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Energy and climate scenarios within the doughnut?

Treatment of planetary boundaries, social foundations for human prosperity and economic growth in energy and climate scenarios

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Summary

Humanity is moving towards ecological, social and economic crisis unless trends in environmental degradation and social inequality are broken. Multiple challenges create the need for integrated approaches to solve several problems simultaneously. Many governmental and research institutions are exploring possible actions to deal with climate change by developing energy and climate scenarios (ECS) which present possible trajectories and images of low-carbon societies. However, little is known about how ECS integrate wider sustainability aspects in their scenarios.

The purpose of this thesis is to analyse how the planetary boundaries, social foundations and economic growth are treated in energy and climate scenarios. 30 scenarios were initially scanned and 8 of those were selected for a deeper review. They are global and Swedish energy and climate scenarios exploring trajectories toward low-carbon futures. The chosen scenarios represent a diversity of methodological approaches and perspectives on the studied aspects sustainability.

The theoretical framework used for the review was Kate Raworth's concept of a safe and just operating space for humanity (doughnut economy). The framework envisages an inclusive and sustainable economic development within the environmental ceiling of the planetary boundaries and above the social foundation of the human rights.

To summarise, it seems that most energy and climate scenarios focus only on technological energy aspects of climate change and do not handle planetary boundaries and social foundations. The ones which handle them treat only a few of them and often only partially, except for the IPCC which treats most aspects of sustainability extensively. Biodiversity, land use change, water use and global equity have been treated by at least one scenario other than the IPCC. Some other planetary boundaries and social foundations are treated partially and peripherally. Undertreated planetary boundaries are i.e. water cycle and chemical pollution. Undertreated social foundations are i.e. water use, gender equality, health and resilience to shocks. By not treating planetary boundaries and social foundations, the scenarios risk leading to policies which miss sustainability targets.

Economic change is treated only partially and superficially. Three of the scenarios assume sustained GDP growth rates many decades ahead, although this assumption makes it increasingly difficult to reach low-carbon climate targets. Most of the scenarios do not explore growth dynamics such as productivity, consumption, investments and public spending.

Some aspects of the connections between bio-energy, food and water and work and the connections between work, income, consumption and stress on the planetary boundaries are treated by a few scenarios. However, many aspects of these connections are underexplored, especially with regard to economic change.

Qualitative trend-based studies seem to treat planetary boundaries, social foundations and economic change to a higher extent. However, they often lack detail in the descriptions of outcomes and trajectories. Model based, technology-rich scenarios of the preserving type barely treat planetary boundaries and social foundations. They also usually assume that socio-economic development will continue as today. Because of this they risk reproducing path-dependency and techno-institutional lock-in.

In order to avoid path-dependency, lock-ins and missing sustainability targets, ECSs should to a higher extent incorporate planetary boundaries, social foundations and a critical perspective on economic change in their inquiries. They should also combine different methodologies. Combining the quantitative technology-based perspective with the socio-technical actor-based and the critical value-based perspective would produce more robust and politically tractable scenarios. Inclusive and deliberative development processes are crucial for success.

Sammanfattning

Titel: Hantering av planetära gränser, sociala grunder för mänsklig välfärd och ekonomisk tillväxt i energi- och klimatscenarier

Mänskligheten är på väg mot ekologisk, social och ekonomisk kris om inte trender i miljöpåverkan och social ojämlikhet bryts. Mångfalden av utmaningar ställer krav på integrerad hantering för att lösa flera problem samtidigt. Många myndigheter och forskningsinstitutioner utforskar möjliga åtgärder för att hantera klimatförändringen genom att utveckla energi- och klimatscenarier som visar på potentiella bilder av samhällen med låga utsläpp av växthusgaser och förändringar som krävs för att nå dit. Det är dock outforskat hur energi- och klimatscenarier integrerar bredare hållbarhetsaspekter i sina scenarier.

Syftet med detta examensarbete är att analysera hur planetära gränser, sociala grunder och ekonomisk tillväxt hanteras i energi- och klimatscenarier. 30 scenarier undersöktes och 8 av dessa valdes ut för en grundligare granskning. Alla är globala och svenska energi- och klimatscenarier som utforskar banor mot framtider med låga utsläpp av växthusgaser. De utvalda scenarierna representerar en mångfald av metodologier och perspektiv på de studerade hållbarhetsaspekterna.

Det teoretiska ramverket som användes för studien är Kate Raworth's koncept om ett säkert och rättvist utrymme för mänskligheten (doughnut-ekonomi). Konceptet föreställer en inkluderande och uthållig ekonomisk utveckling inom ramen för det miljömässiga taket som utgörs av de planetära gränserna och det sociala golvet som utgörs av de mänskliga rättigheterna.

Det förefaller att de flesta energi- och klimatscenarierna fokuserar enbart på tekniska energiaspekter av klimatförändringen och ej hanterar planetära gränser och sociala grunder. De scenarier som gör det hanterar endast ett fåtal av dem och endast delvis, förutom IPCC som hanterar de flesta aspekter av hållbar utveckling ingående. Biologisk mångfald, markanvändning, vattenanvändning samt global jämlikhet har hanterats av åtminstone ett studerat scenario förutom IPCC. Några andra planetära gränser och sociala grunder har hanterats delvis eller ytligt. Underbehandlade planetära gränser är exempelvis vattencykeln och kemisk förorening. Underbehandlade sociala grunder är exempelvis vattenanvändning, jämställdhet, hälsa och resiliens mot störningar. Genom att inte hantera planetära gränser och sociala grunder riskerar scenarierna att leda till åtgärder som missar hållbarhetsmål.

Ekonomisk förändring hanteras endast delvis och översiktligt. Tre scenarier antar en ihållande BNP-tillväxt många decennier framåt, trots att detta antagande gör det svårt att nå klimatmål med låga utsläpp. De flesta scenarier utforskar inte tillväxtdynamik såsom produktivitet, konsumtion, investeringar och offentliga utgifter.

Vissa aspekter av kopplingar mellan bio-energi, matproduktion, vattenanvändning och arbete samt kopplingar mellan arbete, inkomst, konsumtion och tryck på de planetära gränserna hanteras av några scenarier. Däremot är många aspekter av sådana kopplingar underutforskade, speciellt kopplingar till ekonomisk förändring.

Kvalitativa backcastingscenarier förefaller hantera planetära gränser, sociala grunder och

ekonomisk förändring i en högre utsträckning. De är dock odetaljerade i sina beskrivningar av utfall och vägar dit. Modell-baserade, teknikfokuserade (preserverande) scenarier hanterar knappt de planetära gränserna och sociala grunderna. De antar oftast att den socio-ekonomiska utvecklingen kommer att fortsätta som idag. Därför riskerar de att reproducera stigberoende och teknisk-institutionell inlåsning.

För att undvika stigberoende, inlåsning och missade hållbarhetsmål behöver energi- och klimatscenarier i högre utsträckning inkludera planetära gränser, sociala grunder och kritiska perspektiv på ekonomisk förändring i sina syften. De behöver också kombinera olika scenariometoder. Att kombinera kvantitativa teknikfokuserade perspektiv med socio-tekniska aktörsbaserade perspektiv och kritiska värderingsbaserade perspektiv skulle skapa mer robusta och politiskt hanterbara scenarier. Inkluderande och reflekterande processer i scenarioutvecklingen är avgörande för att lyckas.

1. Introduction

Human economic activities are on the verge of moving the earth system out of the only geological epoch we know can sustain human society (Steffen et al, 2015). We are moving towards abrupt and irreversible climate change, mass extinction of species and land degradation (IPCC, 2014b; Steffen et al, 2015) . The richest 20% of humanity consumes 86% of the world's resources – the poorest 20% only 1.3% (UNDP, 1998). Many of the people living in poverty are deprived of food, water, health care, and other basic human rights (UNDP, 1998). There are no more recent data on global inequalities in consumption. However, according to the World Bank (2009), global income inequalities are rising.

We are facing ecological, social and economic crisis. These multiple threats create the need for integrated approaches to solve several problems simultaneously. To this end, a variety of concepts on sustainability have been developed. One of them is the concept of safe and just operating space for humanity developed by Kate Raworth (2012). Her framework of a doughnut economy envisages an inclusive and sustainable economic development within the environmental ceiling of the planetary boundaries and above the social foundation, our obligation and responsibility to abolish the critical human deprivations.

According to Raworth (2012), providing the additional food needed by the 13% of the world's population facing hunger requires only 1% of the global food supply. Ending income poverty for the 21% who live on less than 1.25$ a day would require only 0.2 percent of the global income. That is a minuscule part the richest people's income. 57% of the global income is in the hands of the richest 10%. The consumption of this minority stands for most of the pressure on the planetary boundaries. What is needed is a far greater equity in the distribution of incomes and use of natural resources (Raworth, 2012).

In recent years, a growing number of energy and climate scenarios (ECS) are exploring possible climate futures (Hughes, 2010). When studying possible solutions to threats for the whole humanity such as climate change, it is important to assess risks and uncertainties by elaborating scenarios (Svenfelt, 2010). One example of this importance is the formation of the IPCC by the UN in order to give a solid scientific view on the knowledge and potential impacts of different types of climate action. Scenarios are also developed in other fields where there is a need to explore the long term consequences of actions today (Hughes, 2010). Furthermore, scenarios are used to challenge existing "world views" and "mind maps" in order to see a fuller range of possibilities and create consensus among scenario users (ibid.). Various studies have been performed, analysing how ECSs can become more useful as policy tools. They have focused mostly on agency, governance and other social impediments to policy implementation (Wangel, 2011; Söderholm, 2011 and Hughes, 2010).

However, little is known about how the ECSs treat the multiple social-ecological and economic challenges to sustainability. If scenarios are to be effective in informing strategic decision making, they have to incorporate the complexity of the issue and develop policy alternatives which are technically, economically and socio-ecologically conceivable and desirable. If the scenarios do not handle social-ecological and economic challenges in an integrated fashion, the risk is that the action they generate reproduces path-dependency and techno-institutional lock-ins. Especially technical solutions might many times solve one problem, only to create an even bigger problem in an area that was out of focus (Clark and York in Hornborg et al, 2012). A notable example is that the introduction of synthetic fertilisers to solve the problem of land degradation is causing eutrophication and greenhouse gas emissions, while barely solving the initial problem (ibid.). There is a risk of missing the sustainability that is aimed for. This thesis explores how different ECSs treat the three dimensions of sustainability and how they integrate the three.

One example of sustainability conflicts is the tension between bio-energy and food production. Cultivation of energy crops has high potential to substitute use of fossil fuels, thereby lowering emissions of greenhouse gases (Raworth, 2012; Åkerman et al, 2007; Milestad et al, 2014). However, a large scale shift in land use to bio-energy production would decrease production of food, raise food prices and exacerbate world hunger (Raworth, 2012). Energy and climate scenarios need to handle connections like these and provide solutions which fulfil a variety of ecological, social and economic criteria.

This thesis is developed in relation to the Beyond GDP-growth research project which studies social-ecological developments in the Swedish society in futures with low growth, zero growth and degrowth. This thesis aims to provide some context to the research project by studying how other scenarios treat sustainability and economic growth.

1.1 Purpose and research questions

The purpose of this thesis is to analyse how planetary boundaries, social foundations and economic growth (BFG) can be dealt with in energy and climate scenarios (ESC).

The following research questions were posed:

1. How planetary boundaries (other than climate change) are treated in the selected scenarios,
2. How social foundations are treated in the selected scenarios,
3. How economic growth is treated in the selected scenarios, and
4. How different scenario methodologies influence the treatment of planetary boundaries, social foundations and economic growth in the scenarios.

1.2 Theoretical overview

This section aims to give an overview of the research and theory in scenario development, sustainability and economic growth theory. Since an exhaustive account of the theory and research history in these three diverse fields of research would be too long, this section focuses mostly on the concepts and notions relevant for the analytical framework of this thesis.

Scenarios are used to improve the quality of decisions made about the future (Hughes and Strachan, 2010). Although there is a great diversity of specific purposes and contexts in which scenario are used, according to Hughes and Strachan (2010) scenarios have one of three general key objectives (p. 6057):

- Protective decision making - To improve robustness to future external events.
- Proactive decision making - To improve the ability to see opportunities to actively shape future events in a beneficial way.
- Consensus building - To improve understanding between multiple actors in identifying a mutually desirable path forward.

Börjesson et al. (2006) structure scenarios according to the question they answer; what will happen (predictive), what can happen (explorative) or how a certain target can be reached (normative). In other words, they describe a possible, probable or preferable future (ibid.). Predictive scenarios are forecasts of current trends or what-if scenarios investigating the effect of an important future event. Explorative scenarios are either external scenarios focusing on factors beyond the control of relevant actors or strategic scenarios which describe possible consequences of measures taken by the scenario user. Normative scenarios are either preserving or transforming. Transformative or backcasting scenarios study futures where the target cannot be reached without a systemic change of the system studied. Preserving scenarios study optimal ways of reaching the target, usually using models to find the most cost-efficient trajectory.

Hughes and Strachan (2010) structure ECSs in technical feasibility studies, modelling studies and trend based studies. Technical feasibility studies demonstrate how the energy system can meet carbon reduction targets while providing for the energy demand and other constraints. Modelling studies represent the whole energy system and the economic connections between different sectors through market relations. Their outputs are usually least-cost solutions to different end-point carbon constraints. Trend based studies explore diverging external high-level trends, typically in a 2x2 matrix. Typically they are qualitative and able to capture social drivers, global political dynamics and unquantifiable cultural shifts.

There are many definitions of sustainability. In 1987, the Brundtland commission coined the term sustainable development, defining it as “meeting the needs of the present without compromising the ability of future generations to meet their own needs” (United Nations, 1987). Consequently, the environmental economic concept of “the triple-bottom-line” was developed, where natural capital is exchangeable for human or manufactured capital (Daly, 2007). Ecological economists prefer the strong sustainability definition, arguing that natural capital provides a critical and unique contribution to welfare and cannot be substituted for other forms of capital (ibid.). The economy needs to be framed by its social purpose of providing welfare and social sustainability, which is contingent on flourishing ecosystems (ibid.).

In 2012, Kate Raworth developed the concept of a safe and just space for humanity. The framework combines the upper ecological limits and the minimal social limits of sustainable resource use (figure 1). Within this, there is space for inclusive and sustainable economic development. The ecological limits are based on the planetary boundaries concept of Rockström et al (2009) and revised by Steffen et al (2015). The social foundation is based on the social priorities in the development of the UN Sustainable Development Goals (SDGs) (Raworth, 2012; UN, 2015).

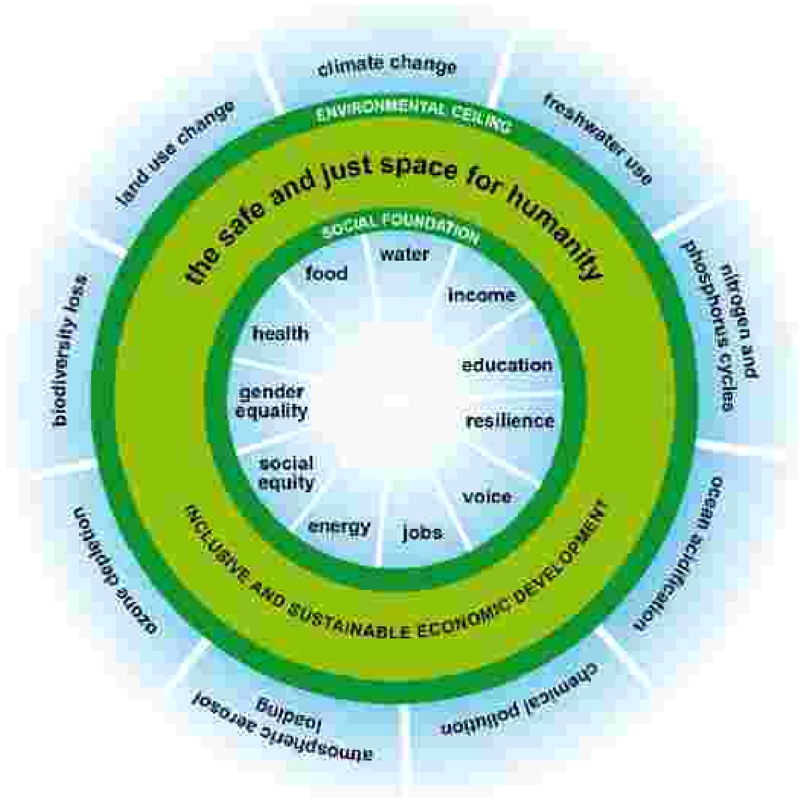

Figure 1. The safe and just space for humanity. Source: Raworth, 2012

The nine planetary boundaries identified by Rockström et al. (2009) are climate change, freshwater use, nitrogen and phosphorus cycles, ocean acidification, chemical pollution, atmospheric aerosol loading, ozone depletion, biodiversity loss and land use change (see the “environmental ceiling” in figure 1). These are critical processes of the earth system which are subject to human pressure.

The planetary boundaries are interconnected and there are feedbacks between them. Examples of feedbacks are the loss of tropical forests (land use change) affecting the climate through changes in evapotranspiration and the consumptive use of freshwater destroying ecological habitats (Steffen et al, 2015). This means that no planetary boundary can be transgressed for long periods of time without jeopardising the safe operating space for humanity (ibid.).

There is a risk of overstepping non-linear thresholds (tipping points) which change the functioning of human-environmental systems (Steffen et al, 2015). The pressure on the planetary boundaries is currently pushing the earth system out of the Holocene geological epoch which has been stable and favourable for human societies (ibid). Four of the planetary boundaries are currently being transgressed; biodiversity loss, climate change, nitrogen and phosphorous cycles and land use change (ibid.). Note that Steffen et al's revision of the planetary boundaries has slightly redefined the planetary boundaries and updated the anthropogenic perturbation levels compared to Rockström et al. They also suggest a hierarchy of boundaries, recognising climate change and biosphere integrity as core boundaries, through which the other planetary boundaries operate (ibid.)

Raworth's social foundations for human well-being are based on the UN human rights declarations and Millennium Development Goals. The Millennium Development Goals were adopted in 2000 with the purpose to achieve eight social targets until the year 2015. The targets include eradication of extreme poverty and hunger; promotion of gender equality and empowerment of women, reduction of child mortality, among others (Un.org, 2015). Although many advances have been made, many of the goals are still far from being reached (ibid.).

The post 2015 development agenda is characterised by the Sustainable Development Goals (SDGs) announced at the Rio +20 summit on sustainable development in 2012. The SDG are in the drafting process and are expected to be adopted in September 2015 (ibid.). The current proposal has 17 targets which integrate social, environmental and economic aspects (UN SDG, 2015). Kate Raworth's definition of the social foundation consists of the 11 social priorities of the nations which participated in drafting the UN Sustainable Development Goals (see the details of the social foundation in figure 1).

GDP growth (many times with different positive prefixes, e.g. green, sustainable, inclusive) is normally assumed to be synonymous with sustainable economic development. The EU:s Europe 2020 economic strategy is focused on "smart, sustainable and inclusive growth" (EU COM, 2010). One of the UN SDGs also aims to promote "sustained, inclusive and sustainable economic growth" (UN SDG proposal, 2015).

However, there is a growing criticism of the growth paradigm, arguing both that it is not feasible in the long term and that it is not desirable. According to Raworth (2012), traditional economic growth policies have largely failed to end deprivation of basic needs and keep within sustainable limits of resource use, which suggests that a different approach to economic development might be needed.

The global economy of today is five times bigger than 50 years ago. With continued GDP growth at the same rate as today, the economy would be 80 times bigger by the year 2100 (Jackson, 2009). With such high economic output, it is increasingly difficult to conceive a resource use which is within the planetary boundaries (ibid.). The planetary boundaries are overshot already today. To get back within the planetary boundaries, material throughput would have to decline at a faster rate than economic output. This suggests an economy approaching zero material throughput per economic output (emissions and material use per unit of economic value produced). According to Jackson (2009), this seems practically inconceivable.

Furthermore, increased income does not correlate with increased health, happiness or other measures of well-being above income levels of 25000 US dollar per year (Wilkinson, 2009). On the other hand, for low-income countries, life satisfaction is correlated with increased income (ibid). It is a paradox that the people whose incomes are actually growing are the ones that do not need it for their well-being. Furthermore, the wealth of the rich nations is connected to the poverty in poor nations through trade and the unequal exchange of embodied energy and labour (Hornborg et al, 2012).

2. Method

This chapter presents the research process, analytical framework and selection of scenarios.

2.1 Analytical framework and research process

The research process included four steps: 1) analysis of the purposes, methodologies and results of the ECSs, 2) analysis of the treatment of social foundations and planetary boundaries in the ECSs, 3) analysis of the treatment of economic growth in the ECSs and 4) analysis of how the methodology of the scenarios might affect their treatment of planetary boundaries, social foundations and economic growth (further on expressed as BFG, standing for Boundaries, Foundations and Growth).

The purposes, methods and outcomes of the scenarios were analysed to create an overview of the types of scenarios included in the study and what perspectives they have on BFG. The typologies developed by Hughes and Strachan (2010) for ECS and by Börjesson et al. (2006) for scenarios in general were used for the purpose. The overview is presented in chapter 3 and section 4.1.

In the next step, the scenarios were analysed for their treatment of the safe and just space for humanity – as in the concept of doughnut economy developed by Kate Raworth (2012). In this thesis, the planetary boundaries and social foundations are defined as Raworth (2012) defined them, that is, the planetary boundaries are based on Rockström et al. (2009) and social foundations are based on the social priorities that the countries submitted in the drafting process for the UN Sustainable Development Goals. It is noted that the planetary boundaries concept has been further developed by Steffen et al. (2015) and that there is a more current draft for Sustainable Development Goals (UN, 2015). However, for simplicity and coherence with the combined doughnut economy framework, the definitions in this thesis are the same as Raworth's.

Every scenario was analysed for its treatment of the 9 planetary boundaries (except for climate change) and the 11 social priorities which constitute the social foundation for humanity according to Raworth (2012)

Climate change is of course part of the core purpose of every ECS studied. The research question in this thesis is how the ESCs treat the other planetary boundaries than climate change; if they treat them jointly with climate change, if they assess the effects of climate change measures on the planetary boundaries or if they do not handle them at all. Because of this, no in-depth analysis was performed on the ECS's treatment of climate change. However, the ECS's treatment of climate change is shortly presented in chapter 3, the description of the selected scenarios.

There are many possible interpretations and perspectives on what could be included under each social foundation. There are no detailed definitions in Raworth's paper from 2012. Defining each and every one of them in detail would be beyond the scope of this thesis. By refraining from defining the social foundations further, the framework allows for any type of interpretation to enter the study results. For example, the UN (2015) defines decent work as wage labour, setting targets for the eradication of child labour, forced labour and protection of labour rights. In this thesis the definition is expanded to include also alternative meanings of work (work for own purposes, play rather than work, guild work) because these definitions were found in the scenarios studied.

The set of 11 social foundations means that a variety of human needs for well-being are addressed and included in this survey. Many more social needs can be identified, for example access to transport, culture and indigenous rights and adequate housing. However, assessing the treatment of the eleven foundations in Raworths framework gives an indication of the extent to which social foundations are treated by ECS. This is enough for the purpose of this thesis, which is more concerned with how the combination of social foundations, planetary boundaries and economic change is treated by the ESCs. The details of different ways that social foundations can be treated would be a topic for further research.

Lastly, the assumptions on economic growth in the ECSs were analysed, using the Kate Raworth’s concept “Doughnut economy”, which identifies economic policy as the means to achieve a safe and just space for humanity and Tim Jackson's (2009) criticism of the feasibility of long term economic growth. The analysis of how ECSs handle economic growth consisted in studying quantitative assumptions on GDP growth, qualitative assumptions on the drivers and components of growth, assumptions on qualitative change in economic activities and if they linked economic activities to planetary boundaries and social considerations. The results are presented in chapter 4.4.

The process was iterative. After analysing every scenario for BFG, the purpose and characteristics of the scenarios were revisited and an overview was created of their treatment of BFG. The scenarios were revisited several times during the analysis of their treatment of the BFG. Comparisons of their different ways of handling them were made. Subsequently, reflection on the BFG not handled was developed into a discussion about the consequences for the scenarios usefulness in policy making and as tools for knowledge creation about future possibilities.

2.2. Selection of scenarios

A literature search was made with key words including “sustainable energy scenario” “energy and climate scenario” and “low carbon scenario” in the ScienceDirect, Scopus and Google databases. Meta studies of energy and climate scenarios (Hughes et al, 2010; Söderholm et al, 2011) were read, references of the documents found were studied and researchers were consulted in an reiterative and snowball-like fashion. 30 documents of interest were initially identified.

The main aspect of the sampling frame was that the scenarios focused on reaching sustainable levels of greenhouse gas emissions from the energy and transport sector (low-carbon societies). They did not have to be normative scenarios with an end point constraint on greenhouse gas or carbon dioxide emissions. Also scenarios exploring different ranges of climate change and more short term trajectories than low-carbon trajectories were included. However, they all at least had to be exploring strategies for emission reductions.

The sampling frame included both Swedish, regional and global scenarios in order to not omit perspectives on sustainability because of a limited geographical scope. For example, scenarios treating nations might not address global social issues or international environmental degradation as extensively as regional and global scenarios. Conversely, global scenarios might not treat social issues of a local nature and may be less specific in their treatment of environmental degradation. However, scenarios treating nations other than Sweden were omitted because this thesis is meant to be of interest to Swedish scenario users and specifically the research project “Beyond GDP growth”, which focuses on possible scenarios for Swedish society assuming different and even negative rates of economic growth.

Energy and climate scenarios are developed by different types of institutions, including academic institutions, governmental and intergovernmental organisations, private organisations and NGOs. All types of scenario developers were included in the sampling frame in order to enlarge the diversity of perspectives as much as possible.

All 30 documents were initially scanned in order to get an overview of the purpose, method and results of every scenario. Since not all of them could be studied in detail, a few had to be selected for in-depth review. The selected scenarios represent a diversity of methodological approaches according to the typologies of Hughes and Strachan (2010) and Börjesson et al. (2006). A balanced number of technical feasibility studies, model based studies and trend based studies was selected, including also hybrids which do not easily fall into one of the three categories.

According to Hughes and Strachan, the different methods have their strengths and weaknesses with regard to their usefulness as policy tools. A hypothesis in this study was that methodology can be a limiting factor in the handling of planetary boundaries, social foundations and economic growth (BFG).

The scenarios published by intergovernmental and governmental institutions were selected immediately. These bodies have been assigned by governments to research energy and climate policy and should thus be expected to treat these issues and their effects on other policy areas extensively and exhaustively. These included IPCC, IEA-NETP, IEA-RECM and Åkerman. The Milestad, Gustavsson, Neuvonen and Markandya scenarios were selected because they used diverse methodologies and brought uniue perspectives on land use, biodiversity, life-styles, social equity and other aspects of sustainable development.

A number of scenarios initially studied which handled only technical aspects of climate trajectories in the energy system were dismissed because they did not add much new in terms of handling of safe and just space for humanity, economic growth, purpose, scope or methodology. Many of them were inquiry- and methodology-wise very similar to the Gustavsson and IEA-NETP scenarios. Excluding these scenarios resulted in a selection that was diverse both in methodologies applied and perspectives on BFG. Because of this, the scenarios in this study treat BFG more frequently than a complete or randomised study of ESCs would.

Various other scenarios were excluded because they were not explicit energy and climate scenarios or because they handled other countries than Sweden. Various scenarios were energy scenarios which did not focus specifically on greenhouse gas emissions. Others were general socio-economic scenarios which only peripherally treated low-carbon futures. Although they have new perspectives on sustainability, which are an interesting topic for further research, they fall out of the scope of the present study.

The selected scenarios are shortly described in the following chapter.

3. Description of selected scenarios

This chapter describes the purpose, methods and short descriptions of the scenario outcomes and trajectories in the selected scenarios. An overview of the methodologies employed by the scenarios is presented in table 1. Descriptions of the scenarios are presented in table 2 and 3.

Table 1. Overview of methodologies employed by the scenarios.

Scenario	Type (Hughes et al.'s typology)	Type (Börjesson et al.'s typology)
Milestad et al. (2014)	Trend based	Explorative/Backcasting hybrid
Neuvonen et al. (2014)	Trend based	Explorative/Backcasting hybrid
Åkerman et al. (2007)	Technical feasibility/Trend based	Explorative/Backcasting hybrid
Gustavsson et al. (2011)	Model-based	Normative/Preserving
IEA-NETP (2013a)	Model-based	Normative/Preserving
IEA-RECM (2013b)	Model-based	Normative-preserving/What-if
Markandya et al. (2014)	Model-based/Trend based	Explorative/Normative-preserving
IPCC (2014)	Model-based	Explorative of a variety of parameters. Three-dimentional matrix architecture

Six of the selected scenarios have an end point carbon constraint. In IEA-RECM the scope is short term, looking at how to break the existing trend of rising rates of greenhouse gas emissions. The IPCC scenario explores an array of pathways reaching different climate outcomes.

Three scenarios (Milestad, Neuvonen and Åkerman) explore low-carbon futures under different societal trends. They illustrate different pathways with regard to climate change because of diverging developments in the economic and social spheres. The Neuvonen scenario expands the definition of a low carbon future to include material footprint in general. They are however all primarily concerned with climate policies and low carbon futures.

Three of the scenarios (Milestad, Neuvonen and Åkerman) are backcasting studies. They all have an end point constraint on greenhouse gas emissions or material use, while exploring how the target could be reached in different future contexts. Two of them (Milestad and Neuvonen) combine the backcasting with a trend based approach, exploring the trajectories under different external trends. Both above mentioned are qualitative scenarios. The Åkerman scenario is quantitative, while having well elaborated qualitative narratives and trajectories.

Five of the scenarios (IEA-NETP, Markandya, Gustavsson, IEA-RECM, IPCC) are model based. The first four use technical-economic models to study the technical composition of the energy system under different climate assumptions. They are normative scenarios, providing least-cost trajectories to their climate targets.

The IEA-RECM is only concerned with the most economically rational measures in the short term (2020) and does not have a normative component. Markandya combines the model based approach with a sort of trend based approach, studying different types of economic development. The IPCC scenario employs a three-dimensional matrix architecture in order to explore in detail an array of climate trajectories and their effects on different sustainability aspects.

There is a variety of time scopes in the studies included. IEA-RECM has the time scope to 2020, while most have the scope of 2050. One has 2060 in order to give the workshop participants enough distance from short term constraints to more freely develop alternative scenarios. IPCC has the time scope to 2100 although 2050 is an important checkpoint in the trajectories.

Four scenarios (Åkerman, IEA-NETP, IEA-RECM and IPCC) were ordered and published by governmental or intergovernmental organisations, although they were mostly developed by academic institutions. The other four were produced and published by academic institutions.

Table 2. Description of selected scenarios, part 1

Milestad, Svenfelt and Dreborg (2014) - Developing integrated explorative and normative scenarios: The case of future land use in a climate-neutral Sweden

Purpose: show how backcasting scenarios fulfilling far-reaching greenhouse gas reduction targets can be integrated with trend based studies on possible external developments, in order to contribute to the discussion on future land use.

Method: Qualitative assessment of different pathways to climate-neutral societies. The normative dimension of climate-neutral pathways has two separate trajectories (centralised or localised power). The contextual element is whether or not there is an international climate treaty.

Building blocks of the scenarios (which are combined to create the four scenarios):

No treaty characterised by: Energy from biomass, intensive forestry, road transport, energy crisis, severe CC	**Treaty** characterised by: investments in electricity prod., environmentally friendly forestry, rail transport of goods, stable world, less severe cc	**Localised power:** Multi-functional land use, small-scale food production, local self-sufficiency, population close to energy and food production	**Centralised powe**r: Differentiated land use, large-scale food prod., population in urban centres,

Neuvonen et al. (2014) - Low-carbon futures and sustainable lifestyles: A backcasting scenario approach.

Purpose: Assess everyday lifestyle changes in low carbon futures; the links between lifestyle and infrastructure, policy and technology.

Method: Qualitative assessment of pathways to low-carbon societies based on two dimensions, source of technological development (pandemic or endemic) and society's governing principle (meritocratic/human-centric)

Examples of characteristics of the four scenarios

Singular super champions(pandemic/meritocratic): Rising energy prices, urbanisation, less spent on mobility, global data (apps for personal informatics etc.) EU-level green new deal.	**Governing the commons** (pandemic/human-centric): Digital reality, online networks, 3D printers, flexible notion of work, wikidemocracy,	**Local loops** (endemic/meritocratic): local and regional production cycles, user-centred design, local adaptation, working hubs, guilds, self sufficiency.	**Empathetic communities (endemic/human-centred):** local experiments with energy and food production, peer-to-peer service provision, sharing, Do-it-yourself, reduction in material expenditure.

Åkerman et al. (2007) - Two degree target in reach? (Tvågradersmålet I sikte?)

Purpose: To present scenarios for the energy and transport system which all meet the global two degree target for climate change, identify trend breaks which are necessary to reach the emission target and discusses necessary changes in planning and decision making.

Method: Quantitative and qualitative assessment of pathways to low-carbon Sweden. Technologically detailed with well developed narratives and trajectories. Two dimensions; (1) Energy supply (high/low global supply of bio-energy) and (2) behaviour (material consumption, service consumption, 30 hour working week).

Scenarios: Five scenarios describing alternative behaviour/everyday life in different consumption and production regimes which all meet the target of 85% GHG emission reduction in 2050, including overseas travel. The high bio-energy scenarios have higher energy use and fewer investments in electricity production then the low bio scenarios. The material consumption scenarios prefer car use, while the service consumption scenarios prefer overseas air travel. Slow pace scenario is a low bio scenario with localised lifestyles.

Gustavsson et al. (2011) – Energy scenario for Sweden 2050

Purpose: Develop a scenario with close to 100% of the energy by renewable sources, produced with a high level of environmental concern and within the carrying capacity of the ecosystems.

Method: Model based study with a high degree of technical detail. After development of the scenario trajectory, costs of the transition are assessed.

Scenarios: Only one scenario. Large expansion of wind and solar power. Nuclear power is phased out after 2030. Investments in bio-refineries connected to industries, producing bio-fuels. Large district heating system. Primary energy use is 65% of that in 2010.

Table 3. Description of selected scenarios, part 2

International Energy Agency (IEA) (2013a)– Nordic Energy Technology Perspectives (NETP)

Purpose: Demonstrate the feasibility of a carbon neutral Nordic energy system and to describe the technological developments and policies needed to achieve it. Carbon neutral: 85% emission reductions in 2050 and carbon credits to offset remaining emissions.

Method: Model based study, using the TIMES model to identify the least-cost path towards stated goals.

Scenarios: The Nordic Climate neutral scenario is compared with the less ambitious global 2-degree scenario and the 4-degree scenario in ETP 2012. The Climate neutral scenario also includes two special cases: a High bio energy scenario (more imports) and high electricity (more interconnected) scenario. Primary energy supply is 85% of that in 2010. Bio-energy is largest energy carrier. CCS and nuclear power are employed.

International Energy Agency (2013b) – Redrawing the Energy-Climate Map (RECM)

Purpose: Present policies for the near term (2020) to keep the 2 degree target alive, without harming economic growth in any country or region.

Method: Model based what-if forecast scenario.

Scenarios: Showing the benefits of four specific short term policies; Improving energy efficiency, limiting inefficient coal use in power, reducing upstream methane emissions and phasing out fossil fuel subsidies.

Other: Also assesses the policy recommendations for co-benefits with handling of local air pollution, energy security, energy poverty and economic growth.

Markandya et al. (2014) - Low climate stabilisation under diverse growth and convergence scenarios

Purpose: Assess global low carbon stabilisation in diverse economic futures, technical feasibility and economic viability of the scenarios. Assess effects on regional growth and costs of the low-carbon transition between the different scenarios and compared to baseline.

Method: Model based study. Four scenarios based on two dimensions; GDP growth (High/low) and global convergence of GDP (high/low). All reaching emission levels compatible with a 2 degree trajectory.

Scenarios: Climate target can be met in all scenarios, although easier in low growth scenarios. Cost is less than 2% of GDP in 2050, approximately a 1 year delay in global GDP growth over the period 2000–2050. The costs are lower in low growth scenarios, although they represent a higher portion of GDP in low growth scenarios.

IPCC Fifth Assessment Report (IPCC AR5 SYR (2014), IPCC AR5 WG3 Chapter 6 (2014), Van Vuuren et al. (2013), O'Neill et al. (2013), IIASA (n.d.)

Purpose: Explore the characteristics of different climate pathways and near term choices which define them. Hundreds of climate researchers from different disciplines contribute to develop a common scenario framework, a tool to explore and evaluate the uncertainties associated with possible future development pathways.

Method: Model based study. Three-dimensional scenario framework, consistsing of Representative Concentration Pathways (RCP), Shared Socio-economic Pathways (SSP) and Shared climate policy assumptions (SPA). The four Representative Concentration Pathways (RCP) represent different magnitudes and extents of climate change. The five Reference Shared Socio-economic Pathways (SSP) represent policy pathways with different degrees of socio-economic challenges to mitigation and adaptation. The SSPs incorporate all policy areas which are not directly related to climate change. These include social policy, economic policy, energy availability policy, health policy etc.

Scenarios: The SSPs have qualitative storylines and different quantitative estimates on GDP growth, population and urbanisation. The five narratives are called Sustainability, Middle of the road, Fragmentation, Inequality and Conventional development respectively. (IIASA, n.d.). The SSP scenarios relate to the Millennium Development Goals, which are achieved quickly in some scenarios while no progress is made in others.

Other: Against the RCP/SSP reference matrix, the climate policy assumptions are assessed and analysed. This allows the exploration of costs and trade-offs between mitigation and adaptation policies, as well as assessment of co-benefits and negative effects on social and environmental targets. Many of the planetary boundaries and social foundations are handled in the ample material. There is an extensive list of co-benefits and trade-offs of all identified climate policy measures. The complexity of the scenario framework allows for dynamic assessment of costs, trade-offs and co-effects but allows less overview of the different pathways.

4 Results

The results chapter presents an overview of how the scenarios treat planetary boundaries, social foundations and economic growth (BFG). It also presents an account of the ways the BFG are handled in the scenarios and of aspects of BFG not treated.

Firstly, in section 4.1 an overview is presented of the types of scenarios included in the study and whether or not they treat the BFG issues in any way. In section 4.2 a detailed account is presented on if and how the ECSs treat each one of the planetary boundaries. In the conclusion of section 4.2 the handling of planetary boundaries is summarised and possible consequences are discussed. Section 4.3 accounts for the handling of the social foundations in the same way as section 4.2 above. Section 4.4 accounts for how economic growth is treated by the scenarios, whether they made quantitative assumptions on gross domestic product (GDP) growth, qualitative assumptions on the drivers and components of growth, assumptions on qualitative change in economic activities and if they linked economic activities to planetary boundaries and social considerations.

An analysis of the integration of planetary boundaries, social foundations and economic growth in the ESCs is presented in the discussion (chapter 5)

4.1 Overview

Table 4 provides and overview of whether the scenarios treat any aspect of planetary boundaries, social foundations or economic growth in an explicit manner. Some of the planetary boundaries, social foundations and aspects of economic change are treated partially and peripherally by some scenarios. These are not marked in table 4. However, they are marked with an (x) in tables 5 and 7 and the treatment of them explained in tables 6, 8, 9 and 10.

Table 4. Overview of treatment of planetary boundaries, the social foundations and the economic growth.

Scenario	Planetary boundaries	Social foundations	Economic growth dynamics
Milestad & Svenfelt (2014)	Land use	Global equity	
Neuvonen et al. (2014)		Global equity	
Åkerman et al. (2007)	Biodiversity, fresh water	Global equity	
Gustavsson et al. (2011)	Biodiversity		
IEA-NETP (2013a)			
IEA-RECM (2013b)		Modern energy services	
Markandya et al. (2014)		Global equity	
IPCC (2014)	See table 5	See table 7	See table 10

Seven of the eight scenarios treat at least some aspect of planetary boundaries, social foundations or economic growth in an explicit manner. Various scenarios treat only one or two of the three aspects. One scenario treats all three of them exhaustively and one does not treat any of the three. Table 3 provides an overview of the typology of the studied and their treatment of the planetary boundaries, social foundations and economic growth.

The scenarios marked in table 3 for treating one or more of the BFG are treating at least one planetary boundary, social foundation or aspect of economic growth explicitly and exhaustively. For example, Neuvonen was not marked as treating planetary boundaries, although they have a normative constraint on material consumption. The reason is that this is not elaborated in the report. Another example is the Gustavsson scenario, which is marked for treating planetary boundaries because it has a normative approach regarding biodiversity with explicit assumptions. It is marked as treating planetary boundaries although it does not treat any planetary boundaries other than biodiversity.

The treatment of economic growth is difficult to categorise since all scenarios in some way relate to economic activities. The criteria finally set were that the scenario assesses the dynamics of production, consumption, productivity, investments and public spending. Only one scenario makes such an in-depth analysis. In sections 4.2-4.4 it is explained in detail how each scenario treats each aspect of the sustainability dimensions.

4.2 Planetary boundaries

Table 5 gives an overview of how the scenarios treat the planetary boundaries. Biodiversity was taken into consideration by three of the scenarios and land use by two. Biogeochemical flows (nitrogen and phosphorous) and chemical flows (novel entities) are partially and implicitly treated by two scenarios. Water use (hydrological cycle) is treated by one scenario and peripherally treated by another two scenarios. No other planetary boundaries are handled.

The IPCC is an exception in that it models the entire earth system, including other processes which interact with climate change, such as ocean acidification and aerosol loading.

The Neuvonen scenario expands the scope of the low carbon society to include a constraint on overall global material consumption, thus implicitly reducing stress on all planetary boundaries. The normative constraint is a material footprint of 10 ton per person and year. The quantitative details of this target and its consequences for the scenario narratives are not disclosed because the focus of the study is qualitative.

Table 5. Overview of whether the scenarios treat the planetary boundaries.

	Fresh water use and hydrological cycle	Nitrogen and phosphorus cycles	Ocean acidification	Chemical pollution	Atmospheric aerosol loading	Ozone depletion	Biodiversity loss	Land use change
Milestad et al. (2014)		(x)		(x)				x
Neuvonen et al. (2014)								
Åkerman et al. (2007)	(x)	(x)		(x)			x	
Gustavsson et al. (2011)							x	
IEA-NETP (2013a)								
IEA-RECM (2013b)	(x)							
Markandya et al. (2014)								
IPCC (2014)	x		x		x		x	x

Table 6. List of how the scenarios treat each planetary boundary.

	Biodiversity loss
Åkerman et al. (2007)	Considered an implicit limit to availability of bioenergy. Explored in the access to bio energy dimension because of uncertainty of availability.
Gustavsson et al. (2011)	Normative. Conservative estimates on biomass output because of environmental concerns. Higher conservation efforts. Lesser hydropower gives “increased natural capital”.
IPCC (2014)	Risks and impacts of future climate change on biodiversity are explored. Emissions from land use and bioenergy integrated into the models. Management of ecosystems included in the trajectories. Biodiversity is barrier for employment of bio-energy.
	Land use change
Milestad et al. (2014)	Explores land use in different trajectories to a climate neutral scenario. Unit scale, level of multi-functionality, external inputs and urban structures differ between the scenarios.
IPCC (2014)	Effects on greenhouse gas concentrations from land use change are explored. Also the effects of climate change on land use are explored. There are scenarios focus specifically on this. Mitigation measures in agriculture and forestry are included in the trajectories.
	Nitrogen and phosphorus cycles
Milestad et al. (2014)	Levels of fertilisers (external inputs in agriculture and forestry) peripherally assessed in the scenario outcome. The different scenarios have different levels of input intensity.
Åkerman et al. (2007)	Feasibility of fertilisers (inputs in agriculture and forestry) assessed in litterature study of potentials for bio-energy.
	Chemical pollution
Milestad et al. (2014)	Levels of pesticides and GM crops (external inputs in agriculture and forestry) peripherally assessed in the scenario outcome. The different scenarios have different levels of input intensity.
Åkerman et al. (2007)	Feasibility of inputs in agriculture and forestry assessed in litterature study of potentials for bio-energy.
	Fresh water use and hydrological cycle
Åkerman et al. (2007)	“Planning and management of agricultural practices necessary so water resources and biodiversity are not degraded” (p. 46). Water is limiting factor in food production.
IEA-RECM (2013b)	Assesses the effects of water scarcity (effect of climate change) on electricity production, fracking, coal production and refineries.
IPCC (2014)	Future climate change risks and impacts on water resources and quality, water security are modeled. Water scarcity is projected as well as floods and extreme precipitation. Co-benefits possible between Climate change, water, energy and land use.
	Ocean acidification
IPCC (2014)	Future levels of ocean acidification due to CO_2 emissions and effects on marine ecosystems are explored.
	Atmospheric aerosol loading
IPCC (2014)	Climate effects of aerosol emissions (cooling) are explored.

4.2.1 Biodiversity

Åkerman conducts a literature review of the global and local potential for bio-energy and finds that there are trade-offs between bio-energy production, food production, biodiversity and water use. Since it is difficult to assess how much bio-energy will be available in 2050, separate scenarios are developed for both high-access and low-access alternatives. This constraint affects the entire composition of the energy system and consumption patterns/behaviour in the scenarios. Even in the high access scenarios there is a limit to bio-energy availability.

Åkerman also notes that biodiversity is a constraint on how much land can be converted to new crop-land and that an out-take of biomass from the forests equivalent to the growth of the forests would probably not be acceptable with regard to biodiversity. Furthermore, urban planning for functional accessibility requires denser cities, but risks fragmenting urban green areas and harming biodiversity.

Also Gustavsson has a normative constraint on Swedish biomass output which effects the energy system configuration, energy prices and consumption in the scenario. The constraint consists in setting aside more forest land for biodiversity conservation and employing less intense forestry methods compared to the study of bio-energy potential, due to biodiversity considerations. The Gustavsson scenario assumes a further increase of 3.5% in protected areas and another 7.5% of the total area to be used as continuous cover forestry compared to the Swedish Forest Agency's environment scenario.

IPCC explores the complex interaction between climate change and biodiversity, noting that increased efforts in climate mitigation and adaptation lead to increasing complexity in the interactions with ecosystems, while the tools to deal with the interactions are limited.

4.2.2 Land use

Milestad's inquiry is to explore land use in Sweden in different global policy contexts and low-carbon trajectories. Type of land use, scale of units, spatial distribution and intensity of land use is the output of the scenarios. All scenarios are constructed so the normative climate target will be met. Where there is no climate treaty, much of the energy use comes from biomass. In the case with a climate treaty, more investments are made in electricity production. A climate treaty is assumed to lead to less intense forestry and reduced stress on forests. The localised power scenario assumes multi-functional land use and small scale production focused on local self-sufficiency both in food and bio-energy. The centralised power scenario assumes the reverse.

IPCC:s scenarios include greenhouse gas emissions from land use change. Part of the IPCC study focuses specifically on this and contains scenarios of future global land use transformation. Large transformations are expected in all of the scenarios. Larger transformations are expected for larger greenhouse gas mitigation. Bio-energy use and the potential employment of carbon capture and storage (CCS) are factors which strongly influence the scale of future land use change.

As noted above, according to Åkerman, biodiversity is a constraint on how much land can be converted to new crop-land. An out-take of biomass from the forests equivalent to the growth of the forests would probably not be acceptable with regard to biodiversity. Through their focus on biodiversity they deal implicitly with land use, without focusing specifically on it.

4.2.3 Nitrogen cycle, phosphorous cycle and chemical pollution

Some of Milestad's scenarios have high levels and others low levels of external input in agriculture and forestry. This refers to fertilisers, pesticides, machinery and novel seeds and breeds. Åkerman et al. assesses the feasibility of intensive agriculture (meaning primarily inputs of energy and fertilisers) in the literature study of potential for bio-energy. Scepticism is expressed about the feasibility of intensive agriculture in a world without cheap fossil fuels.

Fewer inputs of chemical fertilisers would reduce the stress on the biogeochemical flows boundary (nitrogen and phosphorous) and fewer inputs of pesticides and hybrid or genetically modified seeds would reduce the stress from novel entities (chemical pollution). Fertilisers are a substantial part of the total nutrient loading (Steffen et al, 2015) although industrial production, waste management and other sectors also contribute. Chemical pollution (novel entities) includes anthropogenic introduction of some chemicals, other types of engineered materials and organisms and naturally occurring elements accumulated through human activities (Steffen et al, 2015). None of this is explicitly assessed in the ESCs, since none of the scenarios has explicitly focused on the nitrogen and phosphorous cycle and chemical pollution.

4.2.4 Fresh water consumption and the hydrological cycle

Water use is handled by IPCC, IEA-RECM and Åkerman. IPCC studies the effects of the climate policies on the water security. Co-benefits and side effects are assessed. According to IPCC, Solar, wind and ocean power would reduce fresh water withdrawals for thermal cooling while CCS would demand large amounts of water. For bio-energy and land use, it depends on practices. The latter statement is seconded by a comment in Åkerman, who recognises water as a limiting factor in food production and recommends careful planning and management of agricultural practices in order to not degrade water resources.

IEA-RECM handles how the energy system is impacted by climate change, noting that water stress might impede coal and shale gas extraction and thermal power-plant operations. The stress that the energy production causes on the hydrological cycle is not assessed but it is clear that the energy system will have to adapt because of changes in the hydrological cycle.

Fresh water is identified by Åkerman as a limiting factor in the global food production, both in industrial and low input production. Åkerman states that intensive cultivation of energy crops would increase evaporation transpiration and aggravate water scarcity in already dry regions. In areas where the water board is too high because of excessive irrigation it would be a good idea to switch from one year crops to perennial energy crops with longer root systems. These could in turn limit erosion and nutrient leakage, increase soil quality and even clean sewage water.

4.2.5 Other planetary boundaries

Ocean acidification and atmospheric aerosol loading are integrated in the IPCC climate models because of the interconnection between these three planetary boundaries. The fifth assessment synthesis report which gives an overview of the conclusions of the climate change research explores levels of CO_2 absorbed by the oceans and future risks from ocean acidification in different climate trajectories.

Except for the examples above, ocean acidification, atmospheric aerosol loading and ozone depletion are not treated by any of the scenarios.

4.2.6 Summary planetary boundaries

As described above, biodiversity was taken into consideration by three of the scenarios and land use by two. Biodiversity has been considered a normative constraint on bio-energy potentials and land use by two scenarios. Land use change has been explored to assess the effects on sustanability. Biogeochemical flows (nitrogen and phosphorous) and chemical flows (novel entities) are partially and implicitly treated by two scenarios. Water use (hydrological cycle) is treated by one scenario and peripherally treated by another two scenarios.

There are also examples of scenarios which put a general constraint on material resource use, whether materials in general, energy or fossil fuels. These can be assumed to decrease pressure on the planetary boundaries, although it is rarely specified how and in which sectors. Three scenarios do not treat planetary boundaries at all.

The planetary boundaries mostly treated are precisely the ones which are already transgressed (climate change, biodiversity, land system change and nitrogen and phosphorous). Furthermore, the connection between these planetary boundaries and the social foundation of the right to food is considered by three scenarios.

Many aspects of planetary boundaries are not handled. Most of the considerations of the planetary boundaries are related to the agriculture and forestry sector. However, very little attention is paid to the industrial sector and material consumption. Basic industry and manufacturing are causing substantial stress on the planetary boundaries through the use and disposal of chemicals, hazardous substances, landscape change and emissions of aerosols (i.e. carbon and sulphur, which change the atmospheric processes and cause acidification). It would be beneficial if ESCs would quantify methods and amounts of different material production in the scenarios, in order to assess their social and environmental impacts. In various scenarios industrial production is assessed and its energy use included in the scenarios. However, environmental impacts are not assessed.

Likewise, many scenarios do not treat the agriculture and forestry sectors explicitly and therefore miss treating biodiversity and land use concerns. Also in the agroforestry sector it would be beneficial to quantify methods and outputs in order to assess their social-environmental impacts and trajectories towards the outcome.

4.3 The social foundation

Six of the scenarios are treating at least one of the social foundations in some way (table 7). Only the Gustavsson and IEA-NETP scenarios do not treat them at all. Food security, social equity, water and sanitation, education, modern energy services and resilience to shocks (related to energy security) have been treated by at least one scenario, most of them by IPCC.

The IPCC body of scenarios stands out with an extensive treatment of the social foundations. Through their attempt to fully embed their climate scenarios in the framework of sustainability, they have assessed (at least superficially) the effects on social foundations of climate change, mitigation measures and adaptation measures. Global social equity is the only social foundation which was treated in detail (normatively or explored in derail) by any of the other scenarios (except IPCC).

The findings are presented in table 7. When a social boundary has been explored in detail or as a normative assumption, it has been marked with an x. When scenarios have only partially or superficially treated an aspect of a social boundary it has been marked with (x). Table 8 and 9 explain how the social foundations have been handled by the scenarios.

Table 7. Overview of wether the scenarios treat social foundations.

	Food security	Adequate income	Improved water and sanitation	Health care	Education	Decent work	Modern energy services	Resilience to shocks	Gender equality	Social equity (global)	Political voice (local equity)
Milestad et al. (2014)	(x)									x	(x)
Neuvonen et al. (2014)	(x)			(x)	(x)	(x)				x	
Åkerman et al. (2007)	(x)					(x)	(x)			x	
Gustavsson et al. (2011)											
IEA-NETP (2013a)											
IEA-RECM (2013b)				(x)			(x)	(x)			
Markandya et al. (2014)										x	
IPCC (2014)	x	(x)	x	x	x	(x)	x	x	(x)	x	(x)

Table 8. List of how the scenarios treat each social foundation part 1

	Food security
Milestad et al. (2014)	Food-bioenergy conflict explored. Large scale agriculture vs local multi-functional production.
Neuvonen et al. (2014)	Food is locally produced in various scenarios. “Environmentally rational diets”.
Åkerman et al. (2007)	Global food access considered a limiting factor on the access to bio-energy. Food production is prioritised.
IPCC (2014)	Climate change can undermine food security through decreasing fish stocks and decreased harvests of wheat, rice and maize in tropical regions. Food management is important aspect of climate adaptation.
	Adequate income
IPCC (2014)	Inequality globally and within countries part of SSP narratives. Rapid growth in low-income countries assumed to reduce poverty in those countries.
	Improved water and sanitation
IPCC (2014)	Water storage, storm and wastewater management, municipal water management programs, water saving technologies etc. are aspects of climate adaptation. Climate change increases water insecurity.
	Health care
Neuvonen et al. (2014)	Health is a community issue in one scenario. Another scenario includes “healthy local food”.
Åkerman et al. (2007)	Industrial agriculture potentially creates resistant diseases. Less animal product consumption driven by health concerns.
IEA-RECM (2013b)	Health effects of coal power assessed. Tied to pollution control costs
IPCC (2014)	Climate change will exacerbate health problems that already exist. Assesses effects of climate change on air pollution. Healthcare is a key aspect of climate adaptation. Mitigation measures are assessed for their health impact. Many measures have the co-benefit of reduced air pollution.
	Education
Neuvonen et al. (2014)	One scenario: Everyone has access to basic education, learning and knowledge. Leisure time is spent on learning and education that is self-centered yet pragmatic.
IPCC (2014)	Education levels directly tied to population growth assumptions.
	Decent work
Milestad et al. (2014)	Scenarios include: Land reform, self sufficiency, labour intensive agriculture.
Neuvonen et al. (2014)	Scenarios include mentioning of: “flexible notion of work”, “work has a special value, partly because local value chains are very visible”
Åkerman et al. (2007)	Explores changed attitudes towards work. Fewer hours. Other meaning of work
IPCC (2014)	Effects of climate trajectories on employment assessed peripheally.

Table 9. List of how the scenarios treat each social foundation, part 2.

	Modern energy services
Åkerman et al. (2007)	Global equity is assumed in access to energy. No mentioning of global access to energy services.
IEA-RECM (2013b)	Notes trade-off between phasing out fossil fuel subsidies and access to modern energy services for the poor.
IPCC (2014)	Climate change policies could raise energy prices and hamper energy access for the poor. Fuel poverty is alleviated through energy efficiency and equitable access to mobility.
	Resilience to shocks
IEA-RECM (2013b)	Effects of the 4-for-2 scenario on energy security assessed. Leads to lower imports of fossil fuels.
IPCC (2014)	Climate-resilient pathways for sustainable development are explored. They include i.e. climate mitigation and adaptation, social protection, disaster risk management and economic diversification.
	Gender equality
IPCC (2014)	Access to water is subject to gender discrimination (SYR). “multi-dimensional inequalities such as gender, class, ethnicity, age, and (dis)ability” (IPCC, 2014x, p. 70)
	Social equity
Milestad et al. (2014)	Carbon neutral target includes carbon footprint - equal global per capita emissions.
Neuvonen et al. (2014)	Globally equal per capita material consumption.
Åkerman et al. (2007)	Global equity is assumed in energy use and GHG emissions. Consequentially also consumption? Nothing explicit on the local level.
Markandya et al. (2014)	Explores global GDP convergence. Consequently income convergence? Considered necessary from political and social perspective. Reduction targets should differ between developed and developing countries for reasons of fairness.
IPCC (2014)	“Sustainable development and equity provides a basis for assessing climate policies” (IPCC, 2014b, p 76). Levels of international cooperation directly tied to income equality globally and within countries. Sustainability (SSP1) leads to most convergence. SSP4 is inequality scenario.
	Political voice/local social equity
Milestad et al. (2014)	Explored in the centralised/localised power dimension. Scenarios include involvement in decision making, fewer regulations and increased autonomy
IPCC (2014)	Reduction of inequality needed both globally and within economies. This is achieved through governance and institution strength.

4.3.1 Food

Åkerman's study of bio-energy potentials concludes that there competition over land use between food and energy production. They give priority to food production over bio-energy production, thereby creating a constraint on bio-energy availability. Because of global considerations, bio-energy is not imported. Rather, because Sweden has beneficial conditions for both food and bio-energy production, Sweden should be a net exporter of both. If the production of bio-energy is to be high, land for this production is to be freed by decreased consumption of animal products which have a high land use footprint. In this case, Sweden exports less bio-fuel.

All of Milestad's scenarios assume a drastically decreased consumption of milk and animal products. The scenarios with a climate treaty have a slightly smaller decrease than the others. In the “no climate treaty” case, much of the energy supply comes from biomass and in the case with a climate treaty from wind and solar electricity. In the discussion it is recognised that the former case would be negative for food availability and a recommendation is issued for multifunctional land use with simultaneous production of food and bio-energy and cutting the consumption of meat.

Also Neuvonen and IPCC have scenarios which assume a relatively low level of consumption of animal products. Neuvonen has a scenario where “environmentally rational diets become mainstream” (p.73) and local multifunctional land use which is more work-intensive and less input-intensive. The Sustainability SSP (shared socioeconomic pathway) of the IPCC assumes a relatively low level of consumption of animal products as an aspect of a general shift in consumption patterns oriented towards low material growth and low energy intensity. IPCC also notes that climate change can undermine food security through disturbances in food production. Food storage and preservation facilities and food banks are examples of climate adaptation measures.

In conclusion, only the IPCC treats eradication of hunger and global food security. No other scenario focuses on how food supply chains can be managed to ensure a secure food supply. Food consumption patterns and environmental impacts of food production are treated by four scenarios. The most important measure is decreased consumption of meat and dairy products. Also, Milestad is treating increased access to land in Sweden (see 4.3.4).

4.3.2 Social equity (global)

Five scenarios are here considered to have treated global social equity, because they have either explored global convergence of incomes or assumed globally equal resource use. Whether this is enough to say that global social equity has been taken into account is an open question. None of the scenarios has defined social equity explicitly, nor do they treat poverty reduction, income convergence or equitable trade explicitly.

To IPCC, “Sustainable development and equity provide a basis for assessing climate policies. Limiting the effects of climate change is necessary to achieve sustainable development and equity, including poverty eradication.” (IPCC, 2014b, p 76). Their SSP scenarios have different rates of development in low-income countries resulting in different levels of reduction of poverty and inequality, both globally and within economies. Markandya's scenarios study effects of global GDP convergence between countries because this is considered politically and socially necessary. Markandya also assumes a fair distribution of the burden for climate mitigation.

Global social equity is also applied in some ECSs treating only Sweden. Åkerman's normative constraint that global energy use per capita is principally equal produces a more radical transformation of the Swedish energy system and more energy is exported than would otherwise be the case. The beneficial conditions for hydro-power and bio-energy in Sweden are assumed to benefit the global community, not only the Swedish. The Swedish energy use per capita is only marginally higher than the global because of the costs for transmission and transportation of energy. Also Milestad applies a global perspective, in that the climate target assumes globally equal per capita emissions, including imported goods and overseas travel. Furthermore, Neuvonen's constraint on per capita material use is placed on a level which is globally equitable, not only in terms of energy use but consumption in general.

As a contrast, Gustavsson only makes future projections of demand and efficiency improvements in

Sweden. The end point per capita energy use is much higher than Åkerman et al's, which is not globally equitable according to the analysis of Åkerman et al.

4.3.3 Political voice

Political voice is here defined as social equity, income equity, democracy at the local level and equality in political participation. All of the qualitative scenarios in this study treat these issues, although in different ways.

Milestad et al. explores local democracy in the trends concerning centralised/localised power. The localised power scenario assumes greater citizen involvement in decision making, fewer state regulations and authorities and increased local autonomy. Land reform gives more access to land and more people move to the countryside. Also Neuvonen handles local social structures in the scenario narrative, describing a redefinition of the foundations of well-being, intense local collaboration and sharing in guilds with strong focus on the local community, local services and social life.

IPCC mentions in the SSP narratives that development has to reduce inequality both globally and within economies (IIASA, n.d, p. 1). Governance, institutional strength, international cooperation and consensus are assumed necessary for inequality reduction. This is however not further explained. None of the other model based scenarios handle political voice on a local, qualitative level. Possibly, part of the explanation for this lies in the models, which focus on technical and economic structures. They do naturally capture behavioural and social structures.

4.3.4 Gender equality

Gender equality is not handled by any of the scenarios. None of the scenarios have made any assumptions or targets regarding gender equality nor have they assessed their scenario outcomes for effects on women and men respectively. The IPCC only notes that vulnerability and exposure to climate change arise from "multi-dimensional inequalities such as gender, class, ethnicity, age, and (dis)ability" (IPCC, 2014b, p. 70), but does not assess this further.

4.3.5 Adequate income

Adequate income is related to the socio-economical equity described in the political voice section above and to economic growth (consumption) described in section 4.4. No scenario treats adequate income specifically in the sense of wages or social protection for unemployed. However, the ways the scenarios treat poverty is described here.

The IPCC SSP scenarios assume different levels of inequality, both globally and within countries. The Sustainability scenario assumes rapid economic growth in low-income countries which reduces the number of people below the poverty line. On the other side of the spectrum is the Inequality scenario.

4.3.6 Decent work

No scenario specifically treats employment and labour rights. However, the effect on employment of climate mitigation and changed attitudes towards work are treated peripherally.

IPCC handles effects of climate change policy scenarios on employment. Investments in renewable energy, energy efficiency and building retrofitting could create employment. Compact urban form and modal shift in the transport sector would give more equitable mobility access to employment opportunities.

Åkerman, Neuvonen and to some extent Milestad explore changed attitudes towards work. One of Åkerman's scenarios assumes a generalised 30 hour working week and a different meaning of work compared to today. More time is spent on service production for own benefit and increased satisfaction in the own work causes less stress. Also Milestad explores other forms of employment and work than mainstream today. This is related to the productivity aspect of economic growth. See chapter 4.4 for a deeper analysis.

4.3.7 Modern energy services

The IEA-RECM scenario proposes to phase out fossil fuel subsidies but notes that they are often intended to improve access to modern energy services for the poor. However, only 8% of the subsidies reach the poorest income group. The conclusion is that the subsidies are not effective. The IEA-RECM also references the UN Sustainable Energy for all (SE4ALL) programme which is intended to provide universal access to modern energy services. The IEA 4-for-2 scenario is assessed to benefit the energy intensity and renewable energy targets of the SE4ALL, although there is no note on supplying modern energy services to the under-served.

Similarly, IPCC notes that a number of mitigation policies in their scenarios raise the prices of energy services and could hamper the ability of societies to expand access to modern energy services. The potential side effects could be avoided through complementary policies such as income tax rebates or other benefit transfer mechanisms. Energy efficiency measures in the housing sector are assumed to reduce poverty. Urban planning measures and modal shift gives a more equitable access to mobility.

As Åkerman assumes a principally equal global per capita energy use, it could imply that universal access to modern energy services should be achieved, although this is not specified or elaborated on.

4.3.8 Resilience to shocks

According to the IPCC, climate-resilience demands a combination of mitigation and adaptation efforts which take into account the interaction between water, food, energy and biological carbon sequestration. Measures for resilience include insurance, social protection and disaster risk management. Also economic diversification and infrastructure investments may reduce vulnerability to climate induced stress. Mitigation scenarios reaching circa 450 to 500 ppm CO_2e show reduced costs for achieving energy security objectives with significant co-benefits for the resilience of the energy system.

The IEA-RECM has a section dealing with resilience in the energy sector, i.e. managing climate risks to the energy sector. Energy security is assumed to be benefited by reduced demand for fossil fuel imports.

4.3.9 Health care

IPCC identifies municipal services including water and sanitation, vaccination programmes, essential public health services and enhanced emergency medical services as examples of many approaches for managing the risk of climate change through adaptation. Healthi impacts of different climate mitigation measures are also assessed. Many measures have the co-benefit of reduced air pollution. Some measures carry risks of accidends and from waste treatment.

Both Neuvonen and Åkerman mention health consciousness as a driver toward a diet based on less dairy and meat products. In *Neuvonen's* Singular Super Champions scenario “environmentally rational diets become a mainstream lifestyle option”. In the Empathetic communities scenario health ceases to be an individual issue and becomes a communal one. Preventive healthcare is practised in workplaces and neighbourhoods. Policies built on scientific environmental and health objectives eliminate bad consumption choices.

The IEA-RECM scenario assesses the health impacts of energy related air pollution (emissions of particles and sulphur from fuel combustion) and the costs to control the pollution. The 4-for-2 scenario shows that renewable energy and climate abatement would reduce costs for pollution control and benefit health in some urban areas.

4.3.10 Improved water and sanitation

Only the IPCC treats water and sanitation, noting that climate change will increase water insecurity, aggravating water scarcity in many regions and reducing water quality in others. Climate adaptation measures include i.e. water storage, storm and wastewater management, municipal water management programs, water saving technologies. It is noted that water management also helps improve health, security and livelihoods in the near term.

4.3.11 Education

In the IPCC SSP scenarios education levels are directly tied to population growth assumptions. SSP1-2 assume high investments in education and low population growth while SSP3 and presumably also SSP4-5 assume the reverse. Education is also identified as a policy instrument in adaptation and mitigation efforts and lack of education and awareness as a constraint on the implementation of climate action.

Also Neuvonen focuses passingly on education in the scenario narratives of sustainable lifestyles. In the singular super champions scenario everyone has access to “basic education, learning and knowledge” and “leisure time is spent on learning and education that is self-centred yet pragmatic” (p. 72).

4.3.12 Summary social foundations

In summary, social foundations are treated very sparsely in the studied scenarios. Food security is only treated by the IPCC. Some aspects (consumption and food production practices) are handled also by Åkerman, Milestad, Neuvonen. The measure most discussed is decreased consumption of meat and dairy products. Also agricultural practices are handled by the same scenarios. Furthermore, access to land is handled by Milestad.

Five scenarios have handled social equity on a global level, either by exploring global convergence of incomes or assuming globally equal resource use. Åkerman, Milestad and Neuvonen have normative assumptions on equal per capita energy use or material use. Footprint perspective (emissions from imports included in the target) is applied by Milestad. Global convergence in economic output is explored by IPCC and Markandya. Local social equity and political voice is handled peripherally by Milestad and IPCC. Milestad explores local social structures with regard to some aspects of decision making, property and land use.

Modern energy services and resilience to shocks are handled only by the IPCC and partially by IEA-RECM. Similarly, access to health care and health effects of energy production are acknowledged by some scenarios but not assessed in detail. Changed attitudes towards health are treated by two of the qualitative scenarios. Education is handled by two scenarios, as a mean of accomplishing climate abatement and curbing population growth, and as changed attitudes towards education.

Two of the scenarios, Gustavsson and IEA-NETP, do not pay any attention to social foundations. They are both model based scenarios and focus mostly on techno-economic issues relating to low carbon futures.

The differences in how and how much the social foundations are treated by the scenarios seem to be related to the methodologies employed by the scenarios. The trend based scenarios with well-developed qualitative narratives handle social aspects to a higher extent. Model based scenarios operate more on a macro level and do not naturally capture these issues. IPCC is a special case, in being a model based scenario which does handle many of the social foundations.

4.4 Economic growth

This section presents how the studied scenarios treat economic growth. It is divided in subsections corresponding to different components of economic growth. First the scenario's quantitative assumptions on GDP growth rates are presented, followed by their assumptions on what is produced, how it is produced and how much. Next, the assumptions on household consumption are presented. Finally, assumptions on trade, GDP convergence and public spending are presented. The most central assumptions of the scenarios are presented in table 10.

Table 10. List of core assumptions on economic growth

	Assumptions on economic change	GDP growth assumption
Milestad et al. (2014)	Household economy as big as today or a bit smaller than today. Economy focused on consumption of local goods and services or national ones. Imports are heavily cut in all the scenarios. The localised power scenarios imply societal values which favour quality of life over material wealth.	No data
Neuvonen et al. (2014)	Guild-based economy (emphasis on craftmanship that encourages engagement, motivation and purpose of work), localised efficiency and innovation and Do-it-yourself practice. Work has a special value because of visible local value chains.	No data
Åkerman et al. (2007)	In one of the five scenarios people work fewer hours and consume less. People value own disposition of time and reduced stress. The informal economy grows and more work is for ones own purpose and benefit. Also in the other scenarios there is a lower supply of energy services and products than in the baseline scenario.	No data
Gustavsson et al. (2011)	Transport demand grows slower than current trends and pulp production declines due to lack of biomass.	2.2% p.a. in Sweden until 2050.
IEA-NETP (2013a)	Almost quadrupled economy in 2050. Transport demand and industrial growth is reduced compared to baseline GDP assumption. International trade in bio-energy assumed to increase. Nordic countries net importers in 2050 (13% of demand).	2.3% p.a. in Sweden until 2050
IEA-RECM (2013b)	Global GDP rate is 4.1% until 2020 in the 4-for-2 scenario. The actions in the 4-for-2 scenario are assumed to increase growth compared to the baseline “New Policies Scenario”. Proposed policies supposed to keep the 2 degree target alive while “not harming economic growth in any country or region” (p.10).	4.1% p.a. globally until 2020
Markandya et al. (2014)	Climate stabilisation more likely with modest economic growth. Abatement costs higher for low growth because they deminish slower than growth. Costs are circa 2% of GDP in 2050 – one year delay in annual growth.	Low growth=1.5% p.a. globally until 2050. Medium growth=2%
IPCC (2014)	3 different models make growth projections. In the 5 SSPs growth ranging from low to high, with different levels of global convergence. GDP rate in 2050 is 1-3% depending on SSP. In all 3 models the GDP rate declines and levels off from about 4% in 2015 to 0.3-2% in 2100 (Secure.iiasa.ac.at, 2015). Baseline assumptions are GDP growth. Mitigation only decreases consumption very marginally.	Circa 4% globally until 2020. 1-3% in 2050 depending on scenario. 0.3-2% in 2100.

4.4.1 Quantitative GDP growth rates

Gustavsson assumes a 2.2% GDP growth over the whole period, driven by large investments in energy efficiency improvement. *IEA-NETP* similarly assumes a 2.3% GDP growth in the Swedish economy over the whole period, which leads to an almost quadrupled economy in 2050.

The IEA-RECM assumes a 4.1% global GDP growth until 2020. The policies proposed in the 4-for-2 scenario of the RECM report are assumed to increase this growth compared to the baseline “New policies scenario”. A core assumption of the study was that the proposed policies do not harm economic growth in any country or region.

The IPCC scenario has five different growth rate curves, one for each socio-economic pathway (SSP). They assume a global GDP growth of about 4% in the nearest two decades. The growth rates decline to between 1 and 3% in 2050 and further to between 0.3 and 2% in 2100, depending on scenario and data source. The sustainability scenario has relatively high growth rates, although lower than the conventional development scenario.

Markandya et al. compare outcomes for 1.5% and 2% global GDP growth rate, with differing levels of global convergence of regional GDP rates.

Åkerman, Milestad, Neuvonen do not assume any quantitative growth rates. Instead they make many qualitative assumptions and have separate scenarios for cases with different types and quantities of production and consumption. They also explore different attitudes towards time and work and different types of organisation of production.

4.4.2 Production

The default assumption in the scenarios is often that production increases. Four of the model based scenarios (Gustavsson, IEA-NETP, IEA-RECM and Markandya) start from the assumption that production increases according to assumed GDP-growth rate (exogenous GDP-growth assumption) and then model the energy and industry sectors to reach certain climate targets. Little is assumed about Gross value added (the contribution to GDP of different production sectors) by different sectors.

The climate targets put constraints on how much the production can grow. The Åkerman scenario analyses the potential for energy efficiency and carbon reduction with baseline projections in the demand for energy services (Business-as-usual GDP growth assumptions). This “technical scenario” which employs all of today available potential for energy efficiency and fuel shifts reaches emission levels 190% higher than the target level for 2050.

Gustavsson assumes a 2.2% GDP growth over the whole period. They explicitly state that reduction of energy use should come about without a decrease in living standards or economic activity, through decoupling of energy use and economic growth. However, the growth in demand for transports and in the paper industry is assumed lower than this GDP assumption baseline. Without these mitigating assumptions, the climate target would not be reached.

The *IEA-NETP* similarly assumes a 2.3% GDP growth in the Swedish economy over the whole period, which leads to an almost quadrupled economy in 2050. However, transports are reduced by 4% compared to the default assumption and a further 20% are shifted from individual transport to bus and train. Industrial growth follows population growth instead of the much higher GDP growth. The authors are aware that the structure of the economy is likely to change substantially during the period, although this is not assessed.

4.4.3 Household consumption

As described above, Åkerman assumes that behavioural change, in other words reductions in demand for energy services, is necessary to reach the climate targets. Technological change is not enough. To meet this constraint Åkerman introduces two scenario drivers, material vs. service consumption. Among other differences, the material scenario prioritises car use while the service scenario prioritises overseas travelling by air. They both meet the same climate target, though both demands cannot be met simultaneously. Note that service consumption is not assumed to reduce emissions compared to material consumption.

In Milestad's scenario, household economy is as big as today or slightly smaller than today. It is focused on consumption of local goods and services or national ones. Imports are heavily cut in all the scenarios. The localised power scenarios imply societal values which favour quality of life over material wealth. Also the centralised power scenarios would need a change in values, stemming from global instability (of energy, climate and economy). However, these are only schematic narratives of the scenarios and it is not elaborated in more detail what types of changes in consumption are assumed.

The Åkerman, Milestad and Neuvonen scenarios handle different perspectives on time, work and quality of life, which reflects on levels of production and consumption, productivity and economic growth. This is also related to the social priorities decent work, adequate income and political voice (sections 4.3.4-6). Åkerman has one slow pace scenario where the work week is reduced to 30 hours and consumption is generally reduced. Part of the increased leisure time is spent on service production for own benefit ("egenarbete"). This leads to a bigger informal economy and slower GDP growth. On the other hand there is increased satisfaction in work for own benefit and reduced stress. Neuvonen's localised scenarios include notions of guild-based economy (emphasis on craftsmanship that encourages engagement, motivation and purpose of work), localised efficiency and innovation and Do-it-yourself practice. In Neuvonen's scenario, work has a special value because of visible local value chains.

4.4.4 Convergence of GDP

The Markandya and IPCC scenarios are studying global economic convergence through different growth rates in rich and poor regions. Milestad, Åkerman and Neuvonen only assume global equity as discussed in section 4.3.3.

The IPCCs qualitative scenario narratives handle qualitative aspects of the socio-economic development, as described in sections 4.3.3 and 4.3.5. There are qualitative elements of social equity and Millennium Development Goals connected to the growth rates in the different scenarios. The sustainability scenario assumes rapid development of low-income countries and reduction of poverty. In the middle of the road scenario development in low-income countries proceeds unevenly and in the inequality scenario continued divergence is assumed.

Markandya et al. do not make assumptions on the drivers of the growth and convergence scenarios. Instead they study the effects on climate mitigation in the scenarios. Their conclusion is that the overall level of GDP growth is more significant than the level of convergence for the costs of climate mitigation.

4.4.5 International trade

As described in section 4.4.2, the Milestad scenario is focused on consumption of local goods and services or national ones. International imports are heavily cut in all the scenarios. Also the

Åkerman and Neuvonen scenarios assume decreased consumption levels which could mean reduced imports. However, Åkerman only discusses reduced imports of bio-fuels and increased exports of bio-energy. Except for this, neither Åkerman nor Neuvonen discuss trade in further detail.

IPCC's SSP scenarios have examples of both low and high volumes of trade. The fragmentation scenario assumes deglobalisation and little international cooperation, which slows down economic growth in all regions. The sustainability and middle of the road scenarios assume an open, globalised economy and globally connected markets.

IEA-NETP assumes increased levels of international trade in bio-energy. The Nordic countries are assumed to import 13% of their demand in 2050.

4.4.6 Investments, financing and public spending

None of the scenarios discusses overall investment rates, nor general qualitative changes in investments or who is investing. However, there is some mentioning of investment in the energy system here and there.

The IPCC notes that the expansion of renewable energy, energy efficiency and building retrofitting could create employment but there is little discussion on net effects on employment.

Financing of the transition is rarely discussed in the scenarios. Only the Gustavsson and Markandya discuss the issue. Gustavsson states that “the expansion of the technologies could predominantly be made on market terms and not result in any significant public costs” (p. 82). The reason is that there is a net return on the investments needed. However there is no discussion on pay back times for these investments relative to other types of investments.

Markandya explores the costs needed for a 2°C stabilisation of the climate. Additional investments and rise of energy prices (abatement costs) are circa 2% of GDP in 2050 – a one year delay in annual GDP growth. It is more likely that the 2° target will be met with modest economic growth. However, abatement costs as percentage of GDP are higher for low growth cases because the costs increase slower than growth. An important caveat is that macroeconomic costs and welfare costs are not taken into account in the model. Markandya do not discuss who will carry the costs.

The role of public spending, weather for welfare services or public investments and public incomes is not discussed by any of the scenarios. However, Neuvonen does assume redefinitions of what is private and public in some of their scenarios.

4.4.7 Summary

Only one scenario (IPCC) treats the dynamics of economic growth. The four other scenarios which assume quantitative GDP growth rates usually assume on average 2-2.3% annual growth until 2050. Short term growth (until 2020) is assumed at circa 4%. The IPCC is the only scenario studying long term time frames (2100) and assumes continually decreasing growth rates.

Three scenarios (Milestad, Neuvonen and Åkerman) do not make any quantitative assumptions on GDP growth rates. Instead they make many qualitative assumptions and have separate scenarios for cases with different types and quantities of production and consumption. They also explore different attitudes towards time and work and different types of organisation of production.

Various scenarios conclude that forecasts of increasing demand for energy services and products cannot be met only with employment of new technology and energy efficiency available today. Behavioural shifts are also necessary.

Some scenarios are exploring these behavioural shifts. They are mostly qualitative trend-based scenarios. They assume a shift away from neoliberal values and explore other meanings of time, work and well-being. They often assume localised economies. This is consistent with Svenfelt's (2010) strategy for handling uncertainties in social-ecological systems through tightening feedback loops between society and ecosystems.

Also the IPCC has qualitative assumptions, exploring societal trends and loosely connecting them to the quantitative assumptions on GDP growth. This is a broader perspective on economic development than was found in the other model based scenarios. The IPCC relates levels of international cooperation and globalisation to economic growth levels. The speed of global economic convergence corresponds to different global GDP rates.

The Gustavsson, IEA-NETP, IEA-RECM and Markandya all use partial equilibrium energy models, which demand exogenous input assumptions on GDP growth rates. The assumptions are exogenous because the model does not include macro-economic functions, which capture the dynamics of growth (as general equilibrium models do). The GDP-rate is an external variable which determines the model output. Through these assumptions energy and consumption demands are modelled. They generally assume large increases in demand over the long time frames, and it becomes increasingly difficult to reconcile the demand with stringent climate targets as discussed in section 4.4.2 above.

However, many components of economic growth are not treated. None of the scenarios apply a clear macro-economic perspective and no scenario gives a detailed account of: what is produced, at what rates and how; what is imported and exported; what is consumed and by whom; which investments are made and how they are financed; what services and investments are public and how are they financed; and which institutions exist and what are they roles. As presented above, some scenarios give partial accounts for some of these questions, but many are partially or totally omitted.

5. Discussion

5.1 Treatment of connections between planetary boundaries, social foundations and economic growth

The results chapter has described the treatment of planetary boundaries, social foundations and economic growth separately. This section describes shortly how the connections between the three have been treated by the few scenarios which treat various aspects of BFG.

The Milestad, Neuvonen and Åkerman scenarios treat a variety of planetary boundaries and social foundations, although many of them superficially. All these three scenarios to some extent treat the connection between agricultural production, work, land use, biodiversity, water and food consumption. Every scenario treats only some aspects of this nexus and they do not treat them very explicitly and specifically. The little treatment that they have of economic change is qualitative. It handles demand through household consumption, productivity through aspects on work and international trade of specified goods.

To exemplify, the connections could be generally described like this:

Milestad et al. have scenarios with more input intense-agriculture and with more work-intense agriculture. The input intense agriculture puts more stress on the nitrogen and phosphorous cycles and chemical pollution, while work- and land intensive agriculture could put stress on land use and biodiversity. Increased demand for bio-energy puts more stress on the planetary boundaries. However, the demand could be mitigated by a shift to vegetarian food consumption.

The Åkerman scenario puts normative limits on bio-energy production because food production is considered a bigger social priority compared to bio-energy. The Milestad scenario explores new ways of organising agriculture. Examples are multi-functional agriculture where people live closer to the production and own their land. Through this solution, the environmental effects of land use and the food security foundation are connected also to decent work, adequate income and social equity (because more people become land owners).

The economic aspects of the bioenergy-food nexus are also implicitly treated by these scenarios in that international trade in food and bio-energy is curtailed. Through this, the issue is connected to global justice, in line with Hornborg's (2010) analysis that international trade involves unequal exchange of embodied energy and labour.

Also some connections between work, income, consumption/production, social equity and planetary boundaries are peripherally treated by narrative-based scenarios. For example, Neuvonen et al. explore these connections in the life-style based scenarios. In some of their scenarios, work has a different meaning than the today typical labour and there is more satisfaction in producing for the community. This is connected to community values where the produce is shared between the members of the community and many functions in life are a communal rather than a private matter. These perspectives on work and time thus connect to local democracy (community and sharing) and political voice.

Åkerman's scenario of a 30 hour working week is an example of how perspectives on work and time are connected to production, consumption and GDP. Åkerman assumes that production and consumption would decrease in the formal economy, while more work would be dedicated to informal, unpaid work in the household. However, Åkerman does not elaborate on how this would affect the economy. Questions arise about the effects this could have for unemployment, productivity and public income. Questions arise also about the social consequences of such a reform, for example in the areas of health, gender equality and public participation in decision making.

A more profound treatment of the connections between BFG could be made if theoretical and empirical research was studied in detail. One example of when this was done is Åkerman's feasibility study of bio-energy potentials and food production potentials, which emphasises the potential trade-offs and co-benefits or different choices.

5.2 Underexplored sustainability issues

The study of the ECSs revealed that except for the IPCC, quite many planetary boundaries, social foundations and aspects of economic growth were not treated by the scenarios. It also revealed that many implicit assumptions are made, weather knowingly without stating them or unknowingly. These assumptions are mostly about business as usual.

The IPCC handles most of the planetary boundaries, social foundations and dynamics of growth. However, adequate income, decent work, gender equality and political voice/local democracy are treated only peripherally even by the IPCC. Furthermore, no examples of explicit treatment of the nitrogen and phosphorous cycle, chemical pollution and ozone depletion have been found. The conclusions below refer to all the scenarios except for IPCC.

Most of the considerations of the planetary boundaries are related to the agriculture and forestry sector. However, very little attention is paid to the industrial sector and material consumption. Basic industry and manufacturing ought to be given more consideration, since they are causing substantial stress on the planetary boundaries through the use and disposal of chemicals, hazardous substances, landscape change and emissions of aerosols. The planetary boundaries ocean acidification, atmospheric aerosol loading and ozone depletion are not treated by any of the scenarios.

Many of the social foundations are virtually untreated or only partially treated. Eradication of hunger and food security is not treated by any of the scenarios, although some scenarios have assumptions on food production and consumption which might implicitly alleviate world hunger and improve food security. Water use is not extensively addressed although it is tightly related to i.e. food security, health and poverty reduction.

No scenario explicitly treats employment and labour rights. However, various scenarios treat different meanings of work. Resilience in other sectors than the energy system, i.a. ecosystem services, food security, natural or human-induced disasters, has not been addressed. Improved water and sanitation are not addressed. Gender equality is not handled by any of the scenarios. None of the scenarios have made any assumptions or targets regarding gender equality nor have they assessed their scenario outcomes for effects on women and men respectively.

Many components of economic growth are not treated by the studied scenarios. None of the scenarios apply a clear macro-economic perspective and no scenario gives a detailed account of what is produced, at what rates and how; what is imported and exported; what is consumed and by whom; which investments are made and how they are financed; what services and investments are public and how they are financed; and which institutions exist and what are they roles. As presented in chapter 4.4, some scenarios give partial accounts for some of these questions, but many are partially or totally omitted.

In conclusion, it seems that many sustainability issues of high importance for human well-being are underexplored in energy and climate scenarios.

5.3 Methodology and the treatment of BFG

It seems clear that the narrative-based backcasting scenarios have some perspectives on BFG although they do not often treat them specifically and explicitly.

On the other hand the three model-based scenarios IEA-NETP, IEA-RECM and Gustavsson barely treat any of the BFG. Gustavsson treats biodiversity as an isolated environmental issue. IEA-RECM mentions a conflict of aims between phasing out of fossil fuel subsidies and energy poverty without suggesting any solutions. All three just assume sustained GDP-growth without analysing it.

Markandya introduces social equity in their model-based scenario through a trend matrix of different growth rates and global growth convergence. However, this is the only aspect of BFG that is treated by Markandya.

The IPCC create a complex scenario architecture with the explicit purpose to study the sustainability effects of different climate trajectories. Consequently, they treat the majority of the BFG both qualitatively and quantitatively in their vast body of literature.

This suggests that explicit aim to embed ESCs in a sustainability and social equity context is necessary in order to properly treat the BFG. It is possible for ESCs to treat BFG in model based studies. However, qualitative narratives and a number of diverse trajectories are necessary. Treating BFG in ESCs easily becomes complex, time consuming and resource consuming.

5.4 Discussion on selection of scenarios

According to Hughes and Strachan (2010) and Söderholm et al. (2011) the vast majority of ECSs produced are technical feasibility studies focused only on technical energy and climate aspects.

16 out of 20 scenarios reviewed in Söderholm et al (2011) were quantitative studies. The majority were technology-rich models which focus on technological change to reach the climate targets (as oppose to social/behavioural change). They tend to focus more on supply-side technology than energy efficiency. Furthermore, in the majority of the cases, uniform prices on CO_2 are the main drivers for change (ibid), which implies that they subscribe to the neoclassical understanding of the economy. Overall, they ignore measures such as spatial planning and information/behavioural change. On the other hand, the qualitative scenarios in Söderholm et al. do focus on politico-institutional contexts and provide insights on societal and governance aspects of the policy pathways.

In Hughes and Strachan's (2010) study of British and international low carbon scenarios, 17 out of 21 scenarios were focusing on the technical depiction of the energy system. According to Hughes and Strachan, “while many studies focus on technical energy system aspects, including several which also deal with economics of these systems, and others give greater attention to the social sphere, the literature in general lacks studies which make a serious attempt to integrate both societal and techno-economic issues.” (p. 6062). Only one scenario partially treats “natural” or non-energy climate related processes. Also they find, similarly to Söderholm et al, that trend-based studies allow for the exploration of cultural and social contexts and an actor-focus.

The findings of both Söderholm et al. And Hughes and Strachan are in line with the findings in the present study. The initial scan of 30 documents found that the majority were models and technical feasibility studies, dealing almost exclusively with the technical energy aspects of climate trajectories. They were methodology-wise very similar to the Gustavsson, IEA-NETP and to a large extent IEA-RECM. Very few indications of treatment of planetary boundaries, social foundations and economic change were found.

Thus, because various technically focused scenarios were omitted, the finally analysed scenarios had a diversity both in scenario methodologies applied and unique perspectives on planetary boundaries, social foundations and economic growth. It is important to bear in mind that the results in this study show a more frequent treatment of BFG than a complete or randomised study of ESCs would.

5.5 Further research

In order to be able to determine more robustly how Swedish and global ESCs treat BFG, more scenarios should be studied. More than 20 ESCs were found in the search in this study. However, because of time constraints, only eight scenarios were studied in detail.

In order to learn more about how BFG could be treated in ECS, it would be useful to study more general sustainability scenarios or socio-economic scenarios. For example the Sessa and Ricci (2014) scenario explores growth in different possible directions and paradigm shifts connected to the diverse socioeconomic and technological futures, and has some perspectives on BFG that were not found in the scenarios included in this study.

A more in-depth study of research on sustainability would have been beneficial for the analysis of the treatment of BFG and discussion about how ESCs could be developed with regard to BFG. Both a study of empirical research regarding the connections between planetary boundaries, social foundations and economic change and a study of different ontological perspectives on sustainability and BFG would have been beneficial.

Lastly, a deeper review of models employed in ECS and different modelling techniques could be used to make suggestions on how ECS models could better incorporate BFG. For example, it would be beneficial if ECSs would quantify methods and amounts of different material and agricultural production in the scenarios, in order to assess their social and environmental impacts. Furthermore, general equilibrium models are needed to capture the economic dynamics in ECS.

5.6 A note on design of energy and climate scenarios with regard to sustainability

According to Nick Hughes (2013), if an ESC is to be successful as policy tool it has to function on three levels: the technology-based, actor-based and value-based levels. It has to move between them and connect these three levels. Staying on the most obvious technical data level does not contribute to action.

Also Inayatullah (1998) proposes a multidimensional approach which “contextualises data (the predictive) with the meanings (the interpretive) we give them – and then locate these in various historical structures of power/knowledge – class, gender, varna and episteme (the critical)" (p. 387) According to Inayatullah, there are various "causal layers" of reality and ways of knowing. The first is the level of quantitative trends and problems. The second is concerned with their social causes, including economic, cultural, political and historic factors. The third is concerned with the structure and the discourse/worldview that supports and legitimises them.

It seems reasonable to assume that futures in line with the doughnut economy concept of a safe and just space for humanity require a large transformation of values, social structures and institutions regarding production and consumption, social-ecological relations and socio-economic relations. Yet, it seems that there have been no serious attempts to study transitions toward such societies.

The technologically focused preserving scenarios (Gustavsson, IEA-NETP, IEA-RECM and Markandya) make implicit assumptions that many contextual parameters are fixed. The future images are based on the same kind of social, economic and cultural structures as today (e.g. globalised market economy, nation states, representative democracy). Only policies which preserve the social structures on which contemporary society is based are explored. This substantially closes off the scope of possibilities available and does nothing to escape path dependency and long term lock-in of near term decisions (Unruh, 2000; Hughes, 2013). In Inayatullah's (1998) words, the future is colonised by dominant visions of the future.

The three qualitative backcasting scenarios operate more on a value based level. For example, they refrain from using the growth model and do not make explicit assumptions on growth rates. Instead they make qualitative assumptions on a different meaning of work than today, of shorter working weeks and more valued spare time and of post-materialist values. However, only partial and superficial glimpses of organic/low-material futures are given, but no trajectories leading to a clearly defined safe and just space for humanity or sustainable economic development.

The key for avoiding path-dependency and lock-in in the scenarios is to combine qualitative backcasting/explorative approaches with quantitative modelling approaches as a way of addressing the multiple layers and thus providing trajectories which are both physically detailed and socio-economically reflective. Also, the treatment of planetary boundaries and social foundations and explore economic change needs to be part of the purpose of the scenario.

A challenge occurs when scenarios explore wider social, economic cultural and political connections (and ultimately world views which legitimise these assumptions). It is more difficult to legitimise the transformative trajectories to the scenario users. For a scenario process to be meaningful as a policy tool the outcome has to seem plausible and desirable (Hughes, 2013). This is a more difficult task when the scenario outcomes diverge from hegemonic world views. When historic doxa are disregarded as guidance for the future trajectories, the space of possibilities broadens considerably. A new type of uncertainty emerges, that of ambiguity (Svenfelt, 2010) Different trajectories will be interpreted and valued differently by different scenario users. It is essential to involve many diverse stakeholders to participate in the scenario development and to reach a common understanding and agreement about the trajectories.

Possible reasons that so many scenarios stay on the superficial data level is that a more profound approach drastically increases the complexity of the scenarios, making it more time consuming to develop them and making them much more difficult to communicate, as for example van Vuuren et al. (2013) notes. Furthermore, preserving scenarios might be more easily digested by the energy expert and decision maker community, since they are based on contemporary social and economic structures. They do not challenge entrenched worldviews.

5.7 Conclusion

To summarise, it seems that most energy and climate scenarios focus only on technological energy aspects of climate change and do not handle planetary boundaries and social foundations. The ones which handle them treat only a few of them and often only partially. Undertreated planetary boundaries are i.e. water cycle and chemical pollution. Undertreated social foundations are i.e. water use, gender equality, health and resilience to shocks. By not treating planetary boundaries, the scenarios risk leading to uninformed policies which miss sustainability targets.

Economic change is treated only partially and peripherally. Three of the scenarios assume sustained GDP growth rates many decades ahead, although this assumption makes it increasingly difficult to reach low-carbon climate targets. Most of the scenarios do not explore growth dynamics such as productivity, consumption, investments and public spending.

Qualitative trend-based studies seem to treat planetary boundaries, social foundations and economic change to a higher extent. However, they often lack detail in the descriptions of outcomes and trajectories. Model based, technology-rich scenarios of the preserving type barely treat planetary boundaries and social foundations. They also usually assume that socio-economic development will continue as today. Because of this they risk reproducing path-dependency and techno-institutional lock-in.

In order to avoid path-dependency, lock-ins and missing sustainability targets, scenarios should to a higher extent incorporate planetary boundaries, social foundations and a critical perspective on economic change in their inquiries. They should also combine the different methodologies. Combining the quantitative technology-based perspective with the socio-technical actor-based and the critical value-based perspective would produce more robust and politically tractable scenarios. Inclusive and deliberative development processes are crucial for success.

“In futures studies, the question of what you (as individual or as representative of your civilization) desire the future to be like is pivotal. This is especially so if one wishes to explore layers of responses, decolonize dominant visions of the future, and create authentic alternative futures. And if this is all too much, there is always statistics and other fantasies to fall back on. “ - Inayatullah, 1998

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