NUMBER C 79 | DECEMBER 2014 | REPORT

Sustainability assessment of residual heat transfer from Stenungsund to Gothenburg

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Funded by: Swedish Energy Agency and by participating stakeholders (Business Region Gothenburg, Västra Götaland Region, the industries within the Stenungssund Chemical Industry Cluster, and the Göteborg, Kungälv and Stenungsund DH utilities)
Report number: C 79
Edition: Only available as PDF for individual printing

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Summary

This report presents a sustainability assessment of a link for transfer of residual heat from the chemical industries in Stenungsund to the district-heating (DH) systems of Kungälv and Gothenburg. It is part of the output from a package of interrelated projects involving researchers from Chalmers University of Technology, SP Technical Research Institute of Sweden, and IVL Swedish Environmental Research Institute. A consortium of Stenungsund industries, DH companies and other potential stakeholders are also involved in as partners and co-funders of the projects. The Swedish Energy Agency participates as external co-funder.

A sustainability assessment can address different types of questions, for example:

1. Does the DH link make it easier to reach a sustainable society?
2. Does the DH link in itself improve the environmental, economic and social aspects of society?

The first question is about to what extent opportunities for sustainable solutions arise or disappears as a result of the link. The answer to this question is at least partly known at the start of the project: a DH link is in principle likely to make it easier to reach an environmentally sustainable society, because the use of residual heat in the long term reduces the need for other energy sources.

The main purpose of this sub-project is to respond to the second question, which is about foreseeable consequences of the specific DH link on the economic, environmental, and social performance of society. This question is much more complex. It requires that the assessment considers the case-specific local and regional conditions but, at the same time, is broad enough to take into account important and foreseeable impacts regardless of where in society they occur.

The approach used in this report is life cycle sustainability analysis. The methodological objective of the study is to contribute to the development and demonstration of this approach. Particular effort is spent on the procedure to identify the impacts and indicators on which the sustainability assessment should focus. To ensure the relevance of the study, we use a participatory approach for this step, involving different types of stakeholders. It resulted in a set of 14 research questions that together form the sustainability assessment: six questions on the economic impacts, five on the environmental impacts and three on the social impacts.

To answer each of the research questions, we used a mix of quantitative modelling results and qualitative input from researchers from other parts of the project package. We also used a questionnaire to collect qualitative insights and perspectives from the industrial project partners and other stakeholders. This information was collected while the other projects and sub-projects were still ongoing, which means that only preliminary results and conclusions were available to us and to the respondents among the industrial partners.

From a regional economic viewpoint, the model results indicate that the DH link is likely to be profitable. It is likely to help the energy system to provide district heat at a

lower total cost, compared to all other alternatives available in the model. The economic profit is, however, likely to be small and also sensitive to the capital cost (investment cost and interest rates) and to the availability of other energy sources for DH (residual heat from refineries, cheap forest residues, natural gas).

From an environmental viewpoint, the foreseeable benefits of the DH link are even more uncertain. They depend on which fuel is displaced in Västra Götaland, on how much the regional electricity production in CHP plants is reduced, and on what external electricity production is affected.

The social impacts of the DH link are likely to be mixed. The effect in employment is likely to be small. There is a risk for adverse impacts on land owners affected by the pipeline, but these impacts can be reduced by, for example, coordinating the DH pipeline with a pipeline for freshwater.

All in all, the foreseeable consequences of the DH link are uncertain. It is possible to reduce the uncertainty somewhat through additional analyses, but much of the uncertainty will always remain because of the long-term perspectives and complex systems involved. A decision to invest or not invest in the DH link must be made with incomplete knowledge and significant uncertainty regarding the actual consequences of the investment.

Sammanfattning

Denna rapport presenterar en hållbarhetsbedömning av en fjärrvärmelänk för överföring av restvärme från kemiindustrin i Stenungsund till fjärrvärmesystemen i Kungälv och Göteborg. Studien ingår i ett sammanhängande projektpaket med forskare från Chalmers tekniska högskola, SP Sveriges Tekniska Forskningsinstitut, och IVL Svenska Miljöinstitutet. Ett konsortium med Stenungsunds industriföretag, berörda fjärrvärmebolag och andra potentiella intressenter ingår också i projekten som partner och medfinansiärer. Energimyndigheten deltar som extern finansiär.

En hållbarhetsbedömning kan inriktas mot olika typer av frågor, till exempel:
1. Gör fjärrvärmelänken det lättare att nå ett hållbart samhälle?
2. Förbättrar fjärrvärmelänken i sig själv samhällets ekonomiska, miljömässiga och sociala aspekter?

Den första frågan handlar om i vilken utsträckning möjligheter till hållbara lösningar uppstår eller försvinner till följd av länken. Svaret på denna fråga är åtminstone delvis känt redan då projektet startar: en fjärrvärmelänk gör det i princip sannolikt lättare att nå ett miljömässigt hållbart samhälle, eftersom användningen av restvärme på sikt minskar energisystemets behov av andra energikällor.

Det huvudsakliga syftet med denna studie är att svara på den andra frågan. Den handlar om vilka ekonomiska, miljömässiga och sociala konsekvenser som kan förutses för samhället som helhet. Denna fråga är mycket mer komplex. Det kräver att bedömningen beaktar fallspecifika lokala och regionala förhållanden, men samtidigt är tillräckligt bred för att ta hänsyn till de viktigaste förutsebara effekterna oavsett var i samhället de uppstår.

Den metod som används i denna rapport är livscykelhållbarhetsanalys (life cycle sustainability analysis). Studiens metodologiska syfte är att bidra till utvecklingen och demonstrationen av detta bedömningsverktyg. Särskilt fokus har lagts på metoden för att identifiera vilka hållbarhetsaspekter och indikatorer som hållbarhetsbedömningen bör fokusera på. För att säkerställa att studien blir relevant för beslutsfattare och andra intressenter involverar vi olika typer av intressenter i metoden genom så kallade Open-Space-workshops. Det slutliga urvalet av 14 forskningsfrågor gjordes dock av forskarna: sex frågor om ekonomiska effekter, fem om miljöpåverkan och tre om de sociala konsekvenserna.

För att svara på var och en av forskningsfrågorna, använde vi en blandning av kvantitativa resultat från den ekonomiskt optimerande energisystemmodellen MARKAL_WS och kvalitativ input från forskare från andra delar av projektpaketet. Vi använde också en enkät för att samla in kvalitativa insikter och perspektiv från industriella projektpartners och andra intressenter. Informationen samlades in medan arbetet fortfarande pågick i resten av projektpaketet. Det innebär att endast preliminära resultat och slutsatser var tillgängliga för oss, och även för enkätens respondenter.

I ett regionalt perspektiv indikerar modellresultaten att fjärrvärmelänken är lönsam,

det vill säga att den sannolikt skulle bidra till att energisystemet kan producera fjärrvärme till en lägre totalkostnad, jämfört med alla andra alternativ som finns i modellen MARKAL_WS. Den ekonomiska vinsten är dock sannolikt liten och dessutom känslig för storleken kapitalkostnaden, vilken beror på investeringskostnaden och räntorna. Vinsten är även känslig för tillgången till andra energikällor för fjärrvärme, såsom restvärme från raffinaderier i Göteborg, billiga avverkningsrester från skogen, och naturgas.

Ur miljösynpunkt är fjärrvärmelänkens förutsebara fördelar ännu mer osäkra. De är beroende av vilket bränsle restvärmet ersätter, hur mycket den regionala elproduktion i kraftvärmeverk minskar, och hur den elproduktion som faller bort ersätts.

De sociala konsekvenserna av fjärrvärmelänken ger en blandad bild. Effekten på sysselsättningen är sannolikt liten. Det finns en risk för negativa effekter för markägare som berörs av gasledningen, men dessa effekter kan göras mindre kännbara exempelvis genom att byggandet av fjärrvärmelänken samordnas med en rörledning för dricksvatten som redan beslutats.

Sammantaget är de förutsebara konsekvenserna av fjärrvärmelänken osäkra. Osäkerheten kan reduceras något genom ytterligare analyser, men mycket av osäkerheten kommer att bestå, eftersom konsekvenserna uppstår under ett långt tidsperspektiv och i komplexa sociotekniska system. Ett beslut om att investera eller inte investera i fjärrvärmelänken kommer alltid att baseras på ofullständiga kunskaper och under betydande osäkerhet beträffande investeringens faktiska konsekvenser.

1 Introduction

1.1 Background

Large quantities of residual heat are available in Swedish process industries. This is a potentially important source for residential heating through district-heating (DH) systems. An obstacle is that large process industries are often located far from the major towns and cities where DH systems are large enough to utilise the residual heat. One example is the cluster of chemical industries in Stenungsund on the Swedish west coast. They generate much more residual heat than the local DH system in Stenungsund can utilise. Other big potential sources of residual heat are the pulpmill in Värö, north of Varberg, and the PREEM refinery outside Lysekil. These are also on the Swedish west coast.

One solution to this challenge is to transport the residual heat in pipelines from the industry to larger heating systems. The heat from Stenungsund could, for example be transported to the DH system of Gothenburg, which is already connected to DH systems in the nearby municipalities of Kungälv, Mölndal and Partille. This large existing DH system could potentially utilize all the residual heat from the Stenungsund industrial cluster. Heat from Värö could be transported south to Varberg and/or north to Kungsbacka, Mölndal and Gothenburg. Heat from the PREEM refinery could be transported to the sizeable town of Uddevalla.

However, such solutions require a large investment in pipelines between the industry and the DH network. Substantial investments in heat exchangers and other equipment at the industrial site might also be necessary. These investment decisions require a solid basis. A careful assessment of the foreseeable consequences is an important part of the basis for the investment decisions.

Using large quantities of residual heat in DH systems also requires that a form can be found for the collaboration that is acceptable to both the industry and the DH companies. Such collaboration can be complex when it involves several industrial companies and several DH companies.

1.2 The project package

A project package designed to increase the understanding of increased regional energy collaboration between industry and DH companies. The primary focus of the project package is on the transfer of residual heat from Stenungsund industries to Gothenburg. It includes three interlinked projects:

The three projects are:

1. Sustainable use of industrial residual heat – the balance between internal heat recovery and exports to the DH network. This project focuses on the parameters governing the optimal balance between internal recycling and export to a DH

network, and on what techniques / systems are most interesting for internal reuse.

2. Sustainability of utilizing industrial residual heat in district heating networks. This project investigates the impacts of using the residential heat in DH systems. It focusses on the impacts on the regional energy system, but (with the present report) also includes broader environmental, social and economic aspects. In addition, it analyses how different policy instruments affects the use of the residual heat.

3. Opportunities for industrial waste heat for district heating markets and market model significance. This project investigates how the market model and business models can be designed so that a sustainable decision is feasible and all stakeholders have a reasonable share of the economic benefits.

Each project has its own sets of methods and approaches. However, results from each project will affect the analysis in other projects. Good communication between the projects is necessary to facilitate iterations in the analysis when this is called for. Also, for the projects to be consistent, important assumptions and boundary conditions need to be harmonised within the project package. This means that the projects are interlinked and that participants from the different projects have frequent meetings and email exchange.

The project package as a whole is funded by the Swedish Energy Agency and a consortium of the Stenungsund industries, DH companies and other potential stakeholders. The companies are also active partners in the projects together with researchers from Chalmers University of Technology, IVL Swedish Environmental Research Institute, and SP Technical Research Institute of Sweden.

1.3 The report - aim and overarching method

This report is part of the output from Project 2 in the project package. The main purpose of this sub-project is to assess the sustainability of a DH link between the industrial cluster at Stenungsund and the interlinked DH systems of Kungälv and Gothenburg. A sustainability assessment can address different types of questions, for example:

1. Does the DH link make it easier to reach a sustainable society?
2. Does the DH link in itself improve the environmental, economic and social aspects of society?

The first question is about to what extent opportunities for sustainable solutions arise or disappears as a result of the link. The answer to this question is at least partly known at the start of the project:

The DH link will allow for the use of residual heat in the DH systems. Use of residual heat in general has the advantage, from a resource perspective, that the need for other energy sources in the DH systems is reduced. The disadvantage is that the opportunity for use of combined heat-and-power (CHP) production is also reduced in the DH systems. The simultaneous production of electricity and DH in a CHP plant allows for an efficient use of fuel.

However, for any given fuel, the efficiency of electricity production is higher in separate, condensing power plants than in CHP plants. This means that using residual heat in DH systems and producing electricity in separate condensing plants will require less fuel, compared to producing both heat and electricity in CHP plants. The energy-related emissions can be reduced when the total fuel demand is reduced.

The net effect is that more opportunities for resource efficiency and environmental sustainability arise with the use of residual heat. The existence of a DH link between Stenungsund and Gothenburg will make it easier to reach an environmentally sustainable society. As long as the construction of the pipeline itself, including production of the cement, etc., use little resources and cause little emissions compared to the impacts on the DH system, the investment in the DH link is also likely to make it easier to reach an environmentally sustainable society.

The second question is about the foreseeable or likely consequences of the specific DH link. The answer to this question is less apparent, because it will depend on the local and regional energy systems, on the energy policies in place, etc. Our sustainability assessment focuses on this second question. It requires that the assessment takes into account the case-specific local and regional conditions. It also requires a broad systemic perspective that takes into account important and foreseeable environmental, economic and social impacts, regardless of where in society they occur.

The approach used in this report is life cycle sustainability analysis (LCSA). It has the same broad perspective on sociotechnical systems as life cycle assessment (LCA). It has an even broader perspective than LCA in terms of impacts, however: while LCA is limited to environmental impacts, an LCSA includes also economic and social impacts.

A related approach with the same broad scope is life cycle sustainability assessment (also abbreviated LCSA), which has been defined as the sum of environmental LCA, life cycle costing (LCC), and social LCA (SLCA; Klöpffer 2008). Such an LCSA will by definition include the impacts accounted for in LCA, LCC and SLCA.

Our LCSA approach is different in that it does not predefine what impacts will be included in the assessment. It takes as a starting point the LCSA framework developed within the EU project CALCAS (2009). This framework includes a stepwise procedure:

1. specify the object of study,
2. identify the most significant sustainability indicators to quantify in the LCSA,
3. identify the most important mechanisms etc. that decide the outcome for each sustainability indicator,
4. identify the relevant tools for modelling the mechanisms and/or assessing the sustainability indicator,
5. carry through the separate, quantitative analyses, and
6. make a synthesis and improvement analysis based on the separate analyses.

Note that one of the steps is to identify the impacts to account for in the analysis. An additional purpose of our sub-project is to contribute to the development of the LCSA methodology, specifically to the step where the impacts and indicators of the sustainability assessment are identified. To ensure the relevance of the study, we use a participatory approach for this step, involving different types of stakeholders. The full procedure is presented in Chapter 2. It results in a set of research questions that together form the sustainability assessment.

The answer to each of the research questions is to a large extent based on results from other projects and sub-projects in the project package (see Section 1.2). We also used a questionnaire to collect qualitative insights and perspectives from the industrial project partners and other stakeholders. The role of the authors to this report has been to make the final decision on the research questions, to compile the information from the project partners, to perform a very limited analysis of this information, and to draw the overarching conclusions.

Information to answer the questions was collected towards the end of the project package. However, the other projects and sub-projects were still ongoing, which means that only preliminary results and conclusions were available to us.

2 Selecting sustainability aspects

The potential scope of LCSA is exceptionally broad. Each of the three sustainability pillars – environment, economy and social aspects – includes a large number of potential aspects and indicators (see Figure 1).

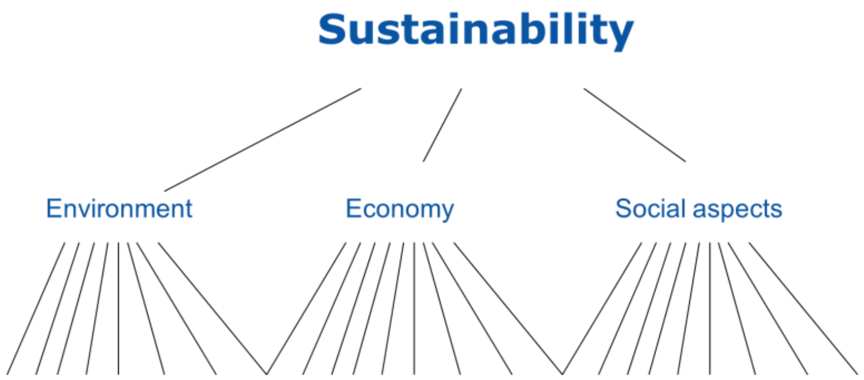

Figure 1: Simplified illustration of the multitude of sustainability aspects that could potentially be included in an LCSA. The real number of aspects is much greater.

To make the LCSA feasible in practice, it must focus on a limited number of sustainability aspects. We use a case-specific participatory approach to identify the most important sustainability aspects for our study. This approach involves stakeholders and experts in a workshop format called Open Space.

2.1 Open-Space workshops with stakeholders

The Open-Space format was developed by Harrison Owen, based on his experience that the coffee breaks are often the most interesting parts of a conference. For this reason Open Space workshops are designed to create ample opportunities for meetings and discussions resembling of coffee-break conversations. The Open Space format is a kind of market place for conversations and discussions, where each individual participant has the freedom to join and leave discussions whenever he/she chooses. Small-group discussions alternate with reporting and discussions in plenum. We use two walls as notice boards for creating a schedule for the group discussions and also for documenting the results of the group discussions and the progress of the workshop.

We had two Open-Space workshops. The purpose of each of these was to generate ideas for sustainability aspects that might be relevant for the case of the DH link, to discuss these ideas and, at the end, to identify the most important aspects through a vote among the participants.

Most important sustainability aspects according to Open-Space workshop 1:

1. Resource efficiency

2. Business opportunities and risks
    - Supply and demand for residual heat
    - Competition from other technologies for residential heating
    - Creation of added value
    - Funding of the investment in the DH link
    - Risk sharing, etc.
3. Impact on climate, pollution and biological diversity

In Workshop 2, the following economic aspects were given priority:
1. Investment principles and economic sustainability: 11 votes
2. Long-term profitability and competitiveness in all parts of the system: 10 votes
3. Heat demand all year? 5 votes
4. New heat sinks: 5 votes
5. Options and cost for the DH customer: 3 votes
6. Flexibility in temperature and demand for residual heat: 3 votes

Note that the top two options got much more votes than the others. Also note that several of the aspects overlap each other and also the ”Business opportunity and risks” given priority in the first workshop. To be used as basis for the sustainability assessment, some of the aspects have to be translated into research questions:
1. Investment principles and economic sustainability: 11 votes
    - Can a good business model be found?
2. Long-term profitability and competitiveness in all parts of the system: 10 votes
    - Are the investments associated with the DH link profitable?
    - If so, can the profit be distributed to make all partners benefit from it?
3. Heat demand all year? 5 votes
    - Is it reasonable to use the residual heat also in the summer?
4. New heat sinks: 5 votes
5. Options and cost for the DH customer: 3 votes
6. Flexibility in temperature and demand for residual heat: 3 votes

The results from Workshop 2 also included some environmental aspects, in particular:
1. The sustainability of the residual heat
2. Lock-in effects

Note that the first of these aspects is essentially the research question of this sub-project as a whole. The second aspect concerns a potential barrier to the transition into a non-fossil production system.

2.2 Internal research-group workshop

As a complement to the Open-Space workshops, we had an internal workshop with two PhD students and a supervisor. This included a brainstorming exercise to list

potentially interesting sustainability aspects. These were stepwise shifted to identify the most important aspects for our study. We concluded with the table below.
Note that the internal workshop put emphasis on some social aspects and on more environmental aspects, compared to the Open-Space workshops.

Table 1: Sustainability aspects identified and discussed in the internal workshop within the research group. Listed in bold are the aspects we found most important to include in the LCSA. The aspects listed in bold italics are aspects we wanted to discuss in qualitative terms only.

Environment	Economical	Social
Climate change Resource depletion: - **Primary energy** - **Biomass/landuse** - Other? (1) **Acidification** **Eutrophication** Local thermal impacts in sea (1) Toxicity - Human - Ecosystem Waste quantity (1)	Investment cost Local DH price Fuel prices (1) **DH system cost** Distribution effects: - Between municipalities - Between industries - **Between each industry, municipalities and DH users** ***Economic resilience of system and its stake-holders to external impacts (2)*** ***Establishment of new industries*** ***Changes in existing industries***	***Stenungsund self-sufficient with energy*** Social conflict: - Disturbed landowners (2) - Other? (1) Democracy - Transparency (2) ***Employment***

(1) unimportant aspect in this LCSA
(2) not quantifyable

The results from the three events (two Open-Space workshops and an internal workshop) were compiled and conclusions were drawn regarding what are the most important sustainability aspects to focus on in this study. These conclusions were presented to the project partners and slightly revised after feedback from the partners. We ended up with the following economic research questions for the LCSA:

1. Are the investments associated with the DH link profitable?
2. If so, can a market model be found to allow all stakeholders to benefit from the profit?
3. Does the DH link reduce or increase business risks for the partners?
4. Is it reasonable to use the residual heat outside Stenungsund also in the summer?
5. What new heat sinks should be accounted for?
6. How is the freedom of choice and the cost affected for the DH customer?

The LCSA addresses the following environmental issues:

7. The use of primary energy,
8. Climate impact,
9. Acidification,
10. Eutrophication, and
11. Transition into renewable energy.

In addition, the LCSA addresses the social aspect of

12. Employment - overall
13. Employment outside large cities
14. Disturbed land-owners

3 Methods to respond to the questions

3.1 Approach per research question

The LCSA is to a large extent based on results and knowledge from other parts and partners in the interlinked project package (see Section 1.2). We used the following approaches to address each of the research questions and issues of the LCSA:

1. Are the investments associated with the DH link profitable?
   Quote and discuss results from the modelling in Projects 1-2.
2. Can a market model be found to allow all stakeholders to benefit from the profit, if any?
   Quote and discuss with Project 3.
3. Does the DH link reduce or increase business risks for the partners?
   Discuss based on input from industrial project partners and Project 3.
4. Is it reasonable to use the residual heat outside Stenungsund also in the summer?
   Quote and discuss results from the modelling in Projects 1-2.
5. What new heat sinks should be accounted for?
   Discuss based on input from industrial project partners.
6. How is the freedom of choice and the cost affected for the DH customer?
   Discuss based on results from the modelling in Projects 1-2 and based on input from the Swedish Society for Nature Conservation (Naturskyddsföreningen).
7. The use of primary energy
   Multiply results from the modelling in Projects 1-2 by emission factors and characterisation factors from an LCA database.
8. Climate impact
   Multiply results from the modelling in Projects 1-2 by emission factors and characterisation factors from an LCA database.
9. Acidification
   Multiply results from the modelling in Projects 1-2 by emission factors and characterisation factors from an LCA database.
10. Eutrophication
    Multiply results from the modelling in Projects 1-2 by emission factors and characterisation factors from an LCA database.
11. Transition into renewable energy
    Discuss based on input from project partners and the Swedish Society for Nature Conservation (Naturskyddsföreningen).
12. Employment - overall
    Discuss based on input from project partners and results from the modelling in Projects 1-2.
13. Employment outside large cities
    Discuss based on input from project partners.

14. Impacts on land-owners
    Discuss based on experience from recent negotiations on a water pipeline in the same area.

The energy systems modelling in another part of Project 2 was refined and expanded almost to the end of the project. The results used in our LCSA are preliminary results from the energy systems model (see also next section).

Similarly, the final conclusions from Project 3 were not available when Question 2 above was investigated. Instead, this part of the LCSA was based on a discussion with the project partner responsible for the ongoing work in Project 3.

Input from the industrial project partners to the LCSA was collected via email before they were presented with final results from Projects 2 and 3. On the other hand, preliminary results and conclusions from the LCSA were presented and discussed with the partners.

3.2 Quantitative environmental assessment

We investigated the environmentally related Questions 7-10 above through a quantitative environmental assessment of preliminary results from MARKAL_West_Sweden (MARKAL_WS). This is an economically optimising dynamic model of each individual district-heating system in Västra Götaland (VG). It calculates how the availability of residual heat from the Stenungsund industries affects the optimum investments and use of DH plants in the interlinked DH systems of Gothenburg, Kungälv, Partille and Mölndal. It also calculates how the forest residues available in the VG region are used in an optimal system, and how this optimum is affected by the availability of the residual heat.

The calculations are made under a series of assumptions regarding future fuel and electricity prices, etc. Such assumptions are highly uncertain, since they depend on, for example, future policies on energy and climate. The calculations have been made for two different policy scenarios and for several cases with different assumptions on fuel availability, DH demand, etc.

We used the results from a selection of model runs as basis for our environmental assessment. Assuming that the system is able to develop at or near an optimum path, the results from MARKAL_WS can be interpreted as a prediction of how the residual heat affects the production and use of various fuels and other energy carriers in different future scenarios. We multiplied these results by factors for the primary energy demand and emissions associated with each energy carrier. The results are presented in Sections 4.1.7 to 4.1.10 below.

There are varying amounts of uncertainty in these figures. While the effects on the district heating system, i.e. natural gas and biomass, are well understood, the effects on electricity production are more uncertain. The effects on transport fuels are even more uncertain, as they are entirely based on an assumption that synthetic natural gas will replace diesel fuel.

3.2.1 Electricity – built margin

The DH link can reduce the coproduction of electricity and heat in CHP plants in the affected DH systems. This will increase the need to produce electricity outside the Västra Götaland region. The decision to build a DH link can affect both the utilization of existing power plants, the construction of new power plants and possibly the demolition of old power plants. In the long run, the construction and demolition of power plants are the most important impacts. We call such effects on the electricity production capacity long-term marginal electricity or built margin. The uncertainty is great regarding what technology is the built margin. To manage this uncertainty, our calculations include two scenarios for the built margin. From a climate perspective they are reasonable best and worst cases. In the worst-case scenario an increase in the demand for capacity of electricity production is met by the construction of new coal-power plants in, for example, Germany or Poland.

In the best-case scenario the demand for electricity capacity is instead met by a mix of 80% extra wind power, for example in Denmark, and 20% expanded regulating power from natural gas turbines. A combination of data and assumptions is needed to define this mix (see Annex A).

3.2.2 System boundaries and input data

The model MARKAL_WS ranges until the year 2050. Towards the end of the period the results become less reliable. One reason is that fuel prices etc. in the far future are extremely uncertain. Furthermore, the model does not take sufficient account of economic costs and benefit that arises after 2050 and this primarily affects the model results towards the end. For this reason, we decided to set the boundary of the environmental assessment at the year 2040 rather than 2050.

Our calculations account for the primary energy demand and emissions from the affected production of electricity, in accordance with the previous section. They also include the primary energy demand and emissions from the affected extraction and transport of fuels and the use of these fuels in the DH or electricity systems.

The use of residual heat from Stenungsund in many cases reduces the use of regionally available forest residues in the DH systems. In the preliminary results, such forest residues find an alternative use as feedstock in the production of synthetic natural gas (SNG). The SNG is in the MARKAL_WS model assumed to displace diesel. The calculations include the primary energy demand and emissions from the production of the SNG and the displaced diesel. However, the calculations do not include emissions from the use of SNG and diesel in the transport sector. The use of SNG among other things results in emissions of renewable CO_2, while diesel results in emissions of fossil CO_2. Instead of accounting for this difference in emissions from vehicles, the calculations include the uptake of CO_2 from the growing biomass that is used in SNG production. In the calculation of climate impacts, this gives approximately the same total result: the production and use of diesel affects the climate, but the production and use of SNG has no significant effect on the climate.

To calculate how the DH link affects the emissions from the energy system, we used sets of life-cycle inventory (LCI) data from the GaBi Professional database of PE International (PE 2013) and Ecoinvent (Ecoinvent 2011). The data used were European average datasets (EU-27) for diesel fuel and natural gas. The heat from biomass was assumed to come from Swedish biomass. Energy content of European diesel fuel (MK3) was 9950 kWh/m^3 and the density was 840 kg/ m^3 (SPBI 2012).

To convert the emissions to global warming potential, eutrophication and acidification impacts, we used the CML 2001 method for life cycle impact assessment, version 2013 (CML 2013). Primary energy was calculated as “Primary energy demand from renewable and non-renewable resources, net calorific value”.

4 Results

This section presents the outcomes and conclusions on each of the questions in the LCSA. The answers are presented in the order in which the questions are listed above.

4.1.1 Q1: Are the investments associated with the DH link profitable?

Figure 2 presents the economic impacts of the DH link according to preliminary results from the model MARKAL_WS. The results are presented for two different policy scenarios, each based on a scenario in World Energy Outlook (IEA 2013):

- NEWPOL: this scenario assumes that existing policies remain and that already decided new policies are implemented.
- 450 PPM: this scenario includes stronger policies to meet the 450 ppm target for the atmospheric CO_2 content. As a result the costs of CO2 emissions increase steeply.

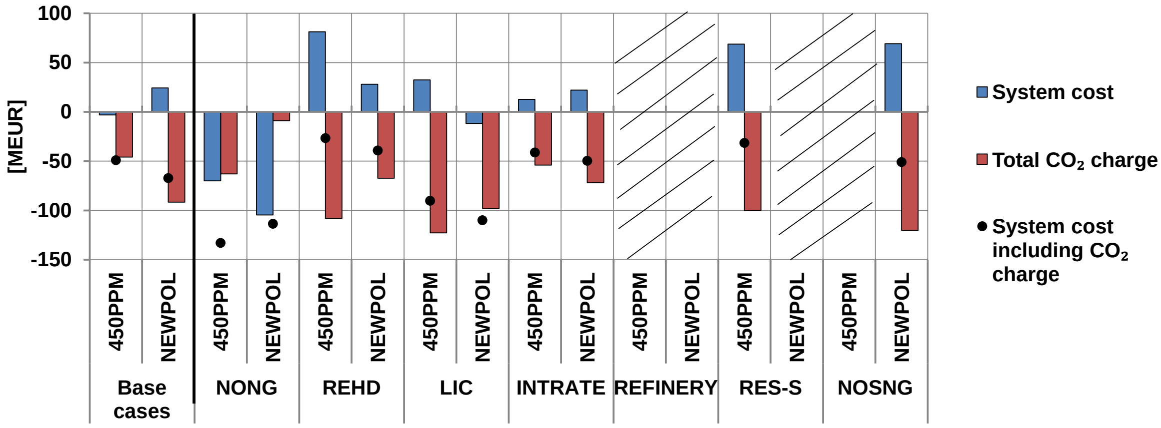

Figure 2: Impacts of the DH link on the total costs until the year 2050 of the DH systems in Västra Götaland, according to the preliminary results from MARKAL_WS. For explanations of abbreviations, see text. Source: Fakhri Sandvall et al. (2014).

For each scenario, the model includes several sensitivity analyses (Fakhri Sandvall et al. 2014):

- NONG: No Natural Gas; as in the base cases, except that no natural gas is allowed in the VG region from 2030.
- REHD: Reduced Heat Demand; as in the base cases, except that the DH demand declines by approximately 20 % until 2050.
- LIC: Low Investment Cost; as in the base cases, except that the investment cost for the DH link is much lower.
- INTRATE: Interest Rate; as in the base cases, except that the requirements on the return of investments are lower on the pipeline between Stenungsund and

Gothenburg and greater on the heat exchangers etc. at the Stenungsund industries.

- REFINERY: as in the base cases, except that the refineries in Gothenburg remain and supply residual heat for the full period until 2050.
- RES-S: Renewable Energy Sources Support; as in the 450PPM base case, except that the subsidies to renewable power generation continues for the full period until 2050.
- NOSNG: No Synthetic Natural Gas; as in the base cases, except that there is no significant alternative demand for the forest residues.

The DH link is not profitable if the refineries in Gothenburg remain (REFINERY results in Figure 2). This is because the refineries currently supply large quantities of cheap residual heat to the DH system. If they remain in the energy system, the economic benefit of supplying residual heat from Stenungsund is not enough to cover the investment costs needed to extract and transfer this heat to Kungälv and Gothenburg.

The DH link is also not profitable in the 450 PPM scenario without the option to produce synthetic natural gas from forest residues. When there is no significant competition over the forest residues outside the DH sector, the economic benefit of using residual heat with biomass might also not be sufficient to cover the investment costs.

The combination of RES-S and NEWPOL was not deemed relevant and was not calculated. The black dots in Figure 2 indicate that the DH link reduces total costs and hence is profitable to the VG region in all other cases. The magnitude of the profit varies, however. It is sensitive to the availability of natural gas and to the size of the investment cost.

The economic profit is in none of the calculated cases greater than 150 MEUR. Although a great amount of money in itself, it should be compared to the approximately 30 TWh of residual heat that would be transferred through the link (Fakhri Sandvall et al. 2014). This indicates that the profit of the DH link is never greater than 5 EUR/MWh. In most of the calculated cases, the profit is less than 2 EUR/MWh.

This economic profit is also partly due to reduced CO_2 charges (red bars in Figure 2). A reduction in CO_2 taxes means reduced revenues for the government. This loss of revenues is not accounted for in the black dots. The blue bars show the effect on a national level if all CO_2 charges are in fact CO_2 tax. The blue bars give a mixed picture where the DH link in many cases increases the system cost. This indicates that the DH link might not be economically profitable from a national perspective, even when they are profitable from a regional perspective.

Note that the reduction in CO_2 taxes is due to a reduction in CO_2 emissions. This environmental benefit is at least as relevant from a national perspective as from a regional VG perspective. For further discussion on the reduction in greenhouse gas emissions, see below.

It is clear from Figure 2 that the profitability of the DH link is sensitive to the availability of other DH sources (residual heat from refineries, cheap forest residues, and natural gas) and also to the investment costs. With the assumptions made in the model, the results indicate that the investments necessary for the DH link are likely to generate a small profit in the VG region, if the refineries in Gothenburg are shut or stop supplying residual heat. The economic profitability for Sweden as a whole is more uncertain, however.

4.1.2 Q2: Can a market model be found to allow all stakeholders to benefit from the profit, if any?

Project 3 of the project package investigates how the market of residual heat from Stenungsund can be designed so that all stakeholders have a reasonable share of the possible economic benefits (cf. Section 1.2). This analysis focuses on the industrial partners in Stenungsund, where the residual heat is generated, and on the DH companies that would utilize the heat. The market model can also include an external stakeholder that invests in and/or owns the DH link itself.

The analysis in Project 3 is not completed as the LCSA is concluded. Instead, we base our response to this question on preliminary results and on a discussion with one of the researchers (Brolin 2014). Based on this input, it seems difficult to design a market model that ensures all partners a share of the economic profit. It is difficult to state in advance what the profit will be (see previous section). It is also difficult to foresee who will gain the most from the DH link. This makes it difficult to allocate the investment costs between the stakeholders in a way that ensures that each of them gains from the investment.

The magnitude of the profit of the DH link will be uncertain even when the link is in place. This is because the DH link will affect other investments in the DH system. When the DH link is in place, it will not be possible to know with certainty what the DH production system would look like if the DH link was not constructed. It will not be possible to precisely calculate how much the DH companies gain from the DH link. This will make it difficult to set the price of the residual heat at a level that ensures that each partner in the deal gets a reasonable share of the gain.

The problem of dividing the profit amongst the partners is made more difficult by the fact that the profit is likely to be small.

If the stakeholder concept is interpreted to be broader than just the Stenungsund industries and the DH companies, it becomes even more difficult to find a market model where all stakeholders benefit:

- The DH users as stakeholder: the DH link is likely to reduce the marginal DH production cost a little bit. In principle, this could benefit DH customers through a small reduction in the DH price. However, the DH price is typically not decided by the marginal production cost of DH but by the price of competing heat sources such as oil, biomass and electricity. For this reason, it is not likely that the DH users will benefit economically from the DH link.

- The government as stakeholder: an important share of the possible economic profit is a reduction in CO_2 charges (see Figure 2). If a significant share of these charges is a tax on fossil carbon emissions or fossil fuel, the DH link is likely to reduce the tax revenues. Hence, the national Treasury might loose from the DH link.

4.1.3 Q3: Does the DH link reduce or increase business risks for the partners?

The industrial companies and DH companies were asked to answer this fundamental question, and describe how the risk, or vulnerability, of their organisation was affected by a realization of the DH link. In this context, risk is mainly interpreted as economic risk. The response was given before the final calculations of economic profitability and environmental impacts were available to the companies.

The industrial companies generating the heat were in general positive to the link, as they saw a possibility for increased revenue from the project.

The DH companies emphasised that details of the market model are important for the risks they take. This is because the economic risk strongly depends on the responsibilities connected to disruptions in the supply or demand for heat etc. Depending on what market model is applied and what happens with the current DH production plants, the risk could increase or decrease for the DH companies. The link could decrease the risk of delivery shortages. On the other hand, if the supply of residual heat would cease, costly back up production may have to be used.

The results from Project 3 highlighted the vulnerability of the stakeholder(s) that invest in and own the DH link. The owner of the DH link will have capital costs associated with the investment in the link. The owner might obtain revenues from the heat transfer. Alternatively, the owner of the DH link can trade in heat: buying it from the Stenungsund industries and selling it to the DH companies at a higher price. In both cases, the stakeholder(s) will be completely dependent on heat being transferred through the DH link, because they have no other sources of revenues. This means the stakeholder(s) will have a weak position in the negotiations over the price of heat and/or the price of heat transfer. There is a risk that the result of the negotiations will be such that the owner of the DH link does not get revenues to fully cover the capital costs. The uncertainty in future interest rates adds to the financial risk of the investors and owners of the DH link.

The business risks of the DH link owner can be reduced through a long-term contract on the revenues. This contract should then be signed before the investment is made. The business risks can also be shared among the Stenungsund industry and DH companies, which stand to profit from the DH link, if they make the investment jointly by, for example, starting a jointly owned company that makes the investment and owns the DH link.

4.1.4 Q4: Is it reasonable to use the residual heat outside Stenungsund also in the summer?

To respond to this question, we consulted model results and also asked partners, primarily DH companies, for input.

The optimising model MARKAL_WS distinguishes between four “seasons”: Summer (5 months), Spring/Autumn (4 months), Winter (2 months), and Cold winter (1 month). According to the model results the DH link is used to its full, or almost full, annual capacity in all cases when it is built. This indicates that it is not just reasonable but economically optimal to use the pipeline also during the summer season. This result holds even though the model does not assume any increase in heat demand over time.

It should be noted that the link is not constructed at all in the model, if the refineries in Gothenburg are not phased out (see Figure 2). If the DH link is in reality constructed while the refineries are still in place, it might not be reasonable to use the residual heat from Stenungsund in the summer. It will be difficult for it to compete in the DH systems with the residual heat from the refineries.

The DH companies stressed that there must be a demand for the heat during summer to make the use of it reasonable. Some respondents thought that seasonal storage for excess summer heat might be a possibility to increase the utilization of residual heat generated in the summer. This could potentially make room for residual heat from both the refineries and Stenungsund. Others were sceptical towards this solution, since seasonal storage requires extremely large quantities of heat to be economically feasible.

4.1.5 Q5: What new heat sinks should be accounted for?

The industrial companies and DH companies were asked to provide input on this question.

The sinks suggested by stakeholders were district cooling, drying of biomass, algae farming or seasonal storage. Seasonal storage can be low or high temperature, where low temperature solutions require heat pumps. The amount of heat required for storage is mentioned as a limiting factor for economic profit. This makes it difficult to estimate to what extent seasonal storage would be economically sound or not without further investigation.

Drying of biomass is not highly requested in Sweden, but could be economically interesting in continuous production, where investments are paid off faster. If larger amounts of biomass was to be dried, this would most probably be carried out in Stenungsund, and hence be independent of the pipeline.

4.1.6 Q6: How is the freedom of choice and the cost affected for the DH customer?

Results from MARKAL_WS, and interviews with the Swedish Society for Nature Conservation (Naturskyddsföreningen) provided the basis for our response to this question.

The establishment of the link means there are more actors in the district heating system. If this leads to more options and higher transparency regarding the source of the heat (if it is bio based, from waste incineration or fossil based etc.), this can be very positive for the customers. To realise this transparency is mainly up to the DH companies.

Furthermore, the link can potentially reduce the marginal cost for DH production. It is up to the companies if this lower cost results in lower prices for the customers or not. Since the potential cost reduction is quite marginal according to the model, it does not ensure that it is practically possible to offer lower prices to the customers. It depends, among other factors, on what price the district heating companies have to pay for the excess heat.

4.1.7 Q7: The use of primary energy

This question was answered through the use of a selection of the preliminary model results from the model MARKAL_WS, together with LCI data (see Section 3.2). The model results are presented in Table 2. Positive numbers in this table means that the use of residual heat increases the production and use of these energy carriers (marginal electricity and synthetic natural gas). Negative numbers represent a reduction in the production and use of the energy carrier (natural gas, biomass and/or diesel). According to the preliminary results from MARKAL_WS, the DH link primarily reduces the need for natural gas in Västra Götaland but increases the need to produce electricity outside Västra Götaland.

As discussed in Section 3.2, we made the calculations with two different assumptions regarding what electricity production capacity is affected: a carbon-lean mix of 80% wind power and 20% regulating power from natural gas turbines, and a reasonable worst-case scenario with new coal-power plants.

The difference in primary energy demand between the two electricity scenarios is not dramatic but sufficient to affect the conclusions of the calculation. The DH link is likely to reduce the primary energy demand when the built marginal electricity is wind power and natural gas (see Figure 3 and Figure 5). This is mainly because the use of residual heat reduces the need for natural gas. In addition, it reduces the use of biomass in the DH systems. Most of this biomass is, in the model, converted into SNG that displaces diesel. The primary energy in the displaced natural gas and diesel is likely to be greater than the primary energy in the marginal electricity production, if this is produced from wind and regulating power.

Table 2: Effects of the DH link on the energy system until the year 2040 in four of the scenarios according to preliminary results from the model MARKAL_WS. For explanation of the four cases (NEWPOL Base, etc.), see Section 4.1.1. Unit: TWh.

	NEWPOL Base	450 ppm Base	450 ppm NONG	450 ppm REHD
Natural gas (district heating)	-37	-6.5	-9.5	-20.0
Biomass (district heating)	-0.5	0	-2.0	0
Marginal electricity (hard coal or wind+ NG)	21.5	8.5	0	12.5
Synthetic natural gas (transport fuel)	3.75	5.0	0	4.5
Diesel, MK3 (transport fuel)	-3.75	-5.0	0	-4.5

If the marginal electricity is produced from coal, on the other hand, this requires more primary energy and the DH link might increase the total demand for primary energy in (Figure 4 and Figure 5). The net increase in primary energy is the largest in the 450 ppm Base scenario with coal on the margin, and dominated by the marginal electricity production from coal. In 450 ppm scenario without natural gas (NONG), the DH link hardly affects the electricity production and, for this reason, reduces the primary energy demand also when electricity is produced from coal.

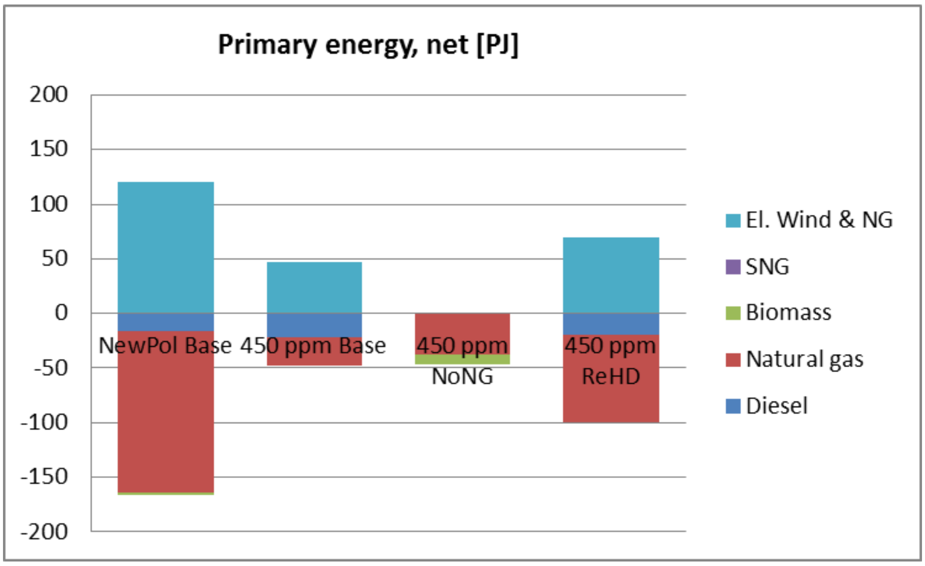

Figure 3: The impact of the DH link on the primary energy demand in the four scenarios until the year 2040, assuming marginal built power is produced from wind power (80%) and natural gas turbines (20%).

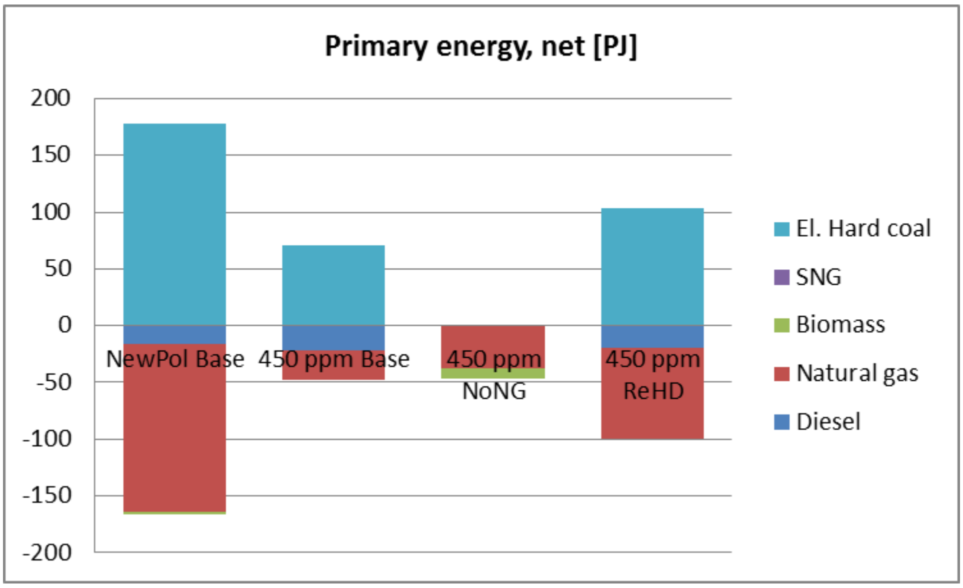

Figure 4: The impact of the DH link on the primary energy demand in the four scenarios until the year 2040, assuming marginal built power plants use hard coal.

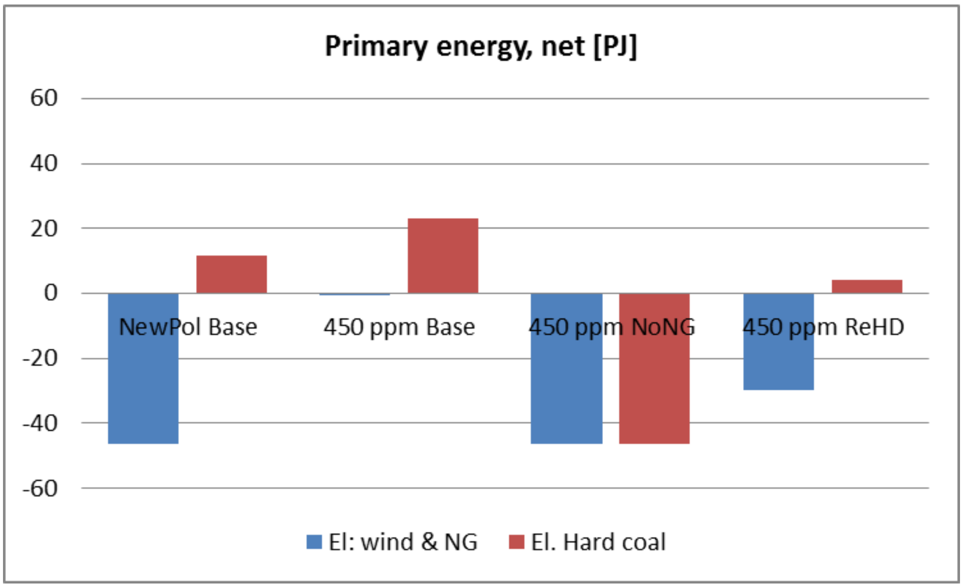

Figure 5: Net result for the four scenarios with the two marginal electricity options.

4.1.8 Q8: Climate impact

This question was answered by using a selection of the preliminary model results from MARKAL_WS, together with LCI data (see Section 3.2). The climate impact results depend heavily on what electricity production is affected. When the marginal electricity is produced from wind and natural gas turbines, the DH link reduces the net climate effect in all our cases. The largest reduction in greenhouse gas emissions is achieved in the NEWPOL Base case. This is because the residual heat displaces large quantities of natural gas in this case. The quantity of natural gas used in the marginal electricity mix is much less.

SNG production contributes to reducing the climate impacts in most cases, while the avoided diesel production has a negligible impact. This is because the calculations include the CO_2 capture of biomass used for SNG, instead of the avoided CO_2 emissions from the use of diesel.

If the marginal electricity is produced from hard coal, the DH link increases the total climate impact of the energy system in most cases. This is because the use of residual heat decreases use of CHP plants in the DH systems. The electricity production in Västra Götaland is reduced and the electricity production in coal-power plants outside the region increases. The increase in greenhouse gas emissions from the coal power are greater than the reductions in emissions from natural gas in the region and the uptake of CO_2 in biomass used for SNG production.

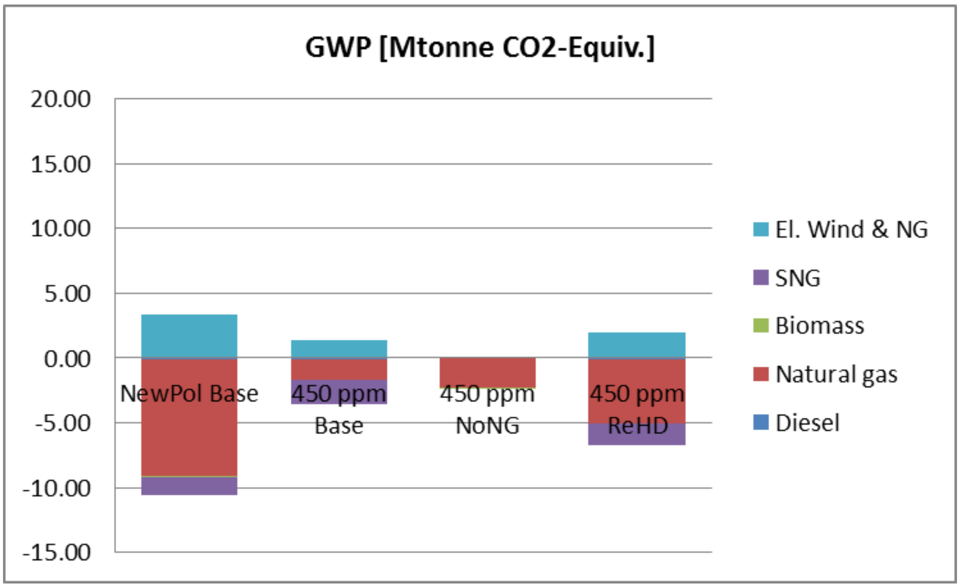

Figure 6: Climate impact in the four scenarios until the year 2040, assuming marginal built power is produced from wind power (80%) and natural gas turbines (20%).

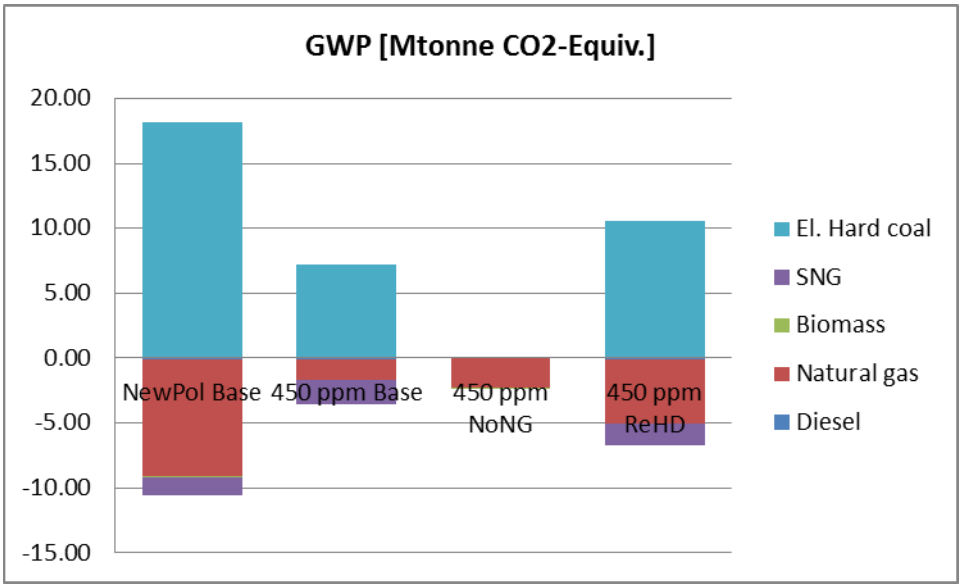

Figure 7: Net climate effect in all scenarios until the year 2040, assuming marginal built power plants use hard coal.

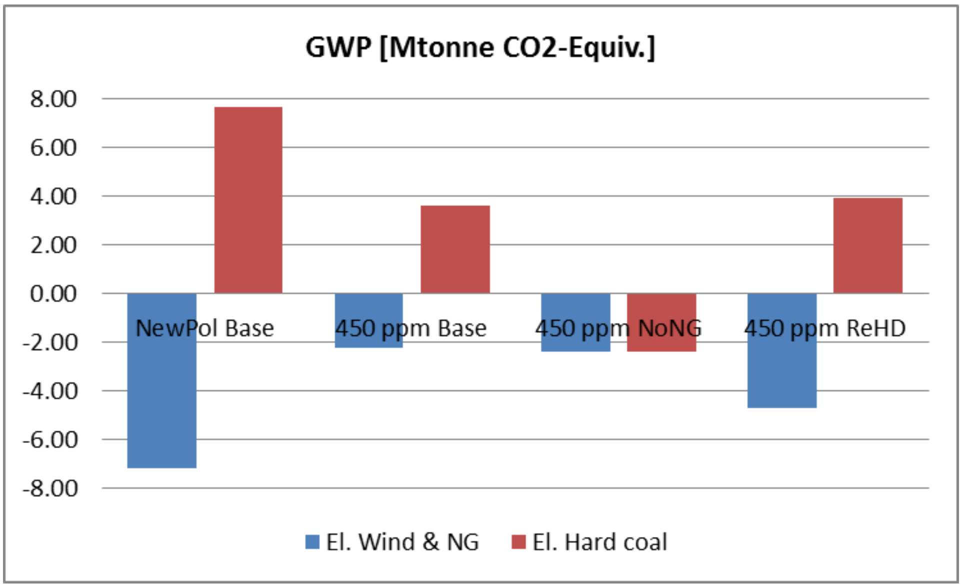

Figure 8: Net result for the four scenarios with the two marginal electricity options.

4.1.9 Q9: Acidification

This question was answered by using the selected preliminary results from MARKAL_WS, together with LCI data (see Section 3.2).

The DH link affects the acidification mainly through reduced use of natural gas in Västra Götaland and through an increase in the electricity production outside the region (see Figure 9 and Figure 10). Reductions in the production of diesel and reduced use of biomass in DH systems also contribute to reducing the acidification.

The difference between the two scenarios for marginal electricity production is much less for acidification, compared to climate change. This is because gas turbines have high emissions of NO_X that contribute to acidification. Since gas turbines provide only 20% of the electricity in the wind-plus-gas mix, electricity from 100% coal power still cause more emissions of acidifying substances. The difference is enough to affect the conclusions from the calculations (see Figure 11). With marginal electricity from wind and gas turbines, the DH link is likely to reduce the acidification. If the affected electricity production is coal power, the DH link is likely to increase the acidification.

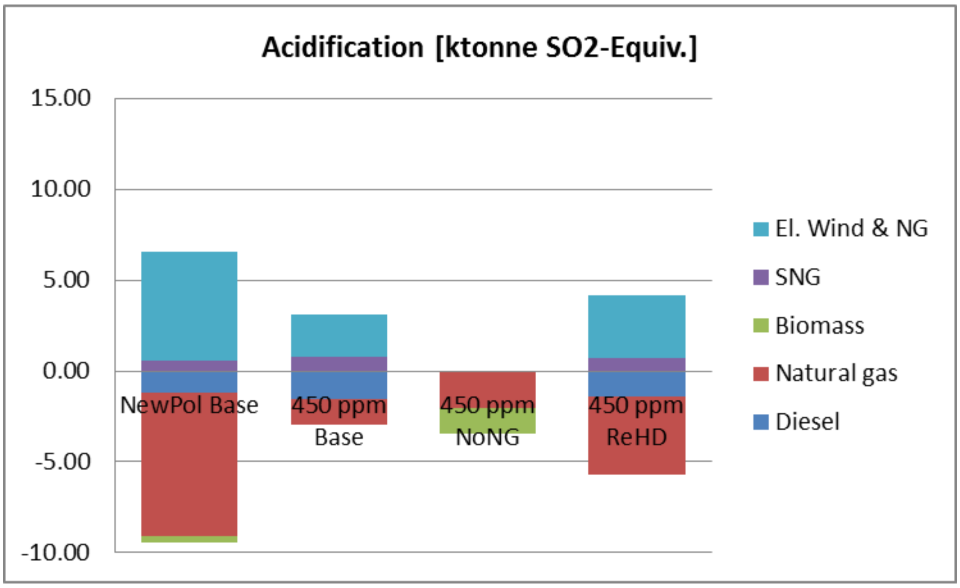

Figure 9: Acidification potential impact in the four scenarios until the year 2040, assuming marginal built power is produced from wind power (80%) and natural gas turbines (20%).

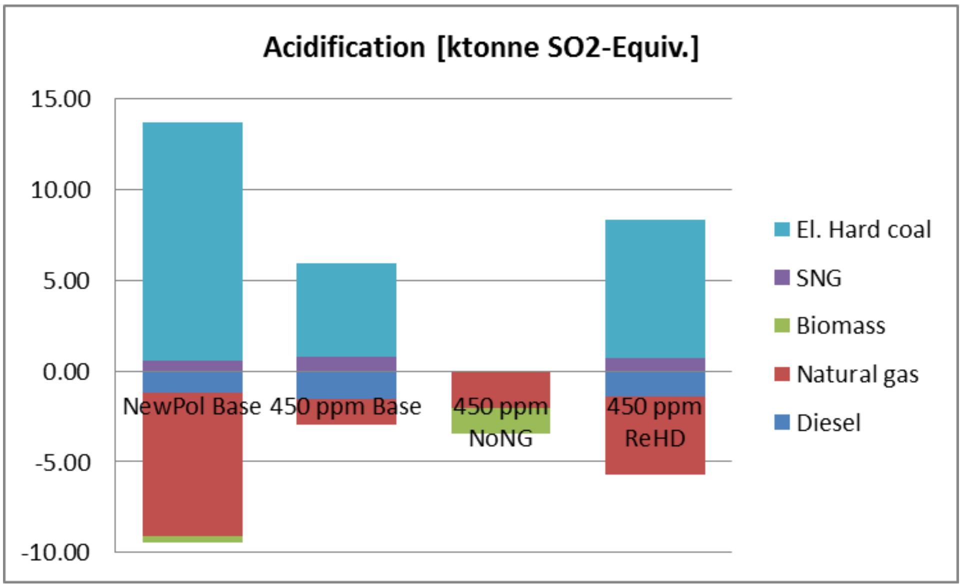

Figure 10: Acidification potential impact in the four scenarios until the year 2040, assuming marginal built power plants use hard coal.

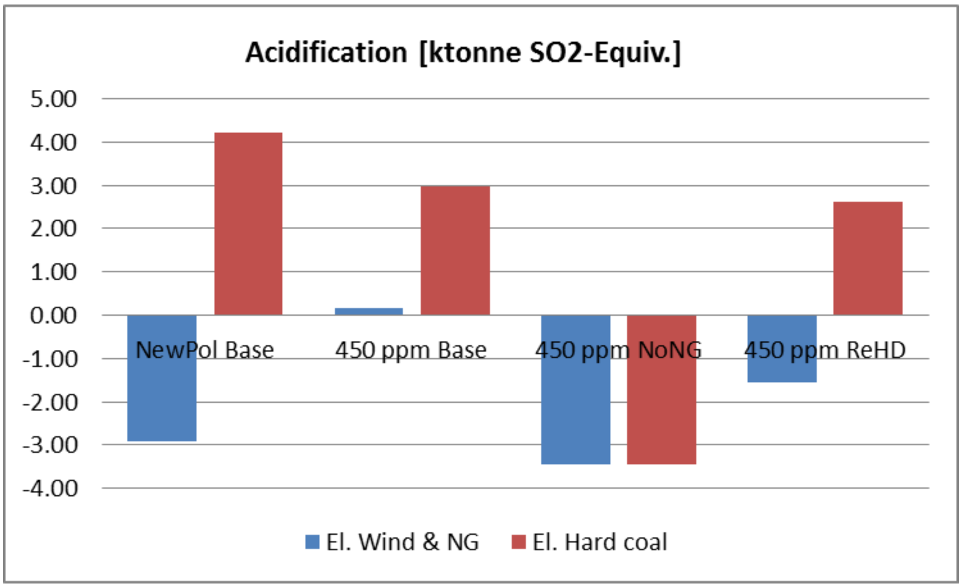

Figure 11: Net acidification result for the scenarios with the two marginal electricity options.

4.1.10 Q10: Eutrophication

The impacts on eutrophication were also investigated using the selected preliminary results from MARKAL_WS, together with LCI data (see Section 3.2).

The calculations indicate that the DH link is likely to increase the total emission of nutrients that contribute to eutrophication. The use of residual heat from Stenungsund reduces the local and regional emissions from combustion of natural gas, etc. However, in most calculated cases it also reduces the electricity production in regional CHP plants. The electricity production outside the region increases instead, and the emissions of nutrients from both types of marginal electricity are greater than the reduction in local and regional emissions (see Figure 12 and Figure 13).

The exception is the 450 ppm scenario with no natural gas available in the region (NONG). In this case, the DH link does not affect the electricity production and the emissions of nutrients are reduced through a reduced use of natural gas and biomass in the DH systems.

The DH link increases the eutrophication the most in the NEWPOL Base case with marginal electricity from coal power (see Figure 14). In this case, the DH link has the greatest impact on the electricity production (see Table 2), and coal power cause nutrient emissions than a mix of 80% wind and 20% gas turbines.

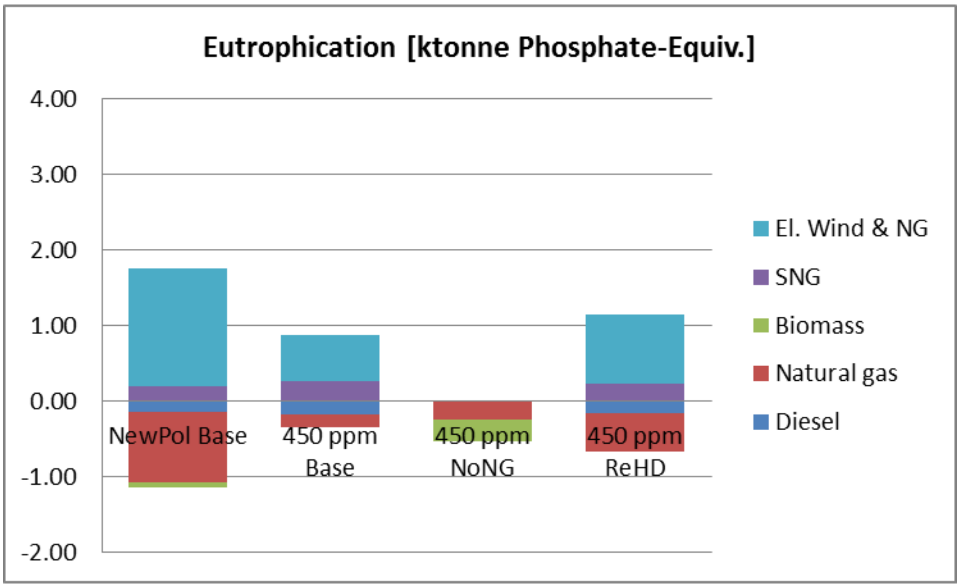

Figure 12: Eutrophication potential impact in the four scenarios until the year 2040, assuming marginal built power is produced from wind power (80%) and natural gas turbines (20%).

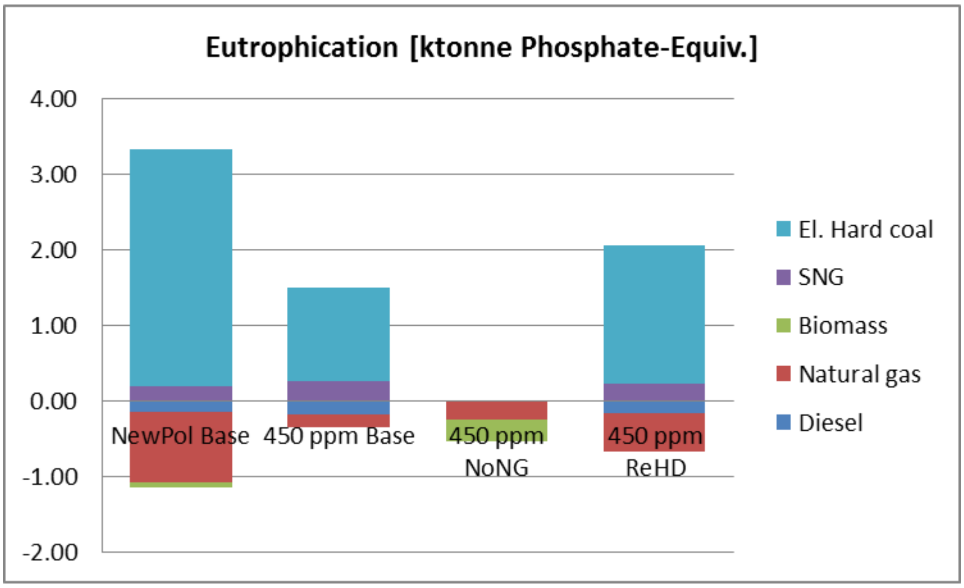

Figure 13: Eutrophication potential impact in the four scenarios until the year 2040, assuming marginal built power plants use hard coal.

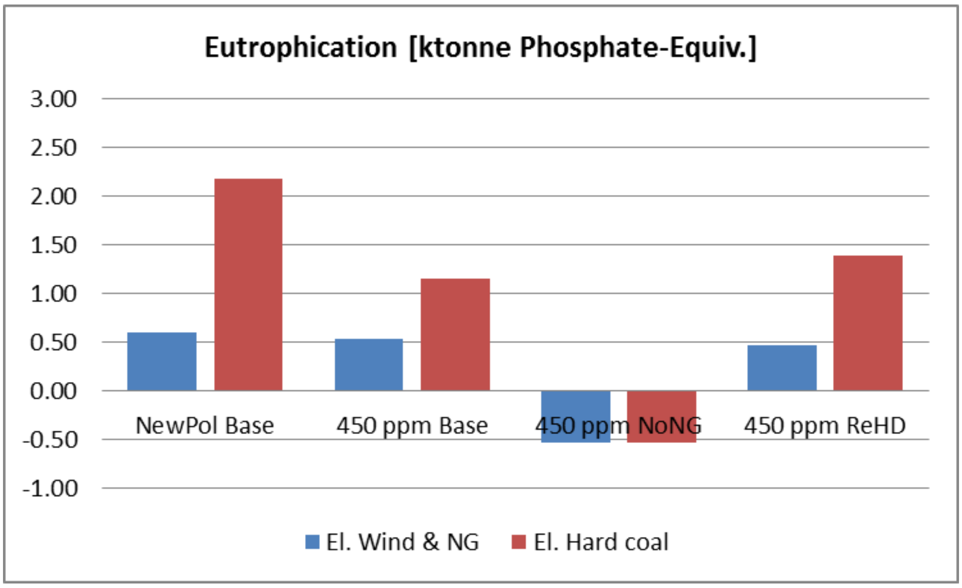

Figure 14: Net Eutrophication results for the scenarios with the two marginal electricity options.

4.1.11 Q11: How does the DH link affect the overall transition to renewable energy?

The stakeholders were asked to provide input to this question. This was before the results from the models had been thoroughly discussed, which means that the input is based on expected results rather than actual results.

Most companies thought that the waste heat should be used, regardless if it was seen as “renewable“ or not. Many actors said that the transition to renewable energy would be helped by the DH link, since it would increase the revenues. Economy and the possibility to get more biomaterials into the system were mentioned as the most important sustainability aspect, while social aspects were thought to be less important, at least by some actors.

An increase in revenues from sales of residual heat could, for example, be used to invest in a biomass gasification plant. This would increase the amount of biobased raw materials in the system. The new biobased processes may also generate additional residual heat that could be distributed through the link. Depending on the size of the revenue, this investment is more or less likely to be realized. The actual model results indicate that the revenues will be small, which means they are likely to have an insignificant effect on the decision to invest in a biomass gasification plant.

The DH link can also contribute to a reduction in the use of fossil fuels when the residual heat replaces heat from electricity-driven heat pumps or other fossil heat production.

However, some stakeholders thought that the DH link would replace heat from CHP plants with biomass. The reduction in electricity from these plants would result in an increased use of coal and other fossil fuel in the electricity system. From that point of view, the link would hinder the transition to renewable energy.

One stakeholder emphasized the transparency and democracy aspects of the district heating system. Despite the positive aspects of an expanded system and utilization of a resource that would otherwise be lost, this actor thought that the development of the district heating system could go either way, depending on the level of transparency. Today, the transparency is low, and there are very few actors in the system, creating a monopoly-like situation. More actors could be positive, if that would lead to more choices for the customers and a higher transparency about the origin of the heat. There is evidence from the electricity system that customers make active choices if they can. This can aid the transition to renewable energy in the DH system.

4.1.12 Q12: Employment - overall

We asked all industrial and DH companies in the project how they expect the employment rate in their organisation to be affected by the DH link. They were asked to specify what types of jobs were affected, both in short term and long term. Most actors believed in more employment in the short term, during the building phase. However, if the DH link is not constructed, investments will be needed in other DH sources, for example a CHP plant for biomass in Kungälv. This investment would result in a similar increase in construction jobs.

In the longer term, some stakeholders foresee a small increase in employment due to maintenance of the DH link, possibly around 20 persons. However, a CHP plant for biomass combustion and other DH sources will probably need more staff to run. In this respect, a DH link might even reduce the employment rate.

Revenues from the DH link might increase the long-term security of jobs in Stenungsund. The availability of residual heat might in the long run also create employment connected to district heating and cooling. This can contribute to keeping the employment up.

Overall we expect the DH link to have a small effect on employment because alternative investments have similar need for staff and because the economic profit from the DH link is likely to be small.

4.1.13 Q13: Employment outside large cities

The industry and the DH companies were also asked how they expected the employment rate to be affected outside the city of Gothenburg. This was meant to highlight potential job creation in less densely populated areas, as a complement to Q12.

Much of the answer to this question is similar to the previous, because the jobs created or secured will to a large extent be in the municipalities of Stenungsund and Kungälv. Some of the jobs created connected to district heating and cooling are likely to be in Gothenburg city, however. This means that the number of jobs created outside will be slightly lower. The conclusion still stands: we expect the DH link to have a small effect on employment in rural areas and smaller towns, because alternative investments have similar need for staff and because the economic profit from the DH link is likely to be small.

4.1.14 Q14: How are land owners affected by the DH link?

The basis for our response to this question is a presentation on the construction of a freshwater pipeline in Kungälv at one of the project meetings (Thorsson 2014).

The DH link will affect owners of the land where the pipeline will cross. To build a pipeline, the municipalities have to try to reach an agreement with the land owners. Such an agreement includes an economic compensation for the land owners for the disturbances from digging etc. associated with building and maintaining the pipeline. Land owners have a weak position in this negotiation, because if it fails and no other good option exists, the municipality can still give the company the right to have the pipeline cross the land. As a result of their weak bargaining power the land owners often find the economic compensation small.

Land owners that are dissatisfied with the agreement might hold a grudge afterwards against the municipality and/or the companies involved in the DH link. The risk of a grudge is increased among land owners that are forced to accept the pipeline against their will. Such feelings can affect the willingness of the land owners to cooperate on other issues. It can also affect how well they comply with environmental regulations and other decrees from the authorities. All this would affect how well and efficient the local society works in the future. In other words, the impact on the feelings of the land owners is a social impact that affects the sustainability of the local community.

Just like a DH pipeline can affect the feasibility of future decisions, the reactions of land owners to the pipeline is likely to depend on past events, negotiations and agreements. The municipality of Kungälv has already made deals with many land owners in order to build a water pipe to Kungälv from Jörlanda, a small community in the southern part of Stenungsund municipality. This might make agreements on a DH pipeline easier or more difficult depending on, for example, how well the previous negotiations where handled.

The chance to reach an agreement that satisfies all stakeholders is greater if the pipeline brings advantages to the land owners. A municipal water pipe brings such advantages. It makes it possible to build new homes on the land. This increases the economic value of the land. Land owners can also sell part of the land to construction companies. The DH link does not bring such clear advantages to the land owners. The DH link can become more sustainable if the negotiations over the DH link and water pipeline are coordinated. This is partly because less resources have to be spent on the negotiations and partly because it increases the chance to coordinate also the construction of the different pipes. Furthermore, a combined agreement on water and DH pipeline will bring the land owners the advantage of municipal water piping, which can make the DH pipeline easier to accept. A coordination of the negotiations can be possible for the part of the pipes that are within Stenungsund municipality. Such coordination can be a significant improvement if the water pipe and sewer are led far into the Stenungsund municipality, perhaps to the town of Stenungsund and to Tjörn.

5 Conclusions

As stated in the introduction (Section 1.3) we could state already at the start of the project that a DH link is likely to make it easier to reach an environmentally sustainable society. This is because the use of residual heat in the long term reduces the need for other energy sources in the energy system.

The sustainability assessment presented in this report addresses a slightly different question, however: do the foreseeable consequences of the DH link improve the economic, environmental, and social aspects of society? The answer to this question is much more complex and less clear-cut.

From a regional economic viewpoint, the DH link is likely to be a good option. With it, the energy system is likely to provide district heat at a lower total cost, compared to all other alternatives available in the MARKAL_WS model. The economic profit is, however, likely to be small and also sensitive to the capital cost (investment cost and interest rates) and to the availability of other DH sources (residual heat from refineries, cheap forest residues, natural gas).

Given the uncertainty in the profit it is difficult to design a market model that guarantees each partner a reasonable share of the profit. An investment will entail an economic risk to the partners. On the other hand it also gives the industry in Stenungsund an additional source of revenue and the DH companies an additional source of heat. The DH customers may also gain from an integrated DH network if it allows them to choose among DH suppliers and/or DH sources.

According to the MARKAL_WS model, it will probably be cost-effective to use the residual heat from Stenungsund in the DH systems all year through, at least if the refineries in Gothenburg stop supplying residual heat. New applications for heat and an expansion of district cooling can also increase the usefulness of the residual heat beyond what the model describes.

From an environmental viewpoint, the foreseeable benefits of the DH link are actually more uncertain. This is in contrast to the conclusion that residual heat in general and in the long term makes it easier to reach environmental sustainability.

The foreseeable environmental impacts of the DH link depend very much on what fuel is displaced in Västra Götaland, on how much the regional electricity production in CHP plants is reduced, and on what external electricity production is affected. If the reduction in regional electricity production is compensated by an increase in coal power, the DH link is likely to have negative impacts on the environmental performance of the energy system. If the affected electricity production is instead a mix of wind-power and gas turbines, the DH link is likely to improve the environment.

The social impacts of the DH link are mixed. The effect in employment is likely to be small. There is a risk for adverse impacts on land owners affected by the pipeline, but these impacts can be reduced by, for example, coordinating the DH pipeline with a pipeline for freshwater.

All in all, the foreseeable consequences of the DH link are uncertain. Part of this uncertainty is because most of the consequences occur one or several decades into the future. The future is inherently uncertain. Part of the uncertainty is because the DH link will affect very complex sociotechnical systems where decisions are made based on a mix of economic rationality, political rationality, and hunches. It is possible to reduce the uncertainty somewhat through additional analyses, but much of the uncertainty will always remain. A decision to invest or not invest in the DH link must be made with incomplete knowledge and significant uncertainty regarding the actual consequences of the investment.

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Annex A: Regulating power in marginal wind expansion

As stated in Section 3.2.1 our best-case scenario for marginal built electricity is a mix of wind power and regulating power. We assume that the marginal regulating power is natural gas turbines.

Wind power needs to be combined with regulating power or electricity storage because the electricity output from wind power varies depending on the wind. The utilisation of wind-power plants is often around 30% (Wikipedia 2015). Nolgren et al. (2014) states that the utilisation of new Swedish wind power is 33% if it is land-based and 42% if sea-based. We assume that the marginal expansion of future wind power will be on locations with less beneficial wind, and that the utilisation will be 30%. To fully meet all variability in wind power, 70% of regulating power would have to be added to the mix. However, this is neither economically realistic nor necessary. Svenska Kraftnät (SVK 2008) estimated that about 1.6 GW of additional regulating power is needed for each additional 10 TWh of wind power, when wind power is greatly expanded. To get 10 TWh annually from wind power with 30% utilization, about 3.8 GW of wind power needs to be installed. The capacity of the additional regulating power is then less than half of the capacity of wind power (1.6 / 3.8 = 42%).

It is reasonably clear that the regulating power will be used only to deal with the worst fluctuations. This means it will be used less than 70% of the time. We assume here that the utilization rate decreases linearly with the quantity of regulating power installed. The utilization rate of the regulating power is then 0.42 * 70 = 29%. For every 10 TWh of electricity from wind power, 1.6 GW of regulating power is installed and with 29% utilization it produces 2.5 TWh. With this assumption, the carbon-lean marginal electricity mix contains 80% wind power and 20% of electricity from gas turbines.

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