP increases relatively modestly.

The estimated additional potential for biomass based electricity generation in the HIGH scenario should easily be covered through the additional biomass production potential within the region as estimated in the Part 1 analysis above. More specifically, the Part 1 analysis revealed an additional biomass production potential of 6 TWh in the region which, assuming this biomass is used in CHP plants with a conversion efficiency of 80%, should yield some 4.8 TWh additional electricty and heat production (with the electricty share depending on the power to heat ratio).

6.4 Solar

At the end of 2013 there was 43.1 MWp of solar photovoltaic (PV) cells installed in Sweden, which constitutes an insignificant part of the total capacity installed in the electricity system and accounts for only 0.03% of generated electricity (Lindhal 2013). However, the installation rate has continuously been increasing since 2009 with 19 MWp being installed during 2013, up from 8.3 MWp in 2012. Virtually all recent as well as cumulatively installed capacity has been installed on the demand side of the power system, i.e. as distributed generation by private households, commercial, public and governmental buildings, with the primary aim to generate electricity for self-consumption. Yet, 91 % of demand side installations are grid tied meaning that any excess electricity they produce can be fed into the grid. There are no data to show how much of the capacity is installed in the regions of VGR and Halland, although 16 % of the national investment support subsidies for solar PV installations have gone to VGR with the corresponding figure for Halland being 4.5 % (Swedish Energy Agency 2014d).

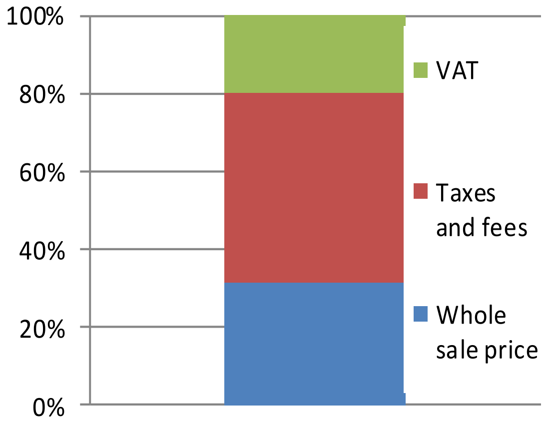


Figure 6.6. The different components constituting the retail price of electricity, these being value added tax (VAT), energy tax and grid transfer fees and the whole sale price.

Using this as indicators of installed capacity 6.9 MWp and 1.9 MWp could be installed in VGR and Halland respectively at the end of 2013.

The reason that almost all investments occur on the demand side is that the economic benefits from generating electricity for self-consumption are higher compared to generating with only the intention to sell. This as energy tax, VAT (Value Added Tax), company overhead, fees and the wholesale price are included in the retail price of bought electricity, and as long as the generated PV electricity is used for self-consumption it only needs to compete with this retail price. This makes a considerable difference as the whole sale price only makes up roughly 30% of the retail price, see figure 6.6.

In Sweden the following support schemes are currently available for PV-systems (They are available to both private persons and companies unless stated otherwise):

- Investment support, maximum 35% of total investment cost up to a cost of 1.2 million SEK and/or 37,000 SEK/kWp. The support is available until the 31st of December 2018 or until the allocated 680 million SEK runs out. What happens beyond that point is unclear although the support has previously been extended.
- Renewable energy certificates (RECs) are issued for each produced MWh which can subsequently be sold on the certificate market. Currently the PV owner needs to apply to get certificates and the PV installation can only receive certificates for the first 15 years of operation. Certificates are only received for electricity fed to the grid, since in order to receive certificates for the total production additional measuring equipment is needed which is not currently economically justifiable. The average value of certificates since their introduction in 2003 has been 230 SEK/MWh.
- Guarantee of origin certificate, works in the same way as renewable energy certificates although the value of these are considerably lower.
- ROT-deduction, half of the labor cost but maximum 50,000 SEK per year. It cannot be combined with the investment support. What this would constitute in reduction per Wp depends on the labor cost, but around 2,300 SEK/kWp is plausible.
- Tax deduction, a tax deduction of 60 öre/kWh of electricity fed to the grid, i.e. the electricity that the household do not self-consume, up to a maximum of 30MWh per year. This will be implemented the 1st of January 2015.
- The two regions in the KASK area also have local support schemes:
  - “Handlingsprogram för hållbar energy” and “Klimatmiljonen Halland”, economic support for investments in PV aimed at various organizations (not specified what kind of organizations but individual companies are excluded explicitly) and the public sector.
  - “Sol i Väst”, gives support for planning and investing in solar PV for its members (primarily municipalities), no economic support is given.

Excess production can be sold to an electricity retailer slightly below the market wholesale price. There are also retailers who offer prices above wholesale price, however, these should be seen as marketing schemes as it would not be feasible to implement on a larger scale.

The VGR and Halland regions receive roughly 925-1000 kWh/m2 of solar irradiation per year with some minor variations. Currently this would translate to 800-1000 kWh/kWp depending on orientation and inclination of the panel. These values are for CSi-panels which together with thin-film (CdTe, CIS) are the most prevailing type of panel available. As solar-PV research is highly material driven there are room for major advances in efficiency and cost through using new materials.

Current Swedish prices for a PV system including installation is 20,000 SEK/kWp (inc. VAT) for household, giving a LCOE (Levelized Cost of Electricity) of around 1.6 SEK/KWh, and the cost for commercial PV systems being 15,000 SEK/kWp (exc. VAT) (Lindhal 2013). Prices have dropped significantly during the last few years primarily due to PV module price reductions and will likely continue to do so although probably not at the same pace. At the current cost levels investments are not profitable without subsidies for consumer side investments and not at all for utility investments, i.e. assuming the support schemes listed above.

Countries with similar resource potentials as Sweden such as Germany and the UK have shown a considerable larger growth in solar PV capacity than Sweden (with current level of 5.2 % and 0.6% of produced electricity in 2013 respectively). The fairly quick expansion seen for these countries is almost exclusively due to the use of Feed-in-tariffs coupled with PV system prices falling quicker than expected. The size of installations have also been governed by the feed-in tariffs (the maximum size covered by the tariff being 5MWp for UK and unlimited for Germany). Given the support system in Sweden a similar development is not likely as the investors are not guaranteed a fixed price for produced electricity and also there is limited funding within the investment support scheme to support a growth of a similar scale. Utility scale installations are practically only supported through RECs, thus installations at this level in Sweden will only be seen when LCOE drop to a level which together with RECs can compete with prevailing spot market prices (2013 average). To reach this level would require an investment cost of around 6,000 SEK/kWp (exc. VAT) unless further support systems are implemented. A more likely scenario is that investment will occur on the consumer side, as they are already profitable with today's subsidies as indicated above. Although as previously mentioned a rapid expansion is limited by the level of investment subsidies. However, assuming implementation of the tax deduction scheme, a simplification of the RECs system and a continued drop in system prices, could together lead to a more rapid expansion as it would lower the dependence on investment support.

What is the potential for PV installations in the KASK region if consumer installations become profitable? Table 6.3 shows an estimated potential for KASK-SE assuming solar PV being installed on between 10 and 100% of potentially "suitable" roof surface area. "Suitable" roof surface area has been derived applying the estimate given in (Kamp 2013) after having reduced the area for tilted roofs by 50% since output is reduced considerably at angles of 45° or more away from due south. An installation size of 150Wp/m^2 is used and a generation of 900Wh/Wp where the lower value is used to account for that not all roofs face south.

Different shares of net roof area potential have been used to indicate the market penetration and the size of the installation where 100% constitutes full market penetration and maximum installations, i.e. using all the presented net area while 50% can represent either a full market penetration with 50% use of the potential installation for each roof or 50% market penetration and 100% use of the potential installation for each roof. Values are shown for single family dwellings (SFD), MFD (Multi Family Dwellings) and non-residential buildings, e.g. hospitals, offices and sport centers in VGR and Halland. Roofs belonging to industry and large storage buildings, holiday homes and supplementary buildings have not been included.

Table 6.3. Estimated potential electricity production (TWh) from rooftop PV in VGR & Halland.

Share of potentially net installable area	VGR				Halland			
	SFDs	MFDs	Non-res	**Total**	SFDs	MFDs	Non-res	**Total**
100%	1.42	0.29	0.26	**1.97**	0.38	0.05	0.05	**0.48**
75%	1.07	0.22	0.19	**1.48**	0.28	0.03	0.04	**0.36**
50%	0.71	0.15	0.13	**0.99**	0.19	0.02	0.03	**0.24**
25%	0.36	0.07	0.06	**0.49**	0.09	0.01	0.013	**0.12**
10%	0.14	0.03	0.03	**0.2**	0.04	0.005	0.005	**0.048**

As can be seen from Table 6.3, given the assumptions specified above, solar PV in KASK-SE is estimated to generate between 0.25 and 2.5 TWh electricity annually combined (adding the total for VGR and Halland) pending on available area and market penetration. The potential in VGR is around four times the potential in Halland. As can also be seen in Table 6.3 SFDs are believed to constitute the major share of production potential for solar PV in the KASK-SE region. This follows, as mentioned above, from the fact that under existing subsidy schemes, SFD owners have the most to gain from an installation of solar PV on their rooftops. The size of the PV installation on SFDs will depend on the available pricing structure for excess produced electricity, with the coming tax deduction scheme (see above) probably leading to larger panels as it will increase the value of excess produced electricity.

If roofs of industrial buildings and other excluded buildings are included the potential is obviously larger. Also, if ground mounted utility scale PV plants become profitable the potential could grow substantially.

To provide a time perspective of the expansion in PV will be highly speculative. However, annual expansion rates of solar PV generation in Germany, Italy and China have been strong, e.g. on a yearly base there was an increase in solar PV generation in Germany from 11.7 TWh in 2010 to 19.6 TWh in 2011, i.e. a yearly increase by almost 8 TWh. Between 2009 and 2013, German solar PV electricity generation increased from 6.6 TWh to 31.0 TWh (BMWi 2014). Which degree of penetration we will see in the KASK-SE region by 2030 and by 2050 will be highly dependent on the price development of PV-panels and how policies will be designed, and it may increase substantially from today’s level.

6.5 Assessment of electricity generation towards 2050

In this section, we present an analysis of the development of the electricity generation in the KASK-SE region towards 2050. Depending on a large number of different factors such a development can, of course, take on different routes. We have limited our analysis to focus mainly on two main scenarios. The analysis is based on a European electricity-system modelling combined with region-specific (the KASK region) considerations for e.g. biomass and wind power. For a more detailed description of the work, see Unger et al., 2014b. The reason for this is that the electricity system is linked to both the Nordic and European systems both physically through interconnectors and through the Nordic common electricity market (Nordpool). Thus, the future of the Swedish and thereby the KASK-SE electricity systems will depend strongly on the development of the European electricity system, especially with respect to Northern Europe and the planned investments in interconnectors in this region (between the Nordic countries as well as the planned transmission corridor in Germany). These issues are included in the modeling of this work.

6.5.1 The main scenarios

The assessment is mainly based on a model analysis limited to two main scenarios that we believe best reflect the purpose of this project. Both these scenarios are defined on a European level and around two dimensions: 1) Energy and climate policy, and 2) Technology development and availability.

The prime assumption behind the first scenario, the “Green Policy” scenario, is a very ambitious European renewable policy target towards 2050, implying that around 90% of total electricity generation is renewable in 2050. This is, of course, a very high ambition and will require strong policy intervention. Our question is, however, not whether this is likely or how such a scenario may be achieved in terms of policy instrument setup across Europe, but rather to analyze what this would mean for the development of electricity generation within the KASK region. One of the core questions of this project is to assess the possibilities for expanding renewable electricity in the KASK region. A very high European renewable ambition in Europe, as stipulated by the “Green Policy” scenario, will naturally impact on the development of renewable electricity also in the KASK region. In the scenario, the renewable target is defined commonly across all EU Member States post 2020, i.e. the targets are not set at a national level. Furthermore, we rule out both the option of new investments in nuclear power and the commercialization of Carbon Capture and Storage (CCS). The reasons for ruling out CCS and new nuclear power plants may be political, technological, or related to public acceptance. Furthermore, the expected operational lifetimes of existing nuclear power plants are relatively short in this scenario at 45 years.

In addition, we also investigate a scenario that takes its starting point in the energy and climate policy package stipulated by the EU towards 2030 (and further on towards 2050). We define this as our “Regional Policy” scenario. Also in this scenario, renewable policy is ambitious – yet not as ambitious as in the first scenario - but accompanied by policies and policy instruments also for increasing energy efficiency especially at the demand side. In 2050, around 65 percent of total electricity generation in Europe is assumed to be renewable in this scenario. This is accomplished through nation-specific targets. The scenario is characterized by detailed policy steering, with emphasis on efficiency measures, and it has a national policy view rather than a common European policy-instrument design. New nuclear power plants are optional if considered profitable by the modelling. In general, we assume that existing nuclear power plants have an expected lifetime of 60 years in this scenario. However, we also assume that three of the oldest existing nuclear power plants in Sweden have an expected lifetime of 50 years based on preliminary estimates made by the utilities.

In the “Regional Policy” scenario we assume that the common Swedish-Norwegian electricity-certificate scheme develops according to present decisions (October 2014). This means that renewable electricity generation shall increase by around 26 TWh, jointly in Sweden and Norway, between the beginning of 2012 (when the common scheme was introduced) and the end of 2020. The system remains in operation until 2035 but without any additional increases in production. Currently, political discussions in Sweden indicate that this target may be subject to revisions and increase in ambitions. This may also be an outcome, once the burden-sharing among the EU Member States of the renewable target corresponding to 27% (of consumption) in the 2030 policy framework, has been established.

In both the “Green Policy” and “Regional Policy” scenarios, we assume that CO2 emissions from electricity generation in Europe are reduced by approximately 95% by 2050. Thus, even though we to various extent assume renewable targets in both scenarios, we must not forget that also the stringent CO2-reduction policies, especially when approaching 2050, increase the profitability of renewables.

Two additional scenarios were analyzed; the Regional Policy 2 scenario analyzing the effects from an expansion of the common Swedish-Norwegian electricity certificate and the Climate Market scenario which focuses exclusively on climate mitigation post 2020. These are here included in a sensitivity analysis. In addition, these scenarios are presented and discussed in more detail in the Appendix (A1).

6.5.2 Analyzing the future development of European electricity generation – ELIN modelling

The model that has been used in this assessment to generate results for the development of European electricity-supply system is the ELIN (ELectricity INvestment) model. ELIN is a long-term dynamic optimization model that describes the present generation system, as derived from the Chalmers Power Plant database, and includes an extensive array of new technologies that are to be used to meet the changes in future demand as existing capacity comes of age or becomes unprofitable (Odenberger et al., 2009a, b, Johnsson F., et al., 2014). The time horizon of the ELIN model is between 2010 and 2050. Typical model outputs from the ELIN model include capacity and production levels of electricity by fuel and region (or country) until 2050, aggregated investment costs, electricity trade between regions (or countries), and marginal costs of electricity. In general, in the model runs, a CO2-emission cap, which is gradually reduced as one nears the year 2050, is imposed on emissions from electricity production. Thus, the marginal cost of CO2-emission reductions is also part of the model output.

The European modelling in the ELIN model includes EU-27, Norway and Switzerland divided into 53 separate regions, or “electricity price areas”, defined by major electricity-transmission bottlenecks (see Figure 6.7, left). This means that Sweden is divided into four regions, which basically coincide with the actual price areas in the Nordpool electricity market (we use a different notation of our price areas compared to Nordpool). Norway, on the other hand, is divided into three regions while, in reality, the Nordpool market divides Norway into five separate price areas.

In our analysis, we use the model results for regions “NOR1” and “SWE2” as prime sources for our assessment of the future electricity generation in the Norwegian and Swedish parts, respectively, of the KASK region (KASK-NOR and KASK-SE). This means, for instance, that if wind power increases by a certain percentage in “SWE2” between 2030 and 2012, we assume that wind power in KASK-SE increases with the same share based on installed capacity in 2012 in KASK-SE. However, we also make certain specific and regional adjustments to that “rule” based on our knowledge of e.g. conditions for renewables and existing single power plants in the KASK region. We do this since it, of course, is a simplification to assume that the development in the KASK region perfectly follows the development in the surrounding regions (here “SWE2” and “NOR1”). We have also used

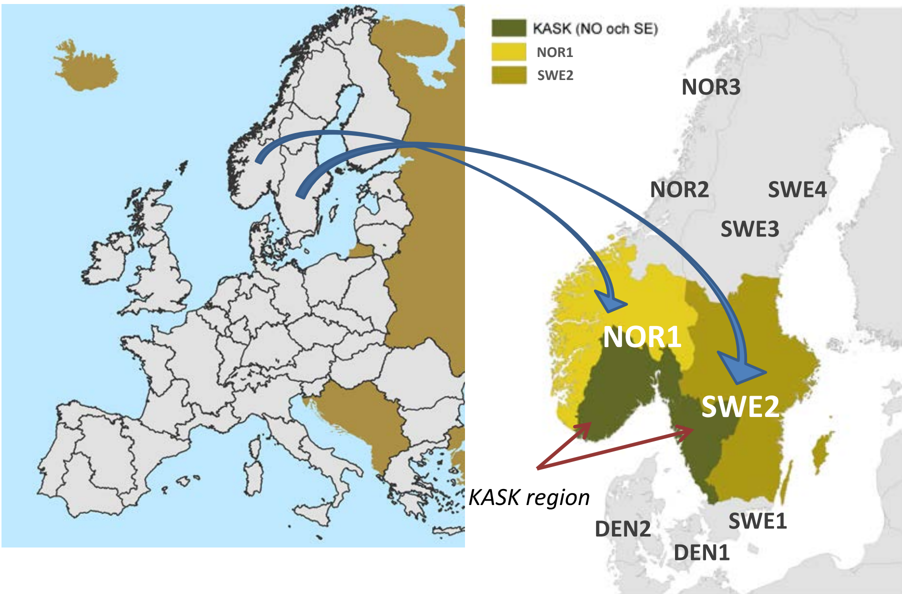
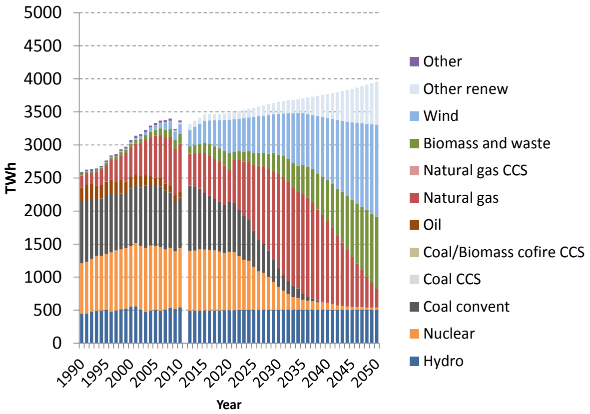


Figure 6.7: Regionalization of EU-27, Norway and Switzerland in the ELIN Regional model (left) and the two model regions, "NOR1" and "SWE2", used for assessing the electricity generation in the KASK region (right; the KASK region is marked in dark green). Please note that we use a different notation for our price regions compared to Nordpool.

other inputs, and not only the model results for the model regions "SWE2" and "NOR1", in order to assess the development of electricity generation in KASK region. The regional mapping of investment plans and prospects for new electricity generation in combined heat and power schemes (CHP) based on biomass and waste incineration applied specifically to the KASK region is, for instance, also used as input to our assessment of the electricity generation in parallel with the model results (see Section 6.3).

6.5.3 Results for Europe (EU-27, Norway and Switzerland)

In Figure 6.8, we present the ELIN model results for EU-27, Norway and Switzerland of the "Green Policy" scenario (left) and the "Regional Policy" scenario (right). As mentioned, overall electricity demand stagnates and slowly decreases in our "Regional Policy" scenario. The massive expansion of renewable electricity generation is obvious, especially in the "Green Policy" scenario. This is, of course, primarily a result of the scenario definition itself. In particular wind power increases, but also biomass-based electricity generation and solar PV. Depending on the relatively rapid nuclear phase-out (assuming 45 years lifetime for existing plants) and stringent CO2-reduction policies, the need for gas power is apparent together with the constantly increasing share of renewable electricity generation in the "Green Policy" scenario. In the "Regional Policy" scenario, the increase in renewables over time is accompanied by, to a limited extent, CCS and new nuclear power capacity. Generally, however, the rather generous support to renewables and the decline in electricity demand entails low wholesale electricity prices. Thus, the profitability for new CO2-lean but non-renewable electricity generation is limited. It is not until after 2040, where investments in these technologies take place in the "Regional Policy" scenario, yet in a relatively limited extension.



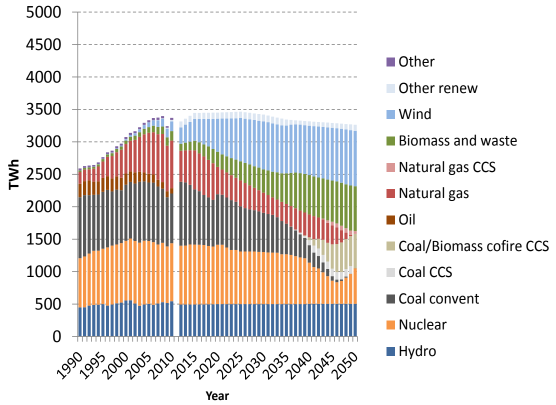


Figure 6.8: Model results for electricity generation in EU-27, Norway and Switzerland in the "Green Policy" scenario (left) and the "Regional Policy" scenario (right).

Table 6.4. Marginal cost of CO2 abatement by scenario as given by the model results, €/ton.

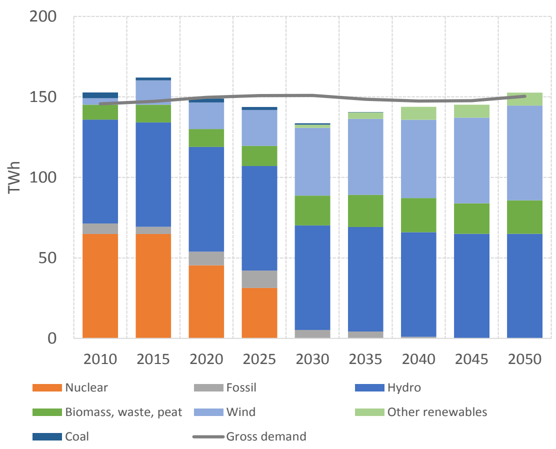
	2015	2020	2030	2035	2040	2045	2050
Green Policy	2	3	45	59	45	38	22
Regional Policy	4	4	2	26	57	79	653

The model also yields marginal cost of CO2 abatement over time reflecting a CO2 emission price which is shown in Table 6.4 for the two main scenarios.

As can be seen from Table 6.4 the indicated CO2 emission price reaches a very high level in the Regional Policy scenario in 2050. It is important to realize however that the CO2-price shown in Table 6.4 does not reflect any flexibility on the demand side or emission reductions in other sectors than the power sector, factors which both may lead to lower CO2 prices than those shown in Table 6.4. In addition, in the end of the period the total carbon being traded is small and, thus, the total cost is low for the system, although the marginal cost to emit CO2 is high.

6.5.4 Results for Sweden

If we take a closer look at the model results for electricity generation in Sweden (Figure 6.9), we may conclude that the share of fossil-fuelled electricity generation already today is at a very low level. This also means that an expansion of renewable electricity or other non-CO2 emitting sources of electricity have very limited impact on CO2 emissions from electricity supply in absolute numbers within Sweden and KASK-SE. However, if we widen our scope to include also neighboring countries, where the share of fossil electricity generation today and in a foreseeable future is of considerable size, the impact on CO2 emissions of investing in renewable electricity generation in Sweden (and Norway) may be of significant size. In such a case, wind power investments in e.g. Sweden may replace coal-fired power plants with significantly higher running costs in e.g. Germany through increased cross-border electricity trade. Thereby, CO2-emissions are reduced from electricity generation in the common North European electricity market. However, even though our electricity-system modeling includes a detailed assessment of the entire European system, the scope of this project is limited to CO2 emissions within the KASK region. Given such a limitation in scope, we may conclude that expanding renewables in Sweden (and Norway) has limited value in terms of reducing



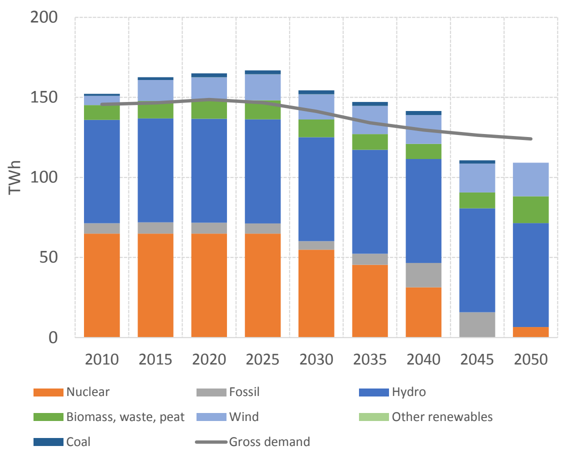


Figure 6.9: Model results for electricity generation in Sweden in the “Green Policy” scenario (left) and the “Regional Policy” scenario (right).

CO2 emissions. If we exclude possible benefits in terms of for instance CO2 reductions outside the KASK region (or outside Sweden), an increase in the share of renewable electricity within the KASK region (or Sweden) may still be justified due to other regional (or national) policy goals such as security of supply, technological development and employment policies.

The nuclear phase-out has significant impact in the Swedish electricity system. Assuming a rapid phase-out as in the “Green Policy” scenario means that Sweden leaves its current state of excess supply and net electricity export (compare the size of the production bars with the demand line in Figure 6.9). It is not until around 2040 that the expansion in renewable electricity is sufficient to balance supply and demand. In the “Regional Policy” scenario, the existing nuclear capacity is available for a longer time period into the future while, at the same time, electricity demand is lower compared to the “Green Policy” scenario. Thus, Sweden is a net exporter up to 2040 according to our model results even though investments in renewable electricity are limited to the existing setup of the common Swedish-Norwegian electricity-certificate scheme.

6.5.5 Results for the KASK-SE region

As mentioned, the results of the European modelling can be further disintegrated into four regions in Sweden (and, of course, several other European regions; cf. Figure 6.7). Thereby, the model region that geographically cover the KASK-SE region (and adjacent regions), i.e. model region “SWE2”, is used as “governing” or “decision” region for the KASK-SE region. Thus, changes that occur in the “governing” region are assumed to occur also in KASK-SE. This is our main method to assess the future development of electricity generation in the KASK-SE region up to 2050. However, since this is a simplification we also use region-specific considerations in order to complete the picture. Such considerations include using a recently updated version of the Chalmers Power Plant database that includes power plants currently under construction and in planning in the KASK region as well as the latest projections for decommissioning of certain power plants. Such plans do, however, generally not go beyond 2020. Furthermore, we use the specific mapping of future CHP schemes based on biomass and waste incineration in the KASK region up to 2030 which is described elsewhere in this report (see Section 6.3).

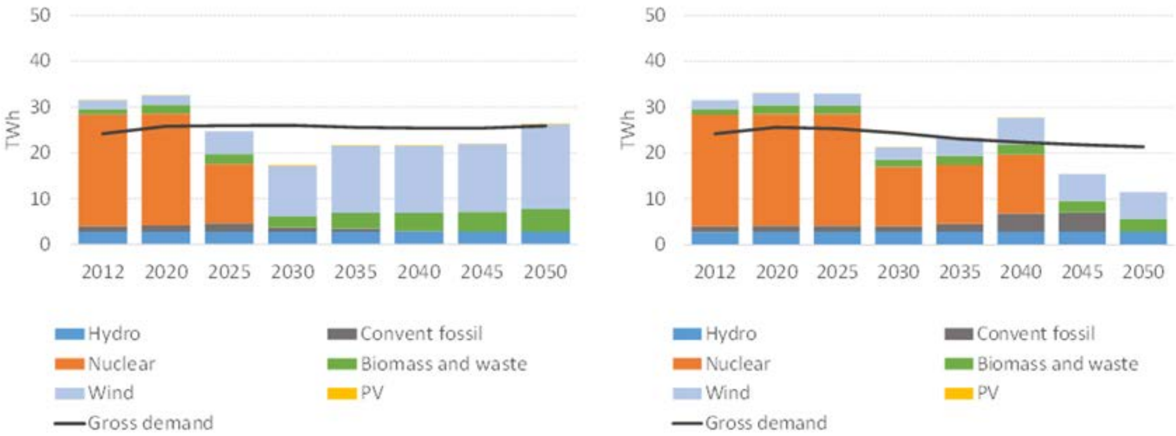


Figure 6.10: Model results for electricity generation in KASK-SE in the "Green Policy" scenario (left) and the "Regional Policy" scenario (right).

The results of the assessment are reported in Figure 6.10. From the results we see that KASK-SE currently is an export region of electricity, mainly due to the Ringhals nuclear power plant, which is one of the largest power plants in the Nordic countries. However, electricity demand in KASK-SE is relatively large since the region includes both Göteborg, the second largest city in Sweden, and several large industries.

In the "Green Policy" scenario we assume a life-length of all European nuclear power plants of 45 years meaning that all four nuclear reactors at Ringhals are decommissioned before 2030. At the same time the contribution from wind power is significantly increased reaching more than 10 TWh by 2030 which is almost five times as much as today. Also the contribution from biomass power is increased but on a considerably lower level. Even though the share of renewables is increased dramatically in the Green Policy scenario it does not fully replace the contribution in production previously from the Ringhals nuclear power plant. Thus, the KASK-SE region needs an annual net electricity import (the solid line in Figure 6.10 shows estimated gross electricity demand in KASK-SE).

In the "Regional Policy" scenario, wind power expands at a slower pace mainly due to the current (limited) target level within the Swedish-Norwegian electricity-certificate scheme. At the same time, the remaining lifetime of the Ringhals power plant is longer than in the "Green Policy" scenario implying that the supply-demand balance issue discussed below is not crucial prior to 2040.

It is important to realize that the need for electricity-transmission capacity across the border of the KASK-SE region may be much larger than indicated in Figure 6.10. Since supply within the region is dominated by wind power post 2030 in the "Green Policy" scenario there will be time periods where wind availability is low, implying a high demand for imported electricity, and periods with high wind availability, implying a high need for exporting excess electricity. Or alternatively, periods with low wind availability may require sufficient back-up capacity within the KASK-SE region. Some of that back-up capacity is supplied by biomass power in condensing mode. Biomass condensing power is an expensive option but becomes feasible, to a certain extent, in our "Green Policy" scenario. In this project we have not further elaborated on the requirements for transmission capacity or back-up capacity in relation to this specific region. Flexible demand such as utilizing electric vehicles for storage of electricity, production of fuels through electrolysis, production of heat by heat pumps or by electric boilers followed by heat storage in grids and buildings or increasing the flexibility in power-to-heat ratio in combined heat and power plants are all alternative methods that may be applied in the future to mitigate the effects of large variations in intermittent power generation.

We may also conclude that the estimated contribution from wind power in the “Green Policy” scenario in 2050, approximately 15 TWh annually, is below the roughly identified “profitable potential” of 10 GW (corresponding to approximately 20-25 TWh; see Section 6.2) given that the total income for wind power installations amounts to 65 EUR/MWh. Model results for the “Regional Policy” scenario indicate that the wholesale electricity price in the Nordic market levels out at around 70 EUR/MWh towards 2050.

When it comes to wind power, we only consider onshore wind power (both in KASK-SE and KASK-NOR). Currently, the costs for offshore wind power are much higher than for onshore wind power at the same time as the potential for onshore wind power is estimated to be very large in the region. Thus, focus should be placed on utilization of onshore sites, at least for the time being.

In Chapter 6.4 it was suggested that the potential for consumer installations of solar PV in KASK-SE could reach up to 2.5 TWh. This may be directly compared to the low PV production volumes reported in Figure 6.10. When it comes to PV installations, the European modelling lacks somewhat in level of detail. The major market for PV installations is likely to be small-scale investments made by electricity end-users such as households, which is not reflected in the model tool. Hence, incentives for PV may be somewhat underestimated in the model calculations of this study.

6.5.6 Sensitivity analysis – Wind power

In this section we finalize the assessment by presenting a sensitivity analysis focusing on wind power in the KASK region. We do this by supplementing the model results from the two main scenarios, “Green Policy” and “Regional Policy”, with two additional ELIN model results, namely based on the “Climate Market” scenario and an alternative version of the “Regional Policy” scenario (for a closer description of these scenarios see Appendix A1). The results for the assessment across all four model runs and for the production of wind power in KASK-SE, are reported in Figure 6.11. It is clear that our two main scenarios span the interval of the outcome. Both “Climate Market” and the second version of “Regional Policy increased ambition” (with a higher target level of the Swedish-Norwegian electricity certificate scheme) place themselves in-between the two main scenarios described above when it comes to wind power.

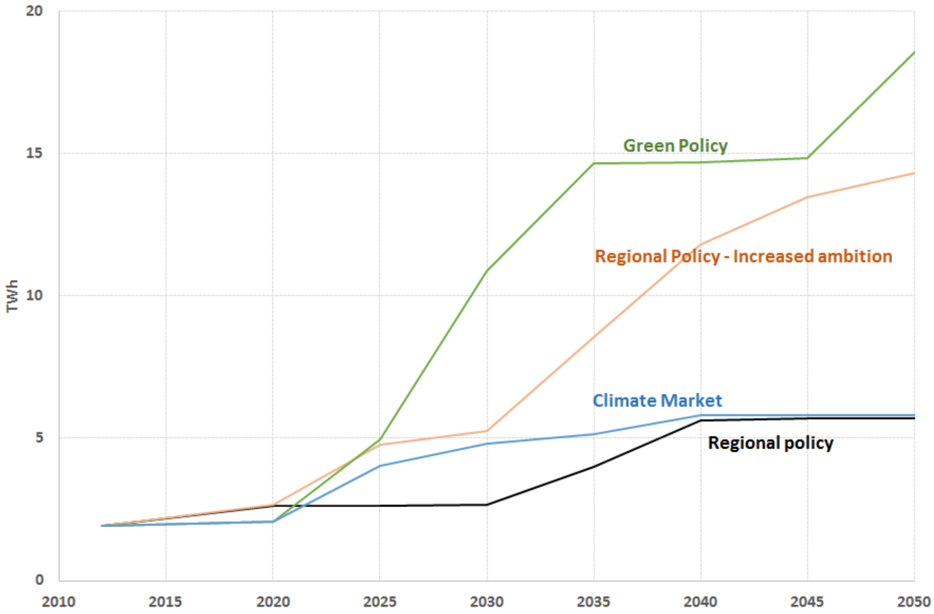


Figure 6.11: Electricity production from onshore wind power in KASK-SE across all four ELIN model runs performed in the sensitivity analysis.

It must be repeated that the “Green Policy” scenario indeed is a challenging scenario in terms of renewables. This is, however, the core definition of the scenario. And under such circumstances investments in wind power are very high in KASK-SE and across other European regions. This, in turn, entails a number of challenges presented to the electricity system associated with balancing power and transmission-grid capacities as we discussed above, in order to maintain balance between demand and supply in each time period. Such challenges are not equally pronounced in our “Regional Policy” main scenario and “Climate Policy” scenario where the total production of wind power is typically around 5 TWh in KASK-SE, in a 2050 perspective. However, also in the “Regional Policy” main scenario there exists a supply deficit post 2040 in KASK-SE due to the phase-out of nuclear power. Hence, due to the relatively smaller contribution from wind power the question of safeguarding security of supply within KASK-SE is still an issue that needs to be resolved, but in a longer time perspective than in “Green Policy”. In the “Climate Policy” scenario (see A1), existing nuclear power at the Ringhals power plant is partly replaced by new capacity. Thereby, some of these issues are dealt with even though new nuclear power schemes within the region may challenge other political considerations. In all scenarios the bottom-up analysis of available land for on-shore wind power siting with high enough wind conditions give that there is enough space, considering the definition of areas of conflict applied in this work.

6.6 Conclusions

In summary, the power sector in the region has a relatively modest consumption of fossil fuels, mainly natural gas, (see for instance Johnsson J., et al., 2014) with corresponding modest CO2 emissions. Therefore, a large scale deployment of renewables in KASK-SE will have relatively little effect on local CO2 emissions. On the other hand, an increase in renewable generation in the KASK-SE region would probably replace fossil based generation in other parts of Europe and thus lead to overall lower emissions. According to the model results for Europe’s power sector shown above, the power generation system in KASK-SE may evolve in several directions and still comply with zero CO2 emissions by 2050. Large-scale deployment of renewables in combination with phase-out of nuclear power may turn the region into an import region with regard to electricity unless adequate methods for storage of the generated electricity can be developed (see above). Large scale penetration of intermittent power is likely to create significant challenges for the electricity grid in the region as well as with regard to balancing of the system. Finally, the work reveals that there is a substantial potential for onshore wind power in the KASK-SE region. Bottom-up studies on available land area have indicated that some 10 GW onshore wind power may be installed at competitive conditions having a generation potential of between 20 and 25 TWh.

7 Transport

This chapter reports the main results from the work on the transport sector, for more details on this work see Sköldberg et al., (2014).

Section 7.1 applies the findings from an assessment of three reports of the national transport system to derive a reasonable scenario to achieve CO2 emission targets for the transport sector in the Swedish KASK region. This part of the study refers to domestic transport including working machines used in the transport sector. The three reports that have been assessed are;

- SOU (2013:84). Fossilfrihet på väg. Betänkande av Utredningen om fossilfri fordonstrafik. Statens offentliga utredningar, Stockholm 2013.
- Trafikverket (2012). The Swedish Transport Administration. Delrapport transporter: Underlag till färdplan 2050. Trafikverket, publikation 2012:224, november 2012.
- Elforsk (2012). Roadmap för ett fossilbränsleoberoende transportsystem år 2030. Rapport för Svensk Energi och Elforsk, Elforsk rapport 12:68, 2012-12-07

Section 7.2 applies a transport model on the transport sector in Göteborg in order to analyze in more detail how the Swedish target of zero GHG emissions in 2050 can be met locally within the transport sector. Section 7.2 deals mainly with road transport.

It is emphasized that the objective of the scenarios developed in Sections 7.1 and 7.2 has been to analyze a possible pathway to 2030 assuming that society makes a concerted effort to achieve significant emission reductions. Thus the objective has not been to show the most likely development. Also, to achieve the considerable changes in the transport system that will be required to meet zero GHG emissions in 2050 (and significant reductions of up to 80% to 2030), will require great will and determination and, thus, require significant political efforts.

A conclusion from the assessment of the three key reports on the national development of the transport sector is that it is possible to reduce fossil fuel consumption in the national road transport system by 80% up to 2030 (relative to 2010) as well as to reach zero overall GHG emissions in 2050, which basically implies a complete phase-out of fossil fuels within the transport sector.

7.1 Transport sector in KASK Sweden

Based on the results from the Elforsk (2012) report, we developed relevant pathways to reach the same targets also for the regional transport system in KASK Sweden. This is done by simply scaling down the results for Sweden in Elforsk (2012) to the KASK-SE region based on population statistics which is considered as a feasible methodology for several reasons:

- The Swedish KASK region may broadly be representative for Sweden in miniature with regard to terrain, road characteristics and in terms of population density. This assumption is supported by statistics on for instance transport work, distribution of different types of roads as well as the length of roads.

- There are also similarities between the national average and KASK Sweden with regard to car ownership per capita and fuel consumption.
- There is a relatively large dependence on cars in Göteborg (which is a large part of KASK-SE) in terms of commuting to/from the Göteborg area. In this respect, Göteborg is distinctly different from other metropolitan regions in Sweden.

What separates the KASK region from the national average and at the same time is typically for the metropolitan regions of Sweden, is the larger part of cars running on alternative fuels and cars that use other than conventional fuels like petrol and diesel. Nevertheless and based on the above, the conclusion that the transport sector in the Swedish KASK region can be considered as representing a national average is considered as reasonable for the analysis performed in this work. Thus the results from the Roadmap given in Elforsk (2012), see Sköldberg et al., 2014, have been applied together with population statistics to derive a scenario for KASK-SE reaching 80% reduction in fossil fuel consumption in the transport sector in 2030. Application of population statistics simply means that all national quantities have been scaled down by the factor 0.199 (i.e. the population in KASK-SE divided by Sweden's population; 1 921 924/9 644 864). For the period 2030 to 2050 which is not covered by Elforsk (2012), we have a qualitative discussion on how to phase out the last 20% of fossil fuels in the transport sector, see Sköldberg et al., (2014).

The Roadmap (Elforsk 2012) applied in the work reported below starts in the Year 2007. Since energy consumption in the transport sector and corresponding emissions have been relatively constant in the region since 2005[10], this has nevertheless been considered as a relevant start year.

7.1.1 Results for KASK Sweden

Through application of the scaling described above we have derived a scenario for how the KASK-SE region can reach zero CO2 emissions by 2050.

With regard to biofuels we conclude that it will be difficult to raise the contribution further beyond what has been applied in 2030 and therefore the proportion of biofuels have been kept constant after 2030. We also assume that transport work in the base scenario (see Sköldberg et al., 2014) will continue to increase after 2030 but that this increase will be neutralized by reduced transport demand and shift in mode of transportation (moving from for instance private to public transport). Due to further increases in vehicle efficiency we assume that demand will decline a further 20% relative to 2030 with the remaining part of fossil fuels being phased out through increased use of electrical cars. Between 2030 and 2050 this implies roughly a doubling of electricity consumption in the transport sector. Figure 7.1 shows the result with regard to energy consumption for the transport sector in KASK-SE applying the roadmap up to 2030 (Elforsk 2012, Sköldberg et al., 2014), the downscaling based on population statistics and the discussions above for the period 2030 to 2050. Figure 7.1 should be interpreted in the following way; demand in the base scenario is given by the height of each bar while actual demand is given by fossil fuels plus renewables plus electricity meaning that all other actions listed in the figure lead to reduced demand.

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[10] Between 2005 and 2012 energy consumption has fluctuated between 17.8 TWh in 2012 to 20.0 TWh in 2008 (Statistics Sweden) while corresponding CO2 emissions have fluctuated between 4.3 Mt in 2012 to 4.8 Mt in 2007 (Länsstyrelserna 2014).

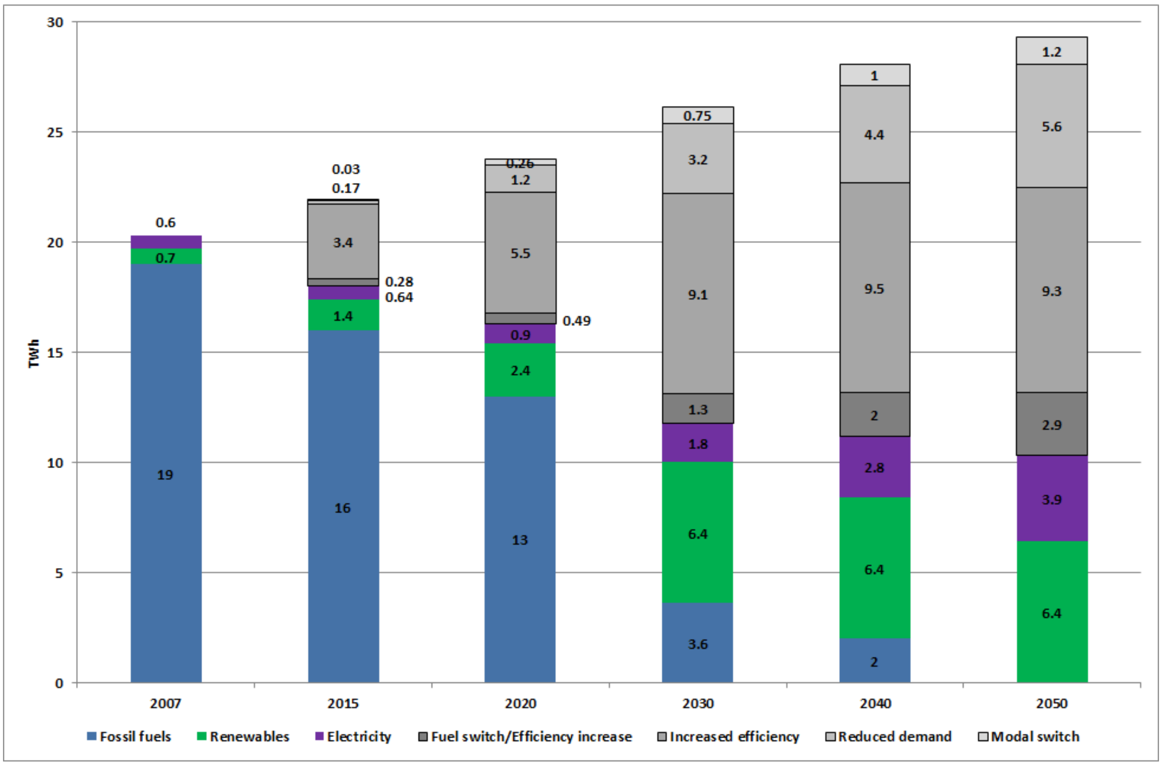

Figure 7.1: Estimated energy consumption up to 2050 in the base scenario in the transport sector in KASK-SE. Demand in the base scenario is given by the height of each bar while actual demand is given by the colored part of each bar (fossil fuels plus renewables plus electricity). Thus the grey parts in each bar refer to actions to reduce demand and CO2 emissions.

As can also be seen from Figure 7.1 demand in the base scenario in KASK-SE would have increased from approximately 20 TWh in 2007 to 29 TWh in 2050 if no measures were taken[11]. Yet, a combination of increased vehicle efficiency, fuel switch (also leading to increased efficiency), modal shift and concerted actions to reduce demand lead to an estimated energy demand for transportation in 2050 of just above 10 TWh. It can also be seen that by 2050 fossil fuels are completely phased out.

Figure 7.2 shows corresponding CO2 emissions, here shown as the part of the bar that has been colored blue. Also shown is the share of emission reductions by the different measures that have been applied to reduce emissions. Thus, it is only the part of the bar corresponding to fossil fuels (strong blue) that refer to CO2 emissions since electricity and renewables do not lead to emissions from end users (cars).

[11] According to Figure 7.1 demand is estimated to 20.3 TWh in 2007 declining to 18.0 TWh in 2015 (including the measures to reduce demand). This may be compared to actual demand of 19.2 TWh in 2007 and 17.8 TWh in 2012 as given by Statistics Sweden (2014a). Since 2009, actual demand in the region has fluctuated between 18 and 19 TWh. Thus, there appears to be a relatively good fit between the real values given by Statistics Sweden and the values estimated in this report.

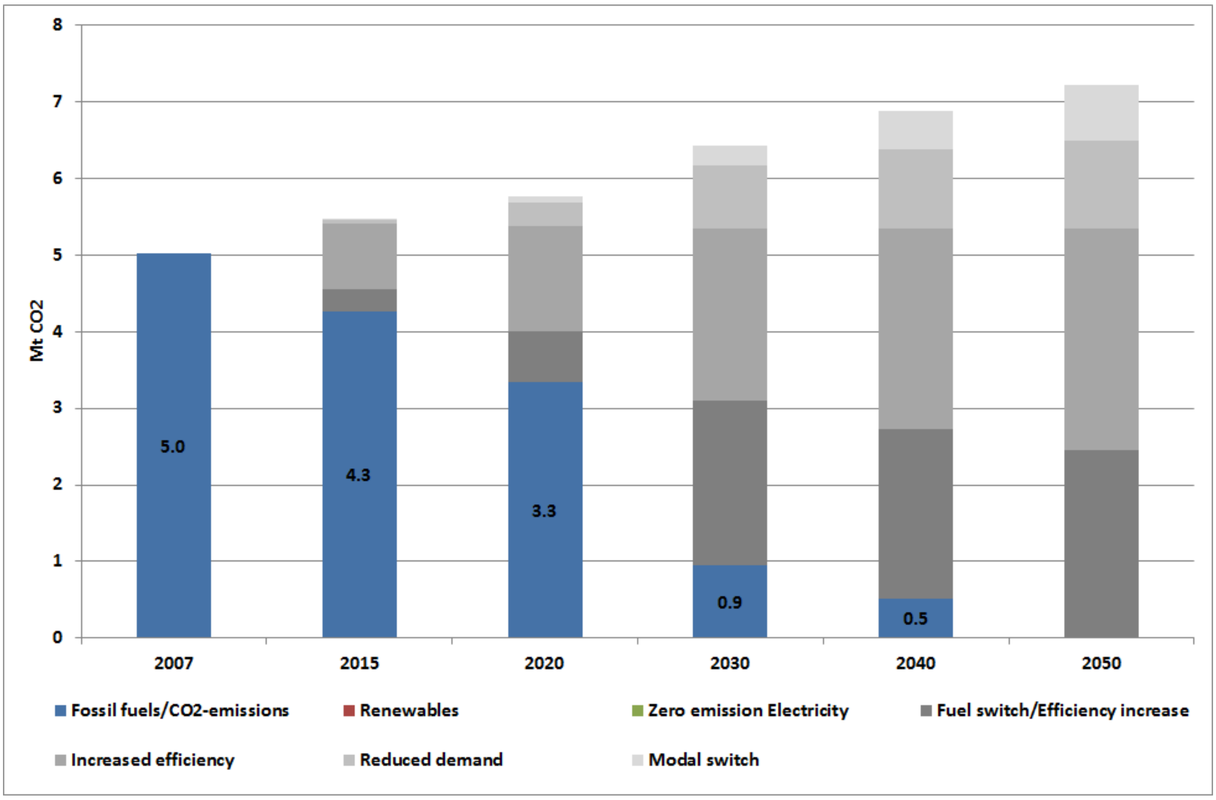

Figure 7.2: CO2 emissions from the transport sector in KASK-SE corresponding to actual demand and fuel mix shown in Figure 7.1. Estimated CO2 emissions are derived from use of fossil fuels only (strong blue) while the rest of the bar (grey parts) refers to CO2 emission reductions by measure. The electricity is assumed to be 100% de-carbonized.

As can be seen from Figure 7.2, CO2 emissions are reduced from ca 5 Mt in 2007 to 4.3 Mt in 2015[12] and to less than 1 Mt in 2030. Fuel switch and increased efficiency account for nearly three quarters of the total emission reductions shown in Figure 7.2.

It can also be noted that estimated emissions in KASK-SE in 2007 as obtained in this work is 5.0 Mt which is similar to the estimated emissions of 4.8 Mt given by Länsstyrelserna (2014). Furthermore, estimated emissions in 2015 are 4.3 Mt according to Figure 7.2 which equals 2012 emissions as given by Länsstyrelserna (2014). Thus, it can be concluded that the roadmap (Elforsk 2012) which forms the basis for the work presented in this report appears to fit well with the development between 2007 and up to at least 2012.

From the above analysis it can be concluded that it is possible to significantly reduce fossil fuel consumption in the transport sector in KASK-SE by 2030 and to eliminate its use completely by 2050. As a consequence, CO2 emissions are reduced to less than 1 Mt in 2030 and to zero in 2050. Nearly three quarters of the emission reductions are derived from fuel shifting and increased vehicle efficiency and in 2050 biomass covers 62% of the transport sector's fuel demand with the remaining 38% being covered by electricity. The significant volumes of biomass that this will require is analyzed and discussed in Sections 8 and 9.

[12] As a comparison; actual emissions from the transport sector including working machines amounted to 4.3 Mt in 2012 (Länsstyrelserna 2014).

7.2 Modeling of the transport sector in Göteborg

This section applies a transport model to determine possible pathways towards zero GHG emissions in the transport sector in Göteborg. The analysis covers the time period from 2012/2013 to 2030. As opposed to the results for KASK-SE obtained in Section 7.1, the results for Göteborg are not based on a down scaling of national results proportionally against population. Instead, a bottom-up approach has been applied starting with the traffic work by transport type which has then been converted to energy consumption based on specific levels of energy consumption for each mode of transport. Base data have been discussed with representatives from the traffic office of the city of Göteborg, but still some ambiguity with regard to the accuracy of these data remains which are being discussed below.

Section 7.2.1 describes the methodology applied in this work based on the model presented in Sköldberg et al., 2014. Section 7.2.2 gives the model results which then are discussed in Section 7.2.3 along with relevant economic incentives and potential barriers and problems linked to these.

7.2.1 Transport model and Methodology

The close-up modeling of the City of Göteborg comprises all road transport with private cars, light and heavy duty trucks and busses within the geographical boundary of the municipality of Göteborg. Although modeling of railway transport is not included, railway transport (and related energy use and emissions) is included as a measure to reduce road transport in the "modal shift package" described below. Modeling of transport by mopeds, motorcycles and working machines as well as by ship and air has not been covered in this work.

Due to insufficient regional statistics for road transport the work starts with determining the traffic work (vehicle kilometers) on all roads within the geographical boundary of Göteborg based on measured transport flows and driving distances.

According to the measurements that have been done in connection with the so-called "West Sweden Traffic package" (spring 2013), the total traffic work per average weekday within the municipality amounts to around 7.3 million vehicle kilometer (WSP, 2013) which has been assumed to represent a relevant value for the traffic work in Göteborg. To convert the estimate for vehicle kilometer per average weekday to an annual average we have used a conversion factor (0.88) estimated by the traffic office of the city of Göteborg. Applying the conversion factor on vehicle kilometer per average weekday yields the estimated total traffic work per day, namely 6.4 Mvkm (Million vehicle kilometer) which in turn gives an estimate of the corresponding annual traffic work in the city of 2,300 Mvkm.

To distribute the traffic work between vehicle types we have used both sources that indicate how the traffic work is distributed among vehicle types within the city (City of Göteborg, 2002) and corresponding information on a national level (Trafikanalys 2013). Comparing the distribution in Göteborg with the corresponding national distribution indicates a similar distribution between vehicle types, at least with regard to the ratio between light and heavy duty vehicles. The estimated distribution of traffic work between vehicle types is given in Table 7.1. The distribution in Table 7.1 has been discussed with Björklind and Tjernkvist (2014) which stated that the estimate appears reasonable.

Table 7.1: Estimated annual traffic work per vehicle type in Göteborg and Sweden, Mvkm.

	Göteborg Mvkm	Göteborg Share, %	Sweden Mvkm	Göteborg share in national, %
Private vehicles	2 000	88%	62 900	3.3 %
Light duty trucks	140	6%	8 100	1.7 %
Busses	35	1%	950	3.6 %
Heavy duty trucks	120	5%	4 600	2.6 %
Total	**2 300**		**76 000**	**3.1 %**

As can be seen in Table 7.1, total estimated traffic work within the municipality of Göteborg accounts for some 3% of the national total. Population wise, Göteborg accounts for ca 5% of Sweden's national population. It is however, reasonable to assume that traffic work per capita is smaller in densely populated municipalities.

The estimated traffic work in Table 7.1 has thereafter been applied to derive the corresponding fuel consumption in Göteborg by relating Göteborgs share of the total transport work in Sweden to total fuel consumption by road traffic in Sweden (distributed by vehicle type and fuel type). Fuel consumption by Swedish road transport is given by the above mentioned model (Sköldberg et al., 2014) for the year 2007 which has been adjusted to current levels based on national statistics for the years 2007 to 2012 (both for the development as a whole and for the changes in fuel mix) given by the Swedish Energy Agency (2014d). As regards the use of biogas in private vehicles we have assumed twice the national growth in Göteborg leading to a slightly lower consumption of petrol. The reason for this assumption is a higher share of biogas cars in Göteborg than nationally, mainly due to availability of a distribution system (natural gas) which is not available in most parts of Sweden. This also facilitates higher future growth.

Thus, fuel consumption for the four vehicle types considered in this study, which will be fed as input to the model, have been adjusted to include the gains in energy efficiency between 2007 and 2012[13]. The derived distribution of fuel consumption by fuel is given in Figure 7.3.

[13] In total the transport sector in Sweden has reduced its energy consumption by almost 13% between 2007 and 2012, mainly due to increased energy efficiency in private cars (Trafikverket 2014).

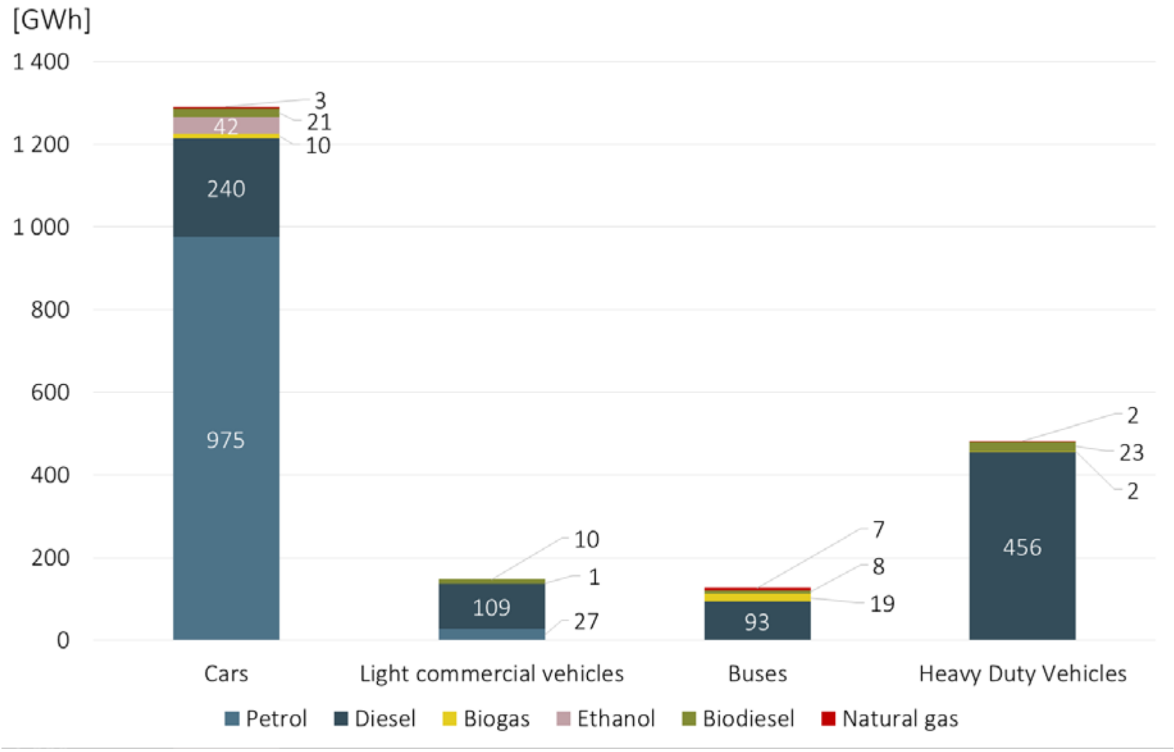

Figure 7.3: Estimated current (2012) annual fuel consumption in GWh by fuel and by vehicle type in the City of Göteborg.

As mentioned above, the estimated fuel consumption shown in Figure 7.3 is used as input for the transport scenario model as a starting point for the potential GHG emission reduction options that can be derived for the future transport sector. GHG emission reduction options in the transport sector have been categorized into four groups;

1. Reduced demand for transport
2. Modal shift (e.g. shift from car to bus or bicycle)
3. Increased vehicle efficiency
4. Fuel shift and corresponding efficiency increase in final use (e.g. shift from gasoline to electricity, resulting in a reduction of more than 50 % of the final energy use)

For each group of emission reduction options outlined above several assumptions have been made with regard to energy consumption up to 2030. For group 1, reduced demand for transport, the following assumptions have been made;

- City planning for less car dependency: -5% for private cars
- Car pool: -3% for private cars
- Travel-free meetings, distance work, e-trade and more: -2% for private cars
- Congestion tax, parking policy, parking fees: -5% for private cars
- Route planning for private cars: -1%
- Logistics for trucks (route planning, less idle running, longer vehicles and more: -15%

The next group of emission reduction options refer to group 2, modal shift, where the following assumptions were made;

- More attractive public transport: -6% for private cars and an increase in bus and rail traffic responsible for this kind of travel.
- From truck to train: -10% for trucks and an increase in rail traffic responsible for this kind of travel.
- Private cars to cycling and walking: -1% for private cars

The third group for emission reduction options is increased vehicle efficiency where the following assumptions have been made;

- Technical vehicle efficiency: -20% to 31% depending on transport type, e.g. -31% for private cars.
- Eco-driving: -5% to -10% depending on transport type, e.g. -10% for private cars
- Intelligent transport systems (ITS): -5% for road vehicles

Finally, for group 4, efficiency increase related to fuel switch, we have made the following assumptions:

- Use of electricity in road transport is assumed to increase to a total of 110 GWh of which 60 GWh in private cars corresponding to 20% of driven kilometers and ca 25,000 electric cars (assuming normal driving distances). For heavy duty trucks it has been assumed that use of electricity increases to 50 GWh in 2030 (both plug-in hybrids – PHEV, electric vehicles – EV and electrified roads). At the end of 2013, there were a total of 347 EVs and PHEVs registered in Göteborg.

The use of electricity in vehicles is assumed to yield no emissions from the vehicle. Instead emissions relate to the properties of the electricity generation. Here we use a long term marginal approach where we, through model calculations, identify the effects on the electricity generation mix due to additional use of electricity. GHG emissions linked to the increased electricity consumption have been calculated by applying an emission factor of 0.8 ton CO2e/MWh electricity in 2012 declining to 0.4 ton CO2e/MWh in 2030 (this is based on model calculations by Profu and that the emission price for CO2 is assumed to increase from less than 10 € today to more than 30 € in 2030). The reason for the relatively high emission factor is the fact that the north European power sector is fully integrated and that fossil fuel power plants will be dispatched on the margin, i.e. that any additional power requirement will be covered through increased fossil based production. Over time it has been assumed that it will be less coal based generation and more gas, biomass and wind based generation (or coal-bio) on the long-term margin leading to a lower emission factor in 2030.

Also consumption of biofuels is assumed to increase significantly to 670 GWh bio-based fuels in 2030 of which ca 280 GWh biogas, the latter based on both forest residues and crops. The rest, 390 GWh, refers to liquid biofuels such as ethanol, FAME, HVO (synthetic diesel) and second generation biofuel from forestry (DME, FT-diesel, and methanol). Current consumption of biofuels in Göteborg is estimated to around 135 GWh.

For each of the four vehicle types included in the study we have used a national base scenario (here denominated “extrapolation scenario”) for the total increase in energy consumption for the period 2007 to 2030 assuming constant vehicle efficiency and no fuel changes (in the same way as in Section 7.1. for the KASK region). Since the start year in this study is 2012 implying a shorter time period (2012 to 2030 instead of 2007 to 2030) and thus also a less increase in energy consumption over the time period studied, the increase in energy consumption from the start year 2012 to 2030 has been scaled down linearly. We have then assumed that the energy use in the transport sector in Göteborg evolves proportional to the national transport sector. In this way an extrapolation scenario has been established for energy consumption for transport work in Göteborg in 2030 to which the four CO2 emission reduction groups outlined above have been applied.

For the first three groups it has been assumed that energy consumption in Göteborg follows the national development on a percentage basis, adjusted of course for the later start year (2012 instead of 2007, see above). The fourth group refers to fuel switch, i.e. switch from fossil fuels to electricity or biomass based fuels. The share of the national potential for biofuels based on domestic biomass which can be assigned to Göteborg has been assumed to be proportionally the same as the share of the national energy consumption (within the transport sector). This has been done *after* having applied the first three emission reduction tools. In the same way, it has been assumed the same proportionally use of electricity in Göteborg.

GHG emission factors expressed as CO2 equivalents (CO2e) and with a well-to-wheel perspective have then been linked to the derived energy consumption. A well-to-wheel perspective is not only based on the emissions from the fuel but also on emissions from production of the raw material from which the fuel originates. The model results yield the contribution from the various emission reduction tools with regard to reduced consumption of fossil fuels and the volume of remaining emissions.

7.2.2 Results for Göteborg

Through application of the methodology described in Section 7.2.1, a scenario has been developed describing how the road transport's energy consumption in Göteborg could evolve up to 2030. The resulting scenario, here denominated "Roadmap 2030", describes a very ambitious transition towards a significant reduction of fossil fuels and is shown in Figure 7.4. As in Figure 7.1 (Section 7.1) the total height of the bar denominated "Roadmap 2030" shows total energy consumption corresponding to the base scenario (the bar denominated "Extrapolation scenario") but where *real* demand corresponds to fossil fuels plus renewables plus electricity, i.e. all the other "actions" listed in the figure refers to measures that reduces demand.

As can be seen from Figure 7.4 total energy consumption has been significantly reduced, from above 2 TWh in 2012 to ca 1.1 TWh in 2030 representing a 45% decline. Use of fossil fuels decline from 1.9 TWh in 2012 to 0.35 TWh in 2030, i.e. down by more than 80%. In 2030,

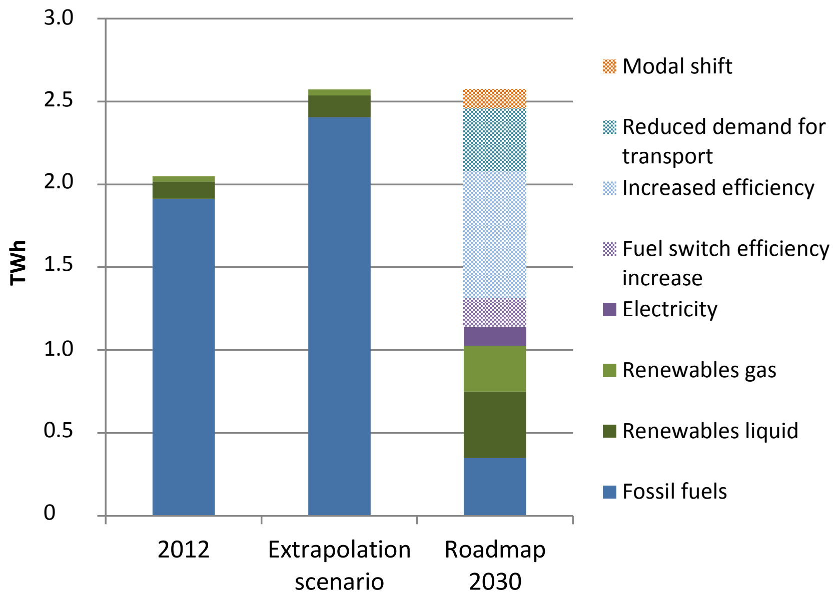

Figure 7.4: Total fuel consumption for road transport in Göteborg in 2012 including the extrapolation (base) scenario and the scenario in which fossil fuel consumption has been reduced (Roadmap 2030). Thus, real demand in the bar Roadmap 2030 corresponds to fossil fuels plus renewables plus electricity while all other measures refer to measures that reduce demand.

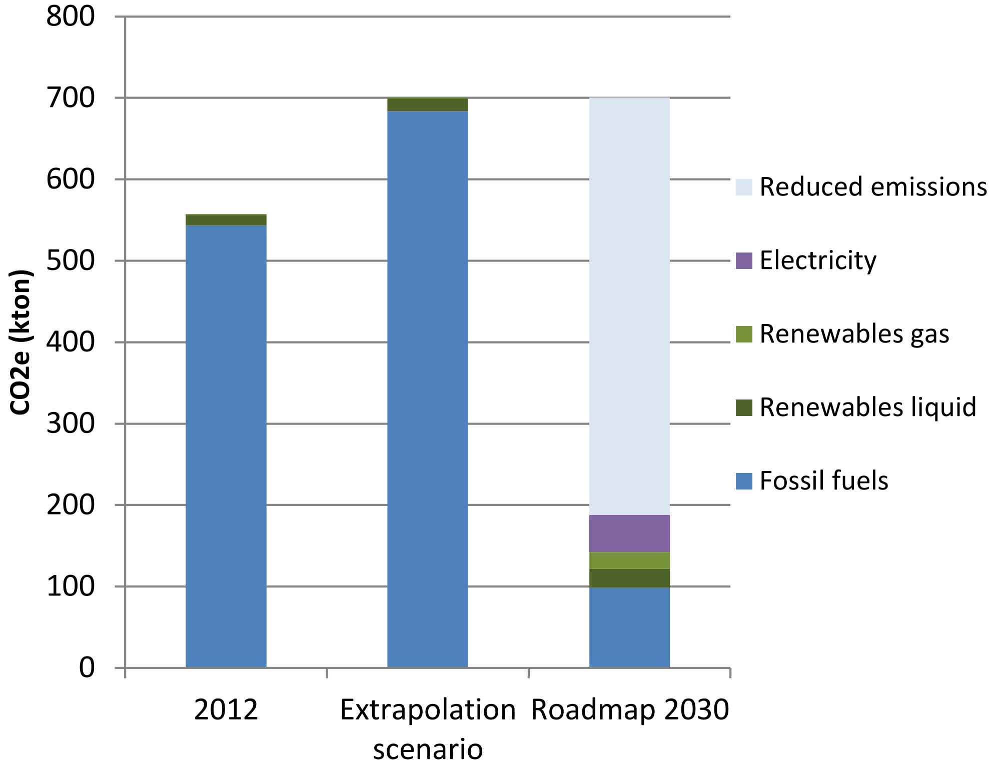

Figure 7.5 GHG emissions in CO2e in 2012, in the extrapolation scenario and in the Roadmap 2030 scenario – well-to-wheel perspective. Note that the white part of the bar refers to reduced emissions through application of the emission reduction groups outlined in Section 7.2.1 and applied to the extrapolation scenario (the bar in the middle).

fossil fuels only account for 30% of the total fuel consumption. Figure 7.5 shows how GHG emissions evolve in the Roadmap 2030 scenario, i.e. emissions correspond to the fuel consumption given in Figure 7.4. Hence the bar denominated "Roadmap 2030" shows real emissions given by the use of fossil fuels, renewables (in a well-to-wheel perspective) and electricity as well as reduced emissions due to the four emission reduction groups described above.

According to Figure 7.5 GHG emissions are reduced by some 65% between 2012 and 2030 (in a well-to-wheel perspective). If instead only direct CO2 emissions from use of fossil fuels by the end-user are considered, i.e. a wheel perspective instead of a well-to-wheel perspective, emissions are reduced from 500 kton in 2012 to 90 kton in 2030 corresponding to a reduction of more than 80%.

7.2.3 Discussion of results for the transport sector in Göteborg

In this section we discuss the results obtained in Section 7.2.2 and compare these results to results reported in other publications. We also compare the results to the official emission targets for the transport sector announced by Göteborg (see Section 3.1).

How does the Roadmap scenario fit with current emission statistics and the officially announced target for Göteborg?

Emissions on municipality level are released by the counties administrative boards (RUS 2014). According to Länsstyrelserna (2014), direct CO2 emissions (not well-to-wheel) for vehicle types relevant for Göteborg's road transport amounted to ca 566 ktons in 2012 which may be compared to 560 ktons estimated in this study. Although the estimate in this study refers to well-to-wheel GHG emissions (typically around 10% higher), the difference between the two estimates is considered acceptable as basis for the reference year of this study (Year 2012). On the other hand, comparing the 2012 emissions obtained within this study with the emissions for the transport sector given in the annexes to the City of Göteborg climate strategic program (City of Göteborg 2014b), the difference is considerable. According to City of Göteborg (2014b), Göteborg's CO2 emissions from the transport sector amounted to just above 700 ktons in 2012, i.e. some 140 ktons above the estimate in this study. The large difference has been discussed with representatives from the traffic office's but no explanation was provided to the large difference form this work such as what kind of emissions are included in the estimate in City of Göteborg (2014b). At the same time it can be concluded that the results obtained in this study fit well with the climate target announced by the strategic program, namely an 80% reduction in CO2 emissions in 2030 relative to emissions in 2010 (see Section 3.1). It can also be concluded that some uncertainty remains related to the quantification of the emissions from the transportation system in Göteborg. But foremost, this study confirms the importance of local support and participation in order to gain access to accurate data and to provide informed judgments of different action potentials. Nevertheless, the roadmap scenario outlined above should provide an approximate illustration to how various actions may contribute to reach the climate targets in Göteborg since it proportionally has the same decline as the climate strategy, i.e. 80% (although relative 2010 instead of 2012 used in this study).

As already commented above, different actors have limited capacity to act regarding development of the transport sector and there are many actors that will be required to move in the same direction to succeed with a complete transformation of the transport sector. Decisions will have to be taken on EU, national and local levels with their joint function to structure and decide incentives and to provide a reasonable framework. The transformation itself will mainly have to be accomplished through real actions taken by the public and companies. Below, it is being discussed what will be required to achieve the transformation.

7.3 Discussion of overall results for the transport sector

It seems obvious that Sweden cannot transform its transport sector completely independent from what happens in other places of the world. A clear example of this is the technical development of vehicles. It is unlikely that car manufacturers would develop vehicle technologies for Swedish markets only since the Swedish market is too small. Rather it should be assumed that vehicles will be developed at least for a European market which means that the vehicles delivered to Swedish markets will be developed according to requirements and rules on EU-level. The EU energy roadmap 2050 gives an idea of the ambitions within the EU with regard to emission levels from the transport sector. Figures 7.6a and 7.6b shows the development of CO2 emissions (7.6a) and final energy demand (7.6b) in the transport sector respectively for a number of scenarios developed in EU's energy roadmap 2050 (EC 2011).

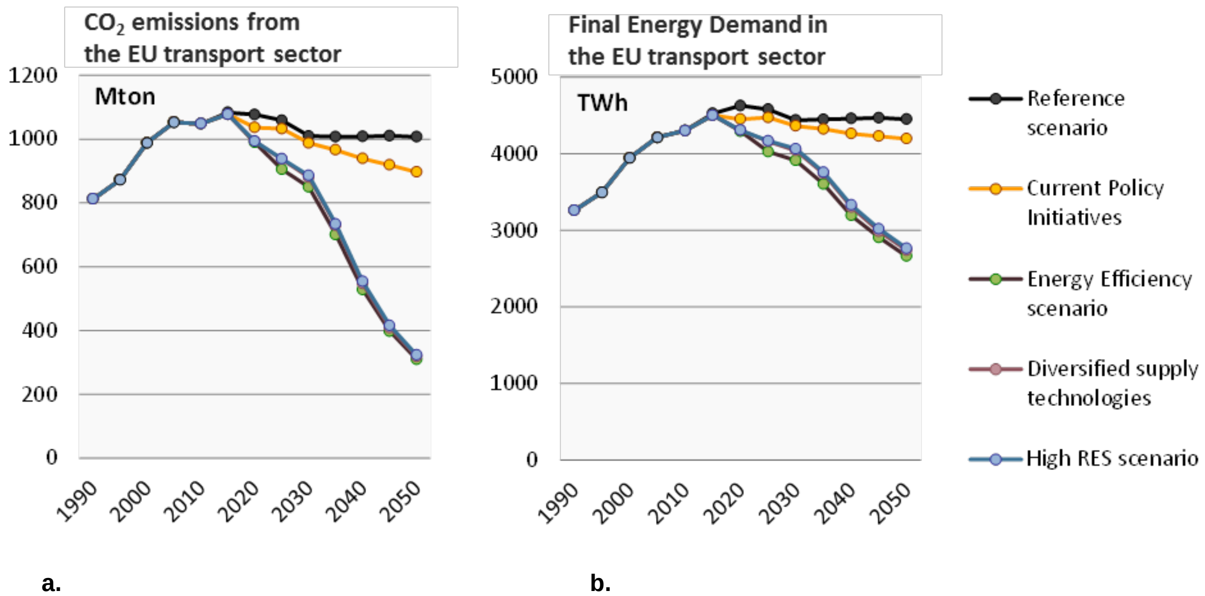

Figure 7.6. CO2 emissions (a) and final energy demand (b) in EU's transport sector according to a number of scenarios in EU's energy roadmap 2050 (EC 2011).

In the most ambitious scenario from EU's energy roadmap 2050, energy consumption in the transport sector declines by ca 10% between 2010 and 2030 while CO2 emissions decline by 20% implying a considerably less ambitious target than the emission reduction targets announced in Sweden, both the national targets as well as other regional and local targets (see Section 3.1). Implementation of very far-reaching Swedish ambitions can be greatly hampered if the rest of Europe has far less ambitious goals. Vehicle development is carried out, as mentioned earlier, for a global or at least a European market and if large international markets cannot push for significantly more efficient vehicles it seems unlikely that such vehicles will become available on the Swedish market. Thus, high ambitions at least on an EU level with regard to CO2 emissions from the transport sector seems a prerequisite for achieving similar ambitions in Göteborg and Sweden to meet their targets.

According to the Fossil Free Vehicle Fleet (FFF) inquiry (SOU 2014), economic incentives are likely to become one of the most important factors affecting to what extent different actions (CO2 emission reduction options) may be realized. Other factors that are difficult to judge but may have a large impact on the extent (rate) of a transition is people's need and interest in owning a car, urban and residential planning and development and people's choice of mode for transport. The pace of the transition will also depend on the lead times not only for renewal of the vehicle park, expansion of production facilities, distribution and market penetration of renewable fuels but also on the time it takes before new innovative thinking and/or shift in preferences have an impact on city planning.

Both Elforsk (2012) and the FFF inquiry (SOU 2013, 2014) have proposed a number of economic incentives that potentially may drive the transformation of the Swedish vehicle park towards less dependence on fossil fuels. A selection of the most important incentives that were proposed in Elforsk (2012) are listed and discussed in Appendix A2 (see also Sköldberg et al., 2014). It should however be emphasized that in addition to the barriers and problems listed in Appendix (A2), the single largest barrier will probably be the citizens willingness to accept the drastic changes that are likely to be required in their lifestyle. Yet, the transportation preferences may change between generations. For example, in urban regions it has become more common not to take a driver license for young people which may be due to several reasons, such as the high cost of taking a driver license, in combination with high unemployment and/or that having a driver license is not to the same extent associated with social status, that young people study longer than previous generations and hence also are older when they have firm employment and stable economy, or that public transportation has improved, see for instance (SR 2014, GP 2014, Trafikanalys 2012).

8 Transforming the energy system in Västra Götaland and Halland – linking short term actions to long term goals

This section discusses relevant pathways to reach national, regional and local goals for reduced energy consumption, increased penetration of renewable energy and reduction of production based CO2 emissions within the KASK-SE region. For a detailed description of the goals see Section 3. Since achievement of the reduced energy consumption and increased use of renewable energy will contribute to reduction in CO2 emissions, i.e. to reach zero GHG emissions in 2050, it seems natural to start with pathways for lower energy consumption and large-scale penetration of renewables followed by pathways for emission reductions. This section builds upon the work described in Sections 4 to 7 and the ambition of this section is to link current status with the political visions as visualized in Figure 8.1.

Pathways for reduced energy consumption are described up to 2030 since there are no goals for reduced energy consumption beyond 2030, either on EU, national or regional level. Pathways for renewable energy and CO2 emissions are described up to 2050.

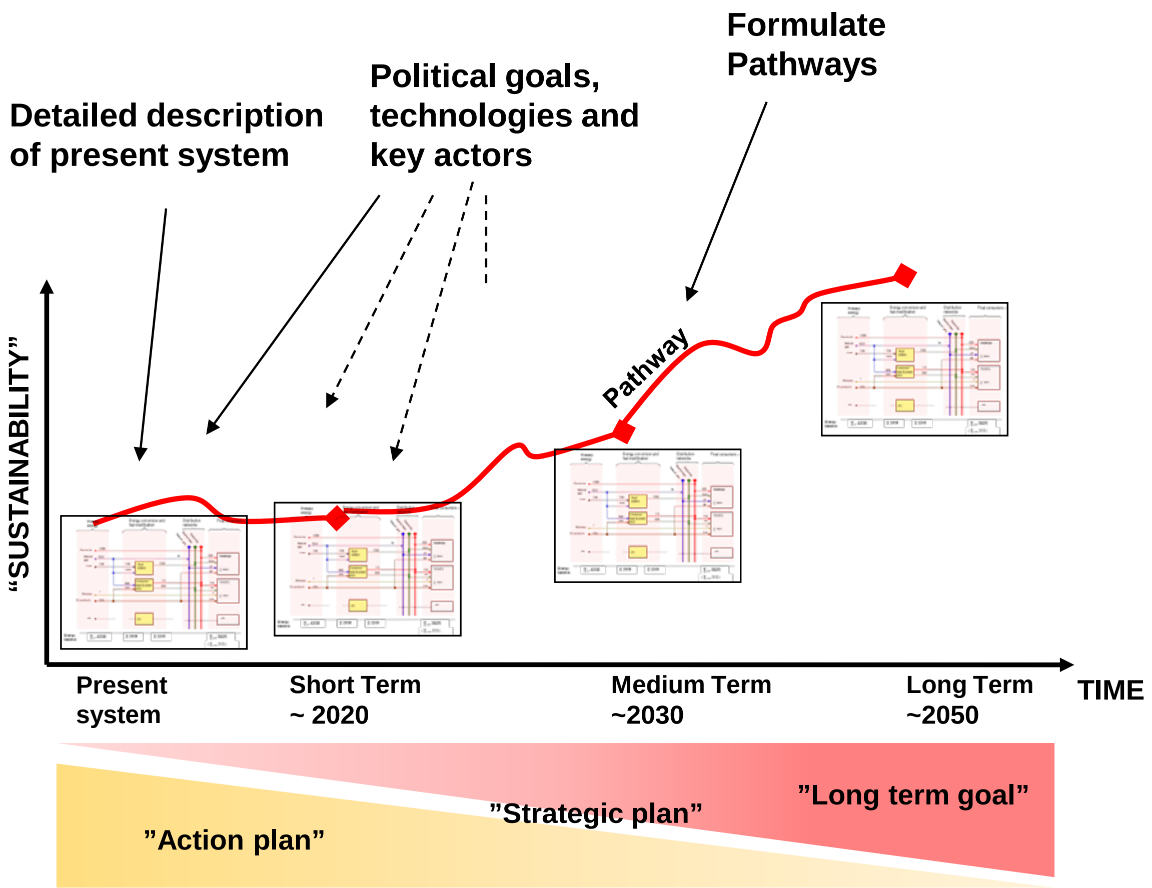

Figure 8.1: Basic description of a pathway and how it interacts with plans and strategies for different time horizons, i.e. in the short-term (2020), medium term (2030) and long term (2050).

8.1. Energy efficiency

As mentioned in Section 3.3 both VGR and Halland follow the national target of reducing energy intensity by 20% between 2008 and 2020 which in turn is the Swedish interpretation of the EU indicative target of 20% less consumption relative to a baseline projection. Additionally, in October 2014, the EU endorsed an indicative target of 27% savings in energy consumption up to 2030 (again relative to a baseline projection) and it is therefore assumed here that the two counties in KASK-SE will follow a national target up to 2030. We assume furthermore that the national target will follow the corresponding EU target but, as for the 2020 target, relate it to energy intensity, i.e. gross consumption divided by Gross Regional Product (GRP) expressed in 2008 prices.

Between 2008 and 2011 apparent[14] energy intensity in KASK-SE declined by 13.5%, from 128 to 111 MWh/kr. However, while it has gone down by 16.5% over the period in VGR it has increased by 5.4% in Halland. Apparent energy intensity has been calculated by dividing Final Energy Consumption (FEC) as described by Statistics Sweden[15] with the GRP in running prices but where running prices have been adjusted based on the development of the Consumer Price Index (CPI) relative to CPI in 2008, i.e. the CPI has been indexed with 2008 as a base year.

The Swedish Institute for Growth Analysis (2009) has analysed development pathways for the GRP between 2005 and 2030 in the largest cities in KASK-SE in a base and an alternative scenario. The suggested development for five large cities in the KASK-SE region is shown in Table 8.1.

Table 8.1: Projected average annual growth (% per year) in GRP between 2005-2030.

	Base scenario	Alternative scenario
Göteborg	2.7%	2.9%
Halmstad	1.9%	2.1%
Borås	2.0%	2.1%
Trollhättan	1.9%	2.1%
Skövde	1.7%	1.8%

Source: The Swedish Institute for Growth Analysis 2009

Assuming that the GRP in KASK-SE will grow by between 2 and 3% annually between 2012 and 2030 will allow the absolute value of FEC to *increase* by between 21% and 45% over the same period and still achieve the target of a 27% decline in 2030 relative to energy intensity in 2008. If we instead assume that GRP will increase by only 1% in average between 2012 and 2030, FEC will have to be reduced by 2% between 2008 and 2030 in order to reach the 27% reduction target in energy intensity. Figure 8.2 shows this development of FEC assuming an annual growth in GRP between 1 to 3% between 2012 and 2030.

[14] The term “apparent energy intensity” has been used since FEC has not been divided by GRP in 2008 prices but instead by GRP in running prices adjusted by the CPI which has been indexed to the year 2008.

[15] According to Statistics Sweden Final Energy Consumption (FEC) is gross supply minus fuel input for production of electricity and heat plus produced electricity and heat (i.e. after conversion) minus energy that has been used by the energy sector itself minus transmission losses.

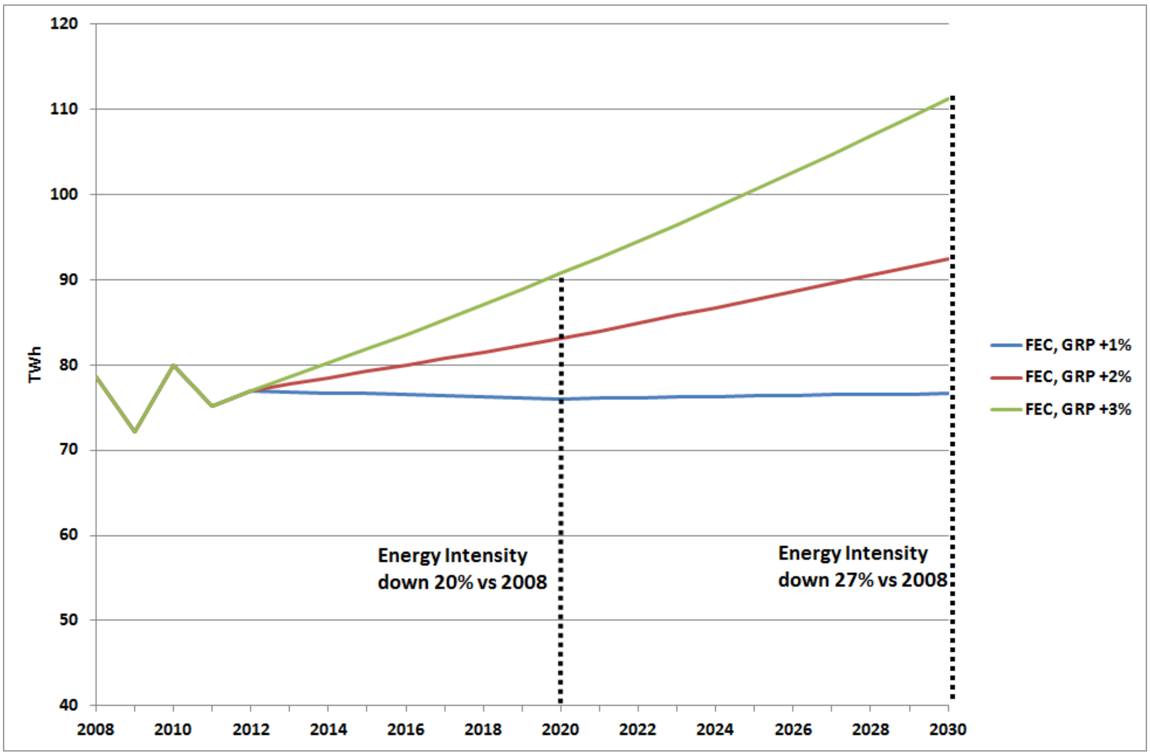

Figure 8.2. Possible growth in Final Energy Consumption between 2008 and 2030 assuming 1% to 3% annual growth in GRP between 2012 and 2030 and still reaching the energy intensity target in KASK-SE of 20% reduction by 2020 and 27% reduction by 2030 (versus 2008).

However, in order to relate to the potential energy savings for buildings, transport and industry derived in the previous sections in this report we also analysed the combined effect of these energy savings on the absolute value of FEC. Between 2008 and 2012, FEC in KASK-SE has remained approximately the same (78.5 TWh in 2008 and 77.0 TWh in 2012) but the variation is considerable with FEC ranging from a low of 72 TWh in 2009 to a high of 80 TWh in 2010 over the 5-year period. The variations should be due to both the economic conditions and average yearly climate (e.g. cold winters during 2009 and 2010) influencing industrial activity and heat demand.

Figure 8.3 shows the potential energy savings for the transport sector up to 2020 and 2030 as derived in Section 7.1 and the calculated techno-economic potential in energy savings in buildings if all ten ECMs are being carried out by 2030 (i.e. ECM Package 3, see Section 5.2). Also shown is the estimated energy savings (fuel input assuming 80% boiler efficiency) derived in Section 4 for the two key industry plants. The latter two plants are included only for comparison.

Finally, Figure 8.3 shows 1) 2008 consumption held constant (black dashed line) and 2) total FEC 2008-12 and a line illustrating a linear decline to reach 20% reduction by 2020 and 27% by 2030 (red dashed line), in both cases relative to 2008. It should be noted that the y-axis starts on 40 TWh. FEC transport has been assumed to decline already from 2008, FEC buildings from 2010 and FEC key industry plants in 2020 and 2030, the latter as given in Table 4.1. The reason for this is that statistics do not provide FEC between 2008 and 2012 for each individual sector in the form that they have been defined in this report.

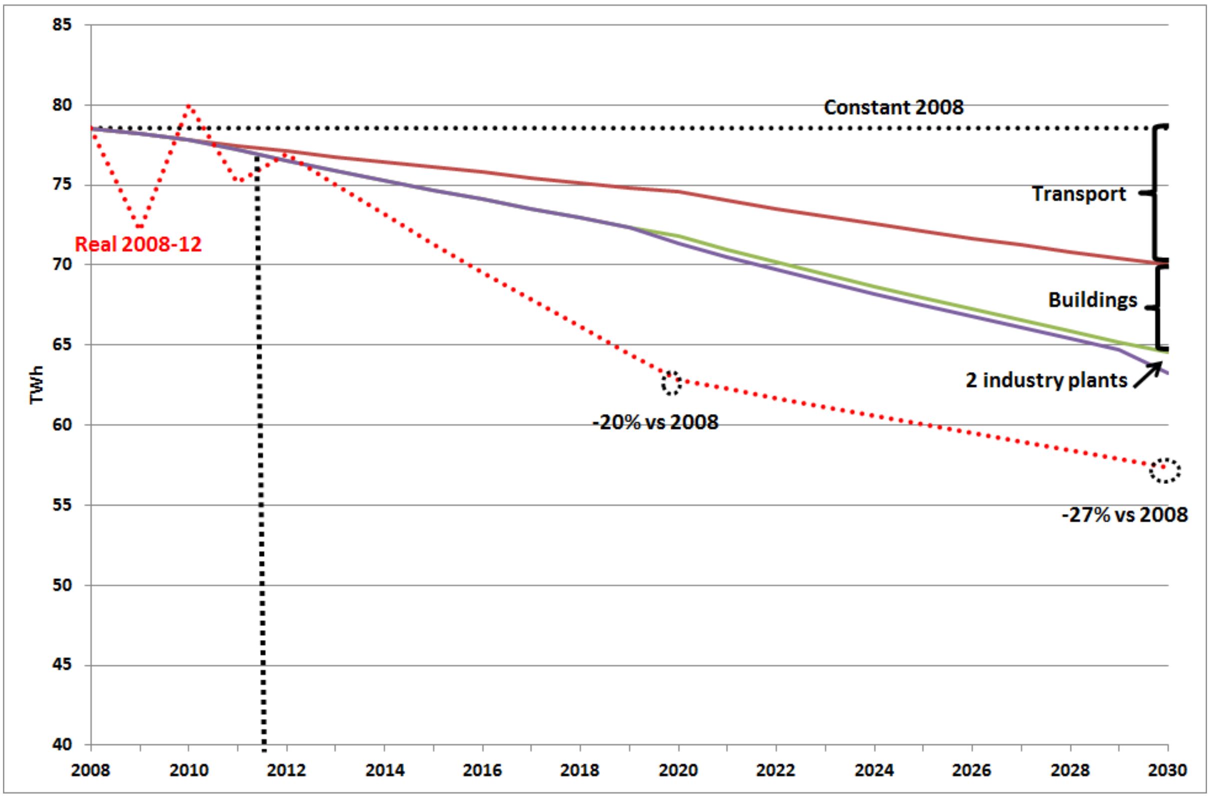

Figure 8.3. Energy savings potential in FEC derived in previous sections for the transport and building sectors and as estimated for the tow key industry in the region. Also shown is 2008 FEC held constant (dashed black line) and real FEC 2008-12 as well as an illustration of a 20% decline in FEC by 2020 and a 27% decline by 2030 (dashed red line), in both cases relative to Year 2008.

As can be seen from Figure 8.3, all the measures derived in previous sections for transport and the building stock as well as for the two investigated industry plants will reduce FEC by 9% in 2020 and by 20% in 2030. However, that is everything else being constant, i.e. no other factors have been considered, such as for instance population growth and structural changes in industry and infrastructure. For instance, as mentioned in Section 2, applying 2010 FEC per capita on the projected population increase in VGR and Halland will raise the absolute value of FEC by 5.3 TWh in VGR by 2025 and by almost 1.6 TWh in Halland by 2030, i.e. a combined increase of almost 9% relative to Year 2010. Also according to Statistics Sweden industry's final energy consumption has increased by almost 50% between 2000 and 2011, from 21.2 TWh to 31.7 TWh while at the same time it has decreased by 9% between 2008 and 2011 due to changes in economic conditions on the world market. As for the continued development there are both plans at several individual facilities for expansion of production capacity as well as there has been recent shut downs, both factors that will affect energy consumption. For instance, Södra Cell's paper mill in Värö (Halland county) will raise current pulp production capacity by 65%, from 425 ktons to 700 ktons between 2014 and 2016. On-site construction has already started and Södra Cell has, among others, already ordered a 64 MWe turbine from Doosan Skoda. At the same time, Stora Enso shut down half its capacity (420 kt) at its paper mill in Hylte in Halland in 2013. Pilkington Glass, the largest fossil based CO2 emission source in Halland (emitted 146 ktons CO2 in 2011), shut down their production plant in Halmstad in 2013 while Cementa Skövde may close down after March 2017 since the environmental district court in Vänersborg in May 2014 rejected continued operation at the limestone quarry associated with the cement plant at the site. Thus, with regard to industries energy consumption in the region, it appears difficult to foresee an aggregated projection on future energy consumption.

In the transport sector baseline demand scenarios indicate that apparent demand in the KASK-SE region will increase from 20.5 TWh in 2007 to 26.2 TWh in 2030 but that efficiency increases, reduced demand and modal shift will reduce apparent demand by more than half to 11.8 TWh (see Section 7.1). As stated above however, vehicles delivered to Swedish markets are likely to be developed according to requirements and rules on EU-level and as shown in Section 7.3 even in the most ambitious scenario from EU's energy roadmap 2050, energy consumption in the transport sector is expected to only decline by ca 10% between 2010 and 2030 (Figure 7.6). Also, as mentioned in Section 7, economic incentives will probably be very important for the development in the transport sector while the single largest barrier is likely to be the willingness by the general public to accept the significant life-style changes which probably will be required to fulfill the long-term EU targets on transportation sector.

As shown in Section 5.2 the techno-economic and technical energy savings potential in the buildings in the KASK-SE region was calculated to 5.5 TWh and 15.5 TWh, respectively. These potentials are under the assumption that the energy conservation measures included in the analysis in Section 5.2 are carried out on *all* the buildings included in the analysis (see Table 5.4, page 41) which may prove to be difficult with buildings having for instance a cultural and/or historical value.

There are significant activities in the region with regard to improving energy efficiency in the building stock, both on the regional and local level. Region Västra Götaland (RVG) supports several programs aiming to increase energy efficiency in buildings and is also owner of one of the largest property managers in the region, Västfastigheter, with 1.7 million m^2 of own premises and 625,000 m^2 of rented premises which they only manage, mostly non-residential buildings such as hospitals, schools and museums. Västfastigheter is aiming to reduce energy consumption in its properties by 50% by 2030 compared to 1995, i.e. from 274 kWh/m^2 to 137 kWh/m^2 and in 2013, consumption had been reduced to 191 kWh/m^2, i.e. by 30% (Västfastigheter 2014). Västra Götaland County is also the county with the second largest stock of so-called low-energy buildings[16] in Sweden, comprising some 434,000 m^2 at end of Year 2014 (LÅGAN 2014).

Eleven[17] out of the fifty-five municipalities in the region have their housing company participating in the so-called "Skåneinitiativet" aiming to reduce energy consumption in their premises (mostly residential) with 20% by 2016 compared to Year 2007 (SABO - the Swedish Association of Public Housing Companies – 2014). As mentioned above, Göteborg is by far the largest municipality in the region having a population of ca 550,000. The City of Göteborg is a large property owner in the municipality, owning around 30% of all residential buildings[18] or 5.9 million m^2 as well as 3.2 million m^2 of non-residential buildings. In addition, the city rents some 500,000 m^2 of premises. According to Göteborg's strategic climate program (City of Göteborg 2014a, b) the city has several goals regarding energy

[16] For new buildings to qualify it is required that energy consumption is 50% lower than required by the building regulations (BBR 16) or, in the case of refurbishment of older buildings, the requirement is either that energy consumption should be reduced by 50% and be at least 40% lower than the BBR 16 regulations or that energy consumption should be reduced by 75% (LÅGAN 2014).

[17] The eleven municipalities are Alingsås, Borås, Trollhättan, Falkenberg, Halmstad, Laholm, Lysekil, Mölndal, Skövde, Uddevalla and Vänersborg.

[18] There are approximately 260,000 dwellings in Göteborg of which ca 50,000 single family houses and 140,000 dwellings owned by private companies (City of Göteborg 2014a, b).

consumption in its building stock. An intermediary goal is to reduce specific energy consumption in both its residential and non-residential stock by 15% between 2009 and 2020. The City of Göteborg is furthermore targeting that energy consumption in residential buildings (both privately and publicly owned) shall be reduced by at least 30% and consumption of electricity (excluding industry and transport) by at least 20%, in both cases by 2020 relative to consumption in 1995. In 2013, specific energy consumption per square meter in the residential buildings had declined by 12% since 1995 to 335 kWh/m^2 while consumption of electricity however had increased by 16% under the same period to 20.5 MWh per capita (City of Göteborg 2014b). For new-built dwellings the aim for the city's property company (Framtiden AS) is to reach an annual energy consumption of less than 75 kWh/m^2 for multi-family houses and 60 kWh/m^2 for single-family houses. For new-built non-residential buildings the corresponding requirement is less than 45 kWh/m^2 and year (City of Göteborg 2014b).

Finally, the City of Göteborg has also set up a target to reduce primary consumption of fuel for heat and electricity production[19] to less than 31 MWh per capita by 2030 which implies a reduction of ca 10% relative to corresponding consumption in 2011. Furthermore, the intention is that by 2030 all district heat should be produced by renewable energy and industrial waste heat and energy efficiency measures should also reduce demand. Currently some 20% of the district heat is produced by natural gas and oil, foremost in Ryaverket CHP.

An important part of reducing energy consumption in the residential sector is refurbishment of the buildings in the so-called "Miljonprogrammet" (the Million programme). Miljonprogrammet refers to the around 100,000 apartments being built annually between 1965 and 1974 (hence the name the Million programme) and of which a large part now is in need of refurbishment[20]. A large fraction of these buildings are owned by the housing companies of the municipalities ("allmännyttan" in Swedish). Yet, a large number of single family houses were also built during this period, houses which are privately owned. In addition, during the last decade there has been a substantial sell-out of the municipality owned multi-family houses. In all, this means that there are presently different owners for these types of buildings, which make efficient renovation a more complex task, although the private sector may very well have more capital for renovation than the municipality owned housing companies. The energy savings potential in these buildings is large, up to 50% according to for instance the Swedish Energy Agency, but at the same time the cost will be large and there are ongoing discussions about who should carry the cost, i.e. mainly how the cost should be distributed among the government and the municipalities in case of the municipality owned buildings. At the same time there are also broader discussions surrounding the refurbishment of these buildings with regard to for instance integration policy and unemployment, both important aspects that need to be considered in an overall system perspective (Tällberg Foundation 2010). According to RenEffekt (2013) there should be a broad national governance of the refurbishment of the residential building stock and interviews with housing companies indicate that economy and profitability play a large role, i.e. the housing companies cannot see that the refurbishment of the residential stock will pay itself and become profitable unless the rents are increased significantly, i.e. to levels which are not in

[19] The target refers to use of electricity and heat in the industry, in the public service sector including electricity to the city's trams as well as use in residential and non-residential buildings.

[20] Around 80% according to Svenska Dagbladet 2010.

line with the purpose of the municipality owned housing companies (to provide affordable housing).

Concluding the discussions above, it appears likely that the KASK-SE region will reach its goal of reducing energy intensity by 20% in 2020 as well as reaching a reduction of 27% in energy intensity by 2030 although the latter has not yet become an officially announced target other than by the EU. At the same time it appears difficult to get an extensive overview of absolute energy consumption and relevant individual plans and targets, both within each sector (transport, industry, buildings) as well as within each municipality. Finally, it appears obvious that refurbishment of the buildings that are included in the so-called Miljonprogrammet, although challenging, offers a great opportunity for large energy savings since such renovations are required in any case. It is therefore important not to lose this opportunity.

8.2. Renewable energy

The Swedish Government is aiming for that at least half the energy consumption in 2020 should be from renewables and at least a 10% share of renewable fuels in the transport sector. In 2012 renewable energy accounted for 51% of total energy consumption in Sweden while the share of renewable fuels in the transport sector reached 12.6%[21]. Thus, as mentioned in Section 3, Sweden has already reached the 2020 targets for renewable energy (The Swedish Government 2013). The Swedish target is part of the EU's common target of 20% renewables by 2020 and in October 2014 the EU Council endorsed a binding target (on EU level) of 27% renewable energy by 2030. However, the Swedish Government has not, at the time of writing this report, announced a specific target for renewable energy beyond 2020.

As mentioned in section 3.2, both VGR and Halland have endorsed the national target for renewable energy in 2020. However, VGR (2014) is also proposing more ambitious targets aiming for a share of renewable energy in total energy consumption of at least 60% in 2020 and 80% in 2030 stating that the latter is a consequence of the county targeting an economy independent from fossil fuels in 2030. Reaching a 60% share for renewables in 2020 is likely to be difficult since the share was only 41% in 2012 (VGR 2014). It should, however, be emphasized that the more ambitious targets given in VGR (2014) have not yet been decided as of early December 2014.

VGR is also aiming for 5 TWh wind based electricity generation by 2020. Finally, and as mentioned above, Göteborg city is aiming for, among others, that all district heat should be produced by renewables, waste and industrial waste heat by 2030 (City of Göteborg 2014a, b).

Accurate and reliable statistics for use of renewable energy in the region over time is sparse and, with regard to final consumption, statistical data cannot be used after 2004 since too much data is missing. However, some data are released with a relatively reasonable accuracy such as electricity consumption and production, production of DH and use of fuels in the transport sector. According to the Reference Energy System (Johnsson J., et al., 2014) for the KASK-SE region for the Year 2010, the following can be stated:

[21] In fact, preliminary figures indicate that the share of renewable fuels in the transport sector in 2013 increased by another 3 percentage points from 2012 to 15.6% (The Swedish Government 2014).

- Industry's total energy consumption amounted to 32.7 TWh in 2010 of which 4.0 TWh was renewable energy, 8.4 TWh was electricity while 1.1 TWh was DH. The remaining part, 19.1 TWh was fossil based, mostly natural gas and mainly in VGR.
- Total electricity production amounted to 29.0 TWh in 2010 of which 3.3 TWh was produced by hydro and wind while 1.6 TWh was produced in CHPs (combined heat and power plants). Nuclear generation in Halland accounted for the largest part, 24.0 TWh or 83%.
- CHPs generated 1.6 TWh electricity and 4.3 TWh DH burning 3.2 TWh biomass/waste plus 2.2 TWh fossil, primarily natural gas.
- Total DH production amounted to 11.1 TWh (including 4.3 TWh in CHPs) of which 6.8 TWh was generated in heating plants utilizing 4.0 TWh biomass/waste, 1.8 TWh fossil, 1.6 TWh waste heat and 0.3 TWh electricity. Almost all the fossil fuel used to generate heat in heating plants was used in VGR.

Thus, most of the fossil based energy consumption outside the transport sector refers to natural gas used to generate process heat, DH and electricity in VGR. In Halland relatively small amounts of fossil fuel is consumed outside the transport sector, in particular after Pilkington Glas shut down its plant in 2013 (see Sections 2 and 6.1). Nevertheless, in 2010, Halland used 390 GWh fossil fuels to generate heat of which some 106 GWh oil and natural gas in district heating plants while the rest, some 285 GWh, was burnt directly in buildings (Johnsson J., et al., 2014, Svensk Fjärrvärme 2014, Averfalk et al., 2014). However, 2010 appears to have been a cold year[22] implying higher than normal demand and in early 2013 Varberg Energi installed a new 2x10 MW biomass based heating plant that will replace natural gas based heat generation.

The KASK-SE region consumes some 24 to 25 TWh electricity annually, of which 80% in VGR and the remaining 20% in Halland. The opposite applies to production, i.e. some 80% is produced in Halland, almost entirely by the reactors at Ringhals nuclear plant. Most of the remaining electricity is produced by hydro, wind and bio based thermal generation and from 2010 to 2012 renewable electricity generation increased from 4.8 to 6.7 TWh (Statistics Sweden 2014a). Wind based generation has continued to grow reaching almost 1.6 TWh in VGR in 2013[23], eight times generation in 2006 (Power Väst 2014). Reaching 5 TWh wind generation in 2020 as targeted by VGR will require a Compounded Annual Growth Rate (CAGR) of around 15% which may be compared to a CAGR of more than 41% between 2006 and 2012. It should also be recalled that in Section 6.2, a rough profitable onshore wind power potential of 10 GW was identified in the region, corresponding to between 20 and 25 TWh generation assuming a total income for wind power installations of 60-70 EUR/MWh. It is expected that the two oldest nuclear reactors at Ringhals will shut down by 2025 leaving a *local* production gap of between 10 to 12 TWh. This local production gap may increase further assuming increasing demand for electricity from for instance the transport sector. The transport sector may also interact with the power generation system contributing to balancing the system with high penetration of intermittent renewables. Apart from a large-scale penetration of wind, solar PV may play a small but yet important role in transforming the electricity generation system in the region. Under the existing support schemes for solar PV it was estimated in Section 6.4 that up to 2.5 TWh could be generated from consumer installations on rooftops. Furthermore, as has been demonstrated in both Germany and more recently also in Denmark and UK, utility scale solar PV could play an important role. For

[22] Fossil based DH generated in DH plants in Halland in the five years period 2008-2012 was 54, 69, 106, 40 and 45 GWh respectively (Svensk Fjärrvärme 2014).

[23] The annual wind statistics from the Swedish Energy Agency (2014a) refers only to wind farms connected to the grid which in 2013 generated 1,023 GWh in VGR and 347 GWh in Halland.

instance in the UK, solar PV capacity has increased from practically zero at the beginning of 2010 to 5 GW by mid-2014 (Solar Power Portal 2014). Also, as mentioned in Section 6.5 increased renewable power generation in KASK-SE may replace marginal fossil based generation in other parts of Europe thus leading to less overall European emissions.

In Section 6.3 the additional production potential for biomass in KASK-SE was estimated to 4.3 and 6.3 TWh in 2020 and 2030 respectively assuming a competitive European and Swedish forest industry which in turn is expected to yield an expansion of existing production capacity. However, as reported in previous sections most sectors explore different applications of biomass;

1) The power and heating sector for production of electricity and DH – see Section 6.5
2) The transport sector – see Section 7.1
3) Industry
    a. To generate process steam – see Section 4
    b. To replace fossil fuels used as a raw material – see Bisaillon et al 2014a

Figure 8.4 shows estimated demand for biomass up to 2050 in two cases, case A and B assuming a gradual replacement of biomass in the four applications listed above (application 1, 2 and 3 a and b).

In case A, demand in the power sector follows the Green Policy scenario discussed in Section 6.5 assuming conversion efficiency for biomass CHPs increasing from current 30% to 35% from 2025 onwards. Demand in the transport sector follows demand given in Section 7.1 assuming an overall biomass-to-fuel conversion efficiency of 60% over the entire period (Bisaillon et al., 2014a). Demand in the industry assumes 25% of the current fossil based production of heat and process steam being replaced by biomass in 2020 increasing to 50% by 2030 and to 100% replacement in 2040[24]. Also 0.8 TWh of bio-pellets currently (2010) being used in industrial processes has been included as raw material to the industry (termed “Industry Feed”). Biomass use for generation of DH and for on-site generation of heat in the building stock (in single family dwellings) has been kept constant at 2010 consumption levels throughout the period, i.e. each at 2.5 TWh biomass. This has been done due to the techno-economic savings potential of between 5.5 and 7.4 TWh identified in the building sector in Section 5.2[25].

Case B is as in case A *plus* biomass assumed to be supplied as feedstock instead of crude oil to the four refineries in the region and that the refineries in turn also provide bio-based feedstock to the chemical cluster in Stenungsund (in the form of process residues). Chemical plants usually buy their fossil feedstock as residues from refineries and this solution will enable the chemical cluster to keep the existing process units (the chemical plants could of course buy bio-based feedstock from other refineries outside the KASK SE region which would reduce biomass demand in KASK SE correspondingly). Besides, it does not appear likely that the petrochemical industry will produce its own bio-based feedstock since the price of this feedstock will be decided by the global biofuel market (See Appendix C for a discussion on this issue). The demand for biomass from the refineries is assumed to

[24] No regards have been taken to energy savings potential in the industry. For instance as mentioned in Section 4.1 harsher environmental regulations for refineries, which is a large energy consumer in the region, are likely to increase process intensity and energy use.

[25] Combined it was burnt ca 3 TWh fossil fuels in 2010 to generate DH and heat on-site in buildings of which parts (oil) are supplied by the refineries.

correspond to the evolvement of demand for biomass from the transport sector in KASK-SE as derived in Section 7.1 (see Figure 7.1), i.e. that fuel to cover overall "real" demand for transport work is reduced by 20% in 2020 relative to 2010 and that the share of biomass in total fuel consumption in 2020 is 15%. By 2050 overall fuel demand has declined to 51% of overall demand in 2010 while the share of biofuels is 62% (see Figure 7.1)[26]. Hence, it has been assumed that the four refineries in the region are fully converted to bio-refineries supplying a global market evolving in the same way as depicted in Figure 7.1 for the KASK-SE region. To convert from demand of crude oil to demand of biomass a conversion factor of 0.6 has been applied yielding that 227 TWh crude oil supplied to the refineries in 2010 requires 378 TWh biomass (Johnsson J., et al., 2014, Bisaillon et al., 2014a). Feed to the chemical cluster in Stenungsund is assumed to start in 2020 where a quarter of the feedstock is assumed to be replaced by biomass increasing to 50% in 2030 and further to 100% in 2040. It has been assumed that 33 TWh biomass is required to replace 16.5 TWh fossil based feedstock to Borealis in 2010 of which almost all was supplied by suppliers outside the KASK-SE region (Bisaillon et al., 2014a, Spetz, 2015). However since the chemical cluster in case B is assumed to receive feed directly from the refineries, efficiency gains have been estimated to reduce overall biomass demand to the industry by 13 TWh. No biomass is supplied to the transport sector in case B since biofuels are assumed to be supplied from any of the four refineries in the region.

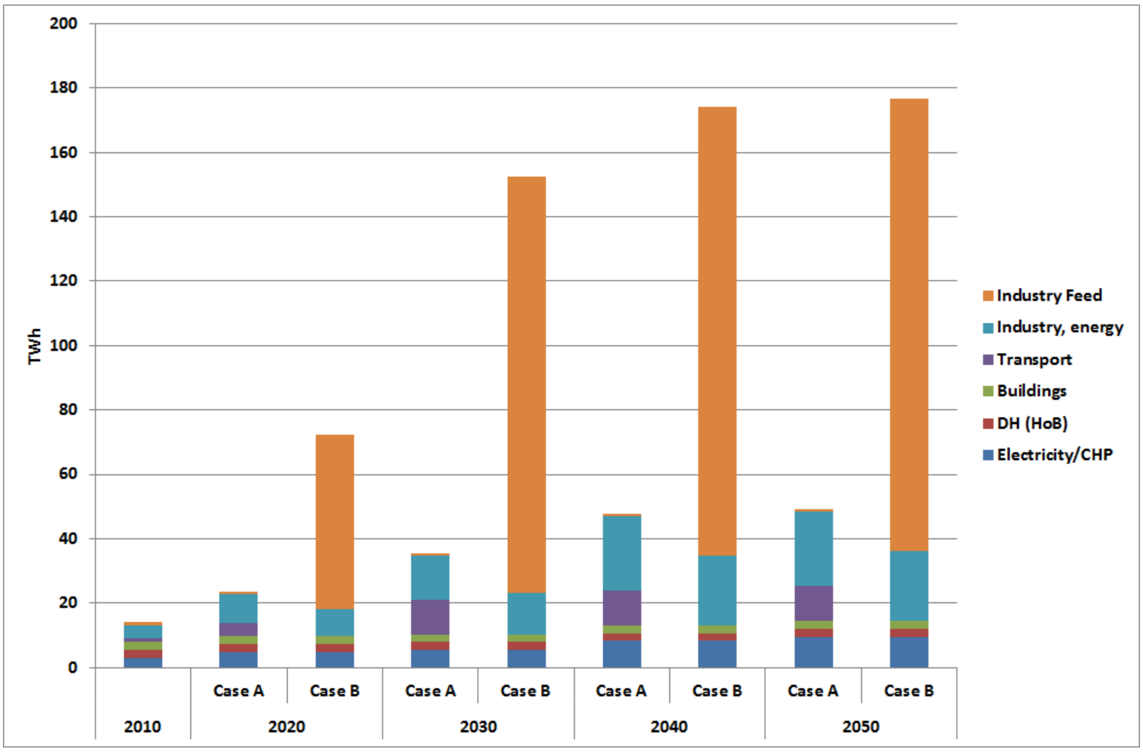

Figure 8.4. Projected biomass consumption up to 2050 in KASK-SE in the two cases A and B. Industry Feed refers to biomass gradually replacing fossil fuels as raw material to the chemical cluster in Stenungsund and to the four refineries in the region (case B). In case B, demand for biomass in the transport sector has been set to zero since demand is assumed to be covered by the four refineries.

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[26] Thus feedstock demand to the transport sector has been reduced by 20% in 2020, by 42% in 2030, by 45% in 2040 and by 49% in 2050 due to anticipated lower demand relative to Year 2007 (see Figure 7.1). Additionally, to calculate demand for biomass in the transport sector it has been assumed that biomass accounts for 15% of total fuel consumption in 2020, for 54% in 2030, for 57% in 2040 and finally for 62% in 2050, also as given in Figure 7.1.

In case A, total annual biomass demand increases from ca 14 TWh today to 24 TWh in 2020, to 36 TWh in 2030 before it reaches a plateau of around 48 TWh in 2040 onwards. In case B where biomass in addition to the demand in case A also gradually replaces natural gas as a feedstock to the refineries in the region which in turn supplies bio-based feedstock to the chemical cluster in Stenungsund, biomass demand increases to ca 72 TWh in 2020 and further to 153 TWh in 2030 before reaching a plateau at around 174-177 TWh during the last decade. To put this in context, total supply of biomass, waste and peat[27] to Sweden amounted to 132 TWh in 2011. It may also be compared to the total additional technical[28] supply potential for biomass produced in Sweden estimated to between 50 and 70 TWh by the Swedish Knowledge Centre for Renewable Transportation Fuels (F3 2013) or the total additional production potential of biomass within KASK-SE of 6 TWh as estimated in Section 6.3. The results in Case B implies that the refineries in the region probably will face severe difficulties in maintaining current activity levels and the results also strongly suggest that electricity probably should have a larger market share in the transport sector and this is further discussed below.

Case A appears more realistic than case B, not at least due to the smaller amount of biomass that will be required. However, with regard to generation of electricity in the selected Green Policy scenario the amount of intermittent power is substantial while at the same time base load power is decreasing rapidly. According to the modelling results discussed in Section 6.5, the contribution from base load power (hydro, conventional thermal, nuclear, bio and waste) in the Green Policy scenario, which was applied in case A, declines from 94% in 2012 to 36% in 2030 and further to 26% in 2050. A high penetration of intermittent renewables (wind, solar PV) along with nuclear decommissioning may lead to significant balancing problems and actually increase the need for renewable base load power, such as biomass. Also, the Green Policy scenario leads to increasing import requirements with export of 7.3 TWh in 2012 being turned into 8.7 TWh import in 2030 (after which import requirements declines however to 0.7 TWh in 2050 due to the high contribution from wind power), see Figure 6.10 (left). This will probably not be an acceptable solution for the energy intensive industry in the region, all the more so since it can be assumed that the penetration of intermittent energy is high also in surrounding regions.

There are few possibilities to reduce biomass demand further in case A. It has been assumed same contribution as today in heating plants while on-site heating has actually been reduced as a consequence of the energy savings made in the buildings (cf Section 5.2). The biomass assumed being required for energy purposes in the industry is used to generate heat and although solar heat generation and further energy savings offer some prospects, the amount of heat used by the industry is significant and there is a problem with intermittency if relying too much on wind and solar. Thus, the only real savings potential that remains is in the transport sector but also there the contribution is modest, ca. 22% of total biomass consumption in case A assuming a significant reduction in demand for transport work (see Footnote 26). Finally, it should be emphasized that case A does not include any considerations with regard to biomass being used as a raw material by the industry in the region.

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[27] In 2012 Sweden used some 2.7 TWh peat for heat and power production, down from almost 4 TWh in 2008 (Hjalmarsson 2013). The emission factor for peat is higher than coal at 107 gram CO2e per MJ fuel as opposed to steam coal with 100 gram CO2e per MJ fuel (Martinsson et al., 2012).

[28] According to the report (F3 2013) the estimated supply potential includes to some extent also ecological and economical restrictions.

The supply and logistical challenges in case B will of course be tremendous. For instance, Preems refinery in Lysekil will alone require almost 60 TWh biomass if completely converting to biomass feedstock which will have to be transported to one or several individual dispatch centrals. Assuming that one truck can carry 146 MWh biomass implies that 411,000 such truck loads will be required annually, or one truck load each 77 second.

Already in 2030, Case B consumes more than the entire Swedish supply of biomass including peat. Also, demand for biomass is in such a scenario of course on the rise in most regions throughout Sweden, Europe as well as globally, both within the power and heat sector as well as in the industry and transport sectors. As mentioned above, Börjesson et al (2013) and F3 (2013) indicate a possible additional biomass supply potential in Sweden of between 50 and 93 TWh while Faaji (2013) suggests that *European* import of pellets from other world regions might increase up to 70-140 TWh by 2020. IEA (2013) suggests in its most climate ambitious scenario, the so-called 450 scenario[29] that European consumption of biomass may increase from 1,500 TWh in 2011 to 1,965 TWh in 2020 and further to 2,965 TWh in 2035, i.e. nearly a doubling of consumption between 2011 and 2035[30]. However, as shown above, Case B implies more than ten times higher consumption levels in 2030 compared to 2010.

IEA (2013) assumes in its 450 scenario that global demand for biomass will increase by some 10,500 TWh by 2035 and in that context, the volumes required in KASK-SE in case B is modest. Thus, in theory, the energy intensive industry could transform to 100% use of biomass as a feedstock but this will require a concerted and rapid transformation as demand for biomass is rising rapidly in all sectors and in all regions in the world. At the same time, IEA (2013) assumes a completely different fuel distribution in the transport sector in EU than what has been envisioned in Section 7.1. In its 450 scenario IEA (2013) assumes that EU's transports sector in 2035 will be covered by 63% fossil fuels (almost 1,600 TWh), 7% electricity, 27% biofuels (675 TWh) and 2% other, not specified fuels.

Overall demand for biomass could be reduced through higher share of electric cars, both locally as well as in Europe and globally. With the large amounts of biomass that otherwise will be required, this seems almost as a prerequisite for a well-functioning transport sector in the future. Also, there will be large amounts of heat available from the refineries and the chemical cluster and at least a small part of this heat could possibly be utilized for DH (see Section 4). Demand for biomass in case B could also be reduced through for instance recycling and energy recovery of plastics leading to overall lower demand for biomass in the chemical industry. However, as shown above, estimated biomass demand in the chemical cluster constitutes a relatively modest share of total biomass demand in case B (approximately 8%) and recycling and recovery of plastics has actually reached quite far in Europe, and in Sweden approximately 95% of all plastics was recycled or recovered in 2011 (around 34% is recycled while the rest, 61%, is burnt for heat and electricity generation), see for instance PlasticsEurope (2012). However, in countries like Finland, Poland, UK and the Baltic States, recycling and recovery rates are considerably lower ranging from less than 30% in Latvia, Lithuania and UK to somewhat below 50% in Finland. Stricter rules for disposal of plastics in landfills is expected to improve these ratios considerably. Moreover, the chemical cluster in

[29] The 450 scenario refers to the concentration of GHG in the atmosphere (450 parts per million) which should yield a 50% chance of limiting the average global temperature increase to 2°C (IEA 2013).

[30] In the New Policy's scenario where consumption of biomass is considerably lower than in the 450 scenario (84% or 2,500 TWh versus 2,965 TWh in the 450 scenario), IEA (2013) indicates that EU is the largest importer of biomass for power generation as well as of biofuels.

Stenungsund has proposed to establish a waste refinery in Stenungsund treating both plastic and construction waste as well as municipal and industrial waste. Finally, Borealis has recently upgraded its cracker in Stenungsund so that more ethane can be used as raw material instead of naphtha, propane and butane while at the same time they have also signed a 10-year supply agreement with Antero Resources for supply of ethane from the US. In addition, Borealis has also recently extended its supply contract for ethane with Statoil for another seven years. Thus, and although the exact quantities are not known, it seems that a substantial part of future supplies of fossil based raw materials to Borealis will be from suppliers outside the KASK-SE region.

To summarize the discussions made above, there are substantial possibilities for expanding renewable energy in the KASK-SE region, both in terms of renewable electricity from wind and using biomass as fuel. There is significant potential for onshore wind power. Additionally, the region may also have a substantial potential for offshore wind power, but as concluded in Section 6.2, offshore wind power is still significantly more costly than onshore wind and availability of suitable onshore sites appears not to be the limiting factor if applying the areas of conflict and population density assumed in this work. Contribution from solar power is not believed to be significant, up to 2.5 TWh could possibly be generated from consumer installations on rooftops under the existing support schemes. Continued expansion of use of biomass for production of heat and electricity appears likely but as indicated above there are limited supply abilities within the region implying that biomass will have to be imported to make a substantial contribution to the energy system in the region. Potential future demand for biomass has been calculated in two cases (Cases A and B), both indicating a substantial increase in consumption levels. Under the assumptions made above, consumption may increase almost threefold to more than tenfold compared to current levels by 2030 and continue to expand up to 2040 and 2050. A transformation of this magnitude will obviously be extremely challenging both from a supply and a logistical perspective and demand for biomass is increasing rapidly in all sectors and in all regions of the world. Hence, if these levels of biomass are to be reached the transformation should start immediately with concerted support both from the industry and from the politicians in the region.

8.3. CO2-emissions

As mentioned in Section 3.1, the new Government has commissioned a parliamentary committee (Miljömålsberedningen) to develop a political framework for a long-term climate policy. The Government states that the framework shall specify the rate at which Sweden should reduce its emissions, establish clear incentives for the transformation to a climate friendly society and create a stable and predictable investment climate for business.

As discussed in Section 3.1 the target for GHG emission reductions in VGR and Halland follows the current national target, i.e.;

- 40% reduction of GHG emissions in 2020 relative to 1990 from sectors that are not included in the European Emission Trading Scheme (ETS).
- Sectors that are included in the ETS shall reduce their emissions by 21% in 2020 and by 43% in 2030, in both cases relative to year 2005 emissions (EC 2014).
- Net GHG emissions should be zero by the middle of this century. In order to reach this target, the Swedish Government has released proposition 2008/09:162 which states that Sweden will prioritize to achieve a “transport sector independent from fossil fuels” by 2030.

As much as one third of the targeted emission reductions can be taken through purchase of external emission credits (NVV 2012, Averfalk et al., 2014). Although tougher intermediate emission reduction targets up to 2030 have been proposed and are under review in VGR and Göteborg, focus in this report has been based on officially announced targets by the end of November 2014. Moreover, as also stated in Section 3.1, the focus has been placed on production based CO2-emissions, i.e. the agriculture sector and non-CO2 greenhouse gases have not been analysed and only CO2 emitted within the geographical boundary of the KASK region has been considered.

Combined, the two counties in KASK-SE emitted 12.9 Mt GHG (CO2e) in 2012, down by 13% since 1990 excluding net changes in LULUCF (Land Use, Land Use Change and Forestry). CO2-emissions amounted to 10.5 Mt, down by 12% since 1990. Energy supply and transport account for ca 90% of total CO2-emissions. Figure 8.5 shows CO2-emissions by sector in 1990[31] (blue) and 2012 (red). Emissions have been taken from Länsstyrelserna (2014) with some minor alterations with regard to distribution by sub-sectors. This has been done in order to facilitate the work below with regard to definition of pathways for CO2 emission reductions. The following changes in sectors have been done:

- The sector "Heat (DH+on-site)" includes the subsectors "Heating plants", "Residential heat" and "Stationary combustion in agriculture, fisheries and forestry".
- The sector "Energy industry" includes "Fugitive Emissions from use of fossil fuels[32]", "Energy supply refineries" and "Combustion in the industry for energy production".
- The sector "Transport" includes working machines.

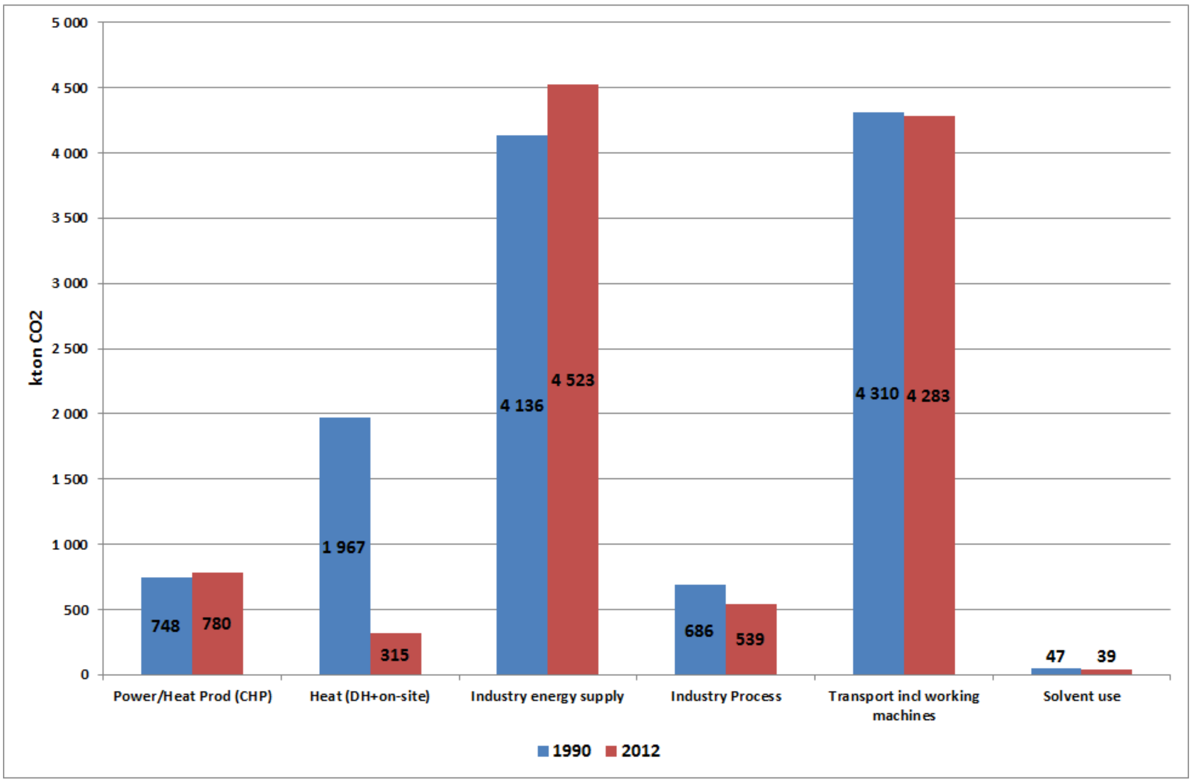

Figure 8.5. CO2-emissions by sector in 1990 and 2012 in KASK-SE, source: Länsstyrelserna (2014).

[31] As pointed out above, emission reduction requirements in industries covered by the ETS refer to year 2005 emissions.

[32] Länsstyrelserna (2014) lists "Fugitive emissions from use of fossil fuels" within the group "Energy Supply". The emissions from this group refer to vented/flared emissions from combustion of pet-coke in a catalytic cracker.

As can be seen significant reduction in emissions have only taken place in the heat generation sector due to the fuel shift in thermal plants in the District Heating systems whereas the other sectors have remained more or less constant or increased their emissions. The fuel shift in Swedish DH systems is due to the tax on fossil fuels for heat generation.

A large part of the emissions in the first group in Figure 8.5, "Power/heat production" comes from Göteborg, some 470 ktons in 2012 and emissions from this group are actually up 4% since 1990.

Emissions from the group "Industry energy supply" are up more than 9% since 1990 as can be seen from Figure 8.5. The three refineries in Göteborg and Lysekil account for a large part of the emissions from this group, some 64% in 2012 and having increased by almost 50% since 1990 from 1,970 to 2,911 ktons. More than half of this increase (508 ktons) refers to increased emissions from "Fugitive emissions from use of fossil fuels" from the refinery in Lysekil. Other large sources that are included in this group are the chemical cluster in Stenungsund (almost 800 ktons in 2012) and the cement plant in Skövde (170 ktons in 2012).

The group "Industry process" have declined by some 20% since 1990. Almost half of the emissions from this group in 2012 came from the cement plant in Skövde (250 ktons) while another 100 ktons originates from Vargön Alloys in Vänersborg.

Emissions from the transport sector include 550 ktons from working machines, up from 488 ktons in 1990 while emissions from the transport sector as a whole practically have remained constant since 1990. Transport related emissions together with emissions from energy supply industry account for the largest share of overall CO2 emissions at 41 and 43% in 2012 respectively.

It is obvious from Figure 8.5 that the biggest challenges to reduce CO2 emissions in KASK-SE lie in the transportation and industry sectors. They are by far the biggest emission contributors at the same time as emissions have shown no evidence of decline during the two past decades. These challenges are further amplified by the fact that the one sector which has delivered substantial cuts in CO2 emissions, i.e. the heating sector, will only contribute marginally to further emission reductions since emissions in this sector are now very low.

8.3.1 Illustrative pathway for reduction of CO2-emissions

This section exemplifies one pathway for how the region can reach zero CO2 emissions in 2050. It is important to underline that this is only one out of several possible pathways which will be discussed in the following sections. The scenario starts with a description of how each separate sector can achieve zero emissions by 2050 building to a large extent upon the work presented in previous sections. The results are then shown in Figure 8.7.

The sector "Public electricity and heat production" was modelled and analysed in Section 6.5. Table 8.2 shows CO2 emissions in the two main scenarios outlined in Section 6.5, namely the Green Policy and the main Regional Policy scenarios (corresponding generation by fuel/technology is given in Figure 6.10). In the scenarios electricity generated by biomass and waste includes combustion from fossil based waste[33].

[33]According to Renova's "Hållbarhetsredovisning" (Environmental Report) for the years 2012-13, combined GHG emissions from combustion of waste (CO2+N2O) reached 142 kt (kton) in 2010, 199 kt in 2011, 202 kt in 2012 and 203 kt in 2013.

Table 8.2. CO2 emissions from CHP plants in KASK-SE 2012-2050 as yielded from modelling of the power sector in Section 6.5, kt CO2.

	2012	2020	2025	2030	2035	2040	2045	2050
Main Regional Policy	778	845	845	741	746	1714	1819	0
Green Policy	778	859	1102	589	270	52	0	0

As can be seen from Table 8.2, both scenarios reach zero emissions by 2050. The reduction is more rapid and distinct for the Green Policy scenario. Emissions increase significantly up to 2045 in the Main Regional Policy scenario and then fall abruptly to zero in 2050. The sharp increase in emissions is due to a relatively large expansion of gas based power and heat generation. Gas-based power is profitable in the long run and in a European context in our Regional Policy scenario which is due to increasing prices on both CO2 and electricity at the wholesale level, at the same time as the renewable target is set at a considerably lower level than in the Green Policy scenario. However, the regional distribution of such long-term gas-power schemes is primarily a model result and does not fully reflect possible regional and local policies for natural gas. We may also conclude from the figures reported in Table 8.2 that this increased contribution from gas power is present only for a limited amount of time, roughly a decade. Even if this is cost-efficient from an integrated European electricity-market point of view, it is questionable whether any investor would be prepared to take such risks to invest in gas-based power even if changes in market design would increase incentives for building power plants with relatively low utilization.

Both scenarios lead to a complete phase-out of nuclear power (Ringhals nuclear plant), in the Green Policy scenario already by 2030 and in the main Regional Policy scenario shortly after 2040. Both scenarios also lead to diminishing export of electricity which eventually is replaced by import (as can be seen in Figure 6.10). In the pathway for zero CO2 emissions shown below (Figure 8.7) emissions have been taken from the Green Policy scenario. As mentioned above, it is important to underline however that it will be a challenging task to handle and balance the power generation system outlined in the Green Policy scenario due to the fossil and nuclear phase-out in combination with the high penetration of intermittent renewables.

Heating has historically been a large emission source but as can be seen from Figure 8.5 above and Figure 8.6 below emissions have declined dramatically since 1990 with increasing contribution from biomass based CHPs and heating plants. Figure 8.6 shows combined CO2 emissions 1990, 2000 and 2005-2012 for the three subgroups heating plants, residential heat generation and stationary combustion in agriculture, fisheries and forestry as given by Länsstyrelserna (2014).

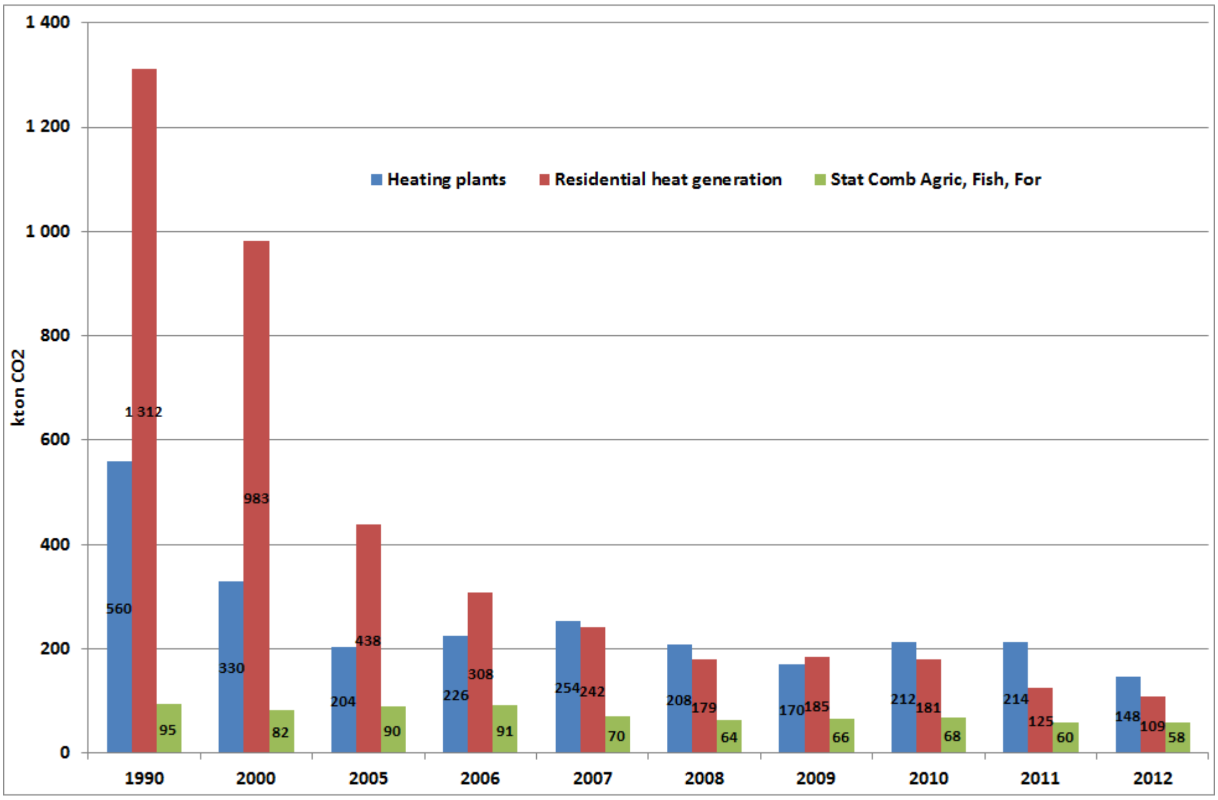

Figure 8.6. CO2 emissions from heating plants, residential heat generation and stationary combustion in agriculture, fisheries and forestry in KASK-SE in 1990, 2000 and 2005-2012 as given by Länsstyrelserna (2014).

As can be seen from Figure 8.6 emissions have declined significantly since 1990, from almost 2.0 Mt combined to 315 kt in 2012. In particular emissions from residential heat have declined dramatically, by more than 90% to 109 kt in 2012. According to the reference energy system for the year 2010 for KASK-SE (Johnsson J., et al., 2014), fossil based generation of heat on-site in buildings and in heating plants only consumed almost 3.5 TWh fossil fuels and 1.5 TWh waste in 2010. At the same time however, Section 5.2 identified a techno-economic energy savings potential of between 5.5 and 7.4 TWh in the building sector. In this section we have assumed that CO2 emissions in the building sector can be completely eliminated by 2040 either through energy savings and/or through fuel switch as old boilers are being replaced.

Emission reductions in the transport sector start from 2010 emissions of 4,627 kton as reported by Länsstyrelserna (2014) following the proportional distribution of emission reduction actions depicted in Figure 7.2. The action called “fuel switch/efficiency increase” has been included in the action called “efficiency increase”.

Emission reductions in the industry are assumed to be achieved partly through fuel shift and partly through Carbon Capture and Storage (CCS). In total, the industry emitted 5.2 Mt in 2010 including process related emissions. It has been assumed that 1.1 Mt CO2 is eliminated through fuel shift, of which 0.5 Mt by 2020 and the remaining 0.6 Mt by 2030. The remaining 4.1 Mt CO2 from the industry is assumed to be eliminated through installation of CCS on the eight largest emitters in the region (based on 2010 emissions) apart from the natural gas combined cycle power plant in Göteborg (Ryaverket CCGT). The reasons that CCS has not been considered for the Ryaverket CCGT are 1) cost of capture is very high due to the limited operating hours and the low content of CO2 in the flue gases (Chalmers-Tel-Tek 2012) and 2) By 2030, Ryaverket CCGT is close to the end of its operating lifetime.

In order to neutralise remaining emissions from the capture plants[34], significant volumes of biogenic CO2 also need to be captured[35]. Thus, raising the volumes of captured fossil based CO2 will also raise the need for captured biogenic CO2. It has been assumed a capture ratio of 75% on all plants leading to that 3.0 Mt fossil based and 1.3 Mton bio-based CO2 is captured while remaining fossil based emissions after the capture process are calculated to 1.3 Mt. The remaining fossil based emissions are however being neutralised by the 1.3 Mt biogenic CO2 that has been captured. It should be underlined that applying a capture ratio of 75% probably is too optimistic for some of the industries like for instance the refineries where the CO2 emissions are divided over several separate emission sources with varying CO2 concentration and content. Thus, the biogenic part of the captured CO2 will have to be raised correspondingly if the capture ratio is lower than anticipated here. With regard to timing, it has been assumed that CCS starts up at Preems refinery in Lysekil and at Borealis cracker in Stenungsund in 2030 capturing some 1.8 Mt CO2 combined with the remaining six plants (see Table 8.3) installing capture in 2040. Assuming that all capture plants will utilise storage sites in the Skagerrak-region or in the North Sea, it would probably initially be most cost efficient to transport the CO2 by ship from Preems refinery and Borealis cracker but from 2040 when all eight plants have installed capture, it is more likely that pipeline transport from a central hub at Lysekil will be a more cost efficient transport solution than ship transport (Kjärstad et al., 2014**)**. The eight plants where it has been assumed that capture is installed are shown in Table 8.3**.**

The specific cost of capture will increase as the capture volume goes down and so will indeed also the cost of transport and storage, see for instance Chalmers-Tel-Tek (2012) and Kjärstad

Table 8.3. Capture plants with initial total and fossil/biogenic emissions 2010, calculated capture volumes and remaining emissions after capture, kton CO2.

Facility	**Initial Total CO2**	**Initial Fossil CO2**	**Initial Bio CO2**	**Captured volume (of which biogenic)**	**Remaining emissions (of which biogenic)**
Preemraff, Lysekil	1 670	1 670		1 253	516
Södra Cell Värö	1 070	20	1 050	803	330
Borealis Cracker	690	690		518	213
Preemraff Göteborg	560	560		420	173
Sävenäs CHP	550	140	410	413	170
St1 Raff, Göteborg	540	540		405	167
Ryaverket, Borås[1]	400	80	320	300	124
Cementa, Skövde	360	350	10	270	111
Total	**5 840**	**4 050**	**1 790**	**4 380 (1 343)**	**1 804 (553)**

1: There are plans to replace the existing Ryaverket CHP in Borås with a 100% bio-fuelled CHP.

[34] The remaining emissions from the capture plants arise partly because you cannot achieve 100% capture ratio in a cost efficient manner, particularly not from industries like refineries, and partly because the capture process itself requires energy which will raise emissions.

[35] Capture of biogenic CO2 can however not yet be counted as negative emissions within the EU's Emission Trading Scheme (ETS) or under the reporting of GHG emissions to the UNFCCC although there are increasing awareness that this will probably be required to meet the 2 degrees Celsius target. Thus, biogenic CCS will need to be properly incentivized.

et al., (2014). Thus, both the capture cost as well as the cost of for instance a 150 km pipeline carrying 270 kt CO2 from Cementa in Skövde to a presumed shipping point at Preem's refinery in Lysekil, will be high. In Chalmers-Tel-Tek (2012) the cost for the entire CCS chain (capture, compression[36], transport and storage) for Preem's two refineries in Lysekil and Göteborg and Borealis cracker in Stenungsund was calculated to range between ca € 70 and 80 per ton CO2 which may be compared to the current CO2 emission price of around € 7 per ton (January 2015). On the other hand, as indicated in Table 6.4, the CO2 emission price can raise to very high levels as the cost of CO2 abatement rises.

Installation of CCS will require planning and development over several years as well as significant up-front investments and will therefore also require stable long-term policies and a sufficiently high price on CO2 emissions. Also, utilization of BECCS will require that bio-CCS is accepted as a mitigation option by the UNFCCC and of course eligible for emission credits according to the European ETS.

As mentioned above, two of the plants in Table 8.3 are assumed to install capture in 2030 implying that planning will have to start already in the early 2020's. For instance a storage site will have to be certified and approved before construction of the capture plant which itself may take 5 years. One question that arises immediately is the CO2-volume that needs to be certified for storage as no-one can assume that another six plants may be connected to the system some fifteen years later indicating that multiple storage sites and injection systems may be required. Also, since cost for CO2 transport by pipeline to a large extent depends on volume and distance and since routing, permitting and approval processes may take many years, it will be important to analyse various transport solutions at an early stage. Additionally, it is currently not allowed to export CO2 for storage according to the London Convention and ship transport of CO2 for storage and bio-based CO2 is not eligible for emission credits according to the European ETS. There should be a great need for the politicians in the region to initiate discussions together with the industry on how CCS can be developed in the region.

The emission reductions by sector described above are depicted in Figure 8.7 assuming constant rate of decline between each decade for each sector (see also Table 9.2) apart from CCS at the industry plants where CCS, as mentioned above, is installed on specific plants in Year 2030 and 2040, each with large emissions resulting in sudden reduction in emissions in these years.

[36] In the case of pipeline transport the CO2 will usually be compressed up to above the supercritical point (73.8 bar, 31°C) while in the case of ship transport the CO2 will be transported as a liquid having a pressure of around 8 bar and a temperature around minus 50°C. However, the most cost efficient way of reducing the temperature of the CO2 to minus 50 degrees will be to raise the pressure to the critical point and then reducing the temperature by expanding the gas.

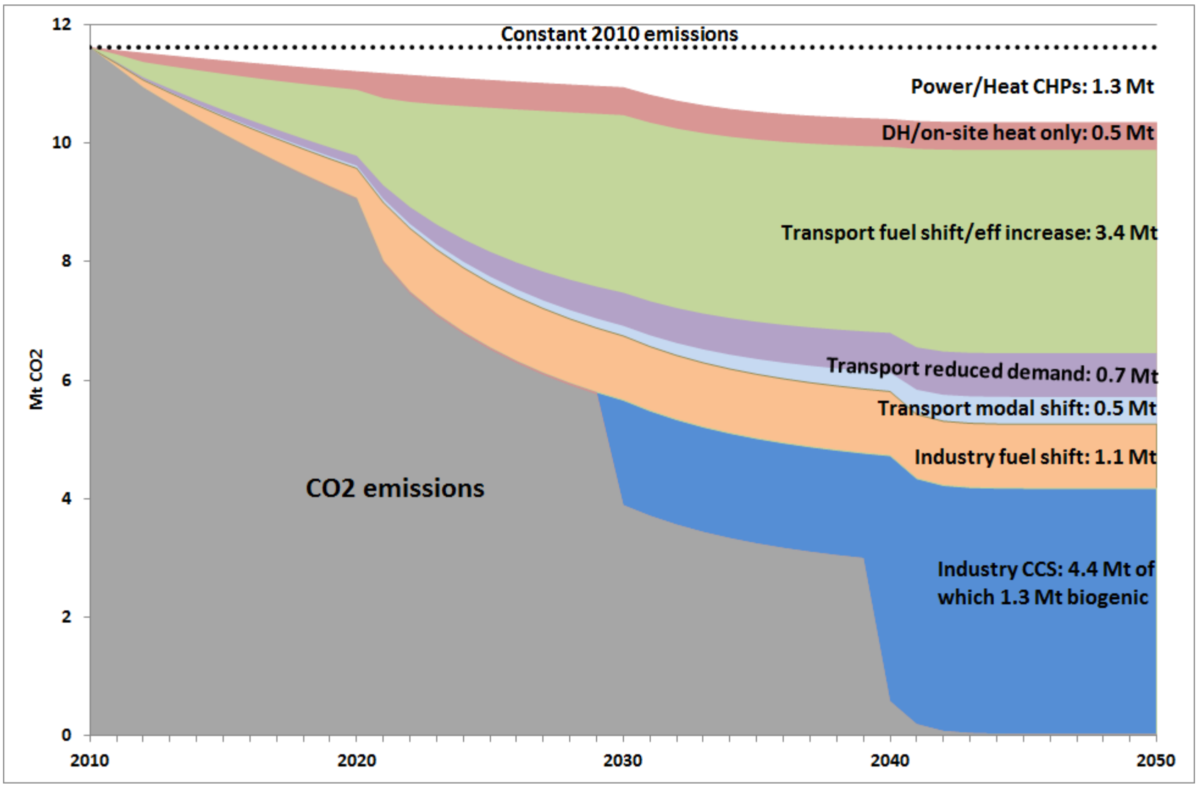

Figure 8.7. Illustration of a possible pathway designed to meet zero CO2-emissions in 2050. The colored fields show reduction wedges corresponding to different technologies and measures between 2010 and 2050.

As mentioned above, the pathway shown in Figure 8.7 is illustrative only presenting one out of several possible pathways to reduce CO2 emissions to zero by 2050. At the same time it should also be stressed however, that if we want to keep existing industries and maintain current activity level there are only the following principal solutions for the refineries in the region assuming that international emission credits will not be utilized;

1) Transformation to bio-refineries and maintain current activity level but as indicated in Section 8.2 this will require extensive amounts of biomass and even more so since this implies a similar development in rest of Europe, i.e. a large scale transformation to bio-fuels. The four refineries in Göteborg will in this case require some 120 TWh biomass annually assuming significant vehicle efficiency gains and a 62% share of biofuels in Europe’s transport sector as derived in Section 7.1 for the KASK-SE region. Total biomass use for energy in Sweden is currently around 130 TWh per year.
2) Transformation to bio-refinery and reduced activity level.
3) Continue to operate with fossil based raw material which will require CCS to eliminate process related emissions. If the fossil based fuel is used by the transport sector in Sweden[37], Bio CCS (BECCS) will be required to neutralise these emissions (i.e. to achieve zero emissions from the entire energy system of the region by the end of the period). Yet, this option opposes proposition 2008/09:162 released by the Swedish Government which states that Sweden will prioritize to achieve a “transport sector independent from fossil fuels” by 2030. This option will also require that BECCS is accepted as a mitigation option by the UNFCCC - United Nations Framework Convention on Climate Change - and that BECCS is eligible for credits according to the European Emission Trading Scheme (ETS).
4) Combination of options 1) to 3)

[37] Fossil based fuels can be exported to regions having less strict restrictions on use of fossil based fuels in the transport sector, e.g. through supply of low sulphur diesel fuels to markets outside Europe.

8.4 Conclusions

It seems clear from the discussions above that in order to meet zero CO2 emissions by 2050 while at the same time maintaining current activity levels for the industry, the region will have to utilize all available options, i.e. energy efficiency measures to reduce energy consumption, significant expansion of renewable energy, in particular biomass, and CCS/BECCS. A complete transformation to a fossil free transport sector will require immediate and concerted policy action probably at least on an EU-level and the results above indicate that electricity will have to play a key role in such a transformation thus also implying reduced activity levels for the refineries in the region.

On one hand, continued nuclear power generation will reduce the requirement for base-load power and for thermal back-up to stabilize the grid in a case with large penetration of intermittent renewables. On the other hand, increased imports of power and/or expansion of transmission grids could reduce the need for nuclear power as well as the need for alternative electricity generation by e.g. biomass in order to supply the region with sufficient electricity. However, in a situation where most of northern Europe relies on large amounts of intermittent power, the question arises who should provide local energy security and the increasing requirements for regulating and balancing power.

As a complement to renewable and dispatchable supply, demand-side flexibility including the use of electric vehicles as back-up or battery capacity will probably play a key role in this transformation. Furthermore, a large share of electric vehicles would reduce the need for biofuels within transportation also in a case where biomass is used to generate the electricity needed for the vehicles due to the higher efficiency for electric engines compared to combustion engines (see for instance Swedish Energy Agency 2015). It seems inevitable that biomass would have to replace fossil based generation of heat to the industry as well as generation of DH and on-site generation of heat in buildings. As evidenced above, energy efficiency measures could reduce biomass consumption for this purpose.

The main efforts will of course be related to reducing emissions from the transport sector and from the industry while at the same time maintaining current activity level at the industry. The region may to some extent utilise the so-called flexible mechanisms to purchase emission rights outside the region at least in a transition period to neutralise emissions from sectors where it will take time to achieve significant reductions, such as the transport sector. BECCS can also be utilized to neutralize such emissions provided of course that remaining regulatory barriers are eliminated and that it is properly incentivized.

9 Challenges and Pathways

This chapter discusses challenges the region will encounter in meeting the CO2 emission pathway described in Section 8. Pathways for energy efficiency and renewables are an integral part of the emission reduction pathways and are therefore not described explicitly but rather as possible actions to reduce CO2-emissions.

As mentioned above, the main climate targets for Sweden and thus also for the KASK-SE region are;

- By 2030 Sweden’s (KASK-SE) vehicle park should be independent of fossil fuels.
- By the middle of this century Sweden’s/KASK-SE’s net GHG emissions should be zero.

However, in this work we have, also as mentioned above, focused on CO2 emissions emitted within the geographical boundary of the KASK-SE region, i.e. so-called production based emissions. A vehicle park independent of fossil fuels has been interpreted as a road transport system which is mainly run on bio-based fuels and electricity reaching an 80% reduction of fossil fuel consumption in 2030 and with a complete elimination of fossil fuels (and emissions) by 2050[38].

The challenges associated with emission reductions within each sector have been assessed applying a concept proposed in the project North European Power Perspectives (NEPP 2013). The concept is based on a scorecard principle, ranking the challenges into three different categories separated by colour: moderate challenges (Green), significant challenges (Yellow) and very significant challenges (Red). Table 9.1 lists possible emission reduction pathways by sector and the challenges associated with each action according to the scorecard principle.

Table 9.1: CO2-emission reduction pathways by sector and with the challenge categorised according to the scorecard principle.

	Possible emission reduction pathways	**Challenge category**
Public Electricity/Heat Prod	fuel switch (bio), technology shift (wind, solar)	Moderate
Heating (DH+on-site)	fuel switch (bio), demand reduction buildings	Moderate to Significant
Transport incl working mach	fuel switch (bio+electricity), efficiency increase, reduced demand, modal shift	Moderate to Very significant
Industry Refineries, Energy	Efficiency increase, fuel switch (bio), CCS, BECCS	Significant to Very significant
Industry Others, Energy	Efficiency increase, fuel switch (bio), CCS, BECCS	Moderate to Significant
Industry Process	CCS, BECCS	Very significant
Solvent use	Phased out alternatively neutralized through BECCS (35 kton in 2010)	Moderate

Figure 9.1 shows the pathway for CO2 emission reductions described in Section 8.3 (and shown in Figure 8.7) with the various measures categorized by challenge according to the scorecard principle given in Table 9.1. This exercise is obviously somewhat approximate and the shape of the curves in Figure 9.1 are different from those in Figure 8.7 since several of the emission reduction options depicted in Figure 8.7 are grouped together over time in Figure 9.1 (as is also indicated in Table 9.1). See also Table 9.2 for emissions by sector each decade as envisaged in Figures 8.7 and 9.1.

[38] As of January 2015 it has not been clarified what the term “a transport sector independent of fossil fuels” actually means in terms of future fossil fuel consumption. However, the proposed scenarios in SOU (2013), in Trafikverket (2012) and the so-called “Målscenario 1” in NVV (2012) all suggest 80% reduction of fossil fuels by 2030 and complete elimination by 2050.

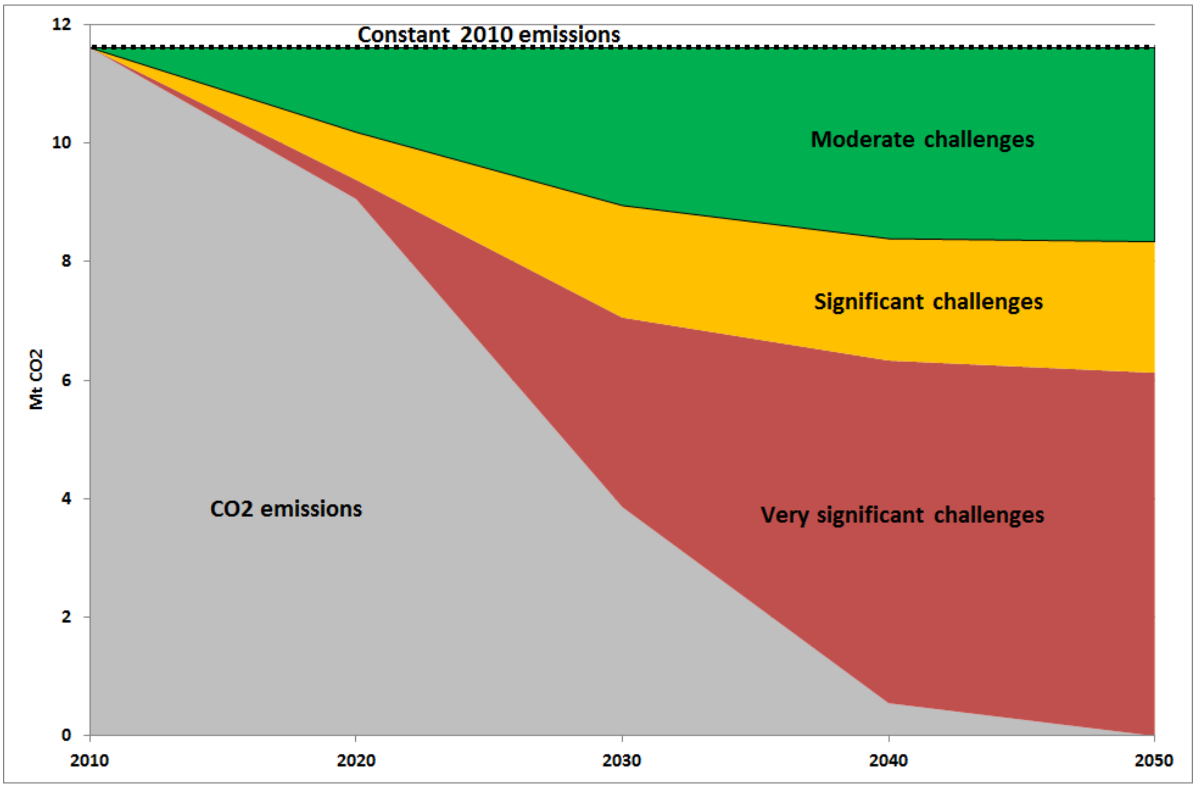

Figure 9.1: Emission reduction pathway shown in Figure 6.7 in Section 6.3 categorized by challenge according to the scorecard principle.

As illustrated in Figure 9.1, a large part of the required emission reductions are likely to face very significant challenges. Emission reductions that fall in this category is foremost the bulk of transport and industry related emissions associated with either use of CCS/BECCS and/or, in the refineries case, a massive and gradual transformation of the transport sector to biofuels not only in KASK-SE but probably also in the whole of Europe and where it has been assumed that the refineries in KASK-SE maintains current market share. It should also be recalled from Section 7.1 that the shift to biofuels is associated with a massive reduction in demand for transport work and thus also for biomass (see Footnote 26). Thus, a more likely way to reduce emissions in the transport sector is foremost a higher share of electrification than anticipated in Chapter 7 plus a combination of CCS/BECCS and consequently also a more modest shift to biofuels, all the more so since a transformation to biofuels of course will have to be gradual. Use of CCS and BECCS implies of course that they both will need to be properly incentivized, but this is definitely not the case as of early 2015. In fact, CCS has faced many problems over the last few years and most CCS projects in Europe have now been shelved while at the same time, there are also several regulatory issues that remain to be resolved.

The emission reduction pathway shown in Figure 8.7 and categorized according to the scorecard principle in Figure 9.1 assumes that a large part of the emission reductions are taken already by 2030. It would of course be less challenging to delay parts of the reductions to later, let’s say to 2040. However, assuming rapidly increasing global demand for biomass it would probably make sense to start the transformation as soon as possible. It would probably also be useful at an early stage to develop an overall energy master plan for the region. This should be done in close collaboration between politicians, industries and other key actors in the region.

Sections 8.2 and 8.3 identify four *main* measures for reducing CO2-emissions; 1) fuel shift from fossil to biomass for public, private and industrial power and heat production, 2) CCS including BECCS in the industry alternatively use of biomass as feedstock to the refineries and the chemical industry, 3) energy savings particularly in the transport sector but also in the industry and building sectors and 4) switch to bio-fuels and electricity in the transports sector. A fifth measure was also identified; namely purchase of emission credits abroad and, as mentioned above, up to one third of the emission reductions may be achieved in this way. In this work however we have assumed that the region will prioritize to reach the targets without utilizing this option. Nevertheless, the fifth option offers the region some transitional flexibility on its way towards zero emissions in 2050.

Section 8.3 also raises an important question; What will be the future activity level for the industry in the region and in particular for the refineries as the bulk of their production is exported, either to other parts of Sweden or abroad, e.g. Preem exported 55% of its production abroad in 2013 (and 65% in 2012, Preem 2013). Section 8.3 concludes that if the activity level should be maintained at current levels[39] there are in principal only four possible solutions for the refineries in the region which can apply in a climate constrained world; use of fossil fuels as raw material in combination with CCS and BECCS, limited use of biomass or a full transformation to bio-refinery or a combination of the three, possibly also as mentioned above with use of international emission credits, at least during a transition period.

Since a large part of the production in the refineries is exported, a partly fossil based feedstock will not oppose to the Swedish or the KASK-SE apparent target of a fossil free transport sector by 2030 (see Footnote 38) provided the fossil based part of the production is exported. However, in a climate constrained world KASK-SE (and Sweden) will of course not be the only region (nation) in Europe (or globally) that will undergo a transition to biofuels. As mentioned in Section 7, such a transition will probably take place at least on a European level and hence it can be anticipated that most of the production in the refineries in the region will have to be bio-based by 2050 (cf Footnote 38).

However, an elimination of fossil based feedstock to the refineries will of course take time. Thus the refineries will have to gradually reduce its fossil based production while at the same time build up and increase its biomass based production. Yet, any future biomass-based production level which is of the same order as present will result in great logistical challenges with respect to biomass supply and handling. The future activity level will of course strongly depend on the development in the transportation sector.

The two biomass cases described in Section 8.2 (Cases A and B) both correspond to a significant increase in biomass consumption, between almost three- and more than tenfold the current consumption in 2030 and between almost four- and more than twelve-fold in 2050. As a comparison, IEA (2013) estimates that between 2011 and 2035 the EU biomass energy demand will increase by 52% in their Current Policy scenario (CPS), by 67% in their New Policy scenario (NPS) and by 98% in their 450 scenario, corresponding to an increase from 1,500 TWh in 2011 up to between 2,280 and 2,965 TWh in 2035. For the transport sector IEA (2013) assumes that demand declines by between 7 and 32% from 2011 to 2035 and that fossil fuels still covers between 63 and 86% of total demand in 2035 depending on scenario and with the smallest share of fossil fuels in the 450 scenario. According to IEA (2013), EU would be the largest global importer of biomass both for power generation as well as for

[39] Maintaining current activity level has in this report been defined as having a constant market share.

biofuels in Year 2035 in the NPS. Assuming that the transport sector in the EU and in the KASK-SE region develops in the same way with respect to demand and fuel/technology distribution (see Figure 7.1) and based on Year 2011 final demand for crude oil in the transport sector in the EU as given by IEA (2013), biomass demand in the transport sector in the EU will reach around 1,820 TWh in 2050. In 2011, the EU consumed just above 160 TWh biofuels in the transport sector (IEA 2013).

Thus, there are many indications that competition for supply of biomass will increase both rapidly over time and substantially by volume and therefore also the price on biomass. Hence, it will probably be useful for the main emitters in the region to start preparing for a transition to biomass at an early stage including securing supply at reasonable prices. It can therefore also be concluded that if the region wants to drastically reduce fossil fuel consumption in the transport sector by 2030 and eliminate it altogether by 2050 while at the same time keep industry activity at current levels (constant market share on all the markets they are represented), the supply and logistical challenges will be very significant and cost will rise accordingly.

However, above all the previous sections imply that electrification of the transport sector will probably have to play a larger role than what has been anticipated in this study[40]. This will of course reduce activity levels at the refineries assuming such a development is governed by the development on European markets but more importantly it will also reduce the demand for biomass. Cutting the share of biomass to 50% from 2030 onwards in case B in Section 8.2 (see also Footnote 26) would reduce annual demand by 15 TWh at the most. Cutting the biomass share to 40% from 2030 onwards would reduce annual biomass demand by 42 TWh at the most which still yields a biomass demand around 130-135 TWh annually in 2050, i.e. corresponding to the entire Swedish consumption. On the other hand, some 7 TWh electricity would be sufficient to cover 100% of demand by 2050 as given in Figure 7.1.

Applying the results in Figure 7.1 on the transport sector in Sweden, there should be at least one million electric passenger cars in Sweden by 2030 (Sköldberg et al., 2014). At end of 2014, there was only around 7,000 electric passenger cars in Sweden which means that the passenger car fleet for electric vehicles will have to grow by more than 36% per year on average between 2015 and 2030. This growth is nevertheless modest considering the 146% increase in all rechargeable vehicles in Sweden during 2014 (of which by far the most are passenger cars). The “significant” growth of electric vehicles during 2014 may in part be due to the premium given by the Government for so-called super clean cars, i.e. cars with CO2 emissions of 50 grams/km or less. Assuming 36% annual growth between 2014 and 2030 also means that almost 270,000 electric passenger cars will be added to the fleet in 2030 which may be compared to 303,364 new passenger cars registered on average per year between 1997 and 2014 (Statistics Sweden 2014a).

Public and on-site production of electricity and heat, i.e. excluding heat produced by the industry, emitted 1.2 Mt of CO2 combined in 2012 burning an estimated 4.0 TWh fossil fuels, primarily natural gas. A combination of energy savings in the building stock in combination with increased wind and solar based power generation and locally produced biomass for

[40] We have not considered hydrogen as a transportation fuel in this work but hydrogen may of course also take a substantial market share in the future, depending mainly on the development of fuel cell-cell technology (whereas the future of electric cars will depend on development of the battery) (see for instance Swedish Energy Agency 2015).

power and heat generation will relatively easy replace the fossil fuels utilized in this sector. It is emphasized however that some 1.6 TWh oil and natural gas is burnt directly on-site in buildings (in 2010) to generate heat and it has not been assessed in this report how easily these facilities can switch to bio-based heat generation. Yet, a fair assumption is that most oil fired boilers are of age and, when phased out, will not be replaced by new oil fired boilers. Thus, the oil part will most likely phase out itself due to ageing of the boilers.

The two main scenarios for the electricity sector outlined in Section 6.5, namely the Green Policy and the Regional Policy scenarios, lead to complete phase-out of nuclear power by 2030 and 2045 respectively. At the same time the share of intermittent power (wind + solar) increases from ca 6% in 2010 to 54% and 74% in 2050 in the Regional and Green Policy scenarios respectively. In the Green Policy scenario, the share of intermittent power reaches 64% already in 2030. The region also transforms from being an exporter of electricity to mainly an importer of electricity although the volumes become marginal by 2050 in the Green policy scenario.

In addition to the two main scenarios for power generation a third scenario was developed; namely the Climate Market scenario which focuses exclusively on climate mitigation post-2020 and not on renewables or efficiency measures *per se*. In this scenario, nuclear power is reduced by two thirds by 2050 but not completely phased out while the share of intermittent electricity is kept relatively low, increasing slowly to 29% in 2050. By 2040, the region turns from being a significant exporter of electricity to a significant importer of electricity due to anticipated relatively larger demand in this scenario[41]. More details of the Climate Market scenario and an alternative Regional Policy scenario are given in the Appendix (A1).

In summary, it can be stated that there are very significant challenges associated with emission reductions in the transport and industry sectors and that the future for the refineries in the region is highly uncertain. Large-scale transformation to bio-fuels in the transport sector will depend on the development in the rest of Europe implying that the volumes of biomass that will be required appear unrealistically high. One way to reduce the amount of biomass used in the transport sector will of course be to raise the share of electricity but again this will depend on factors outside the control of the region since it will require car manufacturers to scale up the production of electric cars which must be driven by markets of a much larger size than the Swedish market. Thus, the most realistic option for the transport sector appears to be a gradual transformation away from fossil fuels that follows the rest of Europe with electricity playing a substantial role (to reduce the biomass that eventually will be required) in combination with CCS and BECCS.

The power sector in the region may evolve in several directions which all can comply with zero emissions by 2050. A complete phase-out of nuclear power will increase the challenges of the transformation with respect to handling high contribution from intermittent energy since a phase-out ultimately will lead to increased requirement for biomass to be used partly for base-load power generation and partly to balance the grid. Biomass should perhaps instead be reserved for the transport and industry sectors. As mentioned in Section 6.5, the large penetration of intermittent power generation will probably also require substantial investments in the power grid but this has not been investigated in this work.

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[41] Demand is higher in the Climate Market scenario due to increased electrification in industry and transportation as well as the absence of specific end-use efficiency policies.

Table 9.2: Derived emissions by sector 2010-50 in Section 8.3 and envisaged in Figures 8.7 and 9.1, kton CO2

	2010	**2020**	**2030**	**2040**	**2050**
Publ. Electricity/Heat Production	1 263	859	589	52	0
Heating (DH+on-site)	461	158	0	0	0
Transport	4 627	3 300	900	500	0
Industry	5 224	4 724	2 372	0	0
Solvent use	35	18	0	0	0
Total	**11 611**	**9 058**	**3 860**	**552**	**0**

With regard to a reasonable timeline (roadmap) for CO2 emission reductions for the region in the short- (2020), medium- (2030) and long term (2050), Table 9.2 shows emissions by sector between 2010 and 2050 as derived in Section 8.3 and envisaged in Figures 8.7 and 9.1.

It should be noted that the Year 2010 was a cold year leading to somewhat higher emissions for electricity and heat production (the two first groups in Table 9.2) than for instance the eight years average between 2005 and 2012 which was some 20% lower.

Emission reductions for electricity and heat production have been assumed to be reached through a combination of lower demand caused by efficiency improvements in buildings, gas and oil boilers being replaced by biomass fuelled boilers and CHPs and large scale penetration of wind based power generation (see Table 9.1). The single largest emission sources in this group are Ryaverket combined cycle gas plant and the waste power plant at Sävenäs, both located in Göteborg, which combined emits between 600 and 700 ktons fossil based CO2 per year. Ryaverket is owned by Göteborg Energi which is owned to 100% by the City of Göteborg while the Sävenäs waste CHP is owned by Renova which is owned to 85% by the City of Göteborg. Both the Sävenäs plant and Ryaverket will be close to the end of their operating lifetime by 2030[42]. Also, as mentioned above, the City is a large property owner. At the same time the City of Göteborg is aiming for that all DH should be produced by renewable sources, waste and industrial waste heat by 2030 (City of Göteborg 2014a, b). Also, Region Halland and Region Västra Götaland[43] are large property owners in the region. Finally, it appears likely that individual boilers currently used for on-site production of heat over time will be replaced by DH and new bio-fuelled boilers. Thus, it can be concluded that it should be reasonably straightforward to reach large emission reductions from electricity and heat production in the region and, even more so, since the capacity to act to a large extent lies on local and regional administrations and politicians.

Emission reductions in the transport sector given in Table 9.2 follows the results described in Section 7.1 (see Figures 7.1 and 7.2). As can be seen from Table 9.2 emissions have been reduced by more than 80% up to 2030 based on the national and regional targets of having a transport sector independent of fossil fuels by 2030 although it has not yet been established what the term “independent of fossil fuels” means in terms of fossil fuel quantities. Considerably more efficient cars, shifting of fuels and change in transport mode yield the

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[42] Another large emitter in the region is Ryaverket CHP in Borås (see table 8.3) which is owned by the City of Borås. There are detailed plans to replace Ryaverket in Borås with a 100% bio-fuelled CHP by 2030. The City of Borås is also aiming for a fossil free city.

[43] Region Halland and Region Västra Götaland are not to be confused with the Counties Administrative Board (CAB), see www.regionhalland.se and www.vgregion.se.

scenario envisaged in Figure 7.1 (and Table 9.2) where fuel demand is reduced by 42% between 2007 and 2030 and with biomass and electricity together covering nearly 70% of total fuel demand in 2030. As mentioned above, this will require immediate and concerted action and strong incentives, not only on regional and national levels but probably also on EU level. However, since the aim is to reach zero emissions in 2050, the transformation may proceed slower than what has been envisaged above pending on potential restrictions on the use of fossil fuels and, as discussed above, this is for instance the case for the most climate ambitious scenarios given by both EC (2011) and IEA (2013). It appears likely that demand in the transport sector in the long term will be covered by biomass and electricity although with a considerably higher share of electricity than what has been envisaged in Section 7.1. Emissions from the transport sector may, at least in a transition phase, be neutralized through use of BECCS and/or purchase of international emission credits. In any case it seems imperative that the Swedish Government as soon as possible clarifies what the term "a transport sector independent of fossil fuels by 2030" means in terms of quantities of fossil fuels (see Footnote 38).

A large part of the industry emissions in Table 9.2 comes from the refineries[44]. If fossil fuels are eliminated altogether from the European transport sector, emission reductions from the refineries are also eliminated although it is difficult to envisage such a transformation. As mentioned above, both EU (EC 2011) and IEA (2013) expect a relatively high share of fossil fuels in EU's transport sector in 2035. In fact, the most climate ambitious scenario in EC (2011) expects that the transport sector in EU will emit more than 300 Mt CO2 in 2050, down from ca 800 Mt in 1990 and from 1,050 Mt in 2010 (see Figure 7.6). It is uncertain whether Sweden alone will be able to (and willing to) eliminate fossil fuels from its transport sector and if Sweden does so, it is difficult to estimate how fast such a transformation will happen. Fossil based emissions from the refineries will require CCS but also BECCS assuming that the fuels are delivered also to Swedish markets. The chemical cluster in Stenungsund, the cement plant in Skövde and the metallurgic industry Vargön Alloys (producer of ferrochrome) are all examples of process industries that cannot reach large emission reductions without the use of CCS, at least with current technology. CCS at the Skövde and Vargön plants will be costly due to the relatively small volumes of CO2 and long transport distance to feasible storage sites. Assuming that CCS and BECCS can be utilized from a technical, economical, regulatory and practical perspective, it seems difficult to envision the start-up of full-scale CCS systems earlier than 2030. From that perspective the emission reduction pathway shown in Figures 8.7 and 9.1 describes an optimistic view. On the other hand, assuming large scale CCS becoming feasible from 2030, it could possibly evolve faster than envisaged in Figures 8.7 and 9.1 involving more sites and larger CO2-volumes.

Finally, only two industry plants have been analyzed in detail with regard to the potential for energy efficiency improvements and fuel switch (see Section 4). Yet, the analysis performed in this work assumes that also the other industries can reduce their emissions through energy efficiency improvements and fuel switch as shown in Sections 8.3 and 9 (see also Figure 8.7 and Table 9.2).

Thus, to summarize, emissions that today originate from burning of fossil fuels generating heat and electricity may be eliminated relatively swiftly within the medium term while

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[44] In 2010, the refineries emitted 2.1 Mt classified by Länsstyrelserna (2014) as emissions from "Energy supply". In addition, the refineries emitted an unknown part of the 800 kton classified as "Fugitive emissions from use of fossil fuels".

substantial emission reductions from sectors such as transport and industry are not likely to materialize until 2030 and later. If the transport sector moves away from fossil fuels it appears likely that demand will be covered by a combination of biomass and electricity and where electricity will have to play a large role. As a consequence, activity levels at the refineries in the region is likely to be dramatically reduced as such a development, if it occurs, is likely to evolve throughout Europe.

10 Conclusions

This report provides an analysis of pathways which can meet climate and renewable targets in the Västra Götaland and Halland counties – i.e. the Swedish part of the KASK region. The work is part of a larger project involving both the Danish, Norwegian and Swedish part of the KASK region (Chalmers-Tel-Tek 2015). Focus is on identification and analysis of relevant pathways towards zero CO2-emissions by 2050 including analysis covering the potential for both increased energy efficiency and large-scale penetration of renewable energy. The work comprises four focus areas; 1) potential for improved energy efficiency in key industries in the region, 2) potential for more energy efficient buildings, 3) potential for large-scale integration of renewable energy and 4) potential for GHG emission reductions in the transport sector. A number of technical reports have been written covering the four focus areas and these are listed in the beginning of this report.

In Section 4 the energy savings potential is analyzed for two key industry sites in the region; Preems refinery in Lysekil and the chemical cluster in Stenungsund. Combined, at these two sites, it is concluded that almost 500 GWh fuel could be saved annually by 2020 increasing to 1,300 GWh per year in 2030 yielding a potential CO2 emission reduction of 120 and 330 ktons respectively. However, it is also concluded in Section 4 that to meet significant CO2 emission reduction requirements in the long-term, the industries in the region must aim for radical change. Such changes could include a switch to biomass feedstock, adoption of new process technology and implementation of ambitious programmes to maximize process energy efficiency and CCS.

Taking basis in the regions specific building structure, the energy savings potential in the building stock in the region is modelled (Section 5) Applying a package of Energy Conservation Measures (ECMs), up to 16 TWh, mostly heat, could be saved. The single most efficient measure would be to install ventilation systems with heat recovery. Considering only those measures where the cost of the measure is lower than the cost of the saved energy, i.e. a techno-economic potential, up to almost 6 TWh can be saved of the currently around 29 TWh used in the building stock of the region (see Footnote 7). Refurbishment of the buildings that are included in the so-called Miljonprogrammet offers a great opportunity for large energy savings although challenging. As for reductions in (direct) CO2 emissions, this has been estimated to range between 330 and 790 kt. It should be kept in mind that the emission reduction potential is based on direct emissions from the region, based on application of national average emission factors for coal, gas and oil and for production of electricity and heat and thereby neglecting overall system effect of CO2 emissions.

In Section 6 it is shown that there is a large potential for renewable energy in the KASK-SE region. Under the assumption that the region maintains a strong forest industry and there is a positive economic development globally, up to 6 TWh additional biomass could be produced within the region. Likewise, under the existing subsidy regime consumer based solar PV installations could reach production levels up to 2.5 TWh electricity, utility scale PV installations could raise this potential substantially but that would require subsidy schemes dedicated for this purpose. Foremost however, the bottom-up study on available land area for wind power reveals a large potential for cost efficient onshore wind power in the KASK-SE region. The analysis in Section 6.2 indicates that up to 10 GW wind power could be installed at electricity prices between 65 to 70 € per MWh, generating between 20 and 25 TWh annually. This result suggests that continued expansion of wind power within the region should focus on onshore sites due to the considerably higher cost of offshore wind power, at least under the existing financial support schemes. Results from the modelling of the electricity generation system in the region indicate that large-scale deployment of renewables in combination with phase-out of nuclear power is likely to turn the region into an import region with regard to electricity. Large scale penetration of intermittent power is also likely to create significant challenges for the electricity grid in the region as well as with regard to balancing of the system. At the same time, the local effect on CO2 emissions would be relatively marginal since this sector already has modest CO2 emissions. On the other hand, renewable generation in the KASK-SE region would probably replace fossil based generation in other parts of Europe and thus lead to overall lower emissions.

Section 7 analyzes the possibilities for the transport sector in the region to reach zero or near zero CO2 emissions by 2050. In section 7.1 it is shown that the region can reach a zero CO2 emission transport sector by 2050, but this will require substantial policy intervention and imply considerable challenges. Likewise, in Section 7.2 it is shown that emissions from road transport in Göteborg, could be reduced by more than 80% by 2030 versus emissions in 2012. In both cases (in KASK-SE and in Göteborg respectively) emission reductions are achieved through an expected significant reduction of base demand in transport work caused by in particular more efficient vehicles including efficiency increases as a result of a shift to electric vehicles. By 2050, fuel demand in the transport sector in KASK-SE is assumed to be covered to two thirds by biomass and to one third by electricity. However, as concluded in Section 7.3, there are significant barriers to such a development. For instance, vehicles will not be developed for a relatively small Swedish market, it will require at the very least a European market and the EU is moving very slowly forward in this regard. Also, as mentioned above, development towards a CO2 emission free transport sector will probably require very strong economic incentives.

As concluded in Section 8.1, it appears likely that the KASK-SE region will reach its goal of reducing energy intensity by 20% in 2020 and by 27% in 2030 although the latter has not yet become an officially announced target other than by the EU. However, it should be emphasized that it is difficult to get an extensive overview of absolute energy consumption and relevant individual plans and targets, both within each sector (transport, industry, buildings) as well as within each municipality.

Section 8.2 discusses the potential contribution from biomass. It is concluded that biomass has an important role to play as base load and balancing power in a power generation system with high penetration of intermittent renewables and, even more so, in the case of a nuclear decommissioning. Section 8.2 also explores potential contribution from biomass being used as raw material by the refineries and the chemical cluster in the region. It is concluded that a full transformation to bio-based raw materials will be a highly challenging task if the refineries are to maintain its current activity level and market share in a European transport system evolving towards a fossil free transport system by 2050. In Section 8.3 we conclude that only four options exist for the refineries in the region if they are to reach zero CO2 emissions:

1) Complete transformation to bio-refineries and maintain current activity level.

2) Transformation to bio-refinery and reduced activity level.
3) Continue to operate with fossil based raw material which will require CCS to eliminate process related emissions. If the fossil based fuel is used by the transport sector in Sweden, BECCS will be required to neutralise these emissions (i.e. to achieve zero emissions from the entire energy system of the region by the end of the period).
4) Combination of options 1) to 3).

Sections 8.3 and 9 also conclude that it will be extremely challenging to reach the goal of zero CO2 emissions by 2050 unless 1) activity levels at the refineries is severely reduced or 2) CCS and BECCS are applied but there are still many regulatory and economic barriers for CCS and BECCS. As a consequence it also seems obvious that electrification of the transport sector will have to play a large role.

An overall assessment of the challenges associated with meeting the long term (Year 2050) climate targets set up by the region shows that more than half the emission reductions required will impose very significant challenges. Many of these challenges can only be overcome by investments in energy infrastructures for which there are only one or a few investment cycles left until Year 2050. Yet, there are also a significant amount of measures to be taken which should be of a less a challenge to implement. Taken together, we conclude that if any chance to meet the long term targets there is an immediate need to develop a framework which can ensure that short term actions can be linked to long term visions. If not, there is a risk that targets required on the long term remain visions. Thus, we conclude that establishment of a roadmap to meet climate and renewable targets in the region – such as the one shown in this report - requires politicians, industries and other key actors to collaborate at an early stage to develop an overall energy master plan for the region.

11 Suggestions for further work

This work constitutes a first attempt to put figures on the different measures that need to be taken to reach energy and climate targets of the region. The work presented in this report is by no means complete in the sense that it answers what actions are to be taken and what is the capacity to act of different organizations and stakeholders within the region. More work is obviously required in order to develop a concrete strategy with action points for the region at the same time as many of the actions required depend on policy measures on national and EU levels as well as development of global markets of export products such as transportation fuels, chemicals and vehicle technologies. Yet, if the Halland and VGR regions (and City of Göteborg) are to have high ambitions in the area of sustainable development (e.g., as expressed in “Regionala Miljömål för Västra Götaland”, VGR 2014), there should be a need to further develop and analyze concrete actions and derive concrete “figures” with respect to what is needed to link short term actions with the long term visions. This so that the region is prepared for the future development of national and international policy measures as well as in order to take local initiatives which are sustainable from an environmental, economic and social point of view. From the work we can identify some important steps for a continued analysis. These are, in no particular order, as follows:

The electricity sector should be analyzed in more detail than what has been done in this work. It is important to analyze the role of nuclear and bio based power in relation to large penetration of intermittent energy (mainly wind power), grid and balancing requirements and the need for increased imports. The overall analysis of the electricity sector should also include detailed analysis of the future role of electricity in the transport sector. The future development of the electricity supply system will obviously depend on corresponding national and EU development, in particular with respect to the future of nuclear power. Yet, the expected penetration of renewable electricity under different scenarios should be further assessed in order to plan for rational allocation of renewable electricity generation, not at least wind power but also what can expected from distributed generation such as solar PV should be analyzed. In connection to this, the prospects of demand side management (especially demand response measures) for variation management should also be investigated in more detail.

This work has identified a considerable potential for onshore wind power. Considering the higher costs and challenges with offshore wind power with respect to expected life time (O&M costs) it would be of interest to make a deepened onshore wind power assessment, considering factors not included in this study such as local interests and public acceptance issues. For example, the analysis done in Section 6.2 on available land area for onshore wind power could be further developed by integrating and comparing the analysis with existing wind plans in each municipality.

As highlighted throughout this report, biomass will obviously play a key role in the region's future energy system as it probably also will in several sectors in Sweden as well as in other regions where the right conditions will be present. Yet, biomass is limited with respect to supply and in a carbon constrained future there will be competition for the biomass both between regions and between sectors. Hence, it should be analyzed how the region can utilize the biomass resource as efficiently as possible as well as how the international biomass market is likely to develop under different scenarios.

It seems likely that the region will need CCS and/or BECCS to meet strict CO2 emission reduction requirements in the future. Thus, it should be investigated what is required for CCS to be utilized in the region including identification of the prerequisites for a relevant local CCS chain, including if and how a CCS infrastructure can be integrated with other regions. The role of CCS in Sweden is obviously strongly linked to the future development of the energy intensive industry and its future role in the region should therefore be analyzed under different scenarios of future development of the economy and relevant markets. Of particular interest is to analyze to what extent the industry of the region could be a forerunner towards sustainable processes. It seems important that such an analysis is carried out in close co-operation with the industry in the region.

The application of energy savings measures in buildings should be analyzed in more detail with respect to non-technical barriers for application of energy conservation measures (such as the role of cultural heritage) as well as the balance between energy conservation measure and to what degree waste heat can be used for heating in buildings with district heating. In addition, there is a need for improved statistics on the building sector of the Swedish KASK region, which would facilitate a better understanding of the existing building stock and its link to the energy system, and thereby facilitate a deepened analysis of how the building sector in the region can be transformed.

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14 Appendices

A1 – Modelling of Europe’s electricity generation system, alternative scenarios.

Prior to the election in Sweden in Autumn 2014, the political parties now forming the new government indicated that they wanted to see an increase in the joint Norwegian-Swedish Green Certificate target by an additional 30 TWh between 2020 and 2030 (Svensk Vindenergi 2014). Such an increase in ambition is in line with the assumptions in a second version of the “Regional Policy” scenario (“Regional Policy 2”) applied in this work (see Section 6.5). The view of Norwegian decision makers on such target increases is currently, however, highly uncertain. It is estimated that renewable electricity generation under the existing electricity-certificate scheme needs to increase by approximately 3 TWh annually between 2014 and 2020 in order to meet the joint target of an increase of 26 TWh between 2012 and 2020 (Swedish Energy Agency, 2014). This annual increase is assumed to remain also between 2020 and 2030 in our second version of the Regional Policy scenario, implying that the total increase between 2012 and 2030 corresponds to around 55 TWh renewable electricity. CO2 emissions from electricity generation in Europe are reduced by approximately 95% by 2050.

Besides, the “Green Policy” and “Regional Policy” scenarios, we also briefly analyze consequences for electricity generation in the KASK region based on a third European scenario, the “Climate Market” scenario. We use this only for a sensitivity analysis of the prospects for wind power in the region. Briefly, the “Climate Market” scenario focuses exclusively on climate mitigation post-2020. Thus, this is distinctively a ”one-goal” scenario and, as in the other scenarios, CO2 emissions are reduced by 95% up to 2050. Due to increased electrification in industry and transportation as well as the absence of specific end-use efficiency policies, electricity demand is relatively larger in this scenario than in the two previous scenarios. Both CCS and new nuclear power plants are optional if considered profitable in the modelling. Figures A1.1 and A1.2 shows the resulting fuel/technology distribution for the power sector in KASK-SE between 2012 and 2050 in the Regional Policy 2 and Climate Market scenarios respectively.

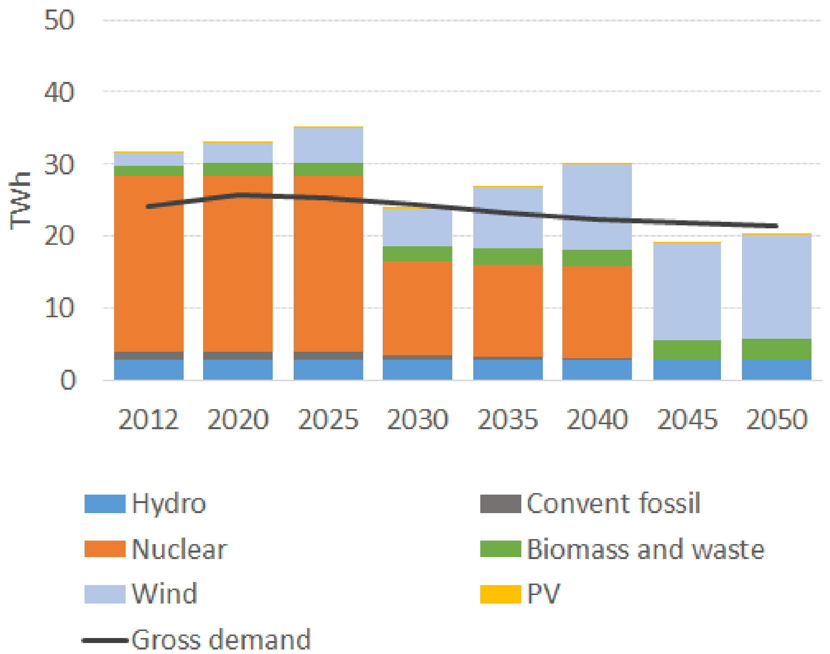

Figure A1.1: Electricity generation by fuel/technology 2012-2050 in KASK-SE in the Regional Policy 2 scenario.

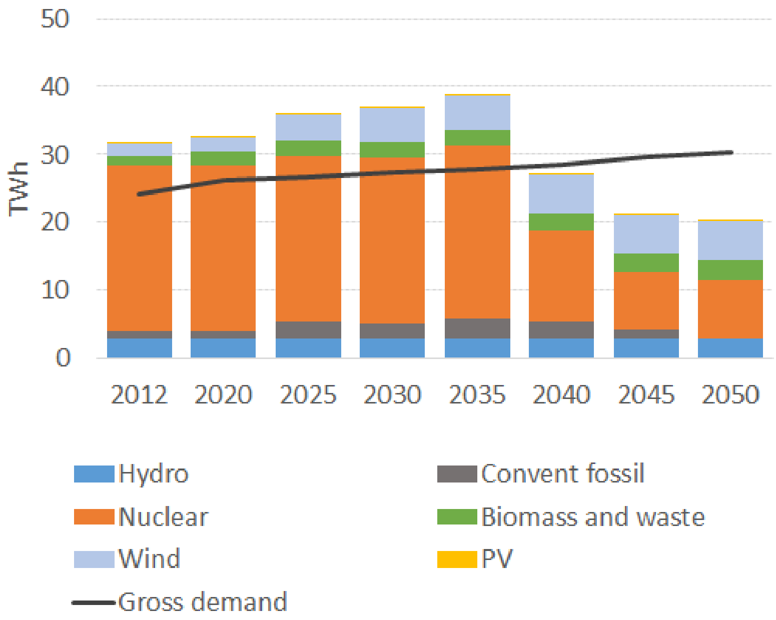

Figure A1.2: Electricity generation by fuel/technology 2012-2050 in KASK-SE in the Climate Market scenario.

A2 - Transport Sector Incentives

A selection of the most important incentives that were proposed in Elforsk (2012) are presented and discussed below (see also Sköldberg et al., 2014).

General incentives that should be introduced immediately:

- Increased fuel tax, e.g. of the CO2-tax on fossil fuels. According to Trafikverket (The Swedish Transport Administration, 2012) it can be necessary to raise the cost of driving by 50% (in addition to other measures and incentives) to reach the targets for the transport sector.
- Investments in railway infrastructure.
- Research on for instance urban planning, public transport, logistics, electric vehicles, second generation biofuels and vehicle efficiency.
- Fringe benefit tax on parking at the workplace.

Incentives with respect to reduced transport demand and modal shift that should be introduced immediately:

- Parking strategies, e.g. limited parking space in the city center and/or higher parking fees.
- Introduction of car-free zones in city centers
- Congestion charges. In Stockholm, the introduction of congestion tax has led to a stable, general decline of traffic of between 18% and 22% (Transportstyrelsen – The Swedish Transport Agency - 2014) while results from a compilation of 16 congestion tax systems in Europe have shown that transport work for private cars has been reduced by between 14 and 23% (CURACAO 2009). The much shorter time period that the congestion tax has been in effect in Göteborg indicates a slightly lower decline than experienced in the European study, i.e. an 11% decline on average (Transportstyrelsen 2014).
- Restrictions on location of shopping centers
- State aid to intermodal terminals leading to increased trans-shipment opportunities, increasing the benefit of railway investment and enabling the most efficient multi-modal transport solutions.
- Requirements for joint distribution of goods from and to city-centers and urban areas.
- Increased efforts to improve public transport systems. Factors like travel time, comfort, safety and information appear to affect the choice of transport more than the fee.
- Speed limitations, lower speed limits

Potential barriers and problems with regard to reduced transport demand and modal shift:

- Long lead times are required to change urban structures and infrastructure.
- Difficult to change public attitude to, and change of, transport mode and to opt out of car ownership.
- A prerequisite for a shift of individual transport from car to public transport is that traffic services that are offered are relevant, reliable, and that travelers find it easy and secure to use. This places great demands on the public transport authorities and companies, and concerted efforts are needed to really make an impact.
- It has proven difficult to get competing companies to collaborate on delivery vehicles and to share a common overall administrative system for co-distribution.

Incentives with respect to higher efficiency that should be introduced immediately or by 2020:

- Should be introduced immediately: Vehicle tax based on a “bonus-malus” system. The higher specific emissions the higher the tax. Low-emission cars could even receive a premium.
- Should be introduced immediately: Tougher EU requirements for emission reductions from trucks. Sweden has a very limited ability to address this issue alone but the EU commission is working on a strategy aiming to reduce emissions from heavy duty vehicles.

- Should be introduced by 2020: Tougher EU emission requirements for private cars. Also with regard to this issue Sweden has a very limited ability to address it alone. The EU commission put forward a proposal to set a mandatory ceiling of 95 grams CO2 per km in 2020. The European Parliament agreed in February 2014 to an amended proposition where the requirement of 95 g/km will be applied to its full extent from 2023. Trafikverket has proposed that Sweden should aim for an EU-wide ceiling of 70 g/km in 2025 and 50 g/km in 2030 (Trafikverket 2012).

Potential barriers and problems with regard to higher efficiency:

- If the EU chooses not to work for further emission reduction requirements after 2015 it will be difficult for Sweden alone to accomplish any significant changes in this respect.
- Higher efficiency yields lower operating cost for the vehicles which in turn may lead to a rebound effect followed by higher transport demand, see for instance VTI (2014 – The Swedish National Road and Transport Research Institute 2014).

Incentives with respect to fuel shift:

- Should be introduced immediately: A tightening of the clean vehicle definition is needed. It is important to consider the long-term nature of the definition to provide security for consumers and market participants.
- Should be introduced immediately: Use of quota system to force the use of desired amounts of renewable fuels.
- Should be introduced immediately: Support the production of biofuels by imposing fees on fossil fuels that can be used for this purpose.
- Should be introduced immediately: Government support for the demonstration of new processes for biofuel production, particularly second-generation fuels.
- Should be introduced immediately: Demonstration support for energy efficient vehicles.
- Should be introduced immediately: Support for the purchase of electric vehicles, for example develop the super green car premium.
- Should be introduced immediately: Government support for demonstration of electrified roads.
- Should be introduced by 2020: Government support for expansion of the charging infrastructure.
- Should be introduced by 2020: Prohibition of fossil fuels from a given date.

Potential barriers and problems with regard to fuel shift:

- There are risks associated with the economic instruments favoring the use of biomass in one sector over another and the difficulty of knowing which are the most resource-efficient.
- In general there are long lead times when it comes to produce new fuels, i.e. to move from pilot through demonstration plants to permitting and construction of full-scale plants.
- Since there are many different alternative fuels it will be difficult/risky for vehicle manufacturers to choose the right “tracks”.
- Although there is great potential for the introduction of electric transport, the different techniques for this type of vehicles are still under development for large-scale commercialization. The most critical factors are believed to be the evolution of cost of batteries and fuel cells.

A3 – Biomass feed to the chemical cluster in Stenungsund

The two main chemicals used in the petrochemical industry in Stenungsund are ethylene and propylene with the ratio on energy basis of approximately 5:1. The simplest way to produce ethylene from biomass is through dehydration of ethanol, which is a well-known and established process. Even though other hydrocarbon sources can be used, all hydrocarbons produced from biomass that is of interest for the petrochemical industry have in common that they can be directly used as a blend in for gasoline or Diesel. Hence, they become part of the established global market for drop-in biofuels. It is highly likely that the biomass fuel market in the year 2050 and beyond will be much larger than the market for biofuels used in the petrochemical industry and, therefore, the fuel market will set the economic value on primary biofuel source, i.e. there will be a global market price. Thus, this will be independent if the petrochemical industry produces the biofuel by themselves or not, as there will be a competing market for the biofuel that will influence the achievable overall income for the petrochemical plant. So if not the petrochemical industry has the intention to become a biofuel producer acting on the global market; it would for them be much more beneficial to buy the biofuel of interest in competition with the refineries than produce it themselves. In summary the cost for producing polymers from biomass is today and will in the future be directly proportional to the global market price on bioethanol. Hence, if the petrochemical industry can identify a sufficient market for biopolymers, all they need to do is to add a dehydration unit to the existing process equipment in order to produce ethylene from bioethanol through a mature process having a well-defined investment cost, high availability both on process and fuel availability, known efficiency and known maintenance and operating costs. Figure A3.1 illustrates current and likely future use of lignocellulosic biomass and its relevant supply chain as discussed above.

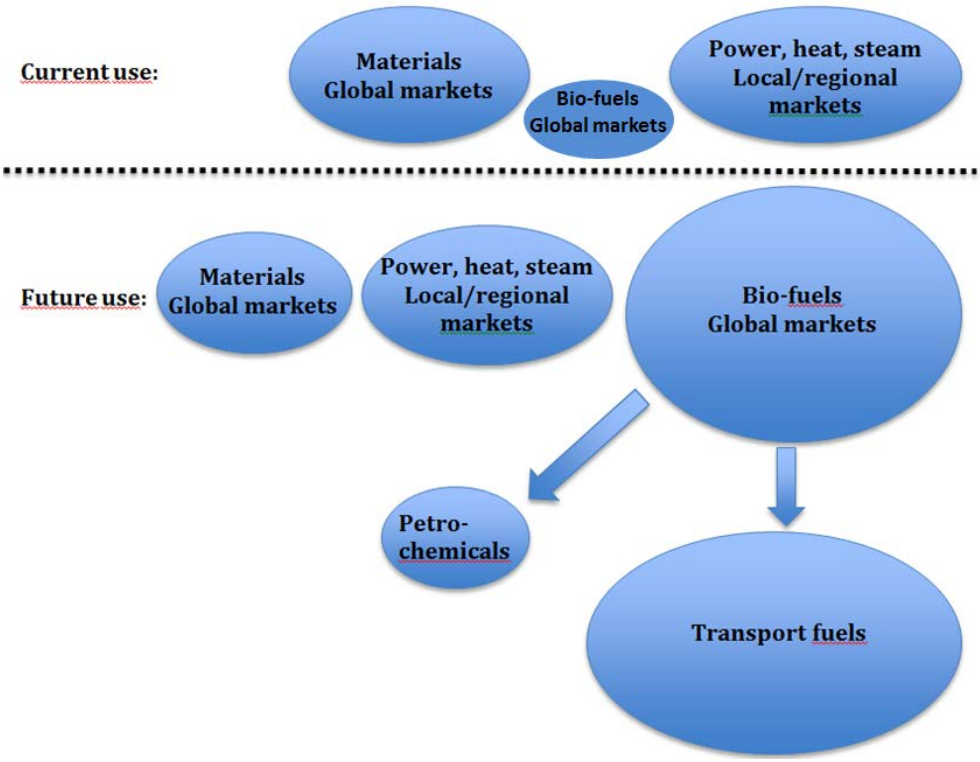

Figure A3.1. Current and likely future use and supply of lignocellulosic biomass in a climate constrained future.

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