An evaluation of regional sustainability by analysing energy and carbon flows – A study of Jämtland, Sweden

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Thesis for Licentiate degree in Ecotechnology and Environmental Science
Mid Sweden University
Sundsvall/Östersund, 2018-11-05
An evaluation of regional sustainability by analysing energy and carbon flows – A study of Jämtland, Sweden

© Torbjörn Skytt, 2018-11-07
Printed by Mid Sweden University, Sundsvall
ISSN: 1652-8948

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Mid Sweden University Licentiate Thesis 145
I dedicate this to all who strive to make the world a bit better.

‘If somebody scratches the spot where he has an itch, do we have to see some progress? Isn’t it genuine scratching otherwise, or genuine itching? And can’t this reaction to an irritation continue in the same way for a long time before a cure for the itching is discovered?’ [Wittgenstein]
Acknowledgement

This study was financed by the EU Interreg Sweden-Norway program, project SMICE, a network for sustainable development as a regional cooperation between Trøndelag in Norway and Jämtland in Sweden.

The cooperation with Søren Nors Nielsen (Aalborg University in Copenhagen) throughout this research project has been most fruitful and all the discussions held and articles written have deepened my knowledge about different kinds of sustainability evaluations, societal complexity and different environmental aspects. My collaboration with Region Jämtland-Härjedalen and the Jämtland county has also been enormously valuable and I would like to give special thanks to Ida Sjölund and Jimmy Anjevall (Region JH), as well as Jimmy Nilsson and Lars Jonsson (Jämtland County) for their continuous efforts to improve sustainability in all of its dimensions. I have found our cooperation most educative and creative. We have additionally developed cooperation with a number of other organisations and individuals, who have contributed with thoughts, ideas and creative criticism, thus increasing the quality of the research performed. Not to be forgotten is the support received from the Ecotechnology and Sustainable Building Department at Mid Sweden University, singling out no one but celebrating your patience and insight when discussing the issues raised.

Professor Morgan Fröling, my former supervisor, tragically passed away in 2017. His contribution and enthusiasm should not be underestimated. His influences on the field of sustainability are still a source of inspiration for those who knew him. I am most grateful to Professor Bengt Gunnar Jonsson who took over as supervisor after Prof Fröling, making it possible for me to continue the research and present this thesis. Prof Jonsson contributed new creative ideas and dimensions of knowledge, stimulating further research.

I am most grateful for the contribution of the reviewers of this thesis. Especially Olof Björkqvist for his penetrating analysis and relevant questions that forced me to clarify the thesis content and the scientific base.
# Table of contents

Abstract ........................................................................................................... viii

Sammanfattning .............................................................................................. ix

List of papers .................................................................................................. x

1 Introduction ..................................................................................................... 1
  1.1 Background ............................................................................................... 1
  1.2 Implications of the choice of sustainability indicators ......................... 2
  1.3 Jämtland County ..................................................................................... 4
  1.4 Aims and reasons for evaluating Jämtland ............................................. 6
  1.5 Thesis content ......................................................................................... 7
    1.5.1 Paper I (Skytt T. et al., 2015) ............................................................ 8
    1.5.2 Paper II (Skytt T., Nielsen, Grönlund, & Fröling, 2016) .............. 8
    1.5.3 Paper III (Skytt, Nielsen, & Fröling, 2018) ................................... 8
    1.5.4 Paper IV (Manuscript) ..................................................................... 9

2 Methodology .................................................................................................. 10
  2.1 Flows of work energy ............................................................................. 12
  2.2 Fluxes of carbon dioxide and methane ............................................... 13
  2.3 Methodological and modelling assumptions ........................................ 14

3 Results ......................................................................................................... 17
  3.1 Work Energy flows in Jämtland (2014) .................................................. 17
  3.2 Carbon dioxide and methane fluxes in Jämtland ................................. 20
  3.3 Combined analysis of WE and CO$_{2eq}$ ................................................. 23
  3.4 Linkages Research – Education – RSI .................................................. 24

4 Discussion .................................................................................................... 25
  4.1 The regional sustainability of Jämtland ............................................... 25
  4.2 Further research .................................................................................... 28
  4.3 Conclusions ........................................................................................... 29

5 Philosophical reflections ............................................................................ 31

REFERENCES ................................................................................................. 35
Abstract

Models showing the anthropogenic and natural flows of two sustainability indicators; carbon based GHG and energy (as work energy) have been made for the Swedish region Jämtland. The methodology used was inspired by the study sustainability analysis conducted on the small Danish island Samsø using the above two indicators. The aim was to upscale the methodology used for Samsø and make necessary adaptations for Jämtland in order to be able to evaluate sustainability in terms of global warming. We also wanted to study the linkages between research, education and regional sustainability initiatives. Working at a regional level has advantages compared to working at a national or global level, as socio-ecological processes can be covered more extensively to reach a deeper understanding of practical aspects. In parallel to this we have also been participating in local and regional sustainability activities to increase our understanding of practical approaches and human behaviour.

Studies of the energy flows in Jämtland show that 46,000 TJ (88% renewable) flows into the region and about 31,000 TJ is exported. The remaining 15,000 TJ (63% renewable) drives ‘the machine Jämtland’. Added to this is about 4000 TJ as matter. The total global warming potential (GWP20) impact of Jämtland (as carbon dioxide equivalents, CO$_{2eq}$) indicating influence on the global mean temperature as radiative forcing) is an annual uptake of 2.4 Mton. The total regional emissions, as CO$_{2eq}$ from anthropogenic activities, including consumption, are 1500 kton. The region has large emissions of methane, 80 kton (6700 kton CO$_{2eq}$), mainly from mires, lakes and animals but also large uptakes of CO2 from assimilation in woody biomass.

Jämtland can be regarded as relatively sustainable from several perspectives, but taking the large forests and a population of only 127,000 inhabitants into consideration, the total uptake of CO$_{2eq}$ is not very large and of the 15,000 TJ driving Jämtland, 37% comes from non-renewable sources. From a national (and global) perspective Jämtland needs to perform better, in view of its considerable reserves of natural resources. How to increase long-term sustainability in the region is a complex issue that requires penetration from many perspectives. Modelling results presented here needs to be interpreted in a broader sustainability context, together with regional stakeholders, to serve as a base for future knowledge development and sustainability activities.
Sammanfattning


Studien av energiflöden i Jämtland visar att 46.000 TJ (varav 88% förnyelsebart) flödar in i regionen och 31.000 TJ exporteras ut och att resterande 15.000 TJ (varav 63% förnyelsebart) driver maskineriet Jämtland. Till detta kommer omkring 4000 TJ i form av material. Den totala GWP20- påverkan från Jämtland är ‘kylande’ och motsvarar ett upptag av koldioxid-ekvivalenter årligen på 2.4 Mton, vilket ungefär motsvarar emissionen från 225.000 genomsnittsvänskar. De totala antropogena emissionerna av CO\textsubscript{2eq}, inklusive konsumtion, är 1500 kton. Regionen upptar betydande emissioner av metan, 80 kton (motsvarande 6700 kton CO\textsubscript{2eq}) från sjöar, myrar och våtmarker samt djur.

List of papers

**Paper I (Conference paper)** (Skytt T., et al., 2015):

**Paper II (Book chapter)** (Skytt T., Nors Nielsen, Grönlund, & Fröling, 2016):

**Paper III (Journal paper)** (Skytt, Nielsen, & Fröling, 2018):

**Paper IV (Manuscript):**

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1 Introduction

1.1 Background

Sustainability science has been evolving since the beginning of the 1980s and has developed into an established field of science ‘defined by the problems it addresses rather than by the disciplines it employs’ (Clark, 2007), dealing with the interaction between natural and social systems (National Academy of Sciences, 2018). In a sustainability research paper meta-analysis covering 20,000 papers published between 1974 and 2010, a logarithmic growth as well as increased geographical distribution can be seen, and sustainability science has become a new field of science integrating theory, practice and policy primarily studying human, social and ecological systems from an engineering or policy perspective (Bettencourt & Kaur, 2011). Sustainability science is predominantly ‘use-inspired’, to be compared with agricultural or health sciences, with ‘significant fundamental and applied knowledge components, and commitment to moving such knowledge into societal action’ (Kates R. W., 2011, p. 19450). Agenda 21 clarifies the role of the sciences, stating that it is essential to ‘ensure that the sciences are responsive to emerging needs’ (United Nations, 1992, p. 311). Kates, et al., (2001) conclude that sustainability science differs in structure and method compared to ‘science as we know it’ (p. 641).

It seems that to a certain extent sustainability science more closely resembles engineering than (traditional) science, since it has a base in needs and problems to be solved; in this case societal needs. A typical definition of engineering is as follows: ‘the application of science to the optimum conversion of the resources of nature to the uses of humankind’ (Encyclopaedia Britannica, 2013, p. "Engineering"). This means that engineering has a built-in goal of resource optimisation which is the key concept of sustainability. Engineering is also about carving out the best possible solution in a reality full of contradictions. But this also means that sustainability research runs the risk of falling into the engineering category instead of science. Mid Sweden University (MIUN) has a 30-year tradition in sustainability research and education within ‘Ecotechnology’ – an interdisciplinary approach to sustainable development that empowers students to ‘take action’ (Fröling, Grönlund, & Carlman, 2015). ‘Ecotechnics’ is a science that aims to establish a sustainable society through the use of
‘ecology, economy, and technology in cooperation’ (Thofelt & Englund, 1996, p. xv).

A conclusive remark about sustainability science is that the domain might suffer from conceptual vagueness and presented results run the risk of being too broad and lacking analytical depth, implying the application of ‘engineering’ – rather than actual ‘science’. References to ‘interdisciplinary’ or ‘transdisciplinary’ approaches may not be enough to motivate scientific development.

The evaluation of Jämtland presented in this licentiate thesis is an upscaling of the sustainability evaluation methodology developed in relation to global warming for the small Danish island Samsø analysing anthropogenic as well as non-anthropogenic work energy (WE) flows (Nielsen & Jørgensen, 2015) and carbon flows (Jørgensen & Nielsen, 2015). Aalborg University (AAU) has a long tradition of sustainability research. An evaluation of AAU as a case study investigating the linkages between academic work in research, education and regional sustainability initiatives (RSI) concludes that both the academy and wider society gain from the interaction of stakeholders and that this interaction is also necessary for the implementation of research results looking at regions as being a key to sustainability development (Lehmann, Christense, Thrane, & Jørgensen, 2009).

1.2 Implications of the choice of sustainability indicators

The idea to model all carbon flows at Samsø, not only of anthropogenic but also of natural processes, is partly grounded in the findings and understanding derived using a carbon cycle model of the Siena district in Italy (Marchi, Jørgensen, Pulselli, Marchettini, & Bastianoni, 2012). The methodology used to map societal WE flows follows an older tradition; see for example studies of flows in Sweden (Wall, 1987) and Italy (Wall, Naso, & Sciubba, 1994). It is more common today to use WE (exergy) to analyse the efficiency of technical systems such as building energy systems (Sangi & Müller, 2016) or the performance of power plants (Wu, et al., 2014) but this analytical approach can be applied to any energy system. Energy is closely related to environmental efficiency, due to the fact that energy sources are extracted from natural resources one way or another, thus affecting environmental sustainability. Fluxes of Green House Gases (GHG) are well
known to affect global radiative forcing (RF) and do not need further justification as a suitable indicator. The case study of Samsø shows that an in-depth modelling of the two indicators makes it possible to understand current complexity and analyse suggested strategies for meeting regional aims related to global warming (Nielsen & Joergensen, 2014). We have chosen to define the concept ‘sustainability’ by using these two indicators to quantify the meaning of the concept as used in the evaluation presented in this thesis. This is however far from a comprehensive definition of sustainability.

The UN Commission for Sustainable Development (CSD) has defined 96 indicators of sustainable development arranged under 14 different main themes (United Nations, 2007, p. 9). These CSD Indicators have been developed and defined to provide a basis for decision making and analysis based on the Agenda 21 action plan (United Nations, 1992, p. Ch 40). They cover issues regarded as relevant to support economic development, social development and environmental protection. The continuous updating of the indicators has resulted in a slight deviation from the original Agenda 21 structure, but there is still an obvious relation to this structure (United Nations, 2007, p. 23). The CSD Indicators are references for national goal setting. Furthermore, with the aim of fighting poverty (‘in its many dimensions’) a set of 48 MDG (Millennium Development Goals) indicators were introduced to monitor progress towards international goals, and today these have increased to 60 indicators (United Nations (MDG), 2018). From the MDGs there has been a development towards the 17 sustainability goals (SDG) which the UN presented in 2012 (United Nations (SDG), 2018). These 17 goals all embrace the ‘triple bottom line approach’ to human wellbeing (economic development, environmental sustainability and social inclusion), embracing the perspective that ‘a shared focus on economic, environmental, and social goals is a hallmark of sustainable development and represents a broad consensus on which the world can build’ (Sachs, 2012).

Applying a minor set of specific indicators (in our case WE and CO$_{2eq}$) to evaluate sustainability is of course a very narrow approach, compared to a definition of sustainability which contains the complete set of indicators. The ecological, social and economic spheres of sustainable development are not independent system, but are connected through numerous critical relationships, creating a large (global) system (Lawn, 2006). The linkages between these spheres are interconnected flows of energy, matter and information. The results and conclusions presented in this thesis make no
claims to cover any broader definitions of sustainability than sustainability relating to global warming, regarded as one of the greatest threats to human wellbeing (IPCC, 2014). When the aim is to penetrate ‘sustainability’ (in this case related to global warming) and the problems and implications inherent in the three spheres of sustainable development, a regional level perspective shows advantages to a national (or global) level perspective. The regional scale is suitable to work with because this is the scale where strategies for sustainability are to be transformed into more concrete decisions and activities, as well as where ecological functioning and human activities directly interact (Graymore, Sipe, & Rickson, 2008). It also relates to the role of the academia; we can take – or perhaps even should take – different initiatives in regional sustainability and development work, and build bridges between network actors (Zilahy & Huisingh, 2009). Universities also have the possibility to develop and evaluate sustainability education initiatives that can be implemented in regional contexts (Haughton & Morgan, 2008).

The application of national and global sustainability assessment methods at a regional level might however be troublesome. The application of five sustainability assessment methods at a regional scale in Australia (ecological footprint, wellbeing assessment, quality of life, ecosystem health and natural resource availability) showed that the methods were rather inefficient because the data available did not fully describe the regional situation (Graymore, Sipe, & Rickson, 2008). Experiences from Samsø shows that an in-depth regional analysis is possible, but generally there is a lack of statistical regional data, and such data therefore have to be built from existing, often insufficient national statistics, combined with knowledge about the region, which is rather time consuming. The results will also show wide error tolerances. On the other hand questions raised during the work and the search for data in the modelling process are important parts of the knowledge building process in sustainability evaluations (Ramage & Shipp, 2009, p. 103).

1.3 Jämtland County

Jämtland covers an area of 48 945 km², which is for example somewhat larger than The Netherlands (41 860 km²), but with a population of only 127 000
Forest land covers about 39,000 km$^2$, which is 80% of the total area of the county (Skogsstyrelsen, 2014). Furthermore, there are many lakes and large areas of mires and wetland. Electricity production comes mainly from hydro power, but also wind power to an increasing extent. The county has one major city area (Östersund) with about 50,000 inhabitants, corresponding to 40% of the total population. There is a large agricultural sector, mainly based on milk and beef production since the climate is not very suitable for grain production. Thanks to the large production forest areas, forestry is a large economic sector. The region holds many small companies and some larger companies. Tourism is a large source of regional income and the region holds one of Sweden’s most popular ski resorts (Åre). A stated vision for Jämtland is to be fossil fuel free by 2030. An established aim since a number of years has been to reduce greenhouse gas (GHG) emissions by 2020 by 50% compared to the base year 1990. Until 2015 it seemed this aim would be achieved, but then emissions increased, and today (2018) the regional reduction from 1990 is about 30% (Naturvårdsverket, 2018). From this it is unlikely that the target will be met by 2020.

An assumption made before starting the project, was that Jämtland would show a large CO$_2$ uptake thus having a powerful cooling effect on the global average temperature (i.e. negative radiative forcing (RF) (IPCC, 2001)). On the whole the electricity production is based on renewable energy sources, and its forests assimilate large amounts of CO$_2$. These premises make the evaluation even more interesting, since Jämtland has the prerequisites to reach ‘full sustainability’ (using the two indicators chosen). From a global perspective it is of course necessary that Jämtland has a high uptake in terms of CO$_2$-balance, because most regions, at least in Europe, do not have the natural resources and low population density that Jämtland has.

Experiences from Samsø show the importance of creating strong forces pushing not only towards sustainability, but perhaps even more towards self-responsibility, self-governance and self-leadership (Nielsen & Jorgensen, 2015). This should not be forgotten when working with Jämtland, which was one of the last regions to be incorporated with Sweden (towards the end of the 17th century), and which has a history of self-governance. During the long period in which Jämtland did not belong to Sweden, Jämtland even had a currency of its own and very low taxes. When it was incorporated into Sweden, the taxes were raised and Jämtland also had to provide military forces and infrastructure (Nationalencyklopedin, 2018, p. “Jämtland”). On a
facetious level Jämtland has a ‘President’ and is named ‘The Republic of Jämtland’. Behind this there is a history of self-sufficiency and self-governance. In this sense a small Danish island and a large Swedish forest region might have more in common than what appears to be the case at first sight.

To make it possible to translate results into support for policy making (and even action), it is necessary to make results comprehensible and to somehow translate ‘indicators into everyday language’ (Becker, 2004, p. 206). One of the ideas behind the modelling draws on the hypothesis that Jämtland has good potential to become ‘sustainable’, thus making it easier to understand the actual problems, while simultaneously making them more difficult to solve. First of all we need to understand Jämtland from a ‘global warming perspective’.

1.4 Aims and reasons for evaluating Jämtland

One aim with the evaluation of Jämtland is to find out the regional sustainability from a global warming perspective. This evaluation was done using the indicators CO$_{2eq}$ and WE from an upscaling of the Samsø study methodology (Nielsen & Joergensen, 2014). The results from Samsø are used as a reference and verification of the results found for Jämtland. Regional models covering both anthropogenic and non-anthropogenic flows of CO$_{2eq}$ and work energy, should make it possible to acquire in-depth knowledge about societal sustainability and make it possible to test future scenarios.

Another aim is to investigate linkages between research results, education and regional sustainability initiatives in order to meet the goals in the Paris agreement (Lehmann, Christense, Thrane, & Jørgensen, 2009). In parallel with the modelling work, active participation in the county’s climate council was fostered in order to create an infrastructure of (interested) stakeholders to work with; municipalities, companies, non-profit organisations, individuals etc. Also one of the major aims of the EU Interreg SMICE-project in financing this research, is to encourage regional sustainability initiatives and to engage people at all levels of society in striving for increased sustainability (Länsstyrelsen Jämtlands län, 2018). The Interreg project covers the Mid Nordic area from the Baltic Sea to the Atlantic, including the Swedish region Västernorrland and also Trondelag in Norway.
The aim is to develop a regional expert body, equipped with tools that will make it possible to investigate potential changes to regional prerequisites, in order to enhance sustainable development, and to decrease RF from Jämtland. But we also want to develop regional educational activities to stimulate inhabitant initiatives and influence regional policy making. The term a regional ‘climate sustainability expert’ implies the development of regional scientific knowledge adapted specifically to the problems in focus. The project has involved close cooperation between MIUN and AAU in order to make effective use of the experiences gained from the Samsø study.

1.5 Thesis content

In the following sub-chapters each paper is briefly presented as parts of the research. Figure 1 presents an overview of the four papers in this thesis along with the research process and general methodology.

Figure 1 The structure of the papers included in this thesis follow the research process as summarised per paper in the figure above. Paper I and II have a general societal focus, and Paper III and IV are technical papers presenting the actual models.
1.5.1 Paper I (Skytt T., et al., 2015)

The first paper is a conference paper that was presented at the annual meeting for the systems sciences (ISSS) in Berlin in 2015 ‘Interdisciplinary Cooperation and System Modelling as Means to Govern the Anthropocene’. It constitutes a basis for the adaptation of modelling and application of systems theory. It also focuses on how to govern and control a society from a juridical perspective, to reach increased sustainability. Furthermore it presents the structural methodology for the model of Jämtland used in this research. The paper provides a background and motives for the modelling project, and should be seen as a philosophical paper rather than a strict scientific base. The paper discusses an interdisciplinary approach and systems thinking in order to develop and implement sustainability thinking into societal processes. There might be a risk of democratic degradation when the power of nations decreases as a result of the increased power of global companies and institutions, intensifying the need to strengthen sustainability initiatives at the regional level.

1.5.2 Paper II (Skytt T., Nielsen, Grönlund, & Fröling, 2016)

‘Involvement of Advanced Level Students Using Ecological Modelling in Research about Regional Sustainability’ (book chapter in Engaging Stakeholders in Education for Sustainable Development at University Level, 2016) focuses on how advanced level students can be involved in sustainability research in a regional context. Drawing on visits to ‘reality’ (farmers, power plants, forestry workers etc.), mathematical models of this reality was made and presented. Also the role of the universities in sustainability work is discussed in the paper, and what tools and knowledge are needed.

1.5.3 Paper III (Skytt, Nielsen, & Fröling, 2018)

The paper ‘Energy flows and efficiencies as indicators of regional sustainability – A case study of Jämtland, Sweden’ (Ecological Indicators, Elsevier, 2018) constitutes the result of a study of one of the two chosen sustainability indicators; energy (as ‘work energy’ (WE) or ‘exergy’). A mapping of the regional sectors shows flows of WE and how it is used to drive societal processes and how efficiency can be calculated in terms of use of
renewable or non-renewable energy. An understanding of the processes involved and the use of energy in the region are fundamental to our understanding of how to find solutions that will allow us to reach the aim of establishing a ‘fossil fuel-free region’ before 2030, which is roughly only 10 years away.

1.5.4 Paper IV (Manuscript)

The manuscript ‘Carbon dioxide and methane fluxes as indicators of regional sustainability – A case study of Jämtland, Sweden’ presents a model for the second of the sustainability indicators chosen, CO₂eq. Flows of CO₂ and CH₄ are presented as CO₂eq flows per sector, as in the study of WE. The paper is complementary to Paper III. We apply a 20-year perspective (GWP20) which means fluxes of CH₄ will show much higher RF compared to the standard 100-year perspective (GWP100) and argue in the paper why it is important to apply the shorter time perspective of 20 years in order to meet the aims set down in the Paris Agreement. We have chosen to study only carbon-based GHG, because these are dominating and this choice limits the parameters involved in the model. Emissions from renewables such as combustion of woody biomass are included in the balance accounting, and also assimilation of CO₂ in growing biomass. Leaving renewable biofuels out as emitters, which is often done in simplified regional accounting would have made the balance accounting impossible and we would no longer have been able to control the input/output carbon flows in forestry and nature.
2 Methodology

The methodology chosen for analysing the carbon flows in the Samsø study (Jørgensen & Nielsen, 2015) does not follow the exact methodology applied for the Siena district (Marchi, Jørgensen, Pulselli, Marchettini, & Bastianoni, 2012) due to the need to adapt the model to existing statistical data and regional preferences. The method applied for Jämtland does not follow the exact methodology applied for Samsø. Practical adaptations to regional circumstances needed to be made. From what we can judge the methodology chosen for Jämtland fulfils the three demands for sustainability assessment tools as being capable of: (1) integrating nature-society systems, (2) assessing different scales of spatial levels and (3) addressing both short and long-term perspectives (Ness, Urbel-Piirsalu, Anderberg, & Olsson, 2007). Not least the latter demand (3) has shown to be very important.

From the basic methodology used in the Samsø case, two models have been built for Jämtland; (1) one model mapping annual sectorial work energy balances and (2) one model showing annual sectorial CO₂ and CH₄ balances. In accordance with the Samsø and the Siena cases, Jämtland has been divided into relevant sectors. This was done to increase the depth of the analysis and not only study the region as a single black box. Sectorial division also forces the modeller to gain a deeper understanding of the major activities taking place within each sector (ref Paper I and II). The sectors chosen are Energy, Agriculture, Forestry, Reindeer herding, Industry & Trade, Private, Public, Tourism, Waste and Nature (Figure 2 from Paper I). For the Energy model Transportation has also been used as a ‘ghost-sector’ in order to analyse the use of liquid fuels for vehicles separately since these are typically non-renewables. The Nature sector was not part of the WE analysis because it has no relevant impact in the analysis. Fluxes of CO₂ and CH₄ in the Nature sector are however relevant which makes this sector one of the most important to model accurately. The large forests in Jämtland are divided into two parts: managed productive forests are allocated to the Forestry sector and non-productive forests (i.e. producing less than 1 m³sk ha⁻¹yr⁻¹) including protected forest areas are allocated to the Nature sector.
For the Jämtland case we decided to build the models using interconnected spreadsheets. Experiences from test models (ref to Paper I) with the modelling program STELLA® (used for the carbon cycling model for Samsø) convinced us that a spreadsheet solution was most suitable for our purposes due to its flexibility. One of the main reasons is the easiness with which parameter changes can be made in spreadsheets compared to STELLA®. If more complex simulations of for example fluxes from mires or soils are to be done, a more advanced mathematical modelling tool will be more relevant (i.e. MATLAB® or STELLA®). The models show estimations and have many shortcomings, but they nonetheless give a reasonable description of reality.

In parallel with the development of the models for flows of WE and CO₂/CH₄, we have chosen a regional engagement as done during the Samsø study to avoid ‘isolation from real world problems and a lack of motivation/interest toward outreach activities’ (Zilahy & Huisingh, 2009, p. 1065). Such outreaching activities extended our understanding of the regional sustainability prerequisites and problem identification. It is important to gain knowledge about sector activities, how regional and municipal governance and administration actually work, and to understand how environmental work is organised and controlled. If knowledge about governmental processes ranging from the national level, to the regional level and further to the local level was not present, there was a risk that we would find no information infrastructure to use as a platform for discussions and expansion.

Figure 2 Structuring the analysis of Jämtland in relevant sectors to cover regional activities. Each sector is treated like a black-box in an input-output analysis. In this figure it is worth noticing that societies are seen as a black-box converting energy to waste, thus degrading the quality of the energy step by step. In principle, each degradation generates emissions of GHG. (From Paper I)
of knowledge. One difficulty with sustainability work is that part of the basic facts are already known, implying that increased awareness is mostly about finding ways to guide people through an ocean of information and concepts. Paper I and II give different perspectives on this.

2.1 Flows of work energy

In the model for energy flows matter is transformed to work energy (exergy) and the application of such a transformation has the aim to estimate societal resource efficiency when ‘pure’ energy flows (from sources such as electricity, petrol etc) and work energy (WE) content in matter can be added together thus showing at least an estimation of the total energy use in a society (Wall, Naso, & Sciubba, 1994). The WE is often expressed as Gibbs free energy, thus not necessarily ‘available’ from a practical perspective (Szargut, 2005). But treated with care, it can be regarded as a measure of energy conversions following the value added chain. Another possibility is to calculate or estimate the ‘Embodied Energy’ (EE), as the actual added energy in the production flow (comparable to LCA) (Hammond & Jones, 2012). WE, however, has an advantage which can be seen for example when energy flows in waste are studied; typically plastic waste has low EE from processing, while WE content is high (about 92 MJ/kg). If only EE is used, the balance in an energy flow analysis is difficult to treat since there will be an export out of Jämtland calculated as EE and the same value will be used for the import to Västernorrland where the incineration takes place. In the incineration process however, the actual Lower Heating Value (LHV, typically 30 MJ/kg) will be released which is higher than the EE, thus showing additional energy in the analysis.

On the other hand recycled steel is troublesome when exported as WE since this WE cannot be extracted, but still needs to be calculated as an ‘energy export’ corresponding to 200 MJ/kg. In the melting process (outside the region) energy has to be added before it can be re-processed, typically to reinforcing steel. This means that product recycling may show some confusing results. Waste flows are interesting in this sense, because they forces the chain of logic to be complete. The problem is treated thoroughly in Paper III. WE content in matter does not necessarily have a practical physical use. It is to be seen as a representation of the physical reality and in this way bears some similarity to
the GWP factors used (see below). The flows of energy and work energy have thus been kept somewhat apart to allow flexibility in the interpretation of the results.

2.2 Fluxes of carbon dioxide and methane

Modelling fluxes of greenhouse gases (GHG) involves the difficulty to convert imported matter into emissions. Ideally we would have been able to translate the WE-model directly into a GHG-flux model, but this was possible only to a certain extent. Each one of the models shows its own complexity so we ended up, just as in the Samsø-case, with two different models. Conversion of imported matter into GHG has been treated in accordance with the models used by Statistics Sweden for national imported emissions (SCB, 2016) and allocated to sectors by using national and regional economic data (Ref Paper IV).

Dealing with flows of CH$_4$ involves a difficulty which does not occur for flows of CO$_2$ because CH$_4$ has to be converted to the RF as if it was CO$_2$ using a time integral (into flows of CO$_2$ equivalents, CO$_{2eq}$). To meet the time horizon in the regional policy goals (max 20-30 years) and referring to national goals derived from the Paris Agreement (United Nations, 2015), we decided to use the GWP20 factor which is 84 for CH$_4$ (IPCC, 2006). Often the GWP100, 28, is used as a ‘standard’, but with the intention to analyse the near future in order to meet the goals of max temperature increase, the GWP20 is more relevant. The reason for the large difference between GWP20 and GWP100, is the short decomposition time of 12-13 years for atmospheric CH$_4$, which at the same time implies the possibility to decrease regional RF by reducing CH$_4$ emissions.

In relation to the role of wetlands we have met some confusion in discussions regarding interpretations of the concept ‘carbon sink’. There is a tendency to equate ‘carbon sink’ with global cooling but this is not the case. It is important to understand that a carbon sink does not necessarily correspond to negative radiative forcing from a global mean temperature perspective. Mires in Jämtland are carbon sinks because there is a larger uptake and sequestration of carbon than emission of carbon. But emissions are primarily CH$_4$ which means that a carbon atom lost from the mire will have an RF influence of 84 to the carbon atom assimilated has an RF influence of 1. This means that quite
a significant amount of carbon can be assimilated by the mire without having a negative RF effect as long as there are some emissions of methane causing positive RF.

2.3 Methodological and modelling assumptions

The unit used in the energy analysis is Joule (1 J=1 Ws ⇔ 1kWh=3.6 MJ). Solar radiation is excluded from the balances since the plant assimilation processes does not contribute to the evaluation of sustainability at this stage. The estimated annual solar energy input in Jämtland is 14 EJ=14,000,000 TJ which totally eliminates the importance of other flows. However, electricity production from photovoltaics is included in the basic calculations for the energy sector but the contribution is very small.

The use of WE for converting matter to energy might cause some confusion. In the analysis of wind power in Jämtland taking WE as the annual share of the infrastructure in relation to wind power electricity production (for 2016 5400 TJ) we find that 20% of the generated annual electricity would be consumed as input to produce new wind turbines. If we instead apply the corresponding EE methodology the result is 9%. For wind turbines the exergy value for metals is dominating total input WE. The WE value for metals (as used in the Samsø study) is 200MJ/kg and the EE value for metals is the result is 50MJ/kg. 200 MJ/kg does not really mirror the use of energy in the production of the metals used give as the EE value. To evaluate the WE concept we have also studied some EE results for comparison.

When studying fluxes of GHG, the problem of defining ‘renewable’ has to be confronted. The typical calculation method is to make emissions from biofuel incineration and forest uptakes of carbon dioxide a zero-sum game. This does not (unfortunately) correspond to the physical reality. The incineration of for example woody biomass, results in a single immediate pulse emission and a certain amount of carbon dioxide (and methane) is added to the atmosphere. The question is now how to look at the uptake and what trees are considered to be allocated to the uptake of this specific amount of CO₂ (methane will not be assimilated, but will instead oxidise into CO₂ over 11-13 years). The fact that the woody biomass would inevitably decompose if not incinerated does not imply a zero-sum game. The decomposition process is quite slow and causes a lower radiative forcing effect from a 20-30-year perspective.
compared to immediate incineration. For example stump harvesting for combustion of biomass, compared to combustion of oil or coal, is counter-productive from an emission perspective in a 20-30 year time horizon, although a 100-200 year time horizon gives a different result. The model for Jämtland is based on a 20-30 year horizon and what can be assumed to be decomposed during this period.

RF responds rapidly to step changes of CH₄ emissions (i.e. increased emissions of CH₄ rapidly give an increased RF, and decreased CH₄ emissions rapidly decrease RF) (Frolking, Roulet, & Fuglestvedt, 2006). A relevant question to ask is what the ‘real’ RF effect of emissions of CH₄ is. If a specific value can be chosen (84, 28, or even 7 as GWP500), it appears to be a philosophical issue rather than a physical one. The answer is that CO₂eq is a construct showing the average RF during a specific period of time. In simplified modelling the ‘real’ RF from CH₄ has to be transformed from an integral to a static value to ‘simulate’ annual CO₂ emissions. CO₂ has a constant RF effect. This makes it important to keep the CO₂ and CH₄ fluxes separated in the analysis. It is of great importance to decide the time horizon to apply, especially if large fluxes of CH₄ or other short living GHG are included.

Furthermore we decided to include tolerance intervals in the analysis of the CO₂ and CH₄ fluxes to be able to somehow judge how sensitive the results are to the actual estimates of the different factors in the model. The problem is of course to find these tolerances, but after having concluded that IPCC sometimes gives quite wide tolerance intervals we decided to use a few broad tolerance categories to reflect the general quality of the data used (IPCC, 2006).

Emissions from combustion of petroleum products are calculated as direct combustion emissions from each type (for petrol 69.3 g CO₂eq/MJ and diesel 74.1 g CO₂eq/MJ) (IPCC, 2006). To include the complete life cycle EU 2015/652 states the standard values for petrol and diesel to be 93.2 g CO₂eq/MJ and 95 g CO₂eq/MJ respectively, as a baseline to calculate a decrease of GHG when substitution for other fuel types are to be calculated. The baseline for national accounting is set to 83.8 g CO₂eq/MJ across all fuel types (Swedish Energy Agency, 2018, p. 20ff). The choice not to apply the stated life cycle values but instead use the IPCC values was made in order to keep control of the actual direct emissions in the region. The indirect emissions in the model for Jämtland were added as imported indirect emissions. If the model is used to
calculate substitution effects this needs to be considered. It is suggested to use 83.8 g CO$_{2eq}$/MJ in such substitution calculations following the principle set by the Swedish Energy Agency.

Complete methodology descriptions can be found in papers III and IV.
3 Results

3.1 Work Energy flows in Jämtland (2014)

Referring to Figure 3 (from Paper III) it can be concluded that from the Energy sector 46,000 TJ flows into the region with 88% renewable share. Excluding electricity production for export (30,800 TJ), and waste export to be incinerated (410 TJ), the remaining 15,200 TJ (63% renewable) is what drives ‘the machine Jämtland’. Added to this is about 4000 TJ WE as matter. The largest WE export comes from woody biomass from the forestry sector, 44,600 TJ. Jämtland can be regarded as a ‘marvellous machine’ with a WE input of 50,000 TJ and an output of 80,000 TJ, which corresponds to an efficiency of 160%. The reason why Jämtland is a ‘societal heat pump’ is the region’s solar radiation input into the agricultural and the forestry sectors. If solar radiation were taken into account, the efficiency would drop to below 1%.

If we compare Jämtland with Samsø we find a societal WE-efficiency of 114% for Samsø (Nielsen & Jorgensen, 2015, p. 24 (fig 9)). Agricultural products (the major output from Samsø) show lower WE-efficiency compared to forestry and electricity production from hydro power. However, if we instead look at the output per km² the outcome changes: Samsø (114 km²) has an output of 14 TJ/km² and Jämtland (48,945 km²) has 2 TJ/km². In other words, Samsø shows higher surface area WE efficiency than Jämtland, while Jämtland shows higher over-all WE-efficiency. As a verification we can look at the input WE per capita; Samsø has (1410/4000=) 0.35 TJ/capita (0.15 TJ/capita renewable) and Jämtland (50,000/127,000=) 0.39 TJ/capita (0.35 TJ/capita renewable).

The characteristics of a specific region will decide prerequisites for regional efficiency. Jämtland cannot change land use to correspond to Samsø, or the other way round, because ecosystem and climate aspects decide to a certain degree what is possible. From the high proportion of renewable energy thanks to hydro power, Jämtland has long been a low emitting electricity producer. In principle what remains as non-renewable input is liquid fuel used in vehicles (including machines and aircrafts). From Figure 3 and information given in Paper III we can look at the share of the input that is non-renewable (NN= non-renewable energy content) and what is produced:
Agriculture: 510 TJ NN (diesel) into food

Forestry: 570 TJ NN (diesel) into biomass

Reindeer: 16 TJ NN (petrol/diesel) into food/matter

Ind./Trade: 1300 TJ NN (petrol/diesel/other) into matter/services

Private: 2200 TJ NN (petrol/diesel/other) into a ‘workforce’

Public: 680 TJ NN (petrol/diesel/other) into societal adm./service

Tourism: 320 TJ NN (petrol/diesel/other) into ‘wellbeing’

(Note that NN as share of the input into imported products is not included in the NN figures above. The share of the diesel that is regarded as renewable has been excluded from the NN-share). The private sector is the largest user of WE, which should not be a surprise then taking the number of individuals and the low WE efficiency of cars and houses into consideration.
Figure 3 Energy flows in Jämtland in TJ. From the energy sector electricity, heat and fuels flow into different sectors as renewables (Green) and non-renewables (Grey). Matter is converted to WE as imports (white). Feedback loops can be seen as manure/feed (Agriculture), biomass (Forestry) and heat/biogas (Waste).
3.2 Carbon dioxide and methane fluxes in Jämtland

In Figure 4 (from Paper IV) the annual flows of CO$_{2eq}$ using GWP20 can be seen for Jämtland. The sector boxes contain emissions from a ‘producer perspective’ as actual (estimated) emissions. Looking at the system as a whole, the private sector is classified as the end user, except for emissions exported from the region (as matter, services, energy). This means that all sectors are partly transferred to the end user in the private sector, and partly exported. This is a simplified model of reality and there are other ways to look at these kind of flows. Figure 4 clarifies that the end user in the private sector carries the emission responsibility. The average per capita CO$_{2eq}$ emission in Jämtland is 11.7 mt (metric tons). An average Swede shows a corresponding 10.7 mt (SCB, 2016), but the per capita figure for private outtake of woody biomass is high and is not part of the official national or regional statistics.

Forest land allocated to the Nature sector shows an uptake but it is not enough to balance the large emissions of CH$_4$ from mires and lakes in this sector. If the forest land now allocated to the Forestry sector were allocated to the Nature sector, the situation would of course change. This exemplifies that the sectors results are merely constructs. Referring to Table 10 in Paper IV, it can be seen that forests in the Nature sector shows an annual CO$_2$ balance as an uptake of 2 Mtons, while the CH$_4$ balance is an emission of 78 ktons. The corresponding CO$_{2eq}$ balance for the Nature sector (GWP20) thus becomes an emission of 4.6 Mtons, which is considerable and a major contribution to total emissions. Applying GWP100 the Nature sector would still contribute to warming but it would be more or less in balance (emission of 170 ktons calculated as CO$_{2eq}$).

In Figure 5 each sector is shown with tolerance intervals and Figure 6 shows the same but without the totally dominating forestry and nature sectors. It can be concluded from Figure 5 that the tolerance intervals of forestry and nature override the total contributions of the other sectors, which does not mean that the analysis is meaningless, but that an evaluation of the uncertainties in the forestry and nature sector is critical.
**Figure 4** This chart shows the simplified carbon based fluxes in Jämtland as the outcome of the model. The total result is an uptake of 2.4 Mton. Blue arrows represent inter-regional sectorial fluxes and grey arrows emissions. An arrow pointing towards the balance is an export of emissions from the region and an arrow pointing away from the balance is a corresponding emission. The negative value pointing away from Forestry (green arrow) represents an uptake. The arrow pointing from Balance to Private ‘empties’ the Private sector. Imported emissions from matter from outside the region not shown.
Figure 5 GWP as carbon dioxide equivalents shown per sector for Jämtland given as an interval of estimated uncertainty with negative value as uptake and positive as emission. The totally dominating sectors are forestry and nature. Refer to Figure 6 for results excluding these dominating sectors.

Figure 6 GWP as in Figure 5 but without the dominant sectors forestry and nature to show the other sectors more clear.
3.3 Combined analysis of WE and CO$_{2eq}$

In Table 1 the results from the energy analysis (Paper III) and the carbon based fluxes (Paper IV) are combined to show a measure of the sector transformation from WE input to emission output. This measure is typically used as an indicator for analysis of energy sources and especially for electricity production (normally as g/kWh, a unit which is also given the table as a reference). The Energy sector includes liquid fuels, not only electricity production, which means the corresponding emissions per energy unit are higher compared the case to if only electricity production would had been included.

<table>
<thead>
<tr>
<th>SECTOR</th>
<th>WE INPUT [TJ]</th>
<th>CO$_{2eq}$ [kg]</th>
<th>CO$_{2eq}$ kg/TJ</th>
<th>CO$_{2eq}$ [g/kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>46000</td>
<td>528 708</td>
<td>11</td>
<td>41</td>
</tr>
<tr>
<td>Agriculture</td>
<td>1010</td>
<td>160 375</td>
<td>159</td>
<td>572</td>
</tr>
<tr>
<td>Reindeer herding</td>
<td>20</td>
<td>52 855</td>
<td>2643</td>
<td>9513</td>
</tr>
<tr>
<td>Industry/Trade</td>
<td>4600</td>
<td>382 088</td>
<td>83</td>
<td>299</td>
</tr>
<tr>
<td>Private</td>
<td>9300</td>
<td>577 640</td>
<td>62</td>
<td>224</td>
</tr>
<tr>
<td>Public</td>
<td>2780</td>
<td>264 314</td>
<td>95</td>
<td>342</td>
</tr>
<tr>
<td>Tourism</td>
<td>980</td>
<td>18 955</td>
<td>19</td>
<td>70</td>
</tr>
<tr>
<td>Waste</td>
<td>2500</td>
<td>36 202</td>
<td>14</td>
<td>52</td>
</tr>
<tr>
<td>Forestry</td>
<td>780</td>
<td>-7 708 796</td>
<td>-9883</td>
<td>-35576</td>
</tr>
</tbody>
</table>

Table 1 Combining the indicators WE from Paper II and CO$_{2eq}$ from Paper III give a measure of GWP per energy input unit. Positive figures are emissions and negative figures are uptakes. The Nature sector has been excluded since it is not part of the anthropogenic energy input to emission conversion.

Reindeer herding shows extremely high emissions in this comparison. The reason is high emissions of methane from the animals, and at the same time quite low energy input. The agricultural sector shows a similar phenomenon with high emissions of methane (but higher input energy amounts than reindeer herding). The forestry sector produces a large uptake of 10 kg per input TJ. The reason is that the Forestry sector contains the major share of the forest land (managed production forests).
3.4 Linkages Research – Education – RSI

Participation in RSI (regional sustainability initiatives) with different stakeholders has been an important part of this research project. This also corresponds with some of the aims set out in the EU Interreg SMICE-project (Länsstyrelsen Jämtlands län, 2018). We have participated in the following regional stakeholder constellations and activities:

1. The SMICE project group
2. The county climate council (and reference group for climate strategy)
3. Different Region initiative groups (Energy saving, stimulation of Electric Vehicles/Photovoltaics etc.)
4. Regional Swedish Forest Agency stakeholder group
5. Different sustainability information activities
6. University student sustainability project supervision
7. Discussions with inhabitants and companies of all kind
8. Sustainability education initiatives

In many situations the modelling approach pushes sustainability discussions towards creativity in the problem analysis and weakens polarisation. Participation in the county climate council has been valuable and the MiUn involvement in regional activities makes it possible to spread information about research results, using the stakeholders as a societal infrastructure for the distribution of information. It has also been an effective way to increase sectorial knowledge.
4 Discussion

4.1 The regional sustainability of Jämtland

Energy and carbon flow indicators focus on the reduction of the global mean temperature. In this sense it would be better to regard them as ‘Radiative forcing’ indicators rather than as ‘sustainability’ indicators, as long as they are not part of a larger set of indicators to be evaluated. A society might suffer an ecological, cultural or economic collapse, and still be regarded as ‘sustainable’ from the perspective of energy efficiency and carbon-based GHG emissions. The situation in Jämtland, however, makes the two indicators (WE and CO₂eq) relevant. There are no large industries in the region, the agricultural sector uses only minor amounts of fertiliser (many farmers are eco-farmers or close to eco-farmers), there are no mineral extractions or similar activities and the region is sparsely populated. Of course, environmental degradation takes place in Jämtland just as in other places, but to a lesser extent. In a global perspective, Jämtland is an economically stable region with a high level of human wellbeing.

The final CO₂eq balance for Jämtland shows a surprisingly low emission uptake (negative RF). Our concern is this: if Jämtland is not ‘more sustainable’ than an uptake of 19 tons/person, how will other regions ever reach sustainability? Jämtland has to ‘compensate’ for highly populated areas. The uptake in Jämtland per capita corresponds roughly to the emissions (as CO₂eq) of (almost) two average Swedes (21 ton), which means Jämtland only compensates for 225,000 (other) Swedes. On the other hand this result is logical because the global mean temperature reference level used to define temperature increase, is based on a situation where the human influence was small and it can clearly be seen in Jämtland that the emissions and uptakes in natural ecosystems show a kind of balance.

Jämtland aims to be fossil fuel free at by 2030 at the latest. To reach this aim in such a short period of time, today’s (2018) technology has to be regarded as a major ‘obstacle’, and a technology transition before 2030 cannot realistically be expected. From Paper III, Table 31, the non-renewable fuel in transportation/machines can be summarised as; 2000 TJ petrol, 2875 TJ diesel
and 420 TJ JetA1 (aviation). From Paper III, table 1, we find 216 TJ as fuel oil to be added to NN. Energy carriers need to be exchanged from fossil diesel to (renewable) biodiesel in existing machine/vehicle fleet, from JetA1 to renewable replacements (ongoing tests show there seems to be no technical obstacles), from petrol to electricity (technology development needed), and from remaining fuel oil to biomass and electricity. If the complete petrol vehicle car fleet would be converted to electricity (less realistic), it can be expected that the 2000 TJ petrol would change into about 750 TJ electricity (assuming an efficiency for a petrol combustion engine of 30%, and an efficiency of 80% charge-to-wheel efficiency for electric vehicles). Emissions of CO$_2$eq will drop from about 170 Mton (using 83.8 g CO$_2$eq/MJ ref to Chapter 2.3) to 4 Mton if the electricity mix CO$_2$eq factor for Jämtland of 20 g/kWh is used. If the electricity mix CO$_2$eq factor for Germany of 512 g/kWh (ref to Table 23 in A7 Paper III) would be used the emission would instead be 110 Mton. This shows the need to study the substitution effects of the electricity used, what mix that will be replaced, and also future expected emissions from electricity production. From a Jämtland perspective a technology transition from combustion to electricity gives a very large reduction of CO$_2$ emissions, but from a German perspective this transition does not give the same effect at all, presuming today’s electricity production methods. This also shows that sustainability efforts always need a regional context.

A WE analysis of a society can be used to reflect upon how energy is being used and converted by humans. As an example referring to the Agricultural sector (Paper III) with the input of 500 TJ of renewable energy and 500 TJ if of non-renewable energy is converted into 500 TJ as human food (WE then measured as human caloric value), we can conclude that the efficiency of the sector is 50% (disregarding the solar energy input). We need to ask ourselves what this actually means and how we should look at the conversion process in terms of sustainability, striving for increased WE efficiency. Furthermore we need to analyse other values emerging from the work done in the sector (open landscapes, an active livestock, practical knowledge about ecological processes, survival of an old culture etc.). Still the model derived in Paper III, allows us at the same time to attempt to track inefficiencies in the energy conversion processes taking place in the region.

An interesting example of how the model might be useful and why the time horizon applied is necessary to take into consideration is the potential to substitute the regional use of diesel and JetA1 with biofuels (from woody
We are then to replace 3300 TJ diesel and JetA1 (ref to Chapter 3.1) with forestry based fuel, which is from today’s perspective a realistic alternative. This corresponds to the WE content in a tree volume of 420,000 m3sk if 100% of the WE content in wood could be extracted (ref to Paper III) which will not be possible in reality. Guessing a 50% efficiency in the wood-to-fuel-chain, 850,000 m3sk will be needed, which corresponds to 15% of today’s harvest in Jämtland. The time horizon applied and alternative use of the forest biomass will be most relevant when calculating changes of the CO₂ uptake in the forest and the substitution effects over the period studied. Such studies need a thorough analysis of the complete material flow and it should be clear that it is not just a matter of changing input parameters in the model, but rather using the model as a base for the calculations made in the analysis of the specific case.

More or less as a rule, the large flows of carbon in the forest make it necessary to be very strict in terms of how they are dealt with. Intuitively, it ‘feels’ as if wood to be used as timber, which can be regarded as long time storage of carbon, should be treated differently to wood which is turned into pulp and paper, which must be regarded as a short-time cycling matter. But since both types are exported out of the region and the fate of the wood is decided outside the borders of the model, it does not matter whether the wood enters storage or is immediately destroyed. It is however important to do some kind of analysis, taking the time horizon into consideration, of how the emissions would be calculated in the other region if the same logic is applied.

It might be worth highlighting the importance of ‘thinking about sustainability’ valuing different aspects of the concept ‘sustainability’, which today is widely used and partly devalued from its original meaning. The tourist sector makes one interesting example, with its frequent use of the standard phrase ‘sustainable tourism’ referring to some aspects showing environmental responsibility. But what we should be aiming for is a method to assess the claimed ‘sustainability’ (Francisco Javier Blancas, 2018). The question to ask might be ‘How much energy can be used for the production of “wellbeing” (and regional income) before we regard it as being “non-sustainable”?’ We then of course also need to assess the ‘wellbeing’ produced in relation to the sustainability assessment, judging ‘good quality of life’ in terms of interaction between nature and humans (Díaz, Demissew, Carlos Joly, & Larigauderie, 2015). An economic assessment is easier to perform than an
assessment of wellbeing. At what point is tourism no longer sustainable and who should decide how to act in response to this change?

Since most of the environmental degradation taking place on Earth is entirely legal, it is important to bear in mind that in democratic societies each individual is free to act within the borders of the law, implying that there are connections between scientific findings and the development of legal procedures (comparable with the development of work safety legislation). Fragmentation of scientific knowledge increases the risk that integrated understanding at a societal level will decrease, thus resulting in an attitude of distrust towards scientific and technological development (a tendency that can be clearly seen today with the expansion of the ‘alternative facts’ concept, when conceptual truths and axiomatic statements no longer seem to exist). The combined effect of a distrust towards science and the limits of the law result in significant difficulties when it comes to achieving the goals set out in the Paris Agreement.

It seems as if education on sustainability should not focus too much on finding solutions. The focus should be on the process of translating reality into mathematical connections, since this is what forces us to examine the problems in detail. We have been able to use findings and experiences from university courses in other contexts, such as discussions with a variety of stakeholders within the region. Since there are no clear solutions to the problem of how to increase regional sustainability, we should strive to find different perspectives on today’s situation using a scientific basis. It is worth remembering that not even evaluations from models presented by IPCC in an extensive report, such as IPCC AR5 (2014), lead to action. It sometimes seems more important to have a model to discuss, rather than to have a fully correct model.

4.2 Further research

The current thesis has highlighted two important aspects of regional sustainability and provides increased understanding of regional flows of energy and carbon. Hence it provides important input to regional planning. However, the thesis also identifies gaps in current knowledge and the following areas for further research have been identified:
(1) Scenario analyses of different alternatives for how to reach increased regional sustainability, taking into account the risks of sub-optimisation relation to global effects, i.e. how the strong resources base in Jämtland could best be utilised to reduce global GHG emissions.

(2) Improved sub-models for RF effects in short-term (20-30 years) and long-term (100-200 years) perspectives for the major RF contributor sectors Forestry and Nature.

(3) Investigate how sustainability research results can be used regionally to affect individual behavioural patterns, and at the same time support the research into sustainability. A base for this could be a model of regional individual consumption patterns and possible changes to support a decrease of RF from consumption.

(4) It is obvious a region cannot optimise sustainability work using only WE and CO2eq as indicators. Other values need to be considered, and the question of how to weigh these values in relation to the indicators now analysed at a regional basis is very complex but it has to be done. The development of a decision tool (expert system) for this is be a possible research area.

4.3 Conclusions

Jämtland shows an 88% over all renewable-energy share, and the region is not only in balance from a global warming perspective but contributes to global cooling with an annual uptake of 2.4 Mton CO2eq. This can be interpreted as Jämtland being at least close to sustainability using work energy and carbon GHG emissions as indicators. Mires, wetlands, lakes and animals are large emitters of methane and the CO2eq balance of Jämtland is thus dependent on how methane emissions are to be calculated in terms of RF (i.e. selection of the time integral).

If we look at Jämtland in a national or international context as a sparsely populated large region with natural resources such as flowing water and large forests, it actually has to be sustainable because such regions have to balance emissions from regions without natural resources and with higher population density. The uptake in Jämtland of 2.4 Mton CO2eq corresponds to the emissions of only 225 000 average Swedes.

The question of how best to govern Jämtland towards increased sustainability from a global warming perspective, without negatively affecting other
indicators of sustainability, is a difficult one. Universities have a role to play in supporting regional governmental decisions and participating in and leading initiatives in regional sustainability work. Governing needs to be based in scientific findings, while using a broad democratic approach to find suitable solutions adapted to the regional context.
5 Philosophical reflections

From the results we can see that humans affect the GHG balance with relatively small emissions, in comparison with natural fluxes. In principle there are two major strategies for how to reduce RF from Jämtland:

1. A reduction of GHG emissions emerging from anthropogenic activities
2. Increase CO₂ uptake and reduce CH₄ emissions in natural ecosystems

The two strategies can of course be combined, but looking at them as two major strategies they clarify two different views: the ecocentric and the anthropocentric perspectives respectively, thoroughly discussed from many perspectives in Keller (2010). This is de facto the fundamentally difficult polarization that appears in discussions of global warming. From both views anthropogenic emissions can be concluded to be the cause of global warming. The polarisation shows when possible solution strategies are to be discussed.

From an ecocentric perspective nature has an intrinsic value which means it should remain as it is (or it should be restored to an earlier presumed state). From an anthropocentric viewpoint nature can contribute to a reduction of regional RF from increased CO₂ uptake in forests, reduced emissions of CH₄ from mires etc. The latter can be regarded as a kind of ‘RF engineering’. In the end, we might have to make a decision on how we should value nature, and natural systems in comparison to human wellbeing ‘as we know it’. The following statements may clarify this complexity to some extent:

(a) A reduction of the ruminant population kept by humans would reduce emissions of CH₄ at the same time making it possible plant trees on agricultural land to increase uptake of CO₂.

(b) Lowering of the water levels in mires to reduce CH₄ emissions also makes it possible to increase CO₂ uptake by planting more trees. This is to say that the restoration of mires and wetlands is positive from a biodiversity perspective, but negative from an RF perspective.

(c) Reduce the elk and deer population to reduce CH₄ emissions and prevent damage to tree plantations (i.e. what is the value of elks and deer?).

(d) Reduce as many human consumption activities as possible to reduce GHG emissions.

(e) Prevent regional population increase and encourage low fertility strategies for a long term reduction of GHG emissions (variant of d).

During the work with the models, ideas and statements like these have been
raised as basic ideas and possible solutions to stress strivings towards sustainability towards an extreme limit. If we were to model each one of them the results would probably not contribute to societal integration because each statement is controversial in some way.

Annual global CO₂ emissions from fossil fuels have been steadily increasing over a long period of time (since the beginning of the 1980s) – with one major exception: 2009 showed a decrease of about 1% (down to 31.8 Gton CO₂), (Hausfather, 2017). The USA and EU together dropped about 8% or 0.8 Gton which corresponds to 330 Jämtland-region uptakes. The reason was the global financial crisis initiated 2008. In 2017 total emissions from fossil fuels were 36.8 Gton, which is an increase of 16% since 2008 following the development of the world economies. We would need 2000 Jämtlands to cover the increase during these 10 years, and 15,000 Jämtlands to cover the total emissions (and that is only from fossil fuels). The emission decrease in 2009 is a very interesting example and 1% is quite a large reduction in global terms. What is especially striking is that ‘nothing’ was done to achieve it in a literal sense, nothing but a global consumption reduction.

The ethical dimension regarding who should carry the responsibility for emissions of GHG is connected to this phenomenon, and the responsibility issue can be seen as a ‘blame-game’ (Jayaraman, Kanitkar, & D’Souz, 2010). Two similar examples can be used to clarify the problem: (1) Photovoltaics (PV) are mainly produced in Asia and installed in Jämtland as ‘fossil fuel-free electricity production’. (2) Electric vehicles (EV) use batteries also typically produced in Asia and we calculate emission reduction as resulting from driving. What has been disregard are the peak emissions caused during production, typically from electricity production using coal. If consumer responsibility is not claimed, but producer responsibility is, it appears that this is a producer problem only.

There is an obvious risk that societal forces will strengthen environmental ‘anorectic behaviour patterns’ and develop moral discipline focusing on guilt and shame, which would be problematic. From a philosophical perspective the ethical dimension of the global warming problem is a difficult one. Who is to be held responsible and what can be regarded as a fair distribution of GHG emissions? The problem lands squarely in traditional philosophy of ethics with many different views possible (Miroiu, 1996). We need to open up societal discussions and try to integrate as much knowledge as possible, thus
reducing the risk of societal polarisation through the establishment of a moralising society where the most admired fellow is the one surviving closest to the death state; eating as little as possible, no excesses, no travelling etc. There is a clear tendency in Sweden today, to use ethical arguments and moral aspects when it comes to individual behaviour to initiate behavioural change. Animal rights are connected to emission factors and consumption patterns to distribution of wealth (which is not always logical since the distribution of wealth in terms of the increased economic strength of a certain group or population, of course means that consumption will increase within this group). Sustainability evaluation might be fundamentally about getting insight into the difficulties of these questions and the uncertainty of their answers (von Wright, 1993 (1957), p. 5).

If the social and economic spheres are excluded and the problem of global warming is to be solved solely within the ecological sphere, the problem might find a solution through a reduction of the population of human beings. This has actually been suggested by the Norwegian environmental philosopher Prof. Arne Næss (who proposed reducing the global population, during a longer period of time, to a total of about 100 million people) (Næss, 1989, s. 29ff). From an ethical perspective such a suggestion appears absurd, but it shows the risks when a human mind focuses too hard on single parameters. We should also not forget the cultural context in which solutions to sustainability issues need to fit, which supports the argument that when finding solutions to the problem of global warming we cannot focus on the global level only (Dlouhá, Macháčková-Henderson, & Dlouhý, 2013). One of the problems with global warming is that it is a global problem without obvious solutions. The German sociologist Niclas Luhmann argues that today’s ecological problem is in fact a distinctly different type of problem compared to those we have seen earlier since it cannot be bound to a specific system, but rather consists of interconnected relations between systems. Society thus has to change substantially if we are ever to find a solution and all constancy is negative since today’s situation is – from a risk perspective – unacceptable. Furthermore, the political system is not adapted to finding solutions to ecological or global problems (Luhmann, 1998, p. 78ff). Ulrich Beck’s analyses of the ‘risk society’ argue that what is at stake in the new ecological conflict is no longer profits, prosperity or consumer goods, but ‘negatives’ such as losses, devastation and threats (Beck, 1995). There are many facets to this matter and the ambition here is not to cover the field of sociology or philosophy, but just to claim that it is necessary to bear the
context of the problem of global warming and sustainability in mind, when analysing today’s status in terms of the search for future solutions. The flows of CO$_{2eq}$ shown in Figure 4 actually clarify collective individual behaviour as summarised. In a time of individualisation this might be more difficult to communicate; what is more, we live in a time when individual rights are more in focus than individual obligations. It might be, as the sociologist Bauman concludes, that in a society that is organised around freedom, the individual will be defined by their consumption (Bauman, 1988, p. 89ff).
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