Student thesis series INES nr 331

Estimation of Cropland Ecological Footprint within Danish Climate Commissions 2050 Scenarios for Land use and Bioenergy Consumption

Andrew Ekoka Mwambo

2015
Department of
Physical Geography and Ecosystems Science
Lund University
Sölvegatan 12
S-223 62 Lund

Andrew Ekoka Mwambo (2015). *Estimation of Cropland Ecological Footprint within Danish Climate Commissions 2050 Scenarios for Land use and Bioenergy Consumption*

Master's degree thesis, 30 credits in Physical Geography and Ecosystems Analysis

Department of Physical Geography and Ecosystems Science, Lund University

Level: Master of Science (MSc)

Course duration: *September* 2013 until *January* 2014

Disclaimer

Estimation of Cropland Ecological Footprint within Danish Climate Commissions 2050 Scenarios for Land use and Bioenergy Consumption

Author: Andrew Ekoka Mwambo

ekoka37@yahoo.fr

Master thesis, 30 credits in Physical Geography and Ecosystem Analysis
Submitted 27 January 2015

Supervisors

Per Bodin
Department of Physical Geography and Ecosystem Science
Lund University Sweden

Marianne Thomsen
Danish Center for Environment and Energy
Aarhus University Denmark

Pia Frederiksen
Danish Center for Environment and Energy
Aarhus University Denmark

Exam Committee

Mats Lindeskog
Department of Physical Geography and Ecosystem Science
Lund University Sweden

Harry Lankreijer
Department of Physical Geography and Ecosystem Science
Lund University Sweden

Abstract

The ecological footprint of Denmark has been rising since (and likely even before) 1961, which signifies an unsustainable living by the Danish population. Global footprint reports show Denmark as one of many countries on earth which has exceeded its biocapacity (BC), which means natural resource consumption in Denmark is faster than the land's regenerative capacity. The residents of Denmark are consuming more than the BC locally available for the population. We would need a land area equivalent to the size of 4.51 planets (Earth) in 2008, if the world's population lived in the same way as the Danish population. The Global Footprint Network suggest that, the life styles in Denmark, with respect to natural resource consumption needs to be changed in order to reduce footprints. In response to Denmark's GHG emission problems, the Danish government formed a Climate Commission which was engaged in cutting down GHG emissions, by phasing out fossil fuels from the Danish national energy consumption by 2050. Fossil energy carriers (Coal, Oil and Gas) constitutes about 75% of the total Danish energy supply and these will be replaced by CO_2 neutral renewable energy sources (wind energy, bioenergy and solar power). The Climate Commission's proposals on how Denmark can phase out fossil fuels within the vision of the Danish government are in the form of policy scenarios aimed for 2050. The sustainability implications of implementing the Climate Commissions policy scenarios for 2050 are not yet known. Thus in this research, the ecological footprint methodology, which tracks human demand on natural resources, was used to assess some underlying sustainability implications with respect to cropland demand which may arise due to the implementation of these scenarios. A sequence of steps was then formulated to assess changes in the sizes of cropland Ecological Deficit (ED), Ecological Overshoot (EO), Ecological Remainder (ER) and Ecological Trade Deficit (ETD) within the scenarios. This research is focused on the Climate Commission land use scenario and bioenergy consumption scenarios, including one "Ambitious" and one "Unambitious" scenario. The research aim and objective is to estimate the size of Danish cropland ED, EO and ETD by 2050. If a scenario is able to decrease ED, EO, ETD and unsustainable cropland intensification while sustaining food crop production, then it can be termed sustainable. The role of drivers in influencing cropland footprint of consumption patterns (EFc) were analysed using the STIRPAT model. Results show that, Danish historic EFc patterns had an increase in ED, Ecological Remainder (ER) and ETD from 1988 to 2008. The size of Danish cropland BC from 2013 reduced slightly under the land use scenario producing an ED, EO, and ETD at 2050 lower than that of 2013. The ED, EO and ETD from the "Ambitious" scenario with biomass had a lower value compared with the land use scenario. The "Ambitious" scenario without biomass had no effect on cropland ED, EO and ETD. The ED, EO, and ETD values from the "Unambitious" scenario were higher than that of the land use, and "Ambitious" scenarios. STIRPAT model results suggests GDP per Capita and quadratic GDP per Capita as the most important influential EFc drivers, as opposed to Danish Population, for the time period 1988-2008. The "Ambitious" scenario without biomass emerged as the best scenario to achieve a sustainable Danish living. The footprint methodology does not take into account cropland intensification or any environmental pressure which may be associated with rising ED, EO and ETD

Keywords: Biocapacity, Ecological Deficit, Ecological Overshoot, Ecological Remainder, Ecological Trade Deficit, Global Footprint Network, STIRPAT Model

Acknowledgements

This thesis “Estimation of Cropland Ecological Footprint within Danish Climate Commissions 2050 Scenarios for Land use and Bioenergy Consumption” which is submitted in partial fulfilment of the requirements of Lund University Master’s Programme in Physical Geography and Ecosystem Science, was written in conjunction with the Danish Center for Environment and Energy-Aarhus University Roskilde Denmark.

I am so grateful for the opportunity given to me by Marianne Thomsen to work on this project. I would like to thank all my supervisors, who kept on guiding me from the very beginning until the end of the writing. Marianne Thomsen and Pia Fredriksen thank you for always taking the time to help me and thanks for all the feedback and advice you gave me throughout. Special thanks to Per Bodin, who has been a great supervisor, providing me with valuable advice, brainstorming discussions and encouragement. Thanks also to Harry Lankreijer for comments on the project proposal and the planning of the project.

Finally, I deeply appreciate the efforts of my family and friends, for all their support towards my studies.

Table of Contents

List of Figures

List of Tables

Acronyms, Abbreviations and Units

An	National available bioproductive Area (ha)
Aw	World equivalent of An (wha)
BC	Biocapacity (ha at country level; gha at global level)
CE	Crop Extract (t DW/t pr)
CIA	Central Intelligence Agency
CP	Copenhagen Post
DCCCP	Danish Commission for Climate Change Policy
DI	Danish immigration
DK	Denmark
DKK	Danish Krone
DMCE	Danish Ministry of Climate and Energy
DMFAF	Danish Ministry for Food Agriculture and Fisheries
DPSIR	Driving force-Pressure-State-Impact- Response
DW	Dry weight
EEA	European Environmental Agency
E	Export (t)
ED	Ecological Deficit (gha per capita)
EE	Ecological Elasticity
EE_{II}	International Trade-Import Elasticity of Impact
EE_{IP}	Population Elasticity of Impact
EE_{IS}	Affluence Elasticity of Impact
EE_{IT}	Technology Elasticity of Impact
EF	Ecological Footprint (gha per capita)
EFc	Ecological Footprint of Consumption (gha per capita)
EFe	Ecological Footprint of Export (gha per capita)
EFi	Ecological Footprint of Import (gha per capita)
EFp	Ecological Footprint of Production (gha per capita)
EKC	Environmental Kuznets Curve
EO	Ecological Overshoot (gha per capita)
EQF	Equivalent Factor (gha/wha)
ETD	Ecological Trade Deficit (gha per capita)
EU	European Union
Eurostat	European Statistics
GDP	Gross Domestic Product
GFN	Global Footprint Network
gha	Global Hectares
GHG	Greenhouse Gases
ha	Hectare
I	Import (t)
IBM	International Business Machine Corporation
Im	Impact

IPCC	Intergovernmental Panel for Climate Change
IYF	Intertemporal Yield Factor
ln	Lin
MAAGR	Average Annual Growth Rate
max	Maximum
min	Minimum
MO	Microsoft Office
MS	Microsoft
NFA	National Footprint Account
OLS	Ordinary Least Squares
OTA	Organic Trade Association
P	Population (Millions)
PJ	Petajoule
pr	Product
RIREG	Ridge Regression
RIREGcoef	Ridge Standardized Coefficient
S	Affluence
SFU	Scandinavian Feed Units (Equivalent of 1kg of average quality dry barley)
SPSS	Statistical Package for Social Sciences
SRC	Short Rotation Coppice
STIRPAT	Stochastic Impact Regression, of Population, Affluence and Technology
YF	Yield Factor (wha/ha)
t	Ton
T	Technology
TFP	Total Factor Productivity
WCy	World Crop Yield (t/wha/year)
WCTy	World Crop Trade Yield (t/wha/year)
wha	World hectare

1. Introduction

As the world's population continues to grow, with constantly changing consumption patterns, more land is expected to be allocated for human activities such as residential areas and cropland productions which exert negative impacts on the natural environment (Nelson et al. 2010). Land is a natural resource with a rising global demand (Weinzettel et al. 2012). The global demand for natural resources is setting pressure on finite natural resources, ecosystems and biodiversity (Weinzettel et al. 2012). The conversion of natural lands to croplands and other uses has replaced land systems rich in biodiversity with systems poor in biodiversity (GRID-Arendal 2013). Cropland production induces land use and land cover changes, greenhouse gas (GHG) emissions, incite ecosystem degradation, biodiversity loss and reduces the ecosystem potential to provide some of its services (GRID-Arendal 2013). A great challenge facing humanity is how to meet growing demands for fuel, food, living space and raw materials while sustaining ecosystems goods and services (Millennium Ecosystem Assessment 2005) and achieving sustainable development which is an acceptable concept of national and international policy (Lafferty 2000). Achieving sustainable development entails pursuing and reconciling social, economic and environmental goals such as environmental protection, social equity and economic advancement for the welfare improvement of current and future generations (Lafferty 2000). Any neglect in reconciling these goals is considered a drift from the sustainable development line (Millennium Ecosystem Assessment 2005).

As a measure to implement sustainable development, Denmark is cutting down its GHG emissions in order to fulfil emission reduction targets as agreed under the Kyoto protocol (EEA 2012). Sectors of large GHG emissions in Denmark are agriculture, transport, and energy (EEA 2012). Danish fossil fuel combustion in 2010 accounted for a 79.9% share of the total national GHG emissions (EEA 2012). The Danish Agricultural sector stands for approximately 15.6 %, transport 21.7%, and energy 58.2% of the total yearly national GHG emissions (EEA 2012). Apart from trying to fulfil the Kyoto targets for GHG emissions reduction, Denmark has put forth an energy transition plan, as a roadmap to phase out fossil fuels (greatest contributors to CO_2 emissions) from its national energy supply by 2050. Fossil energy carriers (coal, oil and gas) constitutes about 75% of total Danish energy supply (DMCE 2011) and will be replaced by CO_2

neutral renewable energy sources such as wind energy, bioenergy and solar power. The removal of fossil fuels will also enable Denmark to move towards the EU policy target of an 80-95% GHG emissions reduction by 2050 (Richardson et al. 2011). To coordinate the Danish energy transition plan, the Danish government created a commission on climate change (The Climate Commission) in 2008 which comprises of ten scientists, specialised in the fields of Agriculture, Climate, Economics and Transportation (DCCCP 2013). The Climate Commission presented proposals in 2010 on how Denmark can phase out fossil fuels within the vision of the Danish government (DCCCP 2013). Some of the proposals presented by the Climate Commission are in the form of policy scenarios aimed for 2050. The Danish case study is interesting because Denmark is the first European country to set up policies that would gradually eliminate its fossil fuel dependency (Richardson et al. 2011). The Climate Commissions land use scenarios (for cropland) and the Policy Scenarios for Climate Emissions Reductions (Bioenergy consumption scenarios) are the two policy scenarios this research is focused on.

The sustainability implications of implementing the Climate Commissions policy scenarios for 2050 are not yet known. Thus this research intends to use the ecological footprint methodology, which is a sustainability indicator tool (GFN 2013), to assess some of the underlying sustainability implications which might arise due to the implementation of the Climate Commissions land use scenarios and the Policy Scenarios for Climate Emissions Reductions. The motivation for choosing the ecological footprint indicator stems from reports (GFN 2013) showing an increase Danish footprint (Figure 1a).

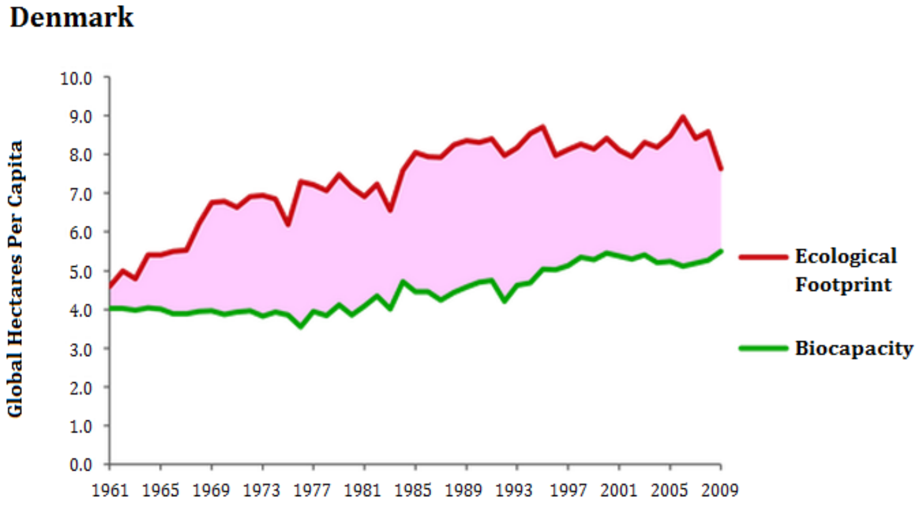
Since first developed by Wackernagel and Rees (1996), the ecological footprint has received worldwide attention as a sustainability indicator and they referred to the ecological footprint analysis as “a planning tool that can help to translate sustainability concerns into public action”. The ecological footprint has also been described as a communication tool which converts unbelievers into believers in order to take environmental problems seriously (van den Bergh and Grazi 2010). A global “Earth Overshoot Day” was recognised on the 20 August 2013, by the Global Footprint Network, as the day “humanity exhausted nature’s budget for the year” (GFN 2013) and after this date, humanity is living in an ecological overdraft (GFN 2013). The ecological footprint is defined as “a measure of how much biologically productive land and sea area an individual, population or activity requires to produce all the resources it consumes and to absorb its waste” (GFN 2013). The footprint concept has also received criticism concerning its conceptual and methodological inconsistencies (van den Bergh et al. 1999; Fiala 2008). Fiala (2008) for example, criticises the ecological footprint as a sustainability indicator which fails to satisfy fundamental economic principles because its basic assumptions are contradictory in both theory and historical data. Van den Bergh et al. (1999) describes the ecological footprint as too aggregate as its application at a regional level can provide information which can be easily misinterpreted since it uses a fixed sustained scenario.

Within the ecological footprint framework biocapacity (BC) is defined as “the ability of an ecosystem to regenerate useful biological resources and absorb waste generated by humans such as carbondioxide emissions from fossil fuels” (GFN 2013). The ecological footprint methodology addresses sustainability through its concept of Ecological Deficit (ED), Ecological Overshoot (EO) and Ecological Trade Deficit (ETD) of individual countries and that of the planet (Earth). The ED and the EO are the differences between a country’s demand on nature or consumption of natural resources (footprint) and the capacity of the country’s natural environment to supply it ecosystem services (BC) (GFN 2013). ETD occurs when the ecological footprint of consumption (EFc) is larger than the ecological footprint of production (EFp), EO occurs when the EFp is larger than its BC, while ED occurs when the EFc is larger than its BC (GFN 2013). Ecological Remainder (ER) occurs when EFp is smaller than its BC. Ecological footprint is scaled in global hectares (gha) (Ewing et al. 2010). Global hectares “converts the physical land demand to world average biologically productive land” (Ewing et al. 2010). By using gha rather than hectares (ha), different land use types with different productivities can be compared with each other (Ewing et al. 2010)

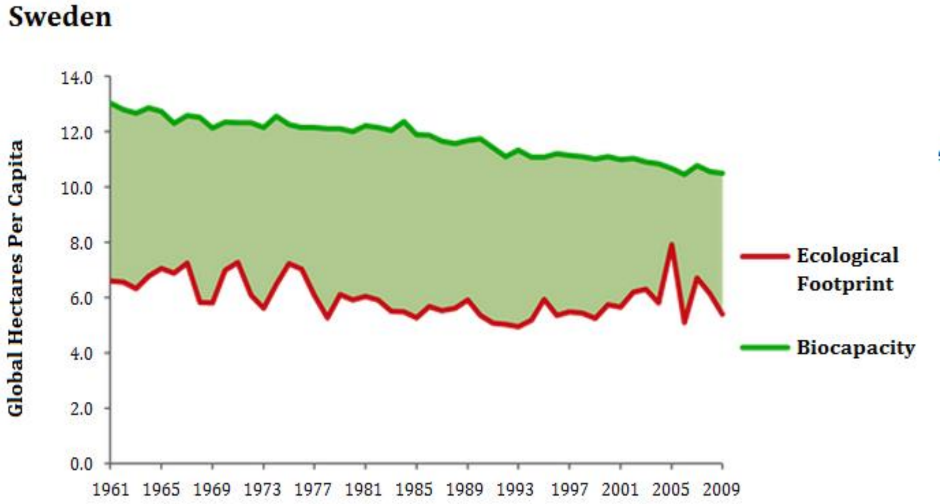
Ecological footprint calculations for the year 2008 showed a global EO (GFN 2013; Borucke et al. 2013) for Denmark, and that a land area equivalent to the size of 4.51 planets (Earth) was needed in 2008, if the world’s population lived in the same way as the Danish population (GFN 2013). Denmark is one of the countries on earth which has exceeded its BC since and likely even before 1961 (Figure 1a), as compared to Finland

and Sweden whose ecological footprints are still below their BC's (Figure 1b; c). In this situation of a high EO, Denmark is an ecological debtor while Sweden and Finland are ecological creditors (GFN 2013). The ecological footprint and BC of Sweden and Finland are chosen in this research and compared with those of Denmark, in order to make a distinction between, sustainable (Sweden and Finland) (Figure 1b; c) and unsustainable (Denmark) (Figure 1a) demand for natural resources (GFN 2013) within these countries as presented by the Global Footprint Network, even though the life styles of the inhabitants of these countries are similar. In Figure 1 a-c, the word "ecological footprint" represents the total EFc per capita Danish, Swedish and Finish population respectively. The total EFc and total bicapacity in figure 1 a-c, have been calculated from all land use types considered by the footprint methodology which are cropland, grazing land, forest land, built up area, fishing grounds, and carbon footprint (GFN 2013). Population is an important driver of ecological footprint (York et al 2003). From 2000-2012, the population growth rate of Denmark declined by 2.4%, while that of Sweden increased by 7.4% and Finland declined by 11.9% (CIA 2013). At the country level, the fundamental principles of the ecological footprint requires the inhabitants of an area to consume natural resources within the earth regenerative capacity of the area which is represented by BC (Borucke at al. 2013; Ewing et al 2010; GFN 2013). Environmentally unsustainable living by the inhabitants of a country is considered by the footprint methodology when a country's footprint exceeds its BC (GFN 2013). When this occurs life style changes are needed with respect to natural resource consumption in order to reduce footprint (GFN 2013). In this research the focus is on changes in the ecological footprint variables (ED, EO and ETD) for cropland under the Climate Commissions scenarios.

a)



b)



c)

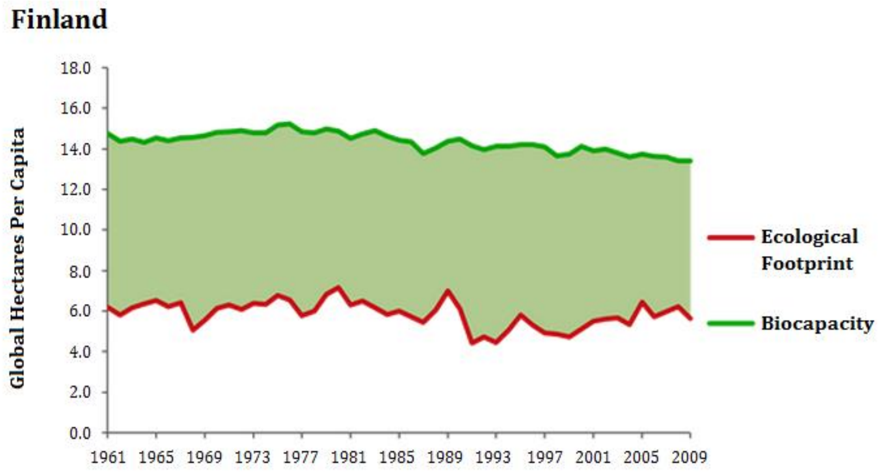


Figure 1 Ecological Footprint and Biocapacity of a) Denmark b) Sweden and c) Finland 1961-2009 (GFN 2013)

2. Background

A high total ecological footprint (Figure 1a) highlights the possibilities of a high ED, EO and ETD caused by a high footprint of production (EFp), imports (EFi), exports (EFe), and consumption (EFc) in the Danish footprint for cropland, grazing land, forests, fishing grounds, infrastructure as well as a its carbon footprint (GFN 2013). Land cover in Denmark has changed historically (GFN 2013) and the Climate Commissions land use scenarios and the Policy Scenarios for Climate Emissions Reductions will have further impacts on Danish cropland EFc through changes it will cause on Danish land cover when implemented. The IPCC (2013) defines a scenario as a plausible, coherent, internally consistent description of the future possible state which also gives an alternative image of how the future can unfold. The land use scenarios by the Climate Commission (Dalgaard et al. 2011) proposes the reduction of conventional cropland area in order to increase the land area which can be used for growing biomass needed for bioenergy production by 2050.

The Policy Scenarios for Climate Emissions Reductions (Bioenergy consumption scenarios) (Richardson et al. 2011) estimate the amount of energy needed to be generated from solid biomass by 2050. This scenario will affect Danish cropland as biomass needed for bioenergy production will require land for the cultivation of new energy crops for biofuel feed stocks or the use of crops already being cultivated in Denmark. Acquiring land for energy crop production without increasing emissions or compromising land for food crop production is becoming a national and global challenge. Denmark has a land area of 42916 km^2 (4291600 ha) (Statistics Denmark 2013) with cropland (2627816 ha) covering more than 50% of the land area in 2013. Independent of other countries, any significant change in Danish cropland EFc would have an impact on the sustainability impression of Denmark with respect to footprint (Figure 1a) as Denmark is a small country. Sections of the Climate Commissions scenarios relevant to this research are described in detail below.

2.1 Land use Scenarios

The scenarios for land use which are officially known as “Projected Land use in the Reference Scenario under Frozen Policy for Development in GHG in Danish Agriculture” were proposed for the Climate Commission by Dalgaard et al (2010; 2011) (Figure 2). In these scenarios, the Climate Commission assumes there will be an increase in yearly crop yields by 0.7% and a sustained food crop production under “Frozen Policy” (Dalgaard et al. 2011). “Frozen Policy” is situation where there is absence of any new policy decision which can affect Danish agriculture and GHG emissions (Dalgaard et al. 2010). This scenario assumes an increase in the area used for organic food production which is according to Danish organic action plan (Bisgaard 2012; DMFAF 2014) and a decrease in the area used for conventional food production in order to increase the land available for other biomass production. The Climate Commissions (Dalgaard 2011) estimates, that more than 0.5 million hectare will be made available from the decrease in land use for conventional food production whereas organic area is estimated to cover 0.3 million hectares in 2050 (Dalgaard et al. 2010). All land available for other biomass production (Freed land) is then assumed to be planted with short rotation coppice (SRC) willow for bioenergy production in the scenario (Figure 2).

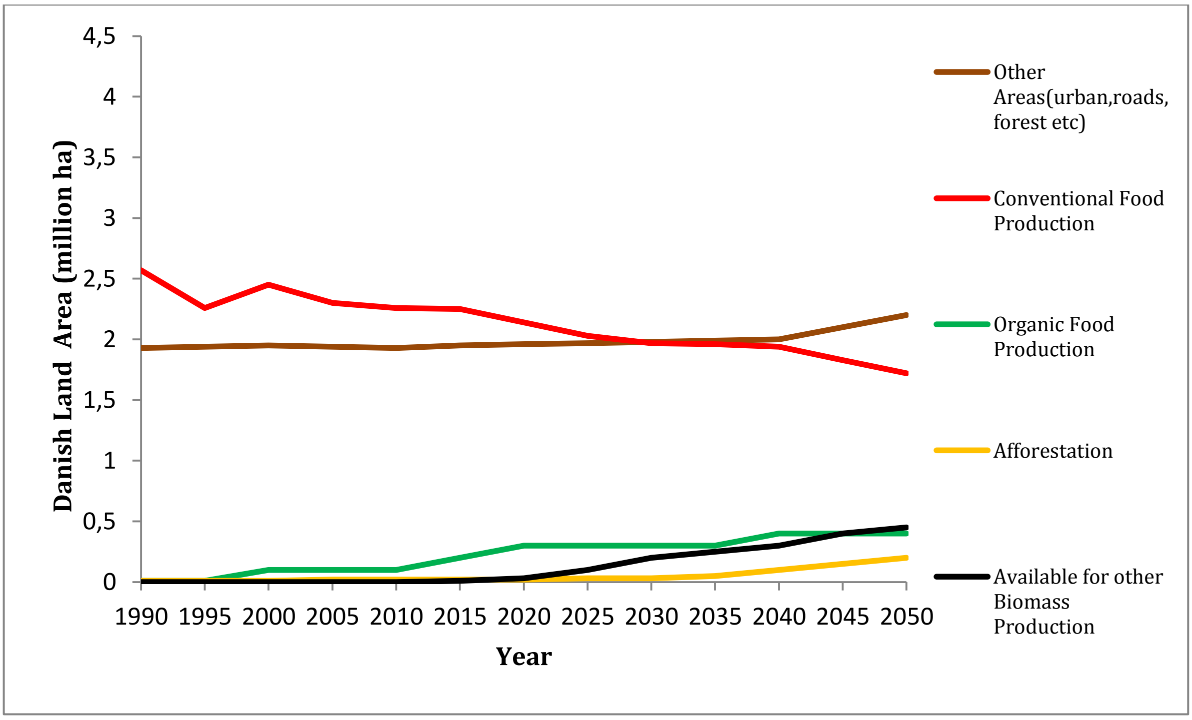


Figure 2 Climate Commissions Land use Scenarios for 2050

2.2 Energy Consumption Scenarios

The scenarios for energy consumption which are officially known as "The Policy Scenarios for Climate Emissions Reductions" were proposed to the Climate Commission by Richardson et al. (2011). Denmark consumes an estimated 600-700 Petajoules (PJ) of energy per year and the Climate Commission intends to generate 433 PJ in the Policy Scenarios for Climate Emissions Reductions by 2050 (Richardson et al. 2011). The Policy Scenarios for Climate Emission Reductions have two 2050 scenarios which are relevant for this research. The "Ambitious" and "Unambitious" scenarios are shown in figure 3 and are described in more detail in Appendix 1. For 2050, the Climate Commission estimates that, in the "Ambitious" scenario (with biomass) solid biomass will contribute to 124 PJ of the 433 PJ. The remaining 309 PJ will come from wind energy carriers (Richardson et al. 2011). In the "Ambitious" scenario (without biomass) all of the 433 PJ of energy will instead be generated from wind energy carriers (Richardson et al. 2011). In the "Unambitious Scenario" solid biomass will contribute to all of the 433 PJ. This contribution will be 183 PJ above the estimated total national Danish biomass potential of 250 PJ (Figure 3). Richardson et al. (2011) estimated the total national Danish biomass and waste energy production potential to be 250 PJ for the year 2008. For clarity, figure 3 was drawn with the scenario specifications given by Richardson et al. (2011).

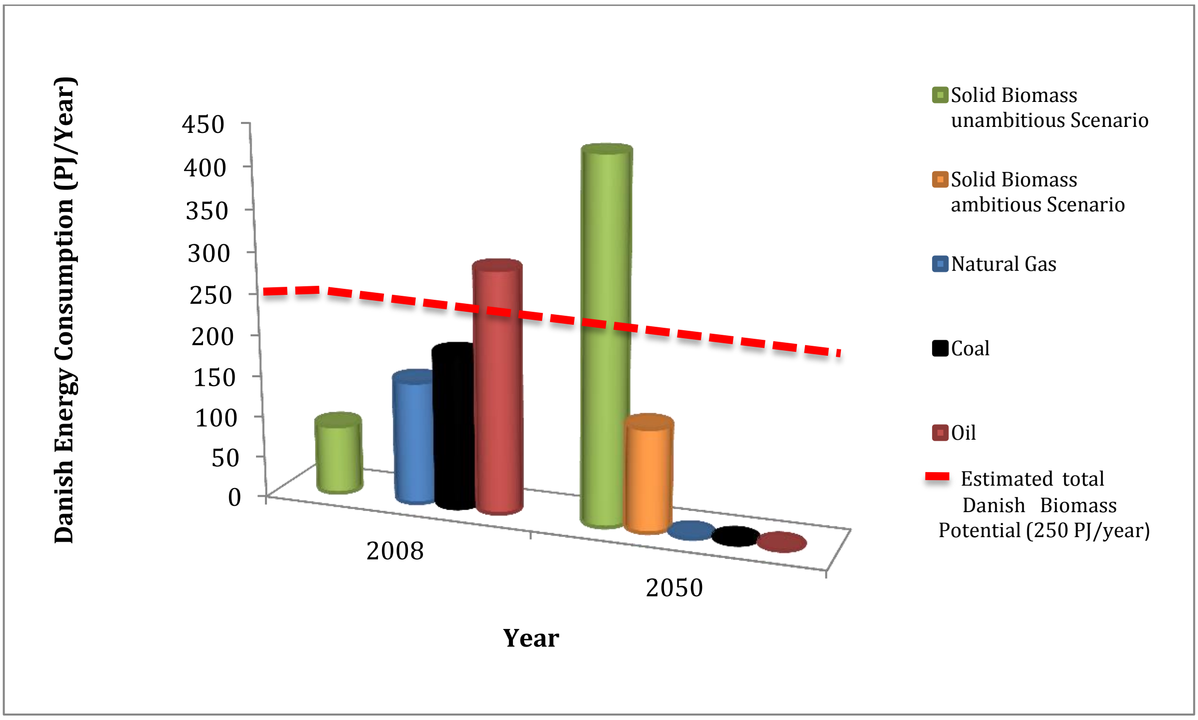


Figure 3 Climate Commission Bioenergy Consumption from Solid Biomass Scenarios for 2050 without Fossil Fuels

The actual energy production in 2008 from solid biomass and waste was 89 PJ (Richardson et al. 2011). The energy consumption from solid biomass and fossil fuels in 2008 is used as a baseline (Figure 3). According to the Climate Commission, fossil fuels will be eliminated in 2050 (Figure 3).

2.3 Interaction between Climate Commission Scenarios, Cropland, EFc and EFc Drivers

The ecological footprint methodology defines cropland as the area required to grow all crop products, which includes rubber and oil crops, fish meals, and livestock feeds (Ewing et al. 2010). Cropland ecological footprint of consumption (EFc) in gha per capita is calculated from equation 1 (Borucke et al. 2013) were EFp, EFi, and EFe are all in gha per capita

$$\mathrm{EFc} = \mathrm{EFp} + \mathrm{EFi} - \mathrm{EFe} \qquad \text{Equation 1}$$

The land use and bioenergy consumption scenarios will affect patterns in Danish cropland EFc directly when implemented on cropland because they will likely cause changes in the growth of Danish cropland production which are used in the calculation of EFp, Danish cropland imports which are used in the calculation of EFi and Danish cropland exports which are used in the calculation of EFe. BC depends on cropland area and it is measured in gha per capita. It is assumed in this research that the scenarios will affect Danish cropland EFc in gha per capita indirectly by causing changes in the growth of EFc drivers which will in turn affect EFc (Figure 4). Aggregate drivers of EFc includes economic growth and technology.

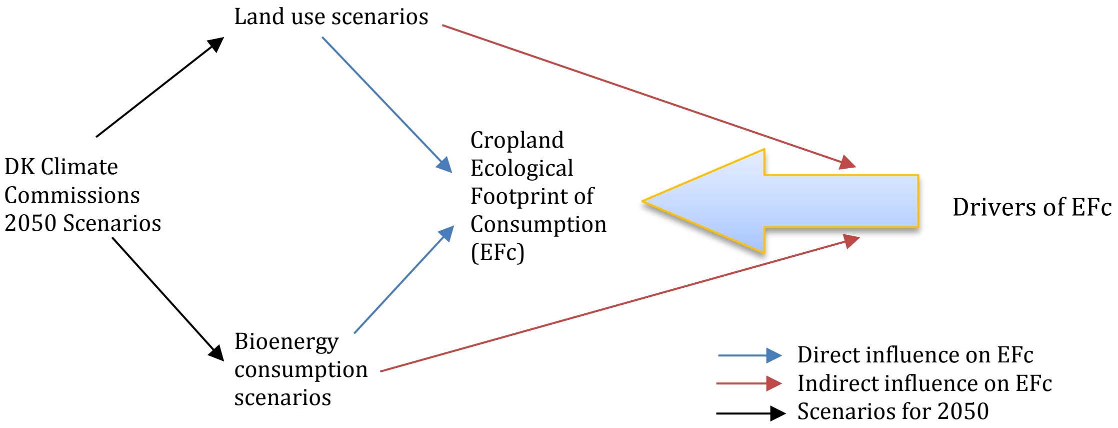


Figure 4 Interactions of Climate Commission scenarios and EFc Drivers

Denmark is one of the most intensively farmed countries in the world (Dalgaard 2004). Danish croplands are being intensively cultivated under conventional and organic management practices to produce food and non-food crops (Norfelt 2011). The IPCC (2014) defines agricultural intensification as the collective application of “farming practices that enhance production and the input of plant derived residues to soil which includes crop rotations, reduced bare fallow, cover crops, high yielding varieties, integrated pest management, adequate fertilization, organic amendments, irrigation, water table management and other proper management practices”. Some studies (e.g. Rudel et al. 2009; Olesen at al. 2010) have associated agricultural intensification to causing both good and bad effects. Positive effects includes, the reduction in agricultural area, increased crop yields and production, efficient use of land, efficient use of production input, increase in the quantity and quality of livelihoods, causing technological change and reduced food crop prices. Negative effects to the environment due to agricultural intensification includes land degradation, GHG emissions and climate change. The good and the bad effects of agricultural intensification has led to the notion of sustainable and unsustainable intensification (Carswell 1997).

An increase in demand for output such as market demands or the decrease in the availability of an input such as scarcity of land in Denmark is usually necessary for intensification to take place (Carswell 1997). Agricultural intensification can be measured from the amount of input per unit land, frequency of cultivation or by Total Factor Productivity (TFP) (Appendix 2) (Carswell 1997). Fuglie (2010) defines TFP as the ratio of aggregate output of what has been produced, for example total crop amounts to the aggregate input in land, labour, capital, and other material used in production. Fuglie (2010) emphasized the necessity to account for changes of services in production inputs. The Climate Commission projects a yearly 0.7% increase in the Danish national agricultural productivity in the land use scenario, which is capable of sustaining food crop production from 2010-2050, but it is up to technological and economic advancements to influence the intensification to make it sustainable. Thus there is a need to investigate whether technological and economic developments which may be incited by the Climate Commission scenarios might influence the sustainability of cropland intensification by 2050. The sustainability of the scenarios will be assessed by exploring the ability of a scenario to reduce cropland ED, EO, ETD which are derived from EFc, reduce unsustainable cropland intensification while sustaining food crop production.

2.3.1 Research Scope

This research will focus on the sustainability assessment of the Climate Commissions land use and energy consumption scenarios by exploring the ability of a scenario to reduce cropland ED, EO, and ETD which are derived from EFc in gha per capita, reduce unsustainable intensification while sustaining food crop production. For the energy consumption scenarios no detailed conversion calculations of different solid biomass to bioenergy or an analysis of bioenergy types will be made. Under the land use scenario the size of ED, EO, and ETD (gha per capita) will be estimated quantitatively. The quantitative estimation is done by using footprint methods and the STIRPAT model (York et al. 2003), because the yearly cropland area amounts in ha and BC in gha per capita of Denmark from 2013-2050 are known. The STIRPAT model is stochastic model introduced by York et al. (2003). The nature of the cropland intensification which can be sustainable or unsustainable intensification (Carswell 1997), will be assessed qualitatively in the land use scenarios due to lack of quantitative data from 2013-2050.

Willow planted on freed land in the land use scenario will contribute solid biomass to the total Danish biomass potential. Under the energy consumption scenarios the total Danish biomass potential with willow as energy crop is estimated quantitatively based on the studies of Jørgensen et al. (2005) and Richardson et al. (2011). The possible changes in ED, EO, and ETD in gha per capita, established in the land use scenario, which might result due to the implementation of the energy consumption scenarios will be estimated qualitatively. The qualitative estimation is done by comparing possible outcomes of ED, EO, and ETD in the energy consumption scenario to those of the land use scenario. Cropland intensification will be assessed qualitatively in the energy consumption scenario as in the land use scenario and for the same reasons. It is from this scope that the research aim, objective, and questions were formulated.

2.3.2 Research Aim and Objective

To estimate the size of Danish cropland ED, EO, and ETD, which are derived from EFc in gha per capita, within the Danish Climate Commissions land use scenarios and energy consumption scenarios of the Policy Scenarios for Climate Emissions Reductions by 2050.

The main research question is: How will the Danish Climate Commissions land use scenarios which are based on reducing conventional cropland to provide land for energy crop production and Policy Scenarios for Climate Emissions Reductions which are based on bioenergy consumption from solid biomass, directly and indirectly affect Danish ED, EO, ETD, and cropland intensification?. If a scenario is able to decrease EO, ED, ETD in gha per capita and unsustainable cropland intensification while sustaining food crop production, then it can be termed sustainable.

Research questions (RQ) and Sub-research questions

To answer the main research question three research questions were formulated;

RQ 1: How can the Climate Commission scenarios affecting cropland management practices (Conventional or Organic) influence Danish cropland sustainability with respect to decreasing ED, EO, ETD, and unsustainable cropland intensification while sustaining energy and food crop production?

RQ 2: How can the Climate Commissions scenarios contribute towards a sustainable Danish cropland footprint with respect to decreasing ED, EO, and ETD?

RQ 3: How can different driving forces of EFc in gha per capita influence future Danish cropland EFc patterns?

RQ1 is directed to the organic and conventional land use scenarios (Figure 2) while RQ2 is for both land use and energy consumption scenarios (Figure 2 and 3)

In order to answer the research questions, the sub-research questions below were derived from the research questions

How can conventional, organic and freed (for planting energy crops) cropland area be estimated?

How can cropland BC, EFp, EFi, EFe, and EFc in gha per capita be estimated?

What can be the possible changes as compared to those of the land use scenarios, in Danish ED, EO, ETD, food crop production, and cropland intensification when the bioenergy scenarios are implemented?

How can anthropogenic driving forces of EFc affect its size?

How can technological and economic advancements influence sustainable intensification?

What are the weaknesses and strengths of the ecological footprint methodology?

RQ 1 and 2 will be investigated through methodological steps (1-5) (page 26 and 27) formulated for assessing the sustainability of Climate Commissions scenarios.

RQ 3 will be investigated through methodological step (6) (page 27) formulated for studying the relationship between EFc and drivers

2.3.3 Definition of Terms

The following terms are defined as applied in the NFA 2011 Edition:

Cropland production amount (t/year): refers to the sum of harvested products of all crops which were planted on Danish cropland in a particular year as stated in the NFA 2011 Edition for the years 1961-2008. These harvest weights are sometimes specified as being wet or dry weights in the NFA, and sometimes not. The summed production in the calculations is therefore a mix of wet and dry weights. This means that although the water content for each crop in the NFA can be assumed to be constant over time, the water content of the cropland production amount may change over time as the production of each crop varies over time.

Cropland productivity (t/ha/year): refers to the total cropland production amounts divided by the total cropland area where production was done.

National bioproductive cropland area (ha/year): refers to land area which has been allocated for growing crops at country level.

Import of cropland products (t/year): refers to the import of crops (food and non-food crops) grown from a cropland.

Export of cropland product (t/year): refers to the export of crops (food and non-food crops) grown from a cropland.

3. Research Methodology

In order to answer the research questions asked, a range of research steps and methods were needed in combination with some data sources. These steps and methods are all described below

3.1 Data Sources

A one year licence of the National Footprint Account (NFA 2011 Edition) database of Denmark was obtained from the Global Footprint Network (GFN) by the environmental research group at Aarhus University. The GFN prepares the NFA database for every country on earth and is coordinated by the founders of the ecological footprint methodology (GFN 2013). The Danish NFA 2011 Edition database contains the calculated total ecological footprint of Denmark from from 1961-2008. In this research the term "Historical" is used as a reference to NFA datasets of the period 1988-2008. The NFA database contains datasets for the various land use types considered by the footprint methodology but cropland is the land use type which is relevant to this research.

The NFA database contains Danish crop production amounts (t/year), crop yields (t/ha/year), cropland area (ha), crop import and export amounts (t), world crop yields (t/wha/year), world crop trade yield (t/wha/year) and crop extract amounts (t DW/t pr) which are necessary for the estimation of Danish cropland ecological footprint from 2013-2050. The GFN claims the datasets in the Danish NFA 2011 Edition were taken from the FAO, but do not disclose how these datasets were collected. Datasets on Danish population growth, GDP, farm machinery amount from 1988-2008, necessary for STIRPAT model analysis were taken from the database Statistics Denmark which is an open source database.

3.2 Steps to assess the sustainability of land use Scenarios

1) *Study of the historical trends in Danish cropland ED, EO and ETD from 1988-2008*

The historical trends will act as a reference for comparison with the trends projected under the Climate Commission scenarios from 2013-2050.

2) *The estimation of conventional cropland, organic and freed area from 2013-2050*. In order to estimate the yearly conventional and organic BC in gha per capita, the yearly land use needs to be calculated from the land use scenario. From 2013, an increase in yearly cropland productivity by 0.7% (Dalgaard et al. 2011) in the land use scenario forms the basis for reducing conventional area, as conventional productivity increases yearly by 0.7% until 2050. The freed land is the yearly area set-aside from the reduction of conventional area for energy crop production. Organic area from 2013 is assumed to develop according to the Danish organic action plan (Bisgaard 2012; DMFAF 2014) which requires the doubling of the organic area by 2020 and then maintaining this area until 2050

3) *Estimation of total cropland YF, BC, EFp, EFi, EFe, and EFc from 2013-2050*. The total cropland yield factor (YF) is necessary for the calculation of total cropland BC. YF, BC, EFp, EFi, EFe, and EFc are calculated following the studies of Ewing et al. (2010) and Borucke et al. (2013) using dataset from Statistics Denmark and NFA

4) *Estimation of cropland ED, EO and ETD from 2013 -2050*. The calculations for EO, ED, and ETD are intended to show the overall changes the scenarios might cause on the Danish cropland footprint sustainability impression and also how the scenarios are able to increase or decrease Danish cropland EFc and BC by 2050.

3.3 Steps to assess the sustainability of Bioenergy Consumption Scenarios

5) *Comparing the possible outcomes with respect to footprint, from assumed implementation of the bioenergy consumption scenarios to those of the land use scenarios*. Energy consumption scenarios are assessed quantitatively by estimating energy with and without willow as energy crop using the studies of Jørgensen et al. (2005) and qualitatively by comparing possible footprint outcomes to those of land use scenarios.

6) *Relating the land use and bioenergy consumption scenarios to drivers of EFc*. Based on the assumption that the implementation of the above scenarios will cause changes in the growth of EFc and the EFc drivers. The relationship between EFc and various socio economic drivers are investigated. The drivers of EFc studied in this research are the Danish Population, Affluence which is represented by GDP per capita), Technology

which is represented by farm machinery and International trade which is represented by import and export of cropland products. Drivers are studied using the STIRPAT model based on the studies of York et al. (2003). The studies of Baumanns (2013) and York et al. (2003) are used to explain the complex relationship and role drivers can play in influencing future Danish EFc patterns.

3.4 Study Area

The study area is defined as total extent of cropland area across Denmark. Denmark is located at latitude $56^{0}09^{\prime}\ 24^{\prime\ \prime}$ N and longitudes $10^{0}\ 12^{\prime}\ 38^{\prime\ \prime}$ E. The size of an average farm in Denmark is 60 ha (Eurostat 2014) and the number of farms in Denmark has gradually decreased over the years (2005-2007) due to the decrease in the number of farms under 100 ha (Eurostat 2014). In 2013, Denmark had 36568 farms (Statistics Denmark 2013) which represented a 28% decrease from the 2005 EU farm structures survey number of Danish farms (50864 farms) (Eurostat 2014). In 2013, the Midtjylland region had the highest number of farms (11169) covering an area of 794382 ha, followed by Syddanmark region with 10183 farms covering an area of 775648 ha (Statistics Denmark 2013). The farm structure of some Danish farms comprises of mixed crop and dairy (Halberg and Kristensen 1997). From 1990 to 2012, Danish cropland area for grasses and green fodder increased from 550900-776500 ha (Statistics Denmark 2013). In 2013 cropland covered 61.3% of Danish national area (Statistics Denmark 2013). Grasses and green fodder (Figure 5) constitutes more than 50% of yearly total Danish cropland production (Statistics Denmark 2013), and covering about 17% of Danish cropland area.

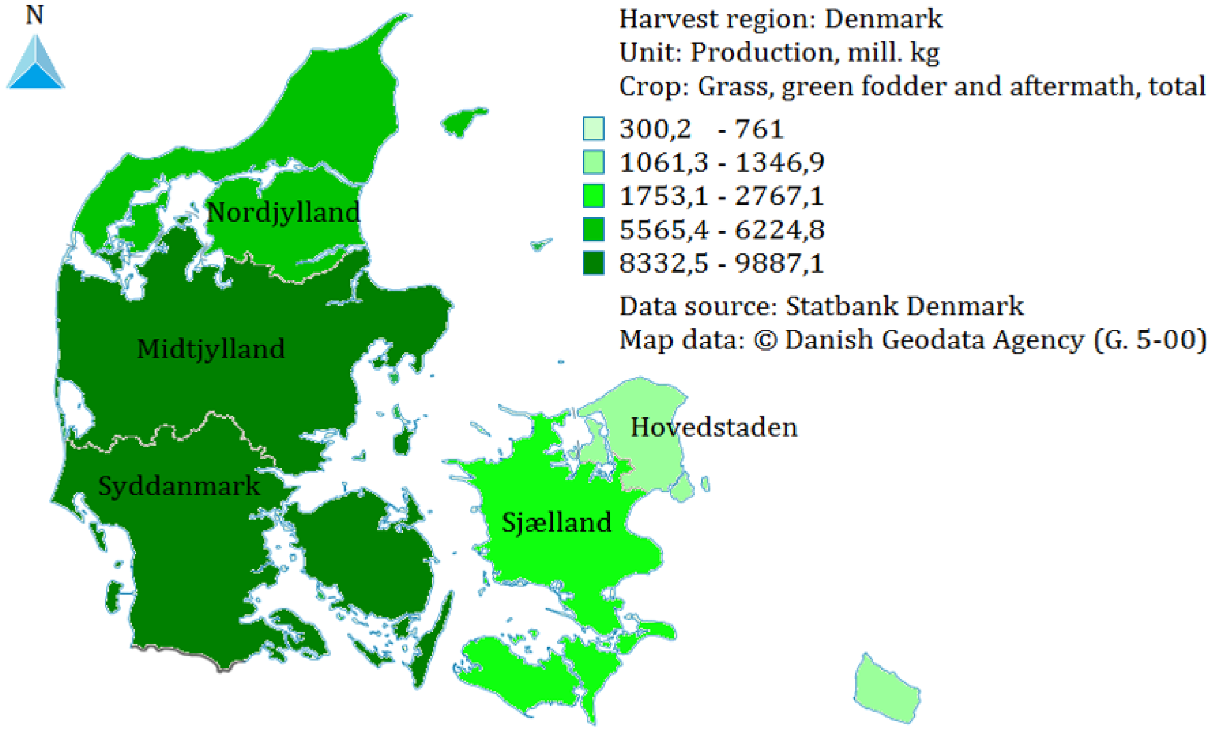


Figure 5 Map of Denmark showing harvest amount by region of grasses and fodder crops in 2012

3.5 Ecological Footprint Method

The ecological footprint method is being revised constantly (Borucke et al. 2013), with the latest revision based on the paper of Borucke et al (2013) which documented the "latest methods for estimating the biocapacity of nations and ecological footprint" (Borucke et al. 2013). The ecological footprint is used as a metric for tracking human demand on the biosphere, with respect to the availability of regenerative and waste absorptive capacity within the biosphere (Borucke et al. 2013). Ecological footprint is expressed in global hectares (gha) by multiplying any of its variables with YF (wha/ha) and EQF (gha/wha) (Ewing et al. 2010). Ecological footprint is an aggregate indicator (van den Bergh et al. 1999) consisting of combining sets of equations. The equations relevant to this research are given below. Cropland BC in gha is calculated as:

$$\mathrm{BC} = \mathrm{An} \times \mathrm{YF} \times \mathrm{EQF} \times \mathrm{IYF} \qquad \text{Equation 2}$$

An, YF, EQF, and IYF are described below.

Area (An in Equation 2) is country specific and measured in ha. An is the national available cropland area or the summation of the bioproductive cropland area available for the production of each crop at the country level (Borucke et al 2013). The GFN 2012 defines BC (ha or gha) as "the area of land and sea available to serve a particular use is called biocapacity and it represents the biosphere ability to meet human demand for material consumption and waste disposal". The total BC (gha per capita) of a country is constantly changing (Figure 1 a-c) (GFN 2012) and it is uncertain and difficult to get a precise and accurate amount when an estimate of Danish cropland BC (step 3 above) from 2013-2050 is done. Thus a range of cropland BC values are estimated following the definition of BC and considering equation 2 above. Maximum cropland BC (MaxBC) can be estimated from a maximum An (total area of land which can be available in a country for cropland, if there are no other land use types: assuming all of the country's land is bioproductive). Minimum cropland BC (MinBC) can be estimated from a minimum An (area of land available for cropland if there are other land use types). The observed values of Danish cropland BC (2013-2050) are expected to range within MinBC and MaxBC.

Yield Factors (YF) (wha/ha) (Equation 2) (GFN 2012) accounts for "countries differing levels of productivity for a particular land use type. Yield Factors are country specific and vary by land use type, year, natural factors such as differences in precipitation, soil quality and anthropogenic differences such as management practices" (Borucke et al. 2013). Cropland YF (At country level) is calculated as:

$$\mathrm{YF} = \frac{\sum \text{World Crop Area}}{\sum \text{National Crop Area}} \qquad \text{Equation 3}$$

Equation 3 was used to calculate YF for only cropland, because cropland does not produce only a single primary product (Ewing et al. 2010). YF for other land use types is calculated using a different equation (Appendix 7; equation c). World Crop Area (Aw) and National Crop Area (An) are calculated as in appendix 7. In appendix 7 equation A-B, Aw is the world equivalent of An. The difference between Aw and gha are explained in appendix 7 section 2.

Equivalent Factor (EQF) (gha/wha) (Equation 2) (GFN 2012) "converts the areas of different land use types at their respective world average productivities into their equivalent areas at global average productivity across all land use types. EQF vary by land use type as well as by year" (Borucke et al. 2013). EQF are calculated "as a ratio of the world average suitability index for a given land use type to the average index for all land use types" (Ewing et al. 2010). EQF are crop specific and the lack of observed crop suitability index data for Denmark from 2009-2050 makes it difficult for EQF to be calculated from raw data in this research. Thus the minimum and maximum EQF value within the period of 1961-2008 which were calculated by the GFN in the Danish NFA 2011 Edition are used for 2013-2050 conversion calculations of Danish cropland BC in ha, EFp, EFi, and EFe in wha to corresponding minimum and maximum values in gha.

Intertemporal Yield Factor (IYF) (unit less) (Equation 2) (GFN 2012) accounts for changes in the world average yield of a particular land use type over time (Borucke et al. 2013). A world average IYF is a ratio of the world-average product-specified yield of a land use type producing product at a particular base year to the world-average product-specified yield of the same land use type producing product at a different base year (Borucke et al. 2013). The lack of observed data on the amount of product (crop) which is going to be harvested in the world from 2013-2050 makes it difficult for IYF to be calculated from raw data in this research. Thus the minimum and maximum IYF value within the period of 1961-2008 which was calculated by the GFN in the Danish NFA 2011 Edition were used for 2013-2050 conversion calculations of Danish EFp, EFi, and EFe in wha to corresponding min and max values in gha.

The various ecological footprint variables are calculated from World Crop Yield (WCy: the yield of all the crops in the world) and World Crop Trade Yield (WCTy: the yield of crops imported to and exported from Denmark). WCTy is calculated based on WCy and Crop Extract (CE: which is the proportion of a crop which is traded). The equations are as:

$$\mathrm{EFp} = \frac{\text{National Crop Prodution}}{\text{WCy}} \qquad \text{Equation 4}$$

$$\mathrm{EFi} = \frac{\text{National Crop Imports}}{\text{WCTy}} \qquad \text{Equation 5}$$

$$\mathrm{EFe} = \frac{\text{National Crop Exports}}{\text{WCTy}} \qquad \text{Equation 6}$$

EFp, EFi and EFe are calculated at crop and country specific level using equation 4, 5 and 6 with wha as unit and at global level, using same equations, with gha as unit (Appendix 8). National Crop Production, National Crop Imports and Exports are measured in tons (t) while WCy and WCTy are measured in t/wha/year

$$\mathrm{WCy} = \frac{\text{World Crop Production}}{\text{World Crop Area}} \qquad \text{Equation 7}$$

WCy (Equation 7) is calculated at crop and global level. The World Crop Production of a particular crop is the summation of all its production amounts in the world (GFN 2012). World Crop Area is the summation of all the area for which the crop of interest is being cultivated in the world (GFN 2012).

$$\mathrm{WCTy} = \mathrm{CE} \times \mathrm{WCy} \qquad \text{Equation 8}$$

CE (Equation 8) is measured in tons derived product per ton parent product (GFN 2012). ED (Equation 9) refers to the difference between ecological footprint and the BC which is locally available to the population (Wang et al. 2010b). The output of ED can be negative or positive values. Negative value of ED signifies the resource demands cannot be achieved locally (Wang et al. 2010b; Borucke et al. 2013): while a positive value of ED signifies resource demand can be achieved locally.

$$\mathrm{ED} = \mathrm{BC} - \mathrm{EFc} \qquad \text{Equation 9}$$

EO is when BC minus EFp gives only negative values. EO is a state at which resources are consumed more rapidly than the biosphere can replenish them (GFN 2013). When EO occurs the rate of resource exploitation exceeds its max carrying capacity and there is depletion of the local ecosystem (Wang et al. 2010b; Borucke et al. 2013).

$$\mathrm{EO} = \mathrm{BC} - \mathrm{EFp} \text{ (Output are negative values)} \qquad \text{Equation 10}$$

ER is when BC minus EFp gives only positive values. It is a state whereby the rate of resource exploitation is less than the maximum carrying capacity, thus the region can support more human activity (Wang et al. 2010b)

$$\mathrm{ER} = -\mathrm{EO} \qquad \text{Equation 11}$$

Positive values of ETD signifies net import of resources and negative values signifies net export (Wang et al. 2010b).

$$\mathrm{ETD} = \mathrm{EFc} - \mathrm{EFp} \ \text{ or } \ \mathrm{EFi} - \mathrm{EFe} \qquad \text{Equation 12}$$

EFc is the sum of EFp and EFi minus EFe (Equation 1)

3.6 STIRPAT Model

The Stochastic Impact Regression of Population, Affluence and Technology (STIRPAT) is a statistical conceptual model for assessing human impacts on the environment at any scale (Dietz 2013) originally proposed by Dietz and Rosa (1994). The STIRPAT model was revised by York et al. (2003) with its concept of Ecological Elasticity (EE) which gives a better analysis of the driving forces of environmental impacts (Xianghao et al. 2011).

The basic nonlinear stochastic STIRPAT model can be expressed as:

$$\mathrm{Im} = \mathrm{a}\mathrm{P}^{\mathrm{b}}\mathrm{S}^{\mathrm{c}}\mathrm{T}^{\mathrm{d}}\mathrm{e} \qquad \text{Equation 13}$$

Where Im=Impact (footprint), P=population, S=Affluence, T=Technology and e=error term. The constant *a* scales the model whereas *b*, *c* and *d* are exponents of P, S and T. To find the relationship between the dependent variable (Im) and the independent variables (P, S and T) the nonlinear form of equation 13 is converted (by taking ln on both sides of equation) to a linear form (equation 14), because it is easier to work with linear equations rather than nonlinear equations.

$$lnIm = lna + blnP + clnS + dlnT + lne \qquad \text{Equation 14}$$

Based on York et al. (2003); Xianghao et al. (2011); Wang et al. (2010); and Wang et al. (2011), Ordinary Least Squares and Ridge regression analysis are used to find regression coefficients in the relationship between I, P, A and T. Other independent variables can be added to the basic STIRPAT model if they are conceptually appropriate as suggested by York et al. (2003). Examples are the quadratic terms of P $(b_2(lnP)^2)$, A $(\mathrm{c}_2(\mathrm{lnS})^2)$ and T $(d_2(lnT)^2)$ as given in equation 15

$$\mathrm{lnIm} = \mathrm{lna} + \mathrm{blnP} + b_2(lnP)^2 + c\mathrm{lnS} + \mathrm{c}_2(\mathrm{lnS})^2 + \mathrm{dlnT} + d_2(lnT)^2 + \mathrm{lne} \quad \text{Equation 15}$$

The variables (P, S, and T) can increase nonlinearly or exponentially over time. To take these nonlinear increase into consideration, the quadratic terms of these variables are added in equation 14 to produce equation 15. The quadratic terms are also necessary to test the Environmental Kuznets Curve (EKC) hypothesis (York et al. 2003) which is the Ecological Elasticity (EE) relationship between the impact (Im) and the cause or the Elasticity of impact. From equation 15, the EE is calculated by taking the first partial derivatives of the drivers. Population Elasticity ($\mathrm{EE_{IP}}$) is $(\mathrm{b} + 2b_2(\mathrm{lnP})$, Affluence Elasticity ($\mathrm{EE_{IS}}$) is $(c + 2c_2(\mathrm{lnS})$ and Technology Elasticity ($\mathrm{EE_{IT}}$) is $(\mathrm{d} + 2d_2(\mathrm{lnT})$ (York et al. 2003). The EE is defined as change in impact due to change in driving force (Elasticity of impact) (York et al. 2003)

4. Data Analysis and Results

4.1 Danish Cropland ED, ER and ETD Patterns (1988-2008)

In order to know the underlying cropland ED, EO and ETD of the total Danish footprint sustainability impression (Figure 1a) from 1988-2008, the data of the Danish cropland footprint sustainability impression are analysed using Cropland BC, cropland EFc and cropland EFp, from the NFA 2011 Edition. The motivation for using this data period is because the footprint sustainability impression of Denmark (Figure 1a) showed high total increase in footprint during this period. The cropland ED, EO and ETD from 1988-2008, based on the NFA 2011 Edition datasets will act as references for comparison with projected cropland ED, EO, and ETD (2013-2050) from the Climate Commissions 2050 scenarios. ED changes (1988-2008) were calculated using equation 9 and displayed in figure 6. BC, EFc, and ED were all calculated in per capita Danish population in the NFA 2011 Edition.

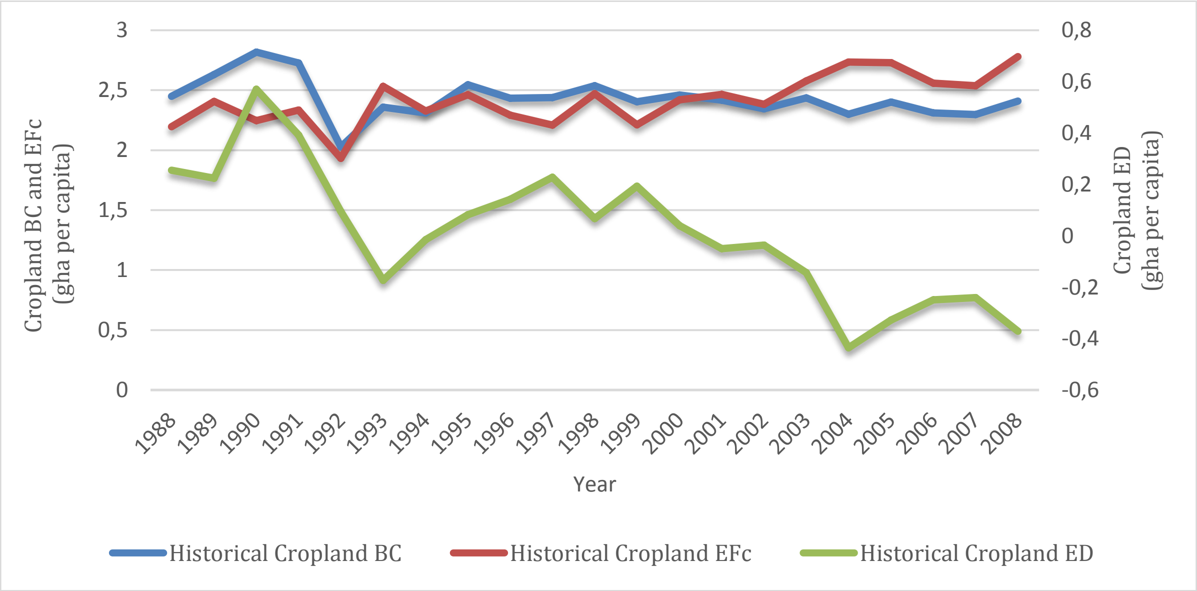


Figure 6 Danish Historical Ecological Deficit (ED) 1988-2008 using BC and EFc (Data source, NFA 2011 Edition)

In figure 6, the historical Danish cropland ED patterns decreases generally from 1988-2008, alternating between positive and negative values. Positive ED values were from 1988-1992 and from 1995-2000, while negative values were from 1993-1994 and from 2001-2008. Following equation 9, the period of positive ED values shows that, the size of BC was larger than EFc, due to low imports amounts of cropland products which decreases EFi and contributes to low EFc and high exports amounts of cropland products which increases EFe and contributes to low EFc. Equation 11 is used for the calculation of the historical ER in figure 7.

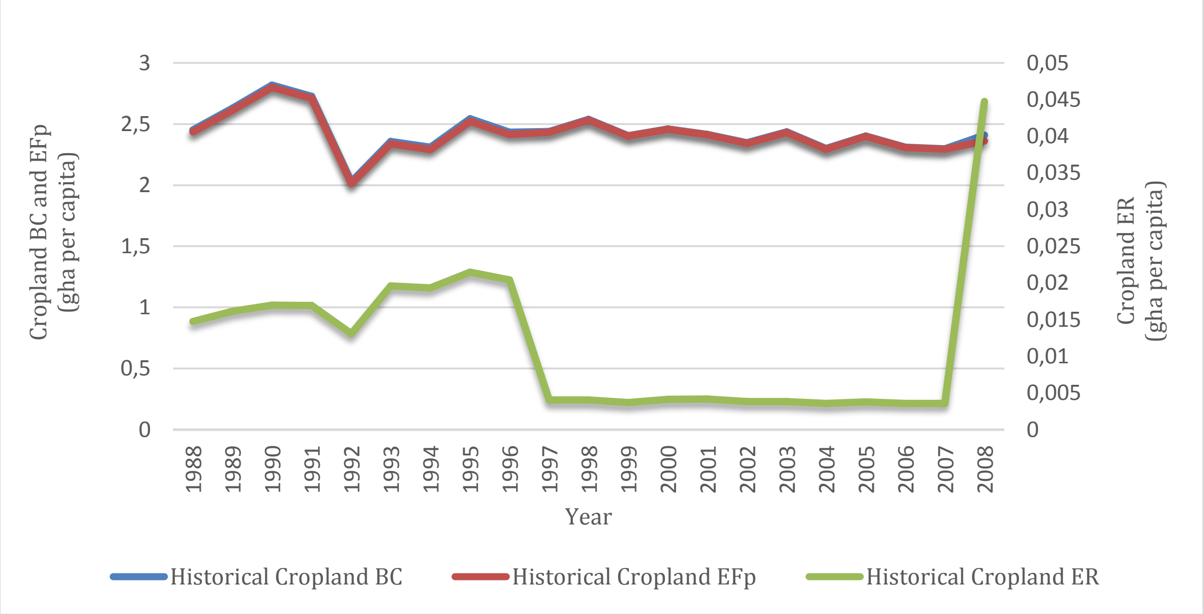


Figure 7 Danish Historical Ecological Remainder (ER) 1988-2008 using BC and EFp (The blue patterns of BC are just directly behind the red patterns of cropland EFp) (Data source, NFA 2011 Edition)

In figure 7, the historical Danish cropland ER patterns are shown. For the years until 1996 there was an increasing trend in ER, which was followed by a sharp decline in 1997. The following years ER remained at a stable low value until 2008 where ER increased drastically. The two break points in 1997 and 2008 are caused by a change in the difference between EFp and BC. For 2008 the change in this difference can be explained by a rapid increase in cropland area which contributes to BC.

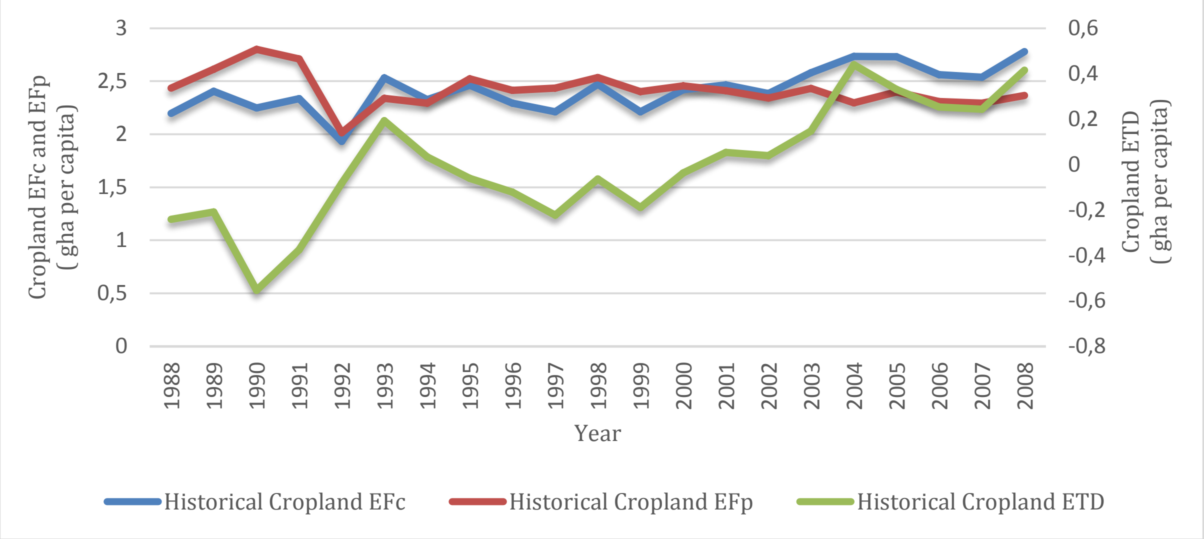


Figure 8 Danish Historical Ecological Trade Deficit (ETD) 1988-2008 using EFc and EFp (Data source, NFA 2011 Edition)

Equation 12 is used for the calculation of the historical ETD in figure 8.

In figure 8, the historical Danish cropland ETD patterns increases generally from 1988-2008, alternating between negative and positive values. Negative ETD values were from 1988-1992, and from 1995-2000, while positive values were from 1993-1994 and from 2001-2008. From equation 12, the period of a negative ETD values, show that, the size of EFp was larger than EFc, due to low imports amounts of cropland products which decreases EFi and contributes to low EFc and high export amounts of cropland products which increases EFe and contributes to low EFc. The size of EFp was smaller than EFc for the period of positive ETD values due to high import amounts of cropland products which increases EFi and contributes to high EFc.

4.2 Estimation of Cropland Area within Climate Commissions 2050 Land use Scenario.

The estimation of yearly cropland amounts (2013-2050) under Climate Commissions land use scenario (Figure 2) is necessary because the yearly cropland area (Organic and Conventional) is needed for the calculation of yearly total BC. In the land use scenario, the Climate Commission estimated area for conventional and organic food production (crops and dairy) (Figure 2) but in this research only land for crop production is estimated because cropland BC estimations requires only cropland area (Equation 2). Firstly the organic cropland area from 2013-2050 is estimated following the land use scenario. From 2010, the Climate Commission assumed the land used for organic crop production, will increase according to the organic action plan which requires the doubling (Bisgaard 2012; DMFAF 2014) of the 2011 organic area (153416 ha) by 2020 (306832 ha) an area which is then maintained until 2050. This gives an expected annual increase (assuming a linear increase) of 17046 ha yearly (2011-2020) (Norfelt 2011). The observed mean annual increase for the years 2010-2012 based on data from Statistics Denmark (2013) is however much smaller (6418 ha). For the scenario in this study the observed trend for 2010-2012 is assumed to continue until 2013 and for the years 2014-2020 to follow a linear trend to reach a doubling compared to 2011 in 2020.

Secondly to estimate the extent of future conventional area (2010-2050), conventional cropland was assumed to decrease at the same rate as the increase in productivity assumed by the Climate Commission, that is, by 0.7% yearly. By reducing the extent of conventional area at this rate food production would be sustained at the 2013 level which is 41755800 t/year; with the proportion of the various crops being assumed to be constant in this research and the fractions of wet/dry weight do not change over time (Statistics Denmark 2013) while providing land (Freed area) for other biomass production (e.g. Energy crop production; SRC willow). Conventional cropland area for the year 2013 is estimated here by subtracting organic cropland area (167400 ha) from total cropland area (2627816 ha) (Table 1) (Statistics Denmark 2013). The cumulative freed area for the year 2050 in this theoretical scenario will be about 563139 ha. If all of this area is used for bioenergy production and assuming the increase in organic cropland area until 2020 total Danish cropland area will stay almost constant from 2020 (Figure 9). If none of the yearly freed areas are used for energy crop production, total Danish cropland area will instead decline yearly from 2020 (Appendix 5).

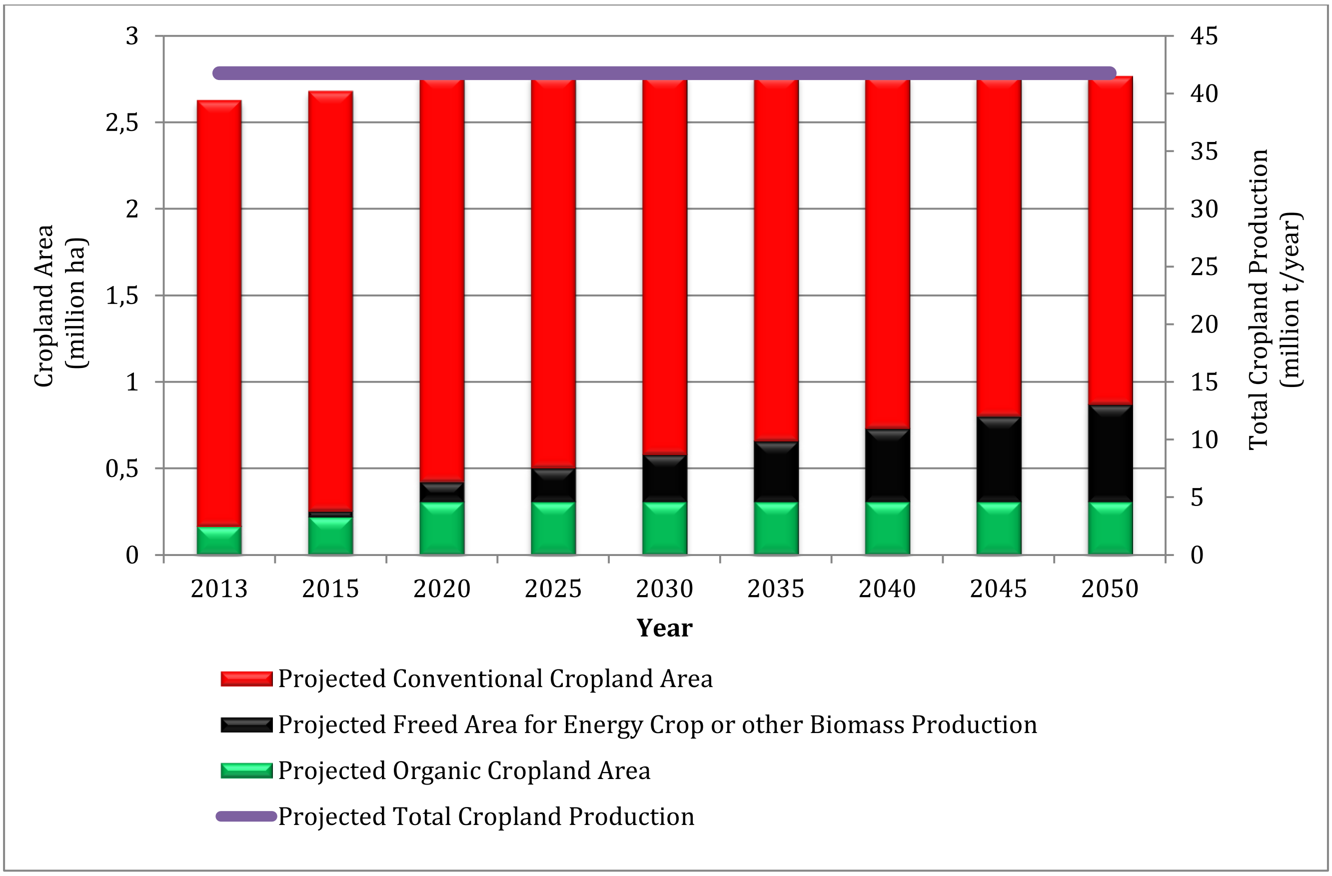


Figure 9 Projected Cropland Area within 2050 Land use Scenario (Data source, Statistics Denmark)

4.3 Estimation of Cropland Ecological Footprint at Climate Commissions Scenarios

The projected cropland BC, EFp, EFi, EFe and EFc are calculated in gha per capita for the Climate Commissions land use scenario from 2013-2050 using the datasets from the NFA 2011 Edition (1961-2008). Projected Danish population data (2013-2050) from Statistics Denmark were used for the per capita calculations by dividing the yearly projected BC, EFp, EFi, EFe, and EFc by the corresponding yearly projected Danish population amount (Table 1).

4.3.1 Estimation of Danish Cropland Biocapacity (BC) from 2013-2050

Cropland BC is calculated using equation 2. In order to calculate BC the cropland YF is first calculated (Equation 3). YF is calculated from the world crop area (For only Danish crops) divided by the total Danish national crop area (Table 1). In the calculation of YF from 2013-2050 in this research, the total world crop area for Danish crops (in the NFA 2011 Edition) is kept constant at 2008 amount (5150655 ha) (Table 1) which is the latest NFA amount because the YF is sensitive to world crop area and there is high uncertainty on how the world crop area for Danish crops might change from 2013-2050.

Table 1 Projected Conventional Area, Freed Area, Organic Area, World Crop Area, National Crop Area, Yield Factor (YF) and Danish Population 2013-2050

	2013	2015	2020	2025	2030	2035	2040	2045	2050
Estimated Conventional Area (ha)	2460416	2426091	2342358	2261515	2183463	2108104	2035346	1965099	1897277
Estimated cumulative Freed Area (ha)	-	34325	118057	198900	276953	352312	425070	495316	563139
Estimated Organic Area (ha)	167400	221600	306832	306832	306832	306832	306832	306832	306832
World Crop Area for only Danish crops (ha)	5150655	5150655	5150655	5150655	5150655	5150655	5150655	5150655	5150655
Total Danish National Crop Area (ha)	2627816	2682016	2767248	2767248	2767248	2767248	2767248	2767248	2767248
Total Yield Factor (YF)	1.96	1.92	1.86	1.86	1.86	1.86	1.86	1.86	1.86
Projected Danish Population	5602628	5629262	5751122	5872987	5994852	6116717	6238582	6360447	6482312

Following the footprint concept, the Maximum cropland BC (MaxBC), is estimated from the maximum bioproductive land area which can be available if there are no other land use types calculated using the total land area of Denmark (4.3 million ha). The Minimum cropland BC (MinBC) is estimated from the available bioproductive land, calculated using land currently under cultivation (2.6 million ha at 2013) (Statistics Denmark 2013). The maximum and minimum values for IYF (max=1; min=0.51) and EQF (max=2.58; min=2.51) used in the calculation of BC from 1961-2008 are taken directly from the NFA 2011 Edition and used in the calculation of BC from 2013-2050 (GFN 2013). The yearly crop area (Table 1), Yield Factor (YF), min and max EQF and IYF are substituted into equation 2 to obtain the min and max BC expressed in gha. The yearly gha are divided by the projected yearly population to get an amount in gha per capita. In general, the yearly range in BC (Figure 10) decreases slightly from 2013 (min=1.17 and max=3.78 gha per capita: for a population of ~ 5.6 million inhabitants) to 2050 (min=1.01 and max=3.18 gha per capita: for a population of ~6.4 million inhabitants). The cropland ecological footprint calculations in this research are done with the minimum BC, just as in the NFA 2011 Edition.

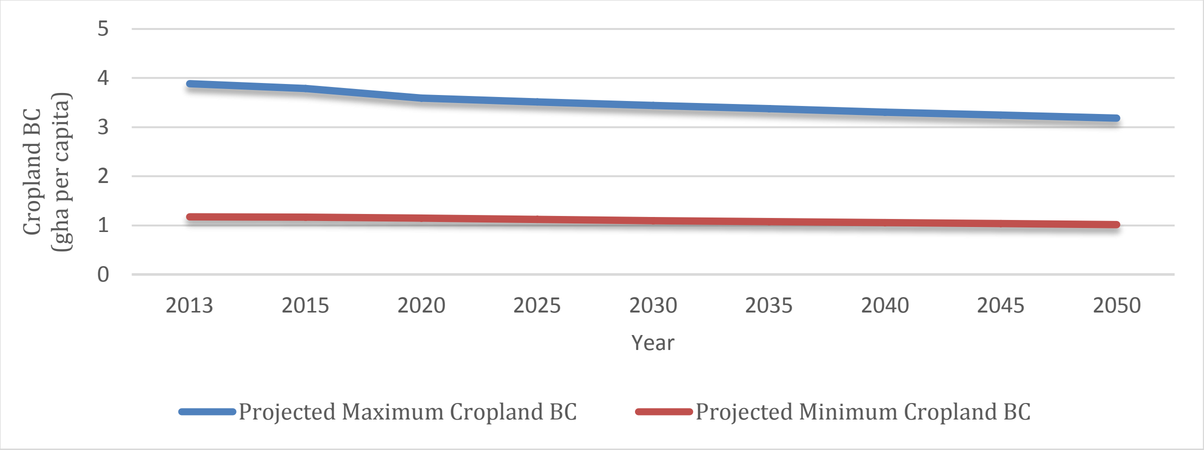


Figure 10 Projected Cropland Biocapacity (BC) 2013-2050

4.3.2 Estimation of Ecological Footprint of Production (EFp)

EFp was calculated for each crop individually using equation 4 based on WCy (Equation 7) taken from the NFA 2011 dataset. The NFA datasets only contain the years 1961-2008 so to calculate the production for each crop in 2013 the total crop production for the year 2013 from Statistics Denmark is used (41755800 t). This value is divided between the different crops following the relative dominance in the NFA. From studying the trends of each crop, most crops in the NFA show a moderate to strong linear WCy trend from 1988-2008. Here it assumed that the historical trends of WCy datasets (In the NFA) continues until 2050, as WCy increase due to technological advancements (Baumanns 2013; Jaggard et al. 2010; Olesen et al. 2012). To get projected WCy (2009-2050) for each crop the best linear fit for the years 1988-2008 in the NFA 2011 data was calculated using the "Forecast" function (MS 2014) in Excel 2013, to project values in a series. Excel 2013, is a software package consisting of a spread sheet application for data analysis developed by Microsoft (MO 2014). For one crop, which was Rye grass (for forage and silage) using these years for the linear fit generated negative future yields. To avoid this, the linear fit for this crop was instead calculated for the years 2004-2008.

The yearly national crop production amount for each crop (conventional and organic) from 2013-2050 which is assumed here to be constant. This is the min requirement for production within the land use scenario, and is divided by its projected WCy (Equation 4) to get the EFp in hectares of each crop. The EFp of each crop in gha is added together to get the total EFp. The total EFp in hectares is converted to gha by multiplying with the max and min IYF and EQF coefficients. From figure 11, the range of total cropland

EFp decreases with an increase in WCy and a constant national crop production amount from 2013-2050.

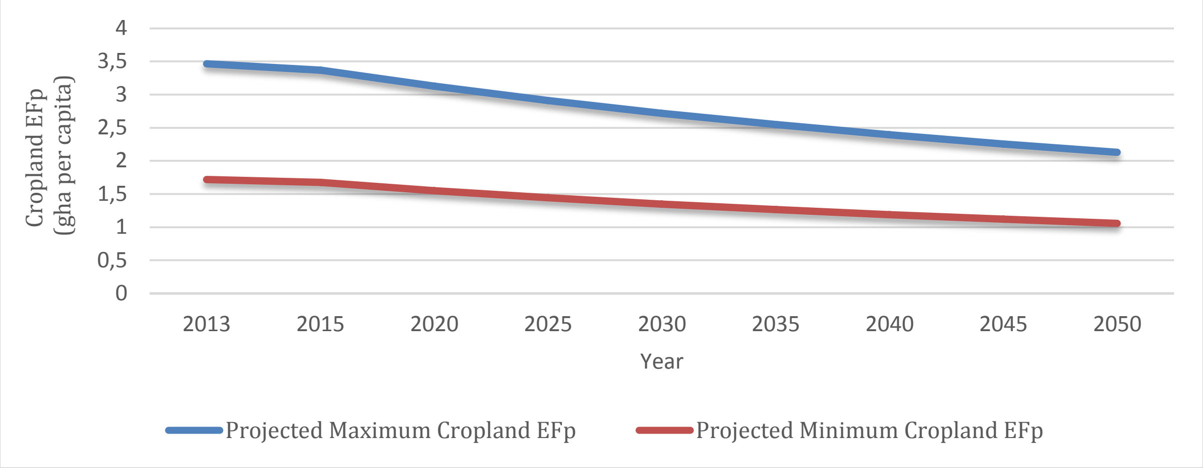


Figure 11 Projected Cropland Footprint of Production (EFp) 2013-2050 (At constant production and increasing world crop yields)

In this project, conventional and organic EFp are estimated qualitatively (since conventional and organic production datasets are not separated) following the ecological footprint concept. In the land use scenario, conventional crop production is expected to increase or remain at constant 2013 production amounts until 2050. Hence to estimate conventional cropland EFp, equation 4 is applied to a constant or increasing yearly conventional crop production and an increasing yearly conventional WCy. While to estimate organic cropland EFp, equation 4 is applied to an increasing yearly organic crop production and an increasing yearly organic WCy. In Denmark, the total yearly conventional crop production amounts is greater than the total yearly organic crop production amounts. Thus, the yearly Danish conventional cropland EFp will be greater than the yearly organic cropland EFp by 2050.

4.3.3 Estimation of Cropland Ecological Footprint of Import (EFi)

EFi is calculated (Equation 5) based on crop WCTy (Equation 8) and national crop imports for each crop. National crop import is kept constant at the 2008 year level for each crop for all years in the scenario period to see the effect of increasing projected WCTy on EFi at constant national crop imports. The EFi of each crop is added to get the yearly total EFi. Total EFi is multiplied by the min and max IYF and EQF to convert its values to gha (GFN 2013). From figure 12, projected total EFi range decreases slightly from 2013-2050 at constant national crop import and increasing projected WCTy

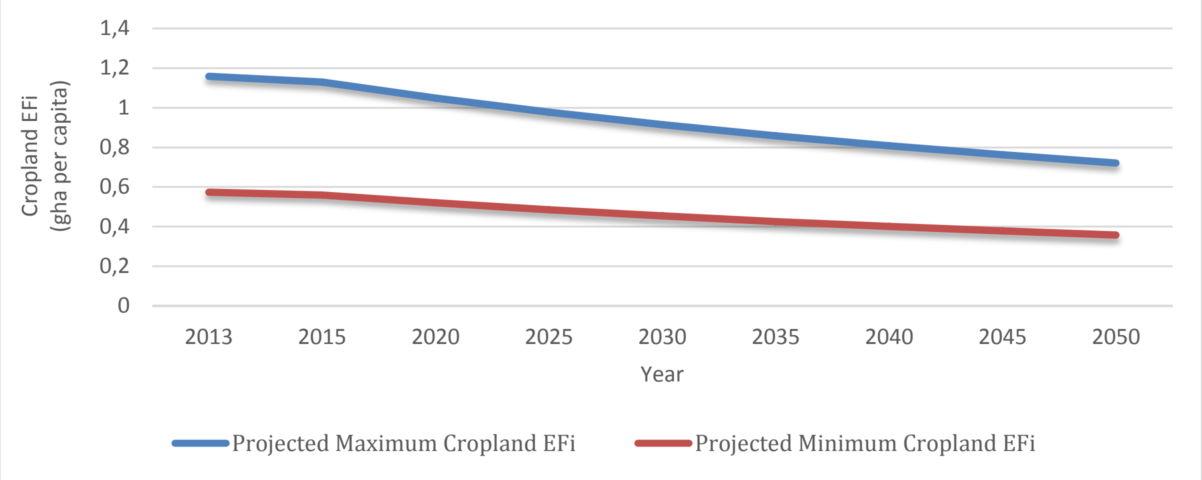


Figure 12 Projected Cropland Footprint of Import (EFi) 2013-2050

4.3.4 Estimation of Cropland Ecological Footprint of Export (EFe)

Cropland EFe was calculated using the same approach as for EFi but for national export data (Equation 6) rather than import data (Equation 5). From figure 13, projected total EFe range decreases slightly from 2013-2050 at constant national crop exports and increasing projected WCTy

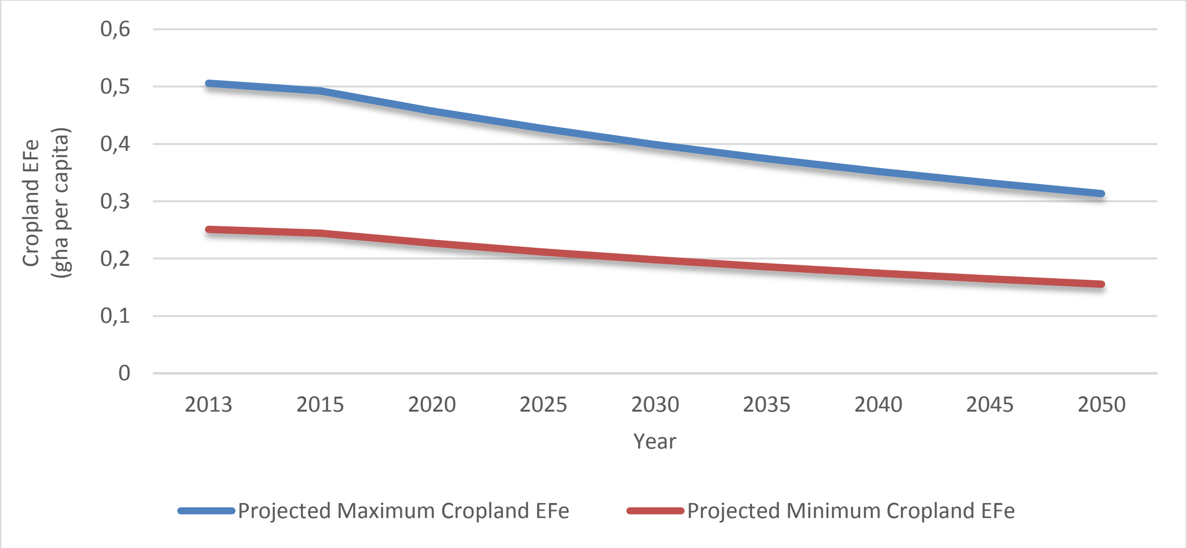


Figure 13 Projected Cropland Footprint of Export (EFe) 2013-2050

4.3.5 Estimation of Cropland Ecological Footprint of Consumption (EFc)

Cropland EFc is calculated from equation 1 using the minimum and maximum values of EFp, EFi, and EFe in gha per capita (2013-2050) for the calculation of minimum and maximum EFc in gha per capita respectively. From figure 14, the range of projected total cropland EFc decreases slightly from 2013-2050, with decreasing yearly EFp, EFi and EFe. The minimum EFc in 2008 is around 2.7 gha per capita, while in 2013 it is 2 gha per capita due to the use of max and min EQF and IYF values to convert EFc value in wha to gha. Min values of EFc are obtained using min values of EQF and IYF and similarly max EFc values are obtained using the max values of EQF and IYF. It is expected in this research that the observed EFc value will occur within this min and max EFc range. Danish EFc in wha decline from 2008-2013 due to the increase in the projected WCy and WCTy used in the calculation of EFp, EFi, and EFe. From 2008-2013, EFp, EFi and EFe decline due to the increase in WCy and WCTy. What is seen here in fig 14 is the Danish EFc value in wha from 2013-2050 that been converted to gha using the max and min EQF and IYF values to get a range because it is not easy to get the precise value in gha

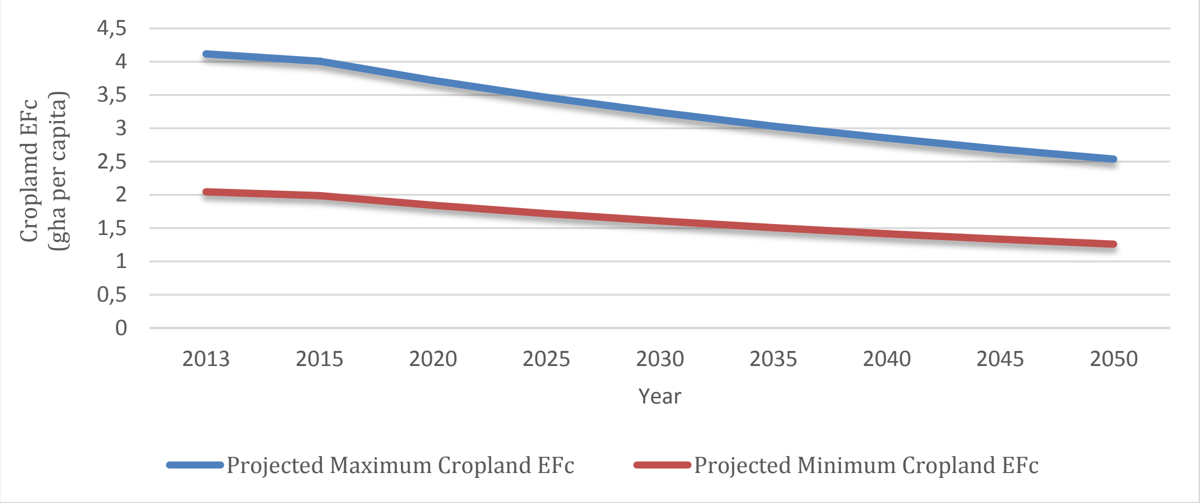


Figure 14 Projected Cropland Footprint of Consumption (EFc) 2013-2050

4.3.6 Estimation of Ecological Deficit (ED)

ED is calculated from equation 9. Projected min ED is calculated using the projected min BC (MinBC) and the projected min footprint of consumption (MinEFc). From figure 15 it can be seen that projected MinBC is smaller than MinEFc for the entire scenario period. As the decrease in BC is smaller than the decrease in EFc the resulting MinED decreases from 2013 (-0.86 gha per capita) to 2050 (-0.24 gha per capita). ED indicates how much land is used as cropland above the cropland amount Denmark can provide (GFN 2013).

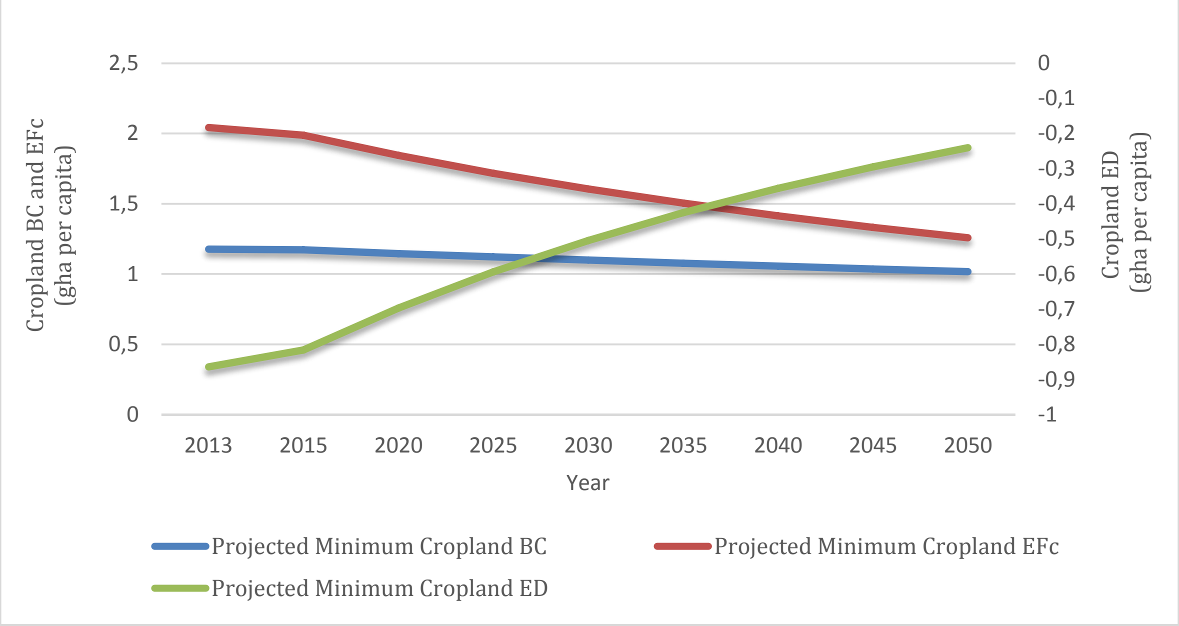


Figure 15 Projected Cropland Ecological Deficit (ED) 2013-2050 using BC and EFc

4.3.7 Estimation of Ecological Overshoot (EO)

EO is calculated from equation 10. Projected min EO is calculated using the projected min BC (MinBC) and the projected min footprint of production (MinEFp). From figure 16 it can be seen that the projected MinBC is smaller than MinEFp leading to an EO. Both MinBC and MinEFp decrease over time but as the decrease in MinBC is smaller than for MinEFp this results in an decrease in EO from -5.4 gha per capita in 2013 to -0.03 gha per capita in 2050. EO indicates how much land is used for cropland production above the cropland amount Denmark can provide (GFN 2013). In a state of an EO, the rate of resource consumption is more than the maximum carrying capacity while in ER, the rate of resource consumption is less than the carrying capacity and the region can support more human activity (Wang et al. 2010b).

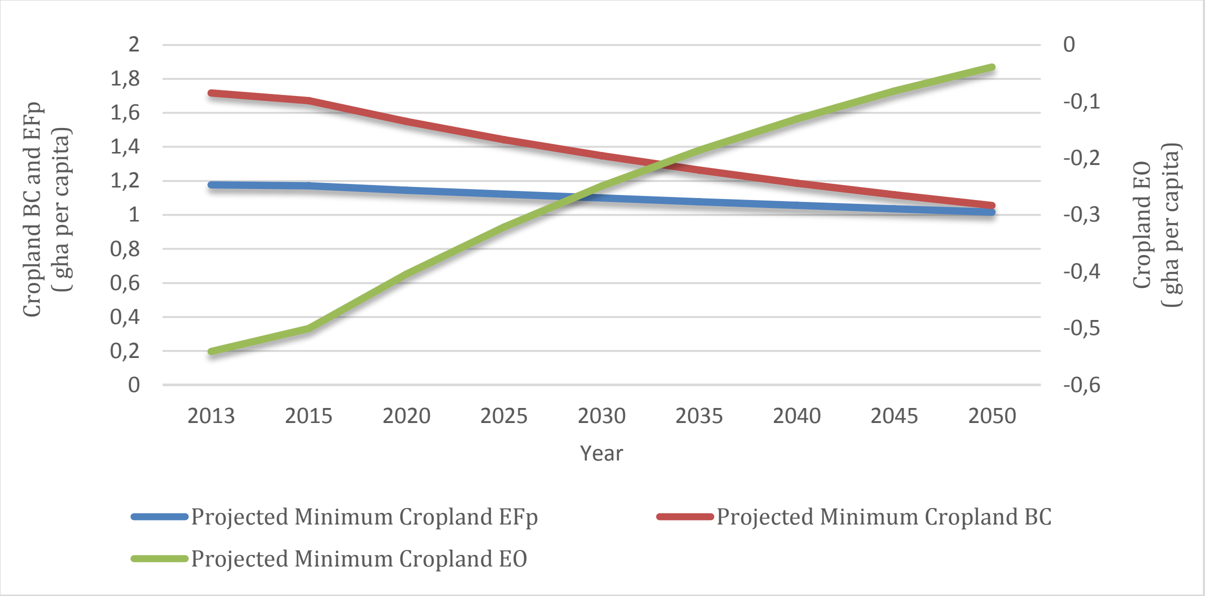


Figure 16 Projected Cropland Ecological Overshoot (EO) 2013-2050 using BC and EFp

4.3.8 Estimation of Ecological Trade Deficit (ETD)

ETD is calculated from equation 12. Projected min ETD is calculated using the projected min footprint of consumption (MinEFc) and the projected min footprint of production (MinEFp). From figure 17 it can be seen that MinEFc is smaller than MinEFp resulting in a positive ETD. Both MinEFc and MinEFp decrease over time generating a small decrease in MinETD from 2013 (0.32 gha per capita) to 2050 (0.20 gha per capita). ETD indicates the land amount displaced by Danish participation in international trade (import and export of cropland products) (GFN 2013; Weinzettel et al. 2012)

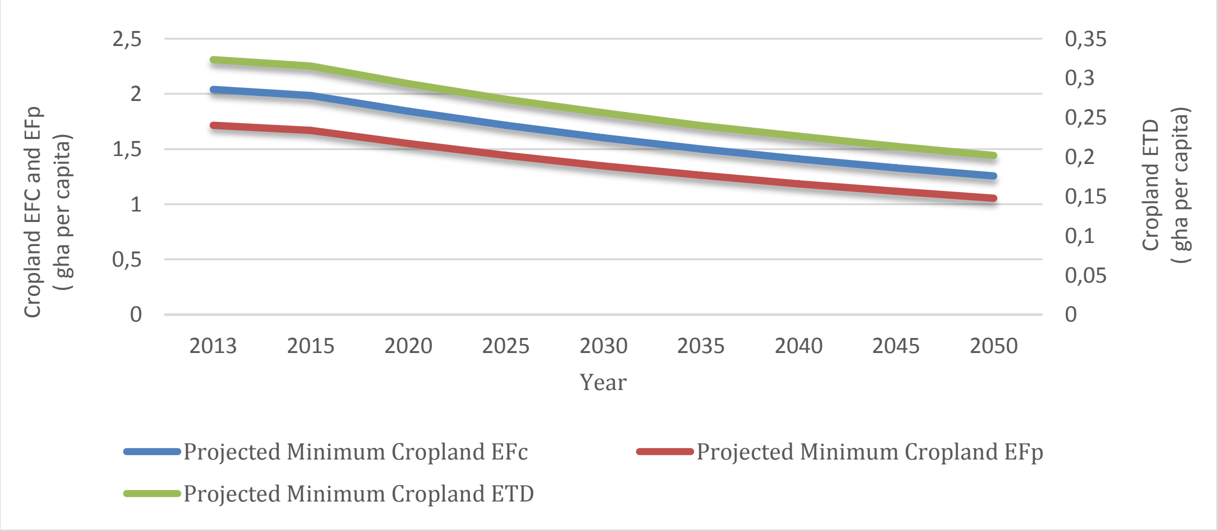


Figure 17 Projected Cropland Ecological Trade Deficit (ETD) 2013-2050 using EFc and EFp

4.3.9 Possible Outcomes from assumed implementation of the Energy Consumption Scenarios

The possible changes in ED, EO, ETD and nature of the cropland intensification when the energy consumption scenarios are implemented were assessed based on the studies of Andersen et al. 2003; Carswell 2007; Dalgaard et al. 2011; Jørgensen et al. 2005; Mola-Yudego and Aronsson 2008; Norfelt 2011; Olesen et al. 2010; Richardson et al. 2011; Rudel et al. 2009. Changes in ED, EO, ETD and nature of the cropland intensification in the energy consumption scenarios are compared with those of the land use scenarios. In this study, it is assumed that the energy consumption scenarios are implemented on top of the land use scenarios. There are many uncertainties in the energy consumption scenarios because Danish energy consumption can change due to technological developments (Richardson et al. 2011). The energy consumption scenarios are assessed quantitatively by estimating energy produced with and without willow (Salix spp) as energy crop and qualitatively by comparing some of its assumed possible and feasible outcomes (with respect to footprint) to those of the land use scenarios. The results are presented in table 2 and 3a; 3b.

Taking values from Jørgensen et al. (2005) it was assumed that willow had a water content 50% and a productivity of 8 t DW/ha/year. The energy content per ton was calculated as 7.4×10^{-5} PJ/t. Based on these numbers the total energy production of the estimated freed land (563139 ha) for energy crop production (Figure 9) is calculated assuming that the entire area is being planted with SRC willow in 2050. The calculated production is 4505112 tons with an energy content of 333 PJ. Richardson et al. (2011) estimated Danish biomass and waste (straw, urban waste, fossil waste, biogas from waste, firewood, industrial wood waste, wood chip, and wood pellets) (Andersen et al. 2003) to have a total resource potential of 250 PJ in 2008 but just 89 PJ was exploited in 2008. If the same amount of energy produced by Danish biomass and waste (89 PJ) in 2008 is produced in 2050, with the production of energy from SRC willow (333 PJ) from the freed land, the minimum Danish biomass potential at 2050 will be about 422 PJ (89+333). Assuming that only willow will be used to fully meet up with Danish bioenergy demand in 2050 (433 PJ) and using values of yield and energy content from Jørgensen et al. (2005) it was calculated that about 5845500 t/year ($433/7.4\times10^{-5}$) were to be needed. To calculate the EFp of willow which have been planted on the freed land its World Crop Yield and production data are needed. Assuming the World Crop Yield of willow to be the same as above (8 t DW/wha/year) and applying equation 4, the EFp of willow will be 730687 wha (5845500/8)(at country level). Adding this EFp of willow (in gha)(at global level) from DK freed land to the EFp for DK cropland (in gha)(at global level) at 2050 (calculated above at 41755800 tons production: figure 11) generates a 10% increase in total DK Cropland EFp at 2050 compared to the total EFp for DK cropland calculated without willow from Freed land. In this research an energy consumption scenario "without willow" (Table 2 and 3a) would mean the freed lands are not used at all for energy crop production and "with willow" implies all freed lands are planted with willow (Table 3b).

Table 2 Possible Outcomes from Assessing the "Ambitious" Scenario at 250 PJ Danish Biomass Potential without willow

Energy to be generated at 2050 from Solid Biomass (433 PJ)	**Ambitious Scenario**	
	With Biomass	Without Biomass
Energy to be Consumed at 2050	124 PJ from biomass and 309 PJ from wind	433 PJ from wind
Possible Outcome (with respect to footprint and compared with land use scenario)	No rising EFc No rising EFp Intensification as in land use scenario No food crop compromise	No rising EFc No rising EFp Intensification as in land use scenario No food crop compromise Increase GDP from industry

Table 3a Possible Outcomes from Assessing the "Unambitious" Scenario at 250 PJ Danish Biomass Potential without willow

Energy to be generated at 2050 from Solid Biomass (433 PJ)	**Unambitious Scenario**	
	Produced in DK	Imported
Energy to be Consumed at 2050	250 PJ generated from exploiting all Danish biomass potential	183 PJ generated from energy crop imports
Possible Outcome (with respect to footprint and compared with land use scenario)	Rising EFp Increase intensification Increase GDP from industry Food crop compromise	Rising crop import Rising EFi Rising EFc Rising food crop prices

Table 3b Possible Outcomes from Assessing the "Ambitious "and "Unambitious" Scenarios at 422 PJ Danish Biomass Potential with willow

Scenario	**Energy to be Generated**	**Possible Outcome**
Ambitious scenario	124 PJ will be generated easily from the 422 PJ potential	No rising EFc, EFp, EFi, EFe No food crop compromise Increase sustainable intensification
Unambitious scenario	From the 433 PJ to be consumed, 422 PJ will be generated from the 422 PJ potential, The remaining 11 PJ from imported willow or by exploiting more national biomass or waste potential	No rising EFc, EFp, EFi, EFe No food crop compromise Increase sustainable intensification 148817 tons of willow to be imported to generate 11 PJ

5. Influence of Drivers on EFc Patterns

The STIRPAT model is applied here to study the relationship between drivers and EFc as illustrated in (Figure 4). In this research the basic STIRPAT model (equation 13) is modified (equation 16) (York et al. 2003) by adding the International trade variables of Export (E) and Import (I) of food and energy crops because International trade would be an important driver of Danish EFc when the scenarios are implemented (Table 2 and 3a; 3b).

Im=$aP^{b}S^{c}T^{d}E^{f}I^{g}e$ Equation 16

Equation 16 is transformed from the nonlinear equation to a linear equation in equation 17 by taking ln on both side of the equation

$lnIm = lna + blnP + clnS + dlnT + flnE + glnI + lne$ Equation 17

Where Impact (Im) =EFc, Population (P), Affluence (S) =GDP per Capita,
Technology (T) =Farm Machinery, International Trade-Imports (I), International Trade-Export (E) and error term (e). The constants, a scales the model; b, c, d, f, and g are exponents of P, S, T, E and I. The quadratic terms of the drivers are added (to test for EKC) to equation 17 to give equation 18, for all drivers which can have a nonlinear growth (S, T, E, and I). The quadratic term for Danish population is not added to the equation because Danish population is not expected to grow nonlinearly or exponentially by 2050, as the other drivers.

$\mathrm{lnEFc} = \mathrm{lna} + \mathrm{blnP} + \mathrm{c_1lnS} + \mathrm{c_2(lnS)^2} + \mathrm{d_1lnT} + \mathrm{d_2(lnT)^2} + \mathrm{f_1lnE} + \mathrm{f_2(lnE)^2} + \mathrm{g_1lnI} + \mathrm{g_2(lnI)^2} + \mathrm{lne}$ Equation 18

The contribution of the drivers to changes in the historical cropland consumption patterns (1988-2008) are analysed (if historical trends of drivers continue, the drivers may still influence EFc patterns with the same magnitude) using data taken from NFA (EFc, Export and Imports) and from Statistics Denmark (Population, GDP per Capita and Farm Machinery). The STIRPAT model requires the application of the Ordinary Least Squares (OLS) (Table 4) and Ridge Regression (RIREG) (Table 5) (Wang et al. 2011a; Wang et al. 2010b; York et al. 2003; Xianghao et al. 2011). SPSS 19.0 is used for OLS and RIREG analysis. OLS is first performed between the dependent variable (lnEFc) and the independent variables (the variables on the right hand side of equation 18).

5.1 Ordinary Least Squares Estimates

Table 4 Ordinary Least Squares estimates for EFc and Drivers. Variance Inflation Factor (VIF), Significance (Sig) level=0.05, Coefficient of determination (R^2=0.70, Adjusted R^2=0.60). Variables (VAR), where Q denoted the quadratic terms

VAR	**ln Population**	**lnGDP per Capita**	**lnQGDP per Capita**	**lnFarm Machinery**	**lnQFarm Machinery**	**lnExport Cropland Products**	**lnQExport Cropland Products**	**ln Import Cropland Products**	**lnQImport Cropland Products**
VIF	196.990	16920.226	114.266	200.260	40338.757	1.128	79666.65	47457.944	7.064
Sig	0.760	0.593	0.812	0.929	0.356	0.116	0.237	0.205	0.224

The OLS analysis indicates the presence of multicolinearity (VIF>10 for some independent variables) (Table 4). Neither of the drivers were significant at the 5% nor at 1% level (Table 5). Multicolinearity is an obstacle which prevents the regression model from capturing the real relationship between the dependent and the independent variables. To overcome this obstacle a RIREG analysis is performed (Table 5) which introduces a bias (ridge or k-value) within the regression steps (IBM 2011)

5.2 Ridge Regression Estimates

Table 5 Ridge Regression estimates for EFc and Drivers. Standardized Betas (St. Beta), Significance (Sig) level=0.05, Partial Correlation (P.Corr). Coefficient of Determination (R^2=0.741, Adjusted R^2=0.529). Variables (VAR).

VAR	**ln Population**	**lnGDP per Capita**	**lnQGDP per Capita**	**lnFarm Machinery**	**lnQFarm Machinery**	**lnExport Cropland Products**	**lnQExport Cropland Products**	**lnImport Cropland Product**	**lnQImport Cropland Products**
St. Beta	0.063	0.091	0.141	-0.161	-0.127	-0.111	-0.106	0.076	0.058
Sig	0.028	0.003	0.000	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
P.Corr	0.349	0.349	0.349	0.000	0.000	0.000	0.000	0.000	0.000

Fifty model runs were made which produced fifty k values. The ridge trace (Figure 18) for EFc shows the bias at different values of k for all standardized beta (Drivers). The best model run was at k= 0.83 (best k). The regression model is run in steps of 0.01: 0.02: 1.0. At the best k, the best model for the relationship between lnEFc and the drivers is detected. The ridge trace for EFc shows how good (reduced variation within drivers) the ridge regression steps were carried out.

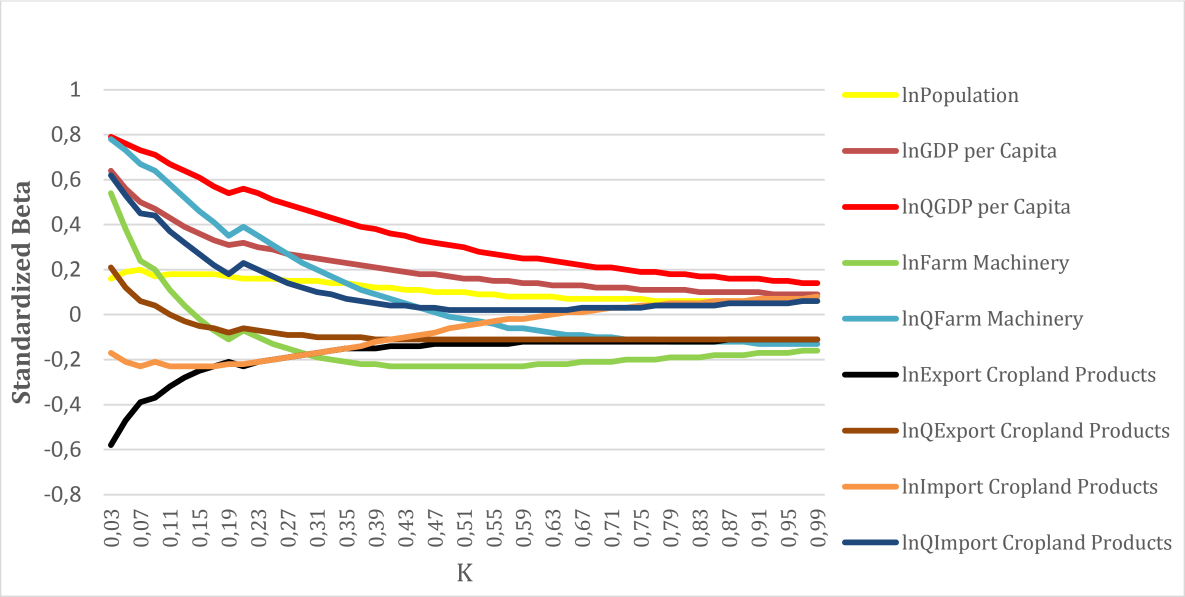


Figure 18 Ridge Trace for Ecological Footprint of Consumption (EFc)

The contribution of each driver to changes in Danish cropland EFc (Figure 19) is calculated as a percentage of the drivers influence on the growth of EFc (Wang et al. 2011a) because the continuation of historical trends will cause drivers to still influence future EFc patterns with the same magnitude. To calculate the contributions of drivers to changes in EFc, three steps are involved (Wang et al. 2011a).

Firstly, following Wang et al. (2011a) the Minimum Average Annual Growth Rate (MAAGR) (%) of each driver and EFc was calculated from 1988-2008 using equation 19 Average Annual Growth Rate was estimated using linear regression. The gradient of the linear equation taking as the Average Annual Growth Rate

$$\text{MAAGR} = \left(\frac{\text{Average Annual Growth Rate } 1988-2008}{\text{Highest Annual Growth Amount } 1988-2008}\right) \times 100 \qquad \text{Equation 19}$$

Secondly, the effect each of drivers (%) on EFc is calculated using equation 20. The corresponding Ridge Standardized Coefficient of each driver is represented by RIREGcoef in equation 20 (Wang et al. 2011a),

Effect of driver on EFc changes = (MAAGR of driver × RIREGcoef of driver) Equation 20

Thirdly the contributions (%) each driver to changes in EFc is calculated from equation 21.

$$\text{Contributions of drivers to EFc changes} = \left(\frac{\text{Effect of driver on EFc changes}}{\text{MAAGR of EFc}}\right) \times 100$$

Equation 21

Subtracting the total contribution of the investigated drivers from 100% gives the estimated total contribution of other drivers (13.9%) (Figure 19).

Results from the contributions of drivers to changes in EFc are displayed in figure 19

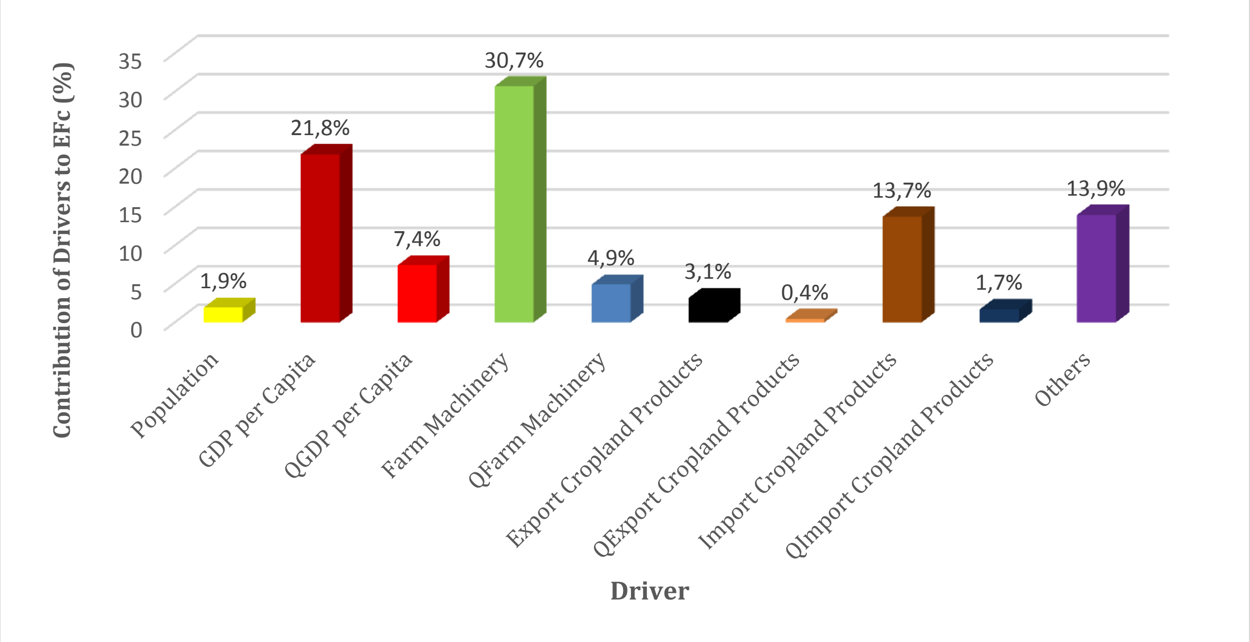


Figure 19 Contribution of Drivers to Historic Changes in EFc (1988-2008)

5.3 Testing the Ecological Elasticity (EE) of Drivers

In order to know how drivers might have influenced impact (EFc) (Figure 19), the Ecological Elasticity (EE) of each driver is calculated. York et al. (2003) defined the Ecological Elasticity (EE) as the “proportional change in environmental impact due to change in the driving force”. With other factors assumed to be held constant, EE is the proportional change (%) in a dependent variable for a 1% change in an independent variable and is a measure of the sensitivity of each impact to their respective driver. The Elasticity of Impact (EE_I) of each driver is calculated by first substituting the Ridge Standardized Coefficient values of each driver (Table 5) into equation 18 to produce equation 22

$$\ln EFc = \ln a + 0.063\ln P + 0.091\ln S + 0.141(\ln S)^2 - 0.161\ln T - 0.127(\ln T)^2 - 0.111\ln E - 0.106(\ln E)^2 + 0.076\ln I + 0.058(\ln I)^2 + \ln e \qquad \text{Equation 22}$$

From equation 22, the Population Elasticity of Impact (EE_{IP}), Affluence Elasticity of impact (EE_{IS}), Technology Elasticity of Impact (EE_{IT}), and International Trade-Import Elasticity of impact (EE_{II}) for any value of lnP, lnS, lnT and lnI are taken. This is done by assuming the values of the other drivers to be constant (e.g. by holding lnP, lnS, and lnT constant when lnI is being calculated) (York et al. 2003). This generates the following elasticity functions for lnP, lnS, lnT and lnI respectively:

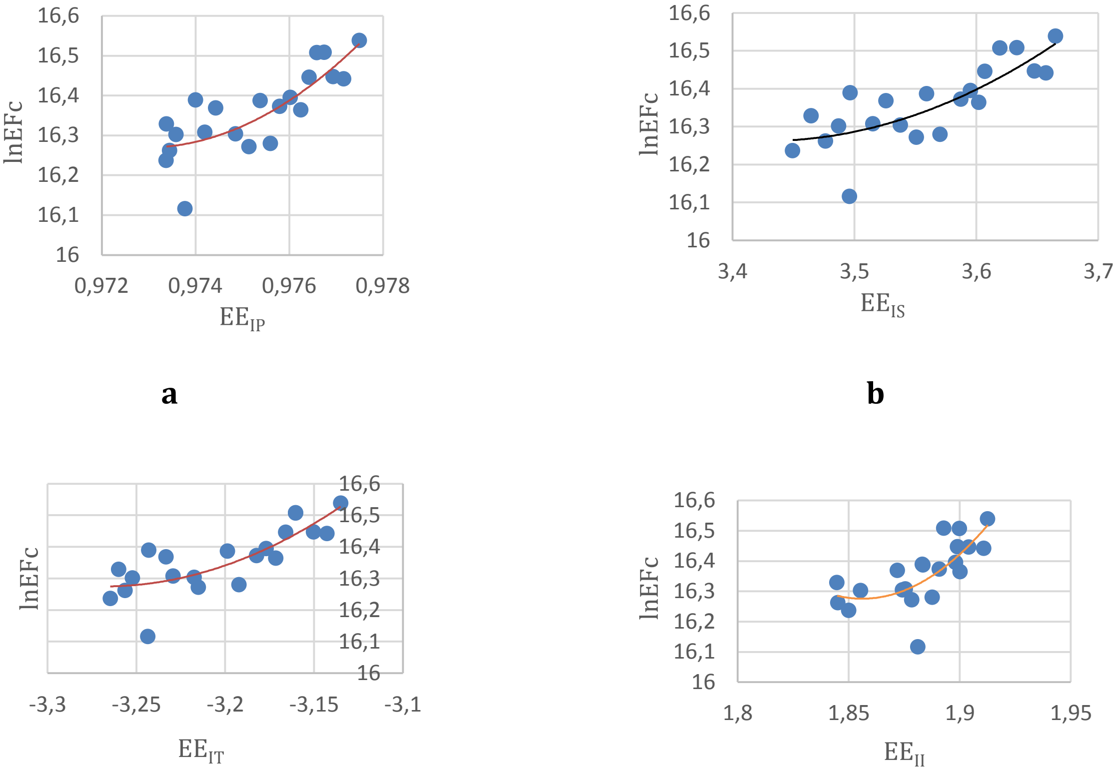
$EE_{IP} = 0.063\ln P$ Equation 23

$EE_{IS} = 0.091 + 2 \times 0.141\ (\ln S)$ Equation 24

$EE_{IT} = -0.161 - 2 \times 0.127\ (\ln T)$ Equation 25

$EE_{II} = 0.076 + 2 \times 0.058\ (\ln I)$ Equation 26

EE_{IP}, EE_{IS}, EE_{IT}, and EE_{II} for each year between 1988 and 2008 are calculated using equation 23 to 26 and values of P, A, T and I taken from the NFA 2011 Edition. The calculated values of EE_{IP}, EE_{IS}, EE_{IT}, and EE_{II} are then plotted against lnEFc (1988-2008) (Figure 20a-d) to check if the resulting function is a U-shape curve (EKC hypothesis) (York et al. 2003). The Elasticity of Impact (EE_I) was not calculated for export because the contribution of Qexport of cropland products to EFc changes (0.4%) is less than 1% (Figure 19) which suggests, export (as a whole) did not follow the EKC hypothesis during the period (1988-2008). As P, S, T, and I show positive trends, looking at this means that it is not likely that a U-shaped EKC curve will occur in the near future.



a

b

C

d

Figure 20 a) Population Elasticity (EE$_{IP}$) of lnEFc, b) Affluence Elasticity (EE$_{IS}$) of lnEFc, c) Technology Elasticity (EE$_{IT}$) of lnEFc, d) International Trade Elasticity (EE$_{II}$) of lnEFc (1988-200

6. Discussion

6.1 Methodological Weaknesses

The historical trend assumptions applied in the land use scenario for the projection of World Crop Area (Equation 7), World Crop Yields (Equation 6), and World Crop Trade Yields (Equation 8), for 2050 did not cause a significant change in BC, because the size of Danish BC (Equation 2) (Figure 10) was dependent on the size of the available national bioproductive cropland area of DK (An) (country level) and not on the World Crop Area of DK crops (Aw) which was used in the calculation of the yield factor because Aw is the world equivalent (global level) of An. The size of EFp (Equation 4) (Figure 11), EFi (Equation 5) (Figure 12) and EFe (Equation 6) (Figure 13), were dependent on yearly production, import and export amounts rather than yearly World Crop Yields and World Crop Trade Yields respectively. This means that, the projected trends in World Crop Yield and World Crop Trade Yield have an insignificant effect on footprint results (EFp, EFi, EFe) and an increase in production, import and export amounts would lead to an increase in EFp, EFi, and EFe which is considered unsustainable according to the footprint methodology. Unsustainability should not be the case, if production, import and export amounts are from a sustainable source.

All footprint results from 2013-2015 which have been expressed in global hectares (gha) in this research could change if these calculations are to be re-made using values from the forthcoming NFA 2015 Edition and if the values of EQF and IYF from that edition are outside the range for EQF and IYF used in this study. Practically in the NFA 2011 Edition calculations in Appendix 8, EQF and IYF are constant for all crops in a specific year, of which theoretically, EQF and IYF are considered as crop specific in the methodological paper of Borucke at al. 2013, thus highlighting a major weakness in the footprint methodology.

According to the fundamental principles of ecological footprint, at the country level, land should have a consumption in balance with the BC because BC represents the limits of the earth's regenerative capacity for natural resources within that particular area, thus exceeding the limits (BC) might lead to depletion of natural resources within that particular area and even beyond. At country and global level, trade within countries are allowed but trade represents a means by which countries can consume natural resources across national borders and must be sustainable according to the footprint methodology. Imports and export of natural resources should be in balance with the country's BC (Limits) for a sustainable trade (van den Bergh et al.1999).

The ecological footprint methodology does not have any indicator in the NFA 2011 Edition to account for changes in the nature of the cropland intensification. This is a major weakness because Danish croplands are being intensively cultivated (Dalgaard 2004; Norfelt 2011) thus separating cropland production with respect to sustainable and unsustainable intensification will give an impression on how good Danish croplands were used. In this analysis EFp, EFi, and EFe were calculated from total amounts of production, imports and exports (Figure 11-13), causing EFp to be larger than BC (leading to an EO). Rather, by considering the regenerative, resilience and waste absorptive capacity (Borucke et al. 2013) of the biosphere and the concept of sustainable and unsustainable intensification, it is logical to argue that cropland productions from sustainable intensification are likely to pose no long term threat (such as land degradation) to the environment, thus should not have been included in the calculation of footprints.

Since cropland footprint methods are focused on the total production of agricultural land with no respect given in how sustainable the agriculture of said land is, this also means that any environmental degradation that may result from cropland intensification (van den Bergh et al. 1999) in the “Unambitious” scenario (Table 2) in this research cannot be accounted for in the footprint methodology. Following the DPSIR framework (Appendix 3) of Smeets and Weterings (1999), ED, EO, and ETD are quantities describing the state of the natural resource being used (land), but the impact which should represent the environmental change (e.g. deterioration of the environment through the depletion of natural resources due to the use of land) is not well addressed by the footprint methodology since the underlying pressures that caused the state are not accounted in the calculation of ED, EO, and ETD. Mozner et al. (2011), also found that, the environmental pressures (nature of pollution or soil degradation) generated by cropland management practices (Organic and Conventional) are not properly revealed by footprint calculations and suggested the use of data on optimal sustainable production and yields to calculate ecological footprint and to show a more realistic representation of EO. Fiala (2008), emphasised on land degradation as an important sustainability issue which the ecological footprint fails to capture, arguing that a large land footprint (with no land degradation) could be better than a small land footprint (with much land degradation).

Van den Bergh et al. (1999) considers the ecological footprint as not providing sufficient information about the ecological impact by highlighting the lack of distinction between sustainable and unsustainable land use in ecological footprint calculations, and that “indicators need to reflect the quantity and quality of renewable resource use”. They also stressed the need for flexibility when dealing with the ecological footprint because different conceptions of sustainability may show different footprints. Van den Bergh et al. (1999) recommends dealing with the ecological footprint through a scenario approach (which gives the flexibility to deal with complex processes in large nonlinear changes) rather than an accounting approach.

In relation to the datasets used for this research, differences were found between the historical datasets provided by Statistics Denmark and NFA 2011 Edition (Figure 6-8) (Appendix 6) on Danish cropland area and production amounts but there are still no concrete reasons to explain these inconsistencies, thus constituting a major weakness. The accuracies of EFi and EFe have not been addressed in this study. This is because these values are projections from the historical dataset (provided by NFA) and realistic scenarios of trade are beyond the scope of this study. The linear trends used in this study are based on the historical import, export and World Crop Yield datasets (provided by NFA) and these trends are likely not to be consistent with those of Statistics Denmark.

Cropland is also including pasture in some data, but the footprint calculations in the NFA 2011 Edition did not make a clear distinction between this two datasets in its calculations which is a major weakness of the methodology. Since some fodder crops are grown in rotation on the same cropland with other food crops in Denmark, BC calculations (at country level) in this case, takes into account the summation of all areas in which crops (fodder and food crops) have been grown in Denmark. But in the calculation of EFp, the production amounts of food crops are supposed to be weighted in tons while those of fodder crops in terms of Scandinavian Feed Units (SFU: which is an equivalent of 1kg of average quality dry barley) (Dalgaard et al. 2011) because Statistics Denmark considers fodder and food crops of not having the same weights (Statistics Denmark 2013). On the same unit area, EFp of food crops in t/wha should be greater than EFp of fodder crops in SFU/wha. Calculations in this research follow the methods of the NFA 2011 Edition where no distinction in weights was made between fodder and food crops as both are weighted in tons. The world crop yields and EFp values for Danish grasses and fodder crops in the NFA 2011 will be lower if calculated in SFU/wha, thus will cause a large change in total cropland footprint values since grasses and fodder constitutes more than 50% of yearly Danish cropland production amounts (Statistics Denmark 2013).

The method used to investigate technology as a driver possess another weakness since technology is an aggregate. The number of farm machinery is just one indicator for technology used in this research. York et al. (2003) emphasized the need to disaggregate technology in the STIRPAT Model because it encompasses of many factors influencing environmental change. They propose to investigate technology through any element that influences impact per unit production (For example growth in total farm machinery). But it should be noted that there is no single operational measure for technology that is free from controversy (York et al. 2003)

Rye grass (for forage and silage) produced negative future yields, when its World Crop Yields were projected from 1988-2050 which caused a hump in their patterns. For the 164 crops listed in the NFA 2011 Edition the World Crop Yields of 163 were projected from 1988-2050 without encountering any hump and by projecting Rye grass from 2004-2050 instead, the hump was fixed with no future negative yields being generated. World Crop Yields are needed for calculating EFp, EFi, and EFi. The fixing did not cause much change in the EFp results since EFp values depended more on crop production amount rather than the World Crop Yields. Rye grass is neither imported nor exported from Denmark, thus its World Crops Yields did not contribute to Danish World Crop Trade Yields used for the calculation of EFi and EFe.

6.2 Assumptions

The assumption made by the Climate Commission in estimating land for conventional and organic food production from 2010-2050 under the land use scenario was also applied to estimate cropland for conventional and organic crop production from 2013-2050 under the land use scenario. The grounds for making such an assumption, especially for estimating organic cropland, was due to the consideration of some past occurrences. In summer of 2012 the Danish agricultural minister (Mette Gjerskov) launched an action plan (Bisgaard 2012; DMFAF 2014) to increase production from organic land area which the government intends to double by 2020. Danish organic area has increased since 1995 through the conversion of conventional lands to organic lands. (Dalgaard et al. 2011). Despite a lower productivity from organic crop production in Denmark (OTA 2014), the Danish government did encourage conversion to organic farms, by giving 1050 DKK /ha/year as subsidies (Norfelt 2011; OTA 2014).

To discourage conventional farming, the Danish government levied high taxes on fertilizers and pesticides products (Norfelt 2011). In 2011, Danish farmers applied for the conversion of 7850 ha of conventional farmland to organic, which was 1000 ha more than in 2010 but still less than the government's 18000 ha annual target (Norfelt 2011). The assumption of keeping the total cropland area almost constant (Figure 9) (Table 1) from 2020-2050 at "Frozen policy" can be questioned as the implementation of old policies that reduces Danish total agricultural area are expected to continue (such as set-aside lands for nature protection and the construction of new wetlands) (Dalgaard et al. 2011) which might affect total cropland area with time.

The yearly increase in productivity of Danish cropland during the scenario period (2013-2050) will be due to cropland intensification which would be influenced by factors such as: choice of crops by farmers due to markets, development in Danish organic agriculture (Norfelt 2011), drastic fertilizer reduction policies in Denmark (Dalgaard 2004), changes in food crop prices (Olesen at al. 2009) and crop production losses (when conventional farms are converted to organic) (Halberg and Kristensen 1997). To sustain yearly cropland productivity by 2050, the above mentioned changes needs to be minimized through the assumption of a "Frozen policy" during the scenario period. It is also assumed that, successive Danish governments will continue incentives (subsidies) to encourage Danish farmers not to abandon the cultivation of certain crops (such as wheat) despite price decrease (Olesen at al. 2009).

The Climate Commissions land use and energy consumption scenarios are based on assumptions since future developments of Danish croplands would be influenced by different factors, such as the willingness of successive Danish governments to implement the organic action plan by 2020, the implementation of Danish afforestation policies (Figure 2) (Dalgaard 2011), policies to increase Danish built up area (Figure 2) (Dalgaard 2011), bioenergy production and GHG reduction policies at country and global level (Dalgaard 2011; Richardson 2011). In the studies of BEC (2011), SRC willow at 30% moisture content generates energy (1.7×10^{-4} PJ/ha/year) which is less compared to energy generated from willow at 50% (5.9×10^{-4} PJ/ha/year), taken from the studies of Jørgensen et al. (2005) and used in the analysis of this research.

Population is an important driver of ecological footprint of nations but this was not the case for Denmark from 1988-2008. The calculations in the figures 10-17, are estimated per capita Danish population (Table 1), but the effect of Danish population growth from 2013-2050 on Danish BC, EFc, EFp, EFi, and EFe will be negligible due to the continuation of the 1988-2008 Danish population growth trend. Statistics Denmark estimated a 10.7% future growth in Danish population from 2008-2050, which does not differ much from the growth of 1988-2008 (7%). In this research, the Danish population is not expected to grow rapidly or exponentially over the years due to the strict Danish immigration policies (DI 2014) and low birth rate in Denmark (CP 2013). Results from the STIRPAT model analysis shows Danish population (1988-2008) was the least important driver of Danish ecological footprint.

The reason for keeping the footprint variables of Danish, import and export from 2008 - 2050 constant is because these variables have shown strong observed nonlinear trends from 1961-2008, thus there is high uncertainty on how these variables might change from 2009-2050. Equation 1 in the analysis of this research, relates increase in EFi and EFe to depend more on an increase in import and export, while increase in EFc depend more on an increase in production, import and a decrease in export. However, this is not always the case because national import, export and consumption in general will adapt to changes in economic conditions created when rules are changing. This would mean Danish cropland footprint will increase in the future, if Danish cropland consumption (with respect to production, import and export) driven by either changes in population, GDP and technology are significant to cause an increase in footprint. Incorporating the STIRPAT model to the footprint model was a suggestion to make footprint results more realistic because STIRPAT model results (Table 5) suggests, that Danish cropland footprint will not change if changes in Danish GDP per capita are not significant. STIRPAT model results opposes equation 1 which supports a one to one relationship between footprint and economic growth. Other suggestions to make footprint results realistic were taken from van den Bergh et al. (1999) and Mozner et al. (2011) and have been explained in the above discussion paragraphs of the report.

6.3 The Possibilities of the Climate Commissions Scenarios in influencing the Sustainability of future EFc Patterns

Effect on Danish Conventional and Organic Cropland Consumption

The scenario's impact on the sustainability of conventional and organic cropland is evaluated from the footprint results. The EFp results under the land use scenario for 2050 suggests both conventional and organic cropland EFp's will be larger than their BC's respectively. Conventional EFp will be larger than organic EFp due to high conventional production amounts. As a result of sustaining food crop production both organic and conventional management practices will produce an EO by 2050 due to an increase in production amounts caused by an increase in intensification but organic EO will be smaller than conventional EO due to differences in production amounts.

The "Ambitious" scenario with biomass (where 124 PJ of the total 433 PJ needed is generated from solid biomass and 309 PJ from wind). (Table 2) suggests no increase in EFp and environmental pressures from neither conventional nor organic production systems due to production intensification. The energy to be generated from solid biomass (124 PJ) is less compared to the estimated total Danish biomass potential (250 PJ), thus it puts no pressure on Danish biomass potential and imports. Intensification, food crop production, EO, ED, and ETD will be stable as in the land use scenario. The “Ambitious” scenario without biomass (where all of the total 433 PJ needed is generated from wind) (Table 2) will have no direct effect on conventional and organic cropland EFc. Maybe some croplands will be used as wind farms in the future, which may have a direct effect on EFc.

The “Unambitious” scenario where all of the total 433 PJ needed is generated from biomass) (Table 3) suggests a possible increase in EFp and environmental pressures for both conventional and organic production systems due to an increased intensification of production in order to exploit all Danish biomass potential. Since generating 433 PJ from solid biomass exceeds the estimated Danish biomass potential (250 PJ) by 183 PJ it is expected that this energy (183 PJ) will be generated from imported solid biomass. This means that EFi will rise due to increase in biomass imports which lead to a rise in EFc and ED. Conventional EO and ED will be greater than organic EO and ED due to higher conventional production amounts. To avoid compromising food production for bioenergy, there is a possibility of the Danish government being forced to increase imports of biomass needed for bioenergy rather than exploiting all of Danish biomass potential which will cause EFc to be greater than EFp and a rise in ETD.

If the freed lands (Table 1) (Figure 9) from the land use scenario are planted with willow (Dalgaard et al. 2011), Danish total biomass potential will increase to a minimum of about 422 PJ at 2050 (Table 3b) and the energy to be generated from both the “Ambitious” (with biomass) and “Unambitious” scenarios will be easily met without putting much pressure on Danish ecosystem (Table 3b). Any extra energy needed to be generated (e.g. the 11 PJ) (Table 3b) would be easily met by further exploiting the Danish biomass and waste (such as manure, fossil waste) potential in order to avoid importing 148817 tons of willow (Table 3b) or other energy crops. SRC willow is chosen because it has a high biomass and energy yield (Jørgensen et al. 2005). Willow also has a high GHG mitigation cost effectiveness compared to other energy crops (Dalgaard et al. 2011). Using values of energy content of willow from Jørgensen et al. (2005), the freed land area estimated in this research (563139 ha) will be enough to generate nearly all of the 433 PJ which needs to be generated from solid biomass. Thus area for food crop production will not be compromised for energy crop production. Results show that the estimated EFp of lands planted with willow will be smaller than the estimated total Danish BC. Therefore if the freed land are planted with willow the "Ambitious" (with biomass) and "Unambitious" scenario will promote mostly organic management practices which might decrease unsustainable intensification and ETD.

Effect on the patterns of Danish Cropland Footprint Sustainability Impression (Figure 6-8)
Danish cropland ED showed a general decline from the historical period (Figure 6) through the scenario period (land use) (Figure 15) and since ED has a negative value the ecological footprint methodology, gives that the local Danish biocapacity will not be able to meet up with the local population's cropland resource demands in 2050 (Wang et al. 2010b; Galli et al. 2012). Furthermore, the historical ER (Figure 7) gained by Denmark will be completely used up under the scenario period (land use) producing an EO (Figure 16) in 2050 which suggests that, cropland resource in Denmark will be rapidly used up and the rate of resource exploitation will exceed the local available biocapacity (Wang et al. 2010b; Galli et al. 2012). Meanwhile there was a general decline in ETD from the historical (Figure 8) through the scenario period (land use) (Figure 17) which suggests an increase in net import of cropland resources in Denmark since ETD at 2050 is a positive value (Wang et al. 2010b).

Results from analysing the "Ambitious" scenario with biomass show that there will be no rising EFp, EFi and EFc compared to those of the land use scenario, since energy consumption from solid biomass will be less because the energy that needs to be generated in this scenario (124 PJ) is smaller than the total Danish biomass potential (250 PJ), meaning that no extra land would be needed to produce this bioenergy (Table 2). The ED, EO, and ETD would be smaller compared to that of the land use scenario. The "Ambitious" scenario without biomass will cause an increase in GDP from industry which will have no direct effect on cropland EFc, EO and ETD since the growth in GDP from industry (Table 2) will be due to developments in wind energy carrier technologies and not by cropland management technologies. However it is possible that development in wind carrier technologies may later stimulate national economic growth which will cause an increase in GDP per capita and an increase in cropland EFc, EO and ETD.

Results from analysing the “Unambitious” scenario, suggests an increase in intensification and a rising EFp, EFi, EFc, EO, and imports since all bioenergy consumption (Table 3) will be generated from solid biomass. Based on values taken from Andersen et al. (2003) and Jørgensen et al. (2005) it can be estimated that Denmark will require about 6 million tons of imported straw or 2.5 million tons of willow to generate 183 PJ energy yearly. Assuming straw as the future imported energy crop, an additional 6 million tons of straw yearly to the EFi of the “Unambitious” scenario will cause its ED and ETD to be higher than the ED and ETD of the land use, and the “Ambitious” scenarios. If all of the freed land is planted with willow and the EO is calculated only for unsustainable production (rather than for total cropland area), it is likely that, the “Ambitious” and the “Unambitious” scenario will produced smaller or no EO.

6.4 The Role of Drivers in Influencing future EFc Patterns

The anthropogenic footprint drivers considered in this research for Denmark following the STIRPAT model in figure 19 can be termed as predetermined factors (Posma 2000) because they are likely to change and their change is highly predictable (Posma 2000). From the results (Figure 19) Technology represented by the number of Farm Machinery contributed the most to the EFc changes between 1988 and 2008 (30.7%), followed by GDP per capita (21.8%) to EFc. In general, all the Climate Commissions scenarios analysed in this research can cause an increase in the growth of GDP (which is a driver of change in EFc) from industry. An increase in GDP from industry could in turn also affect both technology and economic growth which are aggregate drivers of EFc (because GDP from industry is a component indicator to both technology and economic growth) (Appendix 4). A continued future growth in GDP from industry may also affect future consumption patterns (Appendix 4). The role played by drivers in influencing the sustainability of future consumption patterns are however complex and uncertain. Baumanns (2013) explored these complexities and uncertainties through a parsimonious representation (Appendix 4) and concluded that, it is possible that, the increases in agricultural production over the last 20 years is mainly caused by an increase in yield due to technological change and that this increase was much larger than the decrease in production caused by the decrease in agricultural land area. The study by Baumanns (2013) supports the results in this study with Technology having a large influence on crop production, which, according to the EF methodology is the main driver of EFc

From the results (Figure 19), the complex role of drivers can be analysed in a very simple way by assuming that Population will influence cropland footprint when it increases. Population increase implies more people are available to consume food produced from cropland thus causing an increase in crop production and crop imports. GDP per Capita will influence cropland footprint when it increases. An increase in GDP per capita would mean people can benefit more from the growing economy and can be able to afford food produced from cropland, which may cause an increase in crop production and crop imports. Farm Machinery will influence cropland footprint as its growth will increase intensification and may reduce food crop prices (Table 3). Export of cropland products will influence footprint when it increases. Increasing export due to international trade can stimulate more national crop production for export. Import of cropland products will also influence footprint when it increases, as it can reduce national crop production.

For the contribution of drivers to changes in EFc from 1988-2008, equation 22 is used to test the relationship between driving forces and impact (EFc) for Denmark. Equation 22 can be interpreted, as a 1% change in lnP would lead to a 0.063 % change in lnEFc when all other factors in the equation are kept constant (York et al. 2003). Population Elasticity of impact would mean the "responsiveness of an environmental impact due to a change in population size" (York et al. 2003). Thus the Danish population had an elasticity of 0.063% from 1988-2008. Danish Population projected by Statistics Denmark will increase by 10.7% from 2008-2050, thus if 2008 trends continue, impacts on lnEFc at 2050 will be 10.7×0.063=0.63%. From the ridge regression results (Table 5), Danish Population, GDP per Capita and QGDP per Capita showed the highest partial correlation with lnEFc which suggest they are the most important influential drivers within the period (1988-2008) and QGDP per Capita and GDP per Capita are significant at 1% level ($p<0.01$) and at 5% level ($p<0.05$). Population is significant at 5% level ($p<0.05$) but not at 1% level ($p>0.01$). This suggests QGDP per Capita and GDP per Capita are the most important drivers of Danish EFc. In studies carried out in China during the same period by Wang et al. 2011a (1986-2006); Xianghao et al. 2011 (1995-

2008) and Wang et al. 2010b (1998-2009), Population was instead the most important influential driver.

York et al. (2003) applied the Environmental Kuznets Curve (EKC) hypothesis which suggests that, at some higher levels of Affluence (GDP per capita), Affluence may cause no significant impact and even lead to a decrease in impact. As Affluence increases, the relationship between EFc and Affluence may follow the inverted U-shaped Environmental Kuznets Curve (EKC) (York et al. 2003). This means that at low levels of Affluence (GDP per capita) impact per unit economic activity (EFc) increase with increasing Affluence, but at high levels of Affluence, EFc reaches a turning point and then declines (York et al. 2003). Results (Figure 20 a-d) show none of the tested drivers followed the EKC hypothesis.

The result (Figure 27a) also suggests, that changes in Danish Population with a yearly EE_{IP} ~1.0 was in a near one to one relationship with changes in lnEFc (named unit elasticity) (York et al. 2003). Both Affluence (GDP per Capita) (Figure 27 b) (EE_{IA}=3.4-3.7) and International Trade-Imports (EE_{IA}=1.8-2.0) (Figure 27d) showed an elastic relationship with lnEFc (EE_{IA}>1) meaning, that a change in any driver lead to a relatively larger change in lnEFc. Technology (Farm Machinery) (Figure 27c) (EE_{IT}=-3.2 to -3.1) showed a negative elasticity (EE_{IT} <-1) (York et al. 2003) with lnEFc, meaning that lnEFc was decreasing in a greater proportion with an increase in Technology. Since none of the driving forces showed an EKC curve during 1988-2008, results (Figure 20a-d) suggests these driving forces are still increasing and will continue to exert pressures on Danish ecosystems until an EKC curve scenario may be reached.

7. Conclusions

The central purpose of carrying out this research was to assess the sustainability of the Danish Climate Commissions 2050 land use and energy consumption scenarios by using the footprint methodology. The aim and objective was to estimate the size of Danish cropland ED, EO, and ETD, within the Climate Commissions scenarios in order to know if these scenarios can support a sustainable conventional or organic cropland management practice appropriate for growing bioenergy crops and also to know if the scenarios can contribute to a sustainable Danish cropland impression. In the absence of willow, the “Ambitious” scenario without biomass will support a more sustainable conventional and organic cropland management practices while the “Unambitious” scenario will support an unsustainable management practice which would lead to further pressure on Danish and international cropland ecosystem (due to imports of cropland products). All scenarios will be sustainable in the presence of willow, since willow (Salix spp) can still produce high yields even when planted under organic management, cropland EO, ED, ETD and unsustainable cropland intensification will decline and food crop production sustained. Looking at the contribution of the different scenarios in relation to the sustainability impression of Danish cropland, cropland ED, EO and ETD will decline under the land use scenario at 2050 relative to 2013. Following the ecological footprint concept, Danish cropland biocapacity will be insufficient to meet the local populations demands for cropland resources. The cropland ER gained by Denmark from 1988-2008 will be consumed rapidly under the land use scenario and Denmark will be experiencing an EO at 2050. The Danish ED, EO, and ETD under the “Ambitious” scenario (with biomass) are expected to be lower than the amounts from the land use scenario. While the Danish ED, EO, and ETD might have the lowest values under the “Ambitious” scenario without biomass because the “Ambitious” scenario without biomass will have no direct impact on cropland consumption (EFc). The values of the Danish ED, EO, and ETD are expected to increase under the “Unambitious” scenario more than in the land use scenarios at 2050 because the “Unambitious” scenario has a high cropland consumption. GDP per Capita and quadratic GDP per Capita are the most important influential drivers of Danish EFc and not the Danish Population for the time period 1988-2008. All the scenarios will stimulate technological developments which may help in reducing impacts due to rising cropland consumption and intensification. The main research question was partially answered because footprint calculations do not account for intensification or capture the environmental pressures associated with rising ED, EO, and ETD. Footprint only answers the question on how much land is being used but not on how it has been used which makes its results on sustainability assessments controversial.

References

Andersen, P.D., Christensen, J.M., Kossmann, J., Koukios, E. 2003.Emerging and future bioenergy technologies. In Larsen, H., Kossmann, J., Sønderberg, P.L., editors, Risø energy report 2. New and emerging bioenergy technologies. p. 18-22. (Denmark. Forskningscenter Risoe. Risoe-R; No. 1430(EN)).

Baumanns, K. 2013. Drivers of Global Land Use Change: Are increasing demands for food and bioenergy offset by technological change and yield increase? Department of Physical Geography, Faculty of Science Lund University; scientific publications.

BEC-Biomass Energy Center. 2011. Potential Output of Biofuels per Hectare per Annum
http://www.biomassenergycentre.org.uk/portal/page?_pageid=75,163231&_dad=portal&_schema=PORTAL

Bisgaard, M. 2012. Action plan to improve organic production in Denmark
Arc 2020 Agriculture and Rural innovation.
http://www.arc2020.eu/front/2012/06/%E2%80%9Daction-plan%E2%80%9D-to-improve-organic-production-in-denmark/. Accessed 03/06/2014

Borucke, M., Moore, D., Cranston, G., Gracey, K., Iha, K., Larson, J.,
Lazarus, E., Morales, J., Wackernagel, M., Galli, A. 2012. Accounting for demand and supply of the biosphere's regenerative capacity: The National Footprint Accounts' underlying methodology and framework. Ecological Indicators 24. 518–533

Carswell, G. 1997. Agricultural Intensification and Rural Sustainable Livelihoods: A 'Think Piece. IDS working paper 64. Institute of Development Studies. ISBN: 1 85864 212 4

CIA-Central Intelligence Agency.2013.World Factbook.
https://www.cia.gov/library/publications/the-world-factbook/
Accessed 17/09/2014

CP-The Copenhagen Post. 2013. Low birth rate" approaching Epidemic".
http://cphpost.dk/news/low-birth-rate-approaching-epidemic.4323.html.
Accessed 29/09/2014

Dalgaard, T., Jørgensen, U., Petersen, S., Petersen, B., Kristensen, T.,Hermansen, J., Hutchings, N. 2010. Landbrugets drivhusgasemissioner og bioenergiproduktionen i Danmark 1990-2050. Modtager:Klimakommissionen

Dalgaard, T., Olesen, J., Petersen, S., Petersen, B., Jørgensen, U., Kristensen, T., Hutchings, N., Gyldenkærne, S., Hermansen, J. 2011. Developments in greenhouse gas emissions and net energy use in Danish agriculture-How to achieve substantial CO2 reductions? Environmental Pollution 159. 3193-3203

DCCCP-Danish Commission for Climate Change Policy. 2013. Energy Strategy.
http://www.ens.dk/en/policy/danish-climate-energy-policy/danish-commission-climate-change-policy. Accessed 9/07/2013.

Dietz, T., Rosa, E. 1994. Rethinking the Environmental Impacts of Population, Affluences and Technology. Human Ecology. Review 1(1): 277-300

Dietz, T., Rosa, E., York, R. 2013. STIRPAT A Research Programme in Structural Human Ecology. http://stirpat.msu.edu. Accessed on 19/03/2014

DI-Danish Immigration.2014. New to Denmark. The Official Porter For Foreigners. https://www.nyidanmark.dk/en-us/. Accessed on 28/09/2014

DMCE-Danish Ministry of Climate and Energy. 2011. Energy strategy 2050. From Coal, Oil and Gas to Green Energy. Summary

DMFAF-Danish Ministry for Food Agriculture and Fisheries. 2014. Organic Production. http://en.fvm.dk/focus-on/organic-production/. Accessed 03/06/2014

EEA-European Environmental Agency. 2012. Greenhouse gas emission trends and projections in Europe 2012 .Tracking progress towards Kyoto and 2020 targets. EEA Report / No 6/2012

Eurostat-European Statistics. 2014. Farm Structure in Denmark http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Farm_structure_in_Denmark.Accessed 20/09/2014

Ewing, B., Reed, A., Galli, A., Kitzes, J., Wackernagel, M. 2010. Calculation Methodology for the National Footprint Accounts, 2010 Edition*.* Oakland: Global Footprint Network

Fiala, N. 2008. Measuring sustainability: Why the Ecological Footprint is Bad Economics and Bad Environmental Science. Ecological Economics 519-525

Fuglie, K.O. 2010. The Shifting Patterns of Agricultural Production and Productivity Worldwide. Chapter 4; Total Factor Productivity in the Global Agricultural Economy: Evidence from FAO Data. The Midwest Agribusiness Trade Research and Information Center, Iowa State University

GFN-Global Footprint Network. 2012. The National Footprint Accounts, 2011 edition. Global Footprint Network, Oakland, CA, USA

GFN-Global Footprint Network. 2013. The Footprint of Nations http://www.footprintnetwork.org/en/index.php/gfn/page/footprint_basics_overview/ .Accessed 9/07/2013.

GRID-Arendal. 2013. Rapid Response Assessment; The Environmental Food Crises. http://www.grida.no/publications/rr/food-crisis/page/3569.aspx. Accessed 9/07/2013

Halberg, N., Kristensen, S. 1997. Expected Crop yield loss when converting to Organic dairy farming in Denmark. Biological agriculture and horticulture. Vol 14, pp 25-41

IBM-International Business Machine Corporation. 2011. Categorical Regression http://pic.dhe.ibm.com/infocenter/spssstat/v20r0m0/index.jsp?topic=%2Fcom.ibm.spss.statistics.help%2Fidh_catr_regularization.htm. Accessed 15/01/2014

IPCC-UN Intergovernmental Panel for Climate Change (IPCC). 2013. Definition of terms used within the DDC pages. Data Distribution Centre. http://www.ipcc-data.org/guidelines/pages/definitions.html. Accessed 03/07/2013

IPCC-UN Intergovernmental Panel for Climate Change (IPCC).2014. Land Use, Land-Use Change and Forestry Fact Sheet 4.1. Agricultural Intensification and Carbon inputs. http://www.ipcc.ch/ipccreports/sres/land_use/index.php?idp=224.Accessed 19/04/2014

Jaggard, K., Qi, A., Ober, S. 2010. Possible Changes to Arable Crop yields by 2050. Phil. Trans.Soc.B. 365, 2835-2851

Jørgensen, U., Dalgaard, T., Kristensen, E. 2005. Biomass Energy in Organic Farming - The Potential Role of Short Rotation Coppice. Biomass and Bioenergy 28, 237-248.

Lafferty, W.M., Meadowcroft, J. 2000**.** Implementing sustainable development: strategies and initiatives in high consumption societies. Oxford University Press, cop; ISBN 0198294360

Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-being: Synthesis Washington, DC: Island Press. 155 p

MO-Microsoft Office. 2014. What new in Excel 2013. http://office.microsoft.com/en-us/excel-help/what-s-new-in-excel-2013-HA102809308.aspx.Accessed 10/09/2014

Mola-Yudego, B., Aronsson, P. 2008. Yield models for commercial willow biomass plantations in Sweden. Biomass & Bioenergy 32, 829e837

MS-Microsoft. 2014. Description of Forecast Function in Excel. http://support.microsoft.com/kb/828236. Accessed 10/09/2014

Mózner, Z., Tabi, A., Csutora, M. 2012. Modifying The Yield Factor Based on More Efficient Use of Fertilizer-The Environmental Impacts of Intensive and Extensive Agricultural Practices. Ecological indicators, Volume 16, pg 58-66

Nelson, E., Sander, H., Hawthorne, P., Conte, M., Ennaanay, D., Wolny, S., Manson, S., Polasky, S. 2010. Projecting Global Land-Use Change and Its Effect on Ecosystem Service Provision and Biodiversity with Simple Models. Volume 5, Issue 12, e14327

Norfelt, T. 2011.Organic farming in Denmark. Danish Agricultural Advisory Service, National Centre Aarhus. https://www.landbrugsinfo.dk/oekologi/sider/engoeko.aspx#Export. Accessed and Retrieved 15/01/2014

Olesen, J.E., Petersen, J., Haastrup, M., Knudsen, L. 2010. Causes of Yield Stagnation in Winter Wheat in Denmark-Aarhus University. ISBN 87-91949-46-7

OTA-Organic Trade Association. 2014. Export Study- Chapter 3.1 Denmark. http://www.ota.com/organic/mt/export_3_1.html. Accessed 15/01/2014

Postma, T. J., Lieb, F. 2003. How to improve scenario analysis as a strategic management tool ? Technological Forecasting & Social Change 72. 161–173

Richardson, K., Dahl-Jensen, D., Elmeskov, J., Hagem, C., Henningsen, J., Korstgård, J., Buus Kristensen, N., Morthorst, P., Olesen, J., Wier, M., Nielsen, M., Karlsson, K. 2011. Denmark's Road Map for Fossil Fuel Independence. *Solutions.* Vol 2, No. 4. pp. - - http://www.thesolutionsjournal.com/node/954. Accessed 15/09/2014

Rudel, T., Schneider, L., Uriarte, M., Turner, B., DeFriesc, R., Lawrence, D., Geoghegan, J., Hecht, S., Ickowitz, A., Lambin, E., Birkenholtz, T., Baptista, S., Grau, R. 2009. Agricultural intensification and changes in cultivated areas, 1970 –2005. doi10.1073pnas.0812540106. vol. 106.no. 49.20679

Smeets, E., Weterings, R. 1999. Environmental indicators: typology and overview. Technical Report No. 25, pp. 1–20

Statistics Denmark. 2013. Business Sectors. http://www.statbank.dk/statbank5a/default.asp?w=1600. Accessed 12/10/2013

van der Werf, H., Payraudeau, S. 2005. Environmental impact assessment for a farming region: a review of methods: Agriculture, Ecosystems and Environment 107, pg 1–19

van den Bergh, J., Verbruggen, H. 1999. Spatial Sustainability, Trade and Indicators: an Evaluation of the 'Ecological footprint'. Ecol. Econ. 29, 61–72

van der Bergh, J., Grazi, F. 2010.On the Policy Relevance of Ecological Footprints. Environ. Sci. Technol**,** 44, 4843–4844

Wackernagel, M., Rees, W. 1996. Our Ecological Footprint: Reducing Human Impact on the Earth. Illustrated by Phil Testemale. The new catalyst bioregional series, vol. 9.Gabriola Island, BC and Philadelphia, PA: New SocietyPublishers.

Wang, M.I., Che, Y., Yang, K., Wang, M.N., Xiong, L., Huang, Y. 2011. A Local-scale Low-carbon Plan based on the STIRPAT Model and the Scenario Method. Energy Policy 39:6981-6990

Wang, M.Q., Liu, J.S., Wang, J.D., ZHAO, G.G. 2010. Ecological Footprint and Major Driving Forces in West Jilin Province, Northeast China. Chinese Geographical Science 20(5): 434-441.

Weinzettel, J., Hertwich, E., G., Peters, G., P., Steen-Olsen, K., Galli, A. 2012. Affluence Drives the Global Displacement of Land use. Global Environmental Change 23 (2013) 433–438.

Xianghao, Z., Wei, T., Shaoquan, L. 2011. Analysis of Major Driving Forces of Ecological Footprint Based on the STRIPAT Model and RR Method: A Case of Sichuan Province，Southwest China. J. Mt. SCI. 8: 611–618.DOI: 10.1007/s11629-011-1021-2

York, R., Rosa, E., A, Dietz, T. 2003. STIRPAT, IPAT and ImPACT:
Analytic Tools for Unpacking the Driving Forces of Environmental Impacts. Ecological Economics 46: 351-365

APPENDIX 1

The Underlying Assumptions in the Construction of the Danish Climate Commissions “Ambitious” and “Unambitious” Scenarios

To construct the “Ambitious” scenarios, the Climate Commission assumed, that international developments (such as the increase implementation of emissions reduction policies by most countries through the consumption of solid biomass) will be a driver of future global solid biomass prices. The more countries implement emissions reduction policies, the higher the prices of biomass. Solid biomass scarcity will be a major driver of global energy carrier prices. Due to higher biomass prices, Denmark will consume less bioenergy produced from solid biomass. In the “Unambitious” scenario, it is assumed few countries will implement emissions reduction policies; biomass prices might remain the same or will be lower. Due to no change or lower solid biomass prices Denmark will be able to consume more bioenergy produced from solid biomass. The Climate Commission suggests that gross energy demand for Denmark will depend on energy efficient and cost effective strategies (Richardson et al. 2011). The above estimated Danish bioenergy consumption amounts from solid biomass might decrease or the Danish dependence on solid biomass might change if cheaper and new energy efficient technologies and sources are introduced by 2050.

APPENDIX 2

Danish Agricultural and Horticultural Total Factor Productivity (TFP) (1967-2009)

Data source; Statistics Denmark (2013)

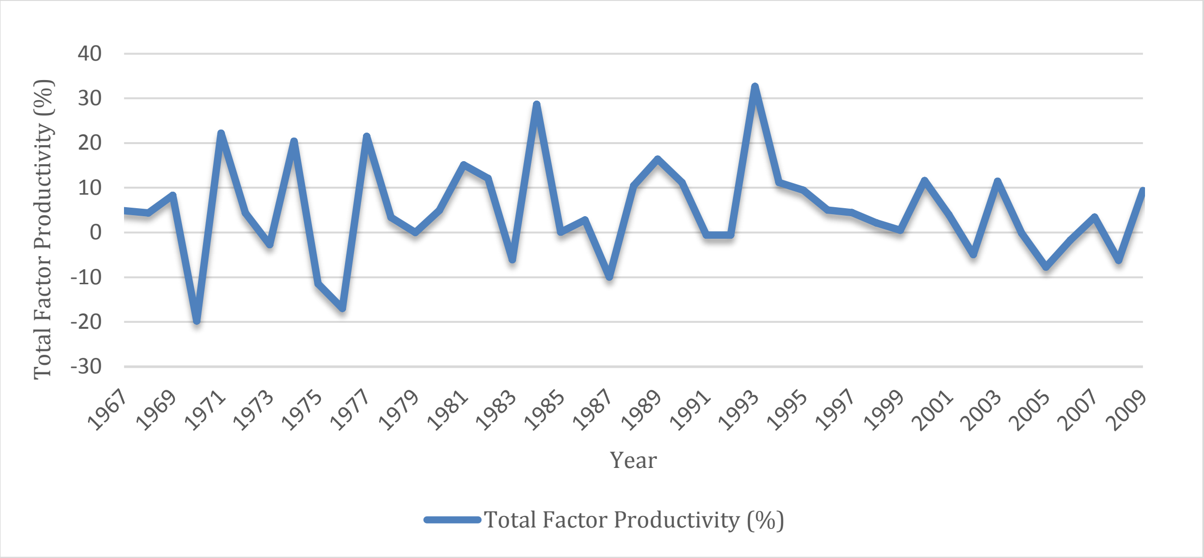


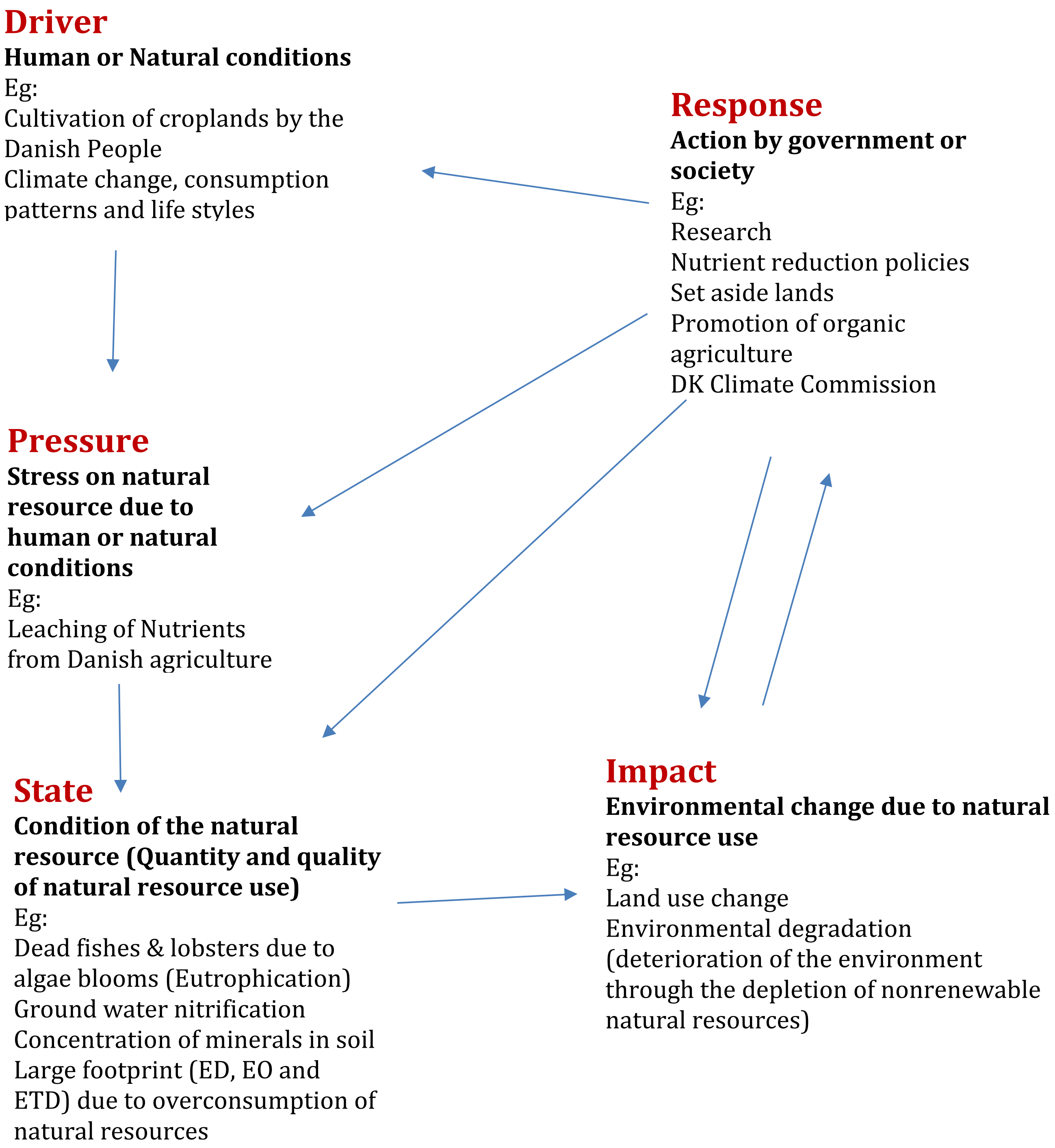
Figure 1 Danish Agricultural and Horticultural Total Factor Productivity (TFP) 1967-2009

The figure shows the Total Factor Productivity of Danish Agriculture and Horticulture from 1967-2009 as presented by Statistics Denmark. Total Factor Productivity is an indicator of agricultural intensification (Carswell 1997) with respect to total agricultural output in production and input in land, labour, capital, and other production factors (Fuglie2010). The figure shows a period of high intensification within Danish agriculture from 1967 to 1994 and a period of decline from 1993 to 1999. This decline corresponds to the period in Danish agriculture were the organic action plan was being implemented and many conventional farms in Danmark were being converted to organic farms (Norfelt 2011; Halberg and Kristensen 1997). TFP is expressed as a percentage of the output and input being considered. TFP is an aggregate, thus researchers are interested in different synergies of this aggregate. Calculating TFP is a broad topic and it’s out of the scope of this research. Here TFP is used as an indicator to show intensification in the Danish agriculture which is the basis for reducing agricultural land needed for energy crop production as considered by the climate commission

APPENDIX 3

The Driving Forces, Pressure, State, Impact, Response (DPSIR) framework

(Smeets and Weterings 1999)



Driver
Human or Natural conditions
Eg:
Cultivation of croplands by the Danish People
Climate change, consumption patterns and life styles

Response
Action by government or society
Eg:
Research
Nutrient reduction policies
Set aside lands
Promotion of organic agriculture
DK Climate Commission

Pressure
Stress on natural resource due to human or natural conditions
Eg:
Leaching of Nutrients from Danish agriculture

State
Condition of the natural resource (Quantity and quality of natural resource use)
Eg:
Dead fishes & lobsters due to algae blooms (Eutrophication)
Ground water nitrification
Concentration of minerals in soil
Large footprint (ED, EO and ETD) due to overconsumption of natural resources

Impact
Environmental change due to natural resource use
Eg:
Land use change
Environmental degradation (deterioration of the environment through the depletion of nonrenewable natural resources)

Figure 2 The Driving Forces, Pressure, State, Impact, Response (DPSIR) framework

APPENDIX 4

Drivers of global land use change conceptualised

(Parsimonious modelling)

Baumanns (2013)

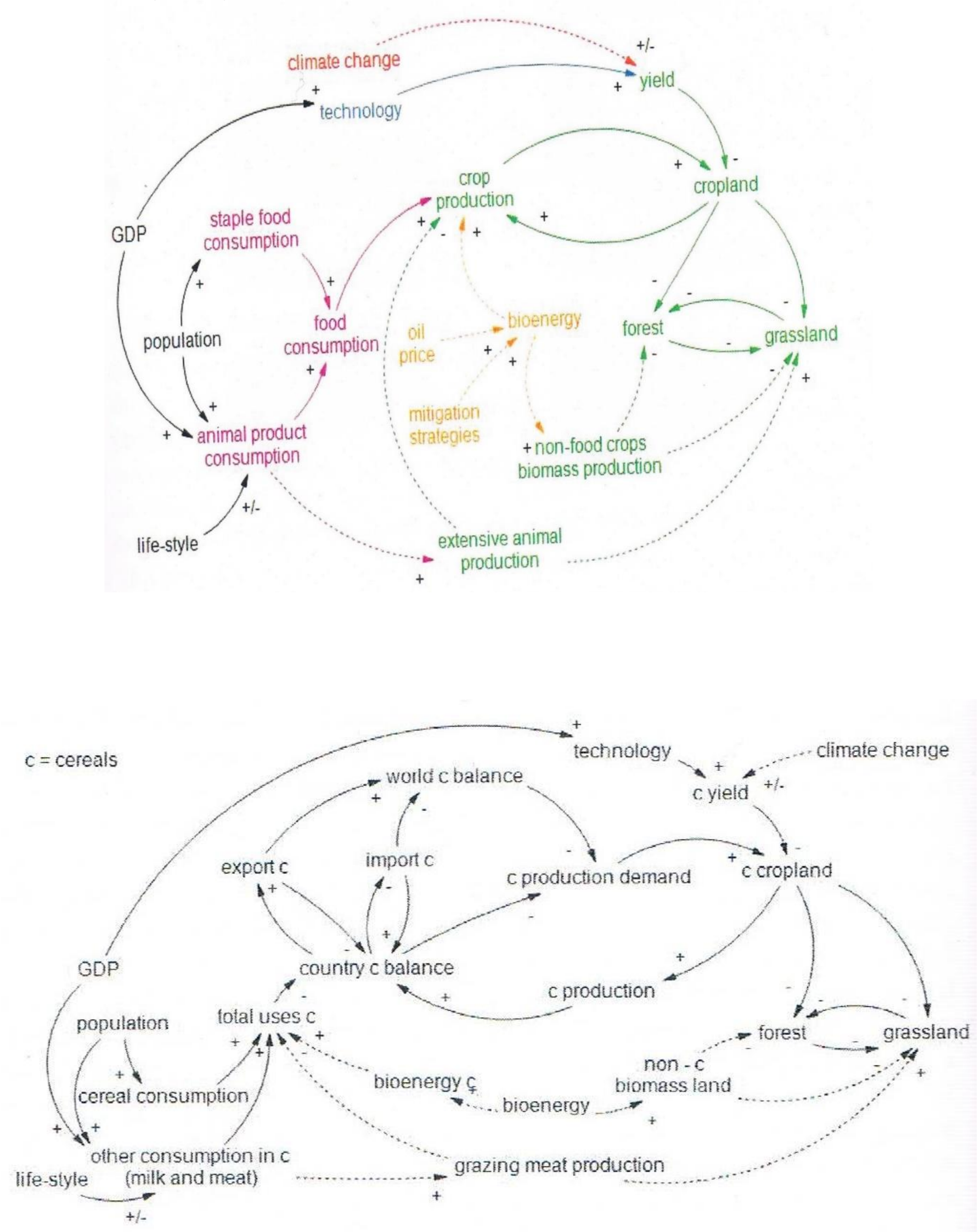


Figure 3 Drivers of global land use change conceptualised

APPENDIX 5

Estimation Cropland within the Danish Climate Commission land use Scenario 2013-2050

Data source; Statistics Denmark (2013)

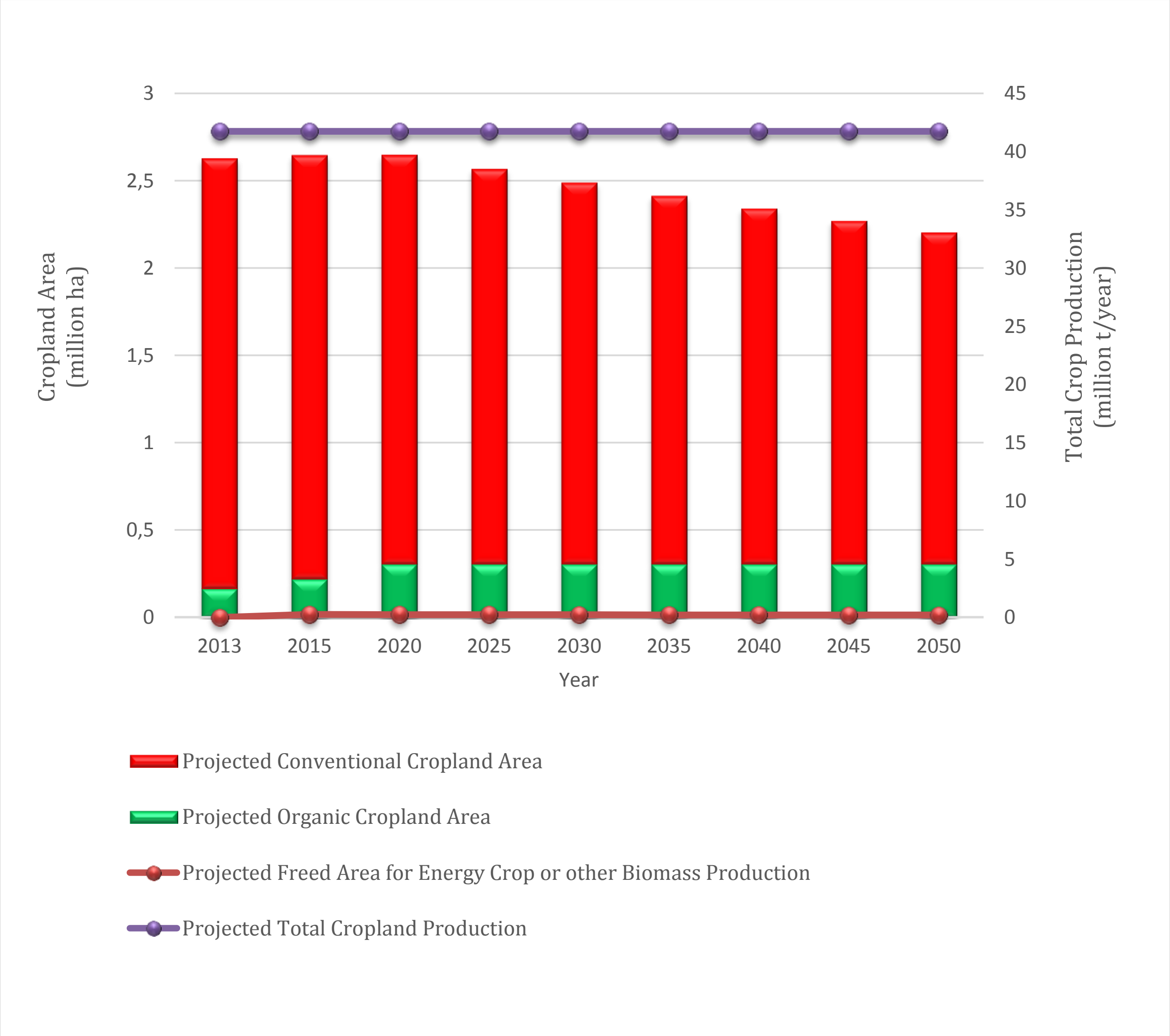


Figure 4 Estimation Cropland within the Danish Climate Commission land use Scenario 2013-2050

APPENDIX 6

Comparison of Cropland Area and Production Datasets of Statistics Denmark and NFA 2011 Edition

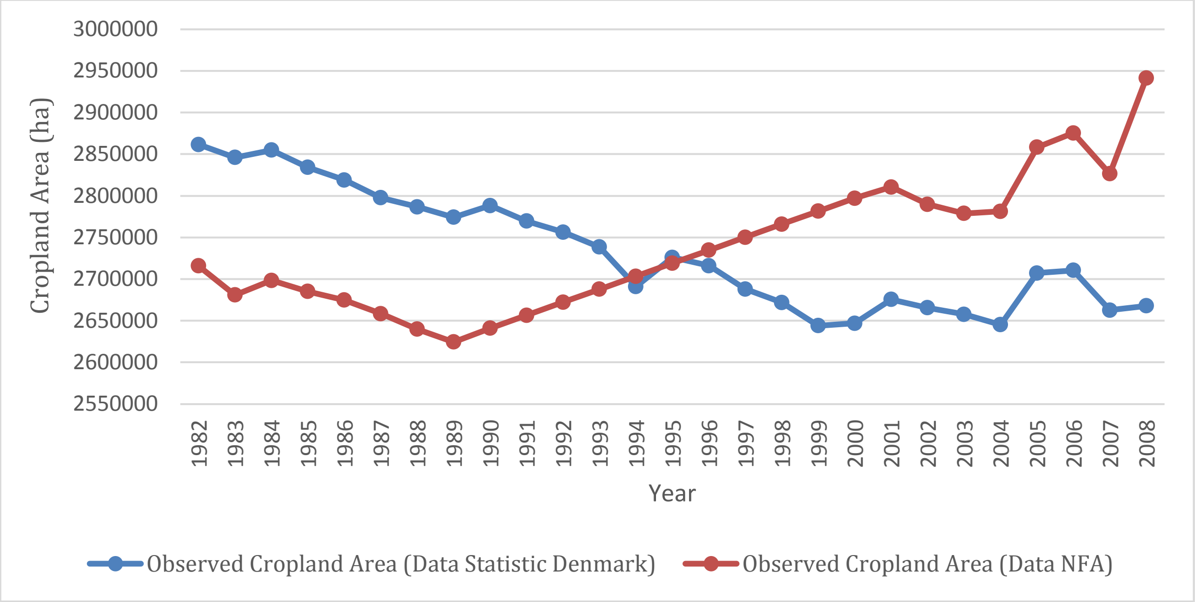


Figure 5 Cropland Area Datasets Compared (1982-2008)

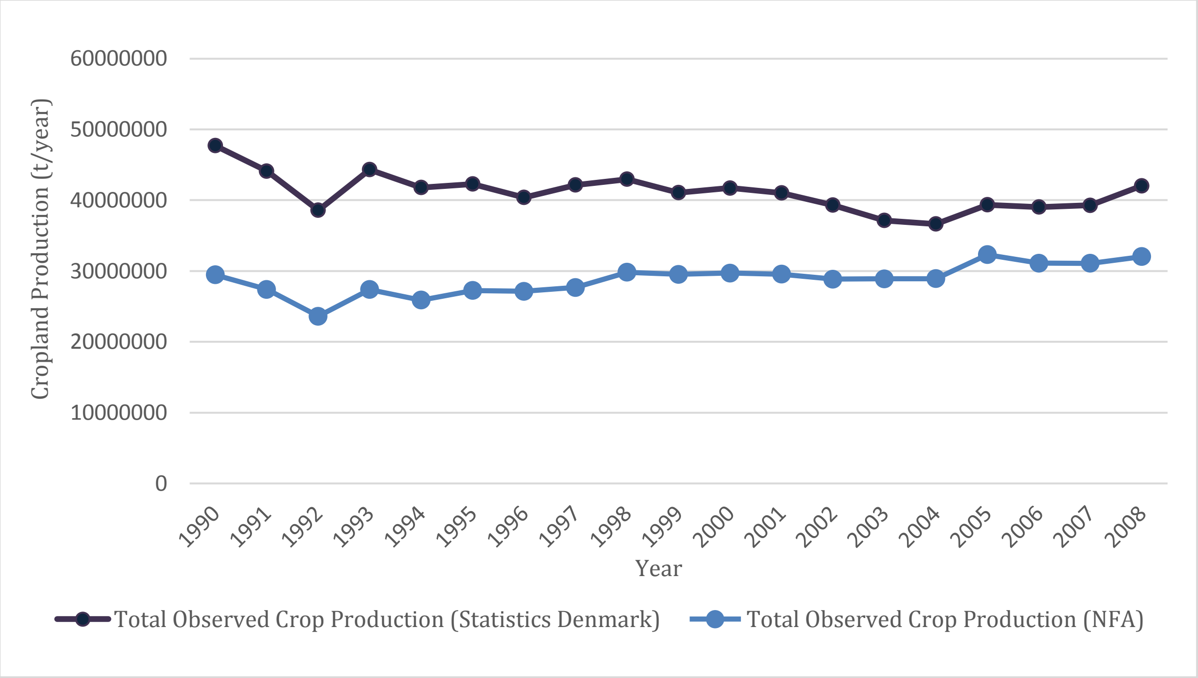


Figure 6 Cropland Production Datasets Compared (1990-2008)

APPENDIX 7 (Section 1)

Calculation Methodology for the National Footprint Accounts, 2010 Edition

Ewing, B., A. Reed, A. Galli, J. Kitzes, and M. Wackernagel. 2010. *Calculation Methodology for the National Footprint Accounts, 2010 Edition.* Oakland: Global Footprint Network.

Yield Factors

Yield factors account for countries' differing levels of productivity for particular land use types. Yield factors are country-specific and vary by land use type and year. They may reflect natural factors such as differences in precipitation or soil quality, as well as anthropogenic induced differences such as management practices. The yield factor is the ratio of national average to world average yields. It is calculated in terms of the annual availability of usable products. For any land use type *L*, a country's yield factor *YFL*, is given by v

$$YF_L = \frac{\sum_{i \in U} A_{W,i}}{\sum_{i \in U} A_{N,i}} \qquad \text{(Equation A)}$$

where *U* is the set of all usable primary products that a given land use type yields, and *AW,i* and *AN,i* are the areas necessary to furnish that country's annually available amount of product *i* at world and national yields, respectively. These areas are calculated as

$$A_{N,i} = \frac{P_i}{Y_N} \text{ and } A_{W,i} = \frac{P_i}{Y_W} \qquad \text{(Equation B)}$$

where *Pi* is the total national annual growth of product *i* and *YN* and *YW* are national and world yields, respectively. Thus *AN,i* is always the area that produces *i* within a given country, while *AW,i* gives the equivalent area of world-average land yielding *i*.

With the exception of cropland, all other land use types included in the National Footprint Accounts provide only a single primary product, such as wood from forest land or grass from grazing land. For these land use types, the equation for the yield factor simplifies to

$$YF_L = \frac{Y_N}{Y_W} \qquad \text{(Equation C)}$$

Due to the difficulty of assigning a yield to built-up land, the yield factor for this land use type is assumed to be the same as that for cropland (in other words urban areas are assumed to be built on or near productive agricultural lands). For lack of detailed global datasets, areas inundated by hydroelectric reservoirs are presumed to have previously had world average productivity. The yield factor for carbon uptake land is assumed to be the same as that for forest land, due to limited data availability regarding the carbon uptake of other land use types. All inland waters are assigned yield factors of one, due to the lack of a comprehensive global dataset on freshwater ecosystem productivities.

APPENDIX 7 (Section 2)

NORMALIZING BIOPRODUCTIVE AREAS FROM HECTARES TO GLOBAL HECTARES

Ewing B., A. Reed, A. Galli, J. Kitzes, and M. Wackernagel. 2010. *Calculation Methodology for the National Footprint Accounts, 2010 Edition.* Oakland: Global Footprint Network.

Difference between global hectares (gha) and world hectare (wha)

Average bioproductivity differs between various land use types, as well as between countries for any given land use type. For comparability across countries and land use types, Ecological Footprint and biocapacity are usually expressed in units of world-average bioproductive area. Expressing Footprints in world average hectares also facilitates tracking the embodied bioproductivity in international trade flows, as *g*ha measure the ecological productivity required to maintain a given flow. Global hectares provide more information than simply weight - which does not capture the extent of land and sea area used – or physical area - which does not capture how much ecological production is associated with that land. Yield factors and equivalence factors are the two coefficients needed to express results in terms of global hectares (Monfreda et al., 2004; Galli et al., 2007), thus providing comparability between various countries' Ecological Footprint as well as biocapacity values

For example, the average hectare of pasture in New Zealand produces more grass than a world average hectare of pasture land. Thus, in terms of productivity, one hectare of grassland in New Zealand is equivalent to more than one world average grazing land hectare; it is potentially capable of supporting more meat production.

APPENDIX 8

A short list of crops from the Danish NFA 2011 Edition (2008 datasets) as an example to show the calculation of EFp at Crop and National level

Equation 4: EFp= National Crop Prodution / WCy which gives EFp in wha.

EFp in wha is multiplied by EQF and IYF to get EFp in gha

Name of Crop	National Production	World Crop Yield (WCy)	EQF	IYF	EFp
[-]	$[t\ year^{-1}]$	$[t\ wha^{-1}\ year^{-1}]$	$[gha\ wha^{-1}]$	[-]	[gha]
Agave Fibres Nes	-	0,68	2,51	1,00	-
Alfalfa for forage and silage	246.467	24,82	2,51	1,00	24.956
Almonds, with shell	-	1,22	2,51	1,00	-
Anise, badian, fennel, corian.	46	0,65	2,51	1,00	177
Apples	33.527	12,29	2,51	1,00	6.858
Apricots	-	6,31	2,51	1,00	-
Arecanuts	-	1,00	2,51	1,00	-
Artichokes	-	9,63	2,51	1,00	-
Asparagus	64	4,27	2,51	1,00	38
Avocados	-	6,96	2,51	1,00	-
Bambara beans	-	0,73	2,51	1,00	-
Bananas	-	16,25	2,51	1,00	-
Barley	3.396.000	2,29	2,51	1,00	3.729.140
Beans, dry	-	0,66	2,51	1,00	-
					Total EFp is 3761169

Equation 4 is applied at each crop to calculate EFp at crop level. The same method applies for EFi and EFe using equation 5&6 in page

Adding all EFp at crop level to get EFp at National Level

Appendix 9

Student Thesis Reports, Department of Physical Geography and Ecosystem Science Lund University

Institutionen för naturgeografi och ekosystemvetenskap, Lunds Universitet. Student examensarbete (Seminarieuppsatser). Uppsatserna finns tillgängliga på institutionens geobibliotek, Sölvegatan 12, 223 62 LUND. Serien startade 1985. Hela listan och själva uppsatserna är även tillgängliga på LUP student papers (www.nateko.lu.se/masterthesis) och via Geobiblioteket (www.geobib.lu.se)

The student thesis reports are available at the Geo-Library, Department of Physical Geography and Ecosystem Science, University of Lund, Sölvegatan 12, S-223 62 Lund, Sweden. Report series started 1985. The complete list and electronic versions are also electronic available at the LUP student papers (www.nateko.lu.se/masterthesis) and through the Geo-library (www.geobib.lu.se)

294 Mattias Spångmyr (2014) Development of an Open-Source Mobile Application for Emergency Data Collection
295 Hammad Javid (2013) Snowmelt and Runoff Assessment of Talas River Basin Using Remote Sensing Approach
296 Kirstine Skov (2014) Spatiotemporal variability in methane emission from an Arctic fen over a growing season – dynamics and driving factors
297 Sandra Persson (2014) Estimating leaf area index from satellite data in deciduous forests of southern Sweden
298 Ludvig Forslund (2014) Using digital repeat photography for monitoring the regrowth of a clear-cut area
299 Julia Jacobsson (2014) The Suitability of Using Landsat TM-5 Images for Estimating Chromophoric Dissolved Organic Matter in Subarctic Lakes
300 Johan Westin (2014) Remote sensing of deforestation along the trans-Amazonian highway
301 Sean Demet (2014) Modeling the evolution of wildfire: an analysis of short term wildfire events and their relationship to meteorological variables
302 Madelene Holmblad (2014). How does urban discharge affect a lake in a recreational area in central Sweden? – A comparison of metals in the sediments of three similar lakes
303 Sohidul Islam (2014) The effect of the freshwater-sea transition on short-term dissolved organic carbon bio-reactivity: the case of Baltic Sea river mouths
304 Mozafar Veysipanah (2014) Polynomial trends of vegetation phenology in Sahelian to equatorial Africa using remotely sensed time series from 1983 to 2005
305 Natalia Kelbus (2014) Is there new particle formation in the marine boundary layer of the North Sea?
306 Zhanzhang Cai (2014) Modelling methane emissions from Arctic tundra wetlands: effects of fractional wetland maps
307 Erica Perming (2014) Paddy and banana cultivation in Sri Lanka - A study analysing the farmers’ constraints in agriculture with focus on Sooriyawewa D.S. division
308 Nazar Jameel Khalid (2014) Urban Heat Island in Erbil City.
309 Jessica, Ahlgren & Sophie Rudbäck (2014) The development of GIS-usage in developed and undeveloped countries during 2005-2014: Tendencies, problems and limitations
310 Jenny Ahlstrand (2014) En jämförelse av två riskkarteringar av fosforförlust från jordbruksmark – Utförda med Ekologgruppens enkla verktyg och erosionsmodellen USPED
311 William Walker (2014) Planning Green Infrastructure Using Habitat Modelling. A Case Study of the Common Toad in Lomma Municipality
312 Christiana Marie Walcher (2014) Effects of methane and coastal erosion on subsea-permafrost and emissions
313 Anette Fast (2014) Konsekvenser av stigande havsnivå för ett kustsamhälle- en fallstudie av VA systemet i Beddingestrand
314 Maja Jensen (2014) Stubbrytningens klimatpåverkan. En studie av stubbrytningens kortsiktiga effekter på koldioxidbalansen i boreal barrskog
315 Emelie Norhagen (2014) Växters fenologiska svar på ett förändrat klimat - modellering

av knoppsprickning för hägg, björk och asp i Skåne
316 Liisi Nõgu (2014) The effects of site preparation on carbon fluxes at two clear-cuts in southern Sweden
317 Julian Will (2014) Development of an automated matching algorithm to assess the quality of the OpenStreetMap road network - A case study in Göteborg, Sweden
318 Niklas Olén (2011) Water drainage from a Swedish waste treatment facility and the expected effect of climate change
319 Wösel Thoresen (2014) Burn the forest - Let it live. Identifying potential areas for controlled forest fires on Gotland using Geographic Information System
320 Jurgen van Tiggelen (2014) Assimilation of satellite data and in-situ data for the improvement of global radiation maps in the Netherlands.
321 Sam Khallaghi (2014) Posidonia Oceanica habitat mapping in shallow coastal waters along Losinj Island, Croatia using Geoeye-1 multispectral imagery.
322 Patrizia Vollmar (2014) The influence of climate and land cover on wildfire patterns in the conterminous United States
323 Marco Giljum (2014) Object-Based Classification of Vegetation at Stordalen Mire near Abisko by using High-Resolution Aerial Imagery
324 Marit Aalrust Ripel (2014) Natural hazards and farmers experience of climate change on highly populated Mount Elgon, Uganda
325 Benjamin Kayatz (2014) Modelling of nitrous oxide emissions from clover grass ley – wheat crop rotations in central eastern Germany - An application of DNDC
326 Maxime Rwaka (2014) An attempt to investigate the impact of 1994 Tutsi Genocide in Rwanda on Landscape using Remote Sensing and GIS analysis
327 Ruibin Xu (2014) Spatial analysis for the distribution of cells in tissue sections
328 Annabelle Finck (2014) Bird biodiversity in relation to forest composition in Sweden
329 Tetiana Svystun (2015) Modeling the potential impact of climate change on the distribution of Western Corn Rootworm in Europe”
330 Joel Forsmoo (2014) The European Corn Borer in Sweden: A Future Perspective Based on a Phenological Model Approach
331 Andrew Ekoka Mwambo (2015) Estimation of Cropland Ecological Footprint within Danish Climate Commissions 2050 Scenarios for Land use and Bioenergy Consumption