How will the proposed emission cuts and climate change in the agricultural sector affect welfare contribution?

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Abstract

Agriculture is one of the biggest sources of emission. The world population is projected to grow towards 9 billion people by the middle of this century, and Norway has targeted an emission reduction of "60 percent from 2018 levels". Global warming is a scientifically accepted fact, and as the agricultural sector is affected heavily by the climate. I will analyze, using the Jordmod model, the social welfare effects arising from the impact of climate change and climate mitigation of the agricultural sector, and how economic policy may be designed in response to these changes in a way to achieve higher welfare and the objectives set for Norwegian agriculture. The results show that the effect of climate policy has a larger effect on welfare and the agricultural sector than climate change towards 2050.

Preface

This thesis represents the end of my studies at the Department of Economics, University of Oslo. I am grateful for the experiences and knowledge the last five years as a student has given me.

I would like to thank Karen Helene Ulltveit-Moe for her supervision, and insightful comments and insights.

My thesis is connected with the LIVESTOCK project, with NIBIO.

I would also like to thank Ivar Pettersen, Klaus Mittenzwei and Siri Voll Dombu, which I have had interesting conversations with about the topics of my thesis.

Lastly, I will thank my girlfriend, Silvija, for helping me out through a stressful period. I love you.

Oslo, May 2021

Henrik Kallåk Hansen

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1 Introduction

Climate change is one of the most relevant topics of this time, and given the importance, Norway has committed to reduce its (non-ETS) emission of greenhouse gases by forty percent by 2030 compared to 1990 levels (Ministry of Climate and Environment, 2020).

In 2020 the Norwegian Environment Agency published a report called "Klimakur 2030" in which there was a proposition to reduce non-ETS emission by fifty percent or more. Since the agricultural sector is not a part of the ETS emission, it is included in Klimakur 2030.

The proposed actions in the report are estimated to reduce the emission in the agricultural sector by the equivalent of 5,1 million tons of carbon dioxide in the period 2021-2030.

However, the climate is already changing, and whether humanity succeed in reducing our emissions as much as we want or not, the climate in year 2050 will be different than it is today. Since agriculture is very dependent on the climate, and will be in 2050 as well, it's important to look at the future of our agriculture using projections of how the climate will be in 2050.

With the Norwegian model for agriculture called Jordmod, I will assess how the proposed emission reductions will affect social welfare through the agricultural sector when the climate is warmer, wetter, and more volatile. I will also try to answer whether there are other policies which might help achieve higher economic welfare and the political objectives of agriculture. I have gained insights on Jordmod through literature and conversations with Klaus Mittenzwei, which I used to prepare the data, which I handed over to Mittenzwei as input for Jordmod.

In the first scenario of Jordmod, the reference scenario, the current trends and policy of the agricultural sector is continued. The second to fourth scenarios includes a ceiling on emission, which can be interpreted as an endogenous carbon tax on emission from the agricultural sector. In the third scenario of the model, the expected changes in agriculture, based on Hanssen-Bauer et.al (2015), is included. The change in output from the second to third scenario will be the effect climate change has on the agricultural sector.

In the fourth, I will analyze whether agricultural policy are effective in satisfying the four main objectives in agriculture; food security, maintain agriculture area across the country, increase the value creation in agriculture, and sustainable agriculture with lower greenhouse gas emission (Meld. St. 11 (2016-2017). This is done through an increase of the land usage subsidy to NOK 200.

The purpose of this thesis is to model the way climate change and climate mitigation policy might affect the agricultural sector, and to assess how welfare associated with agriculture changes. I will also analyze whether there is any specific policy which can improve welfare. Welfare in this master thesis is measured by economic welfare for the actors in the economy, measured by the producer and consumer surplus.

2 Literature review

There exist a few papers on the effect climate change has on agriculture, such as (Ministry of agriculture and food, 2016), which provides a description of how climate change can affect agriculture. Uleberg & Dalmannsdottir (2018) also offers a similar paper, with a focus on Troms and Buskerud in Norway. However, these papers do not utilize a comparative statics model such as Jordmod. Models such as Jordmod is a valued approach to gain insights to agriculture, and with this paper, I wish to contribute by using a model to analyze the changes in the contribution to welfare from the agricultural sector as a result of changes in climate.

3 Background

The agricultural sector in Norway is one of the most protected agricultural sectors in the world. Annually, the government spends over 26 billion NOK (OECD, 2016) through subsidies to farmers, mainly through direct subsidies and trade barriers to protect the farmers from international competition. The practice of heavily subsidizing the agricultural sector is common in developed countries, but in Norway more so than others. Around sixty percent of the salary to farmers in Norway comes from subsidies from the government. This is more than three times the OECD average (OECD, 2020).

There are several reasons for this. One explanation is that Norway is a high-cost country, and agriculture is a relatively labor-intensive sector. This tends to give the cheaper countries with a relatively more unskilled labor-force a comparative advantage. Therefore, Norway must heavily subsidize the sector for it to remain profitable for the farmers, which otherwise would have to find a new line of work.

Another reason is that Norway is not well suited for agriculture. Both its climate and nature restrict where and what kinds of agricultural goods can be produced.

Norway has a few main objectives in its agricultural policy, which warrants a high degree of subsidizing. In my thesis I wish to look at how the climate can be expected to be in Norway in 2050, and use the Jordmod model to analyze which policies are suited for achieving these objectives in 2050, when the climate is expected to be different than it is today.

3.1 Agricultural policy objectives

As an economy becomes more developed, it is normal for industry and services to constitute a larger part of the economy, while the primary sectors in the economy becomes a smaller part of the GDP in the country. This happened to Norway, and since 1950, agriculture has shrunk from contributing 7% of Norway's gross domestic product to 0,5% of it in 2005 (Ladstein & Skoglund, 2008). At the same time, the share of the workforce employed in agriculture has fallen from more than 20% in 1950 to less than 2% in 2019 (SSB, 2020). Yet, agriculture is a very important sector for other reasons than its contribution to the GDP. Food is a necessary good, which makes having a secure supply of it crucial.

The rural parts of Norway would also be under a larger threat from centralization had it not been for the jobs in agriculture.

And due to agriculture being the second largest emitter of greenhouse gases amongst the non-environmentally tradable (non-ETS) sectors (SSB, 2020), after transport, it is important to reduce agricultural emission in order to mitigate climate change. Agriculture is also the second largest contributor to emission of greenhouse gases, after electricity and heat production on world basis (IPCC, 2014), with livestock production alone emitting more than all the worlds transport put together, at 14,5% of all anthropogenic GHG emission (Gerber et al. 2013).

Norway has four main agricultural objectives, which guides policymakers. These are: Food security, maintain agriculture area across the country, not just the most productive part, increase the value creation in agriculture, and sustainable agriculture with lower greenhouse gas emission (Meld. St. 11, (2016-2017)).

Therefore, when evaluating whether a policy is effective, or how the climate change affects the agricultural sector, it’s important to analyze which effect it has on these objectives, as well as the welfare contribution of the agricultural sector.

Norway has also signed the Paris agreement, and agreed to reducing the non-ETS emission by 40% by 2050 compared to 1990 levels (Norwegian Environment Agency, 2020), but are aiming for reductions of around 50-55%.

3.1.1 Food security

Food security in a country means that its inhabitants always have access to, both physically and economically, enough food of safe quality (Meld. St.11, 2016-2017). The conditions for agriculture aren’t very good in Norway, with long winters and over 50% of the total area being mountain, mountain range and marsh, and only 3,5% of the area in Norway are currently used for agriculture (SSB, 2020). Therefore, food security is dependent on large subsidies to Norwegian farmers.

A reason why food security is such an important objective is that, even though unlikely, if Norway for some reason couldn’t import enough food from other countries, it could have fatal consequences if food security hasn’t been prioritized.

There are a few different terms that circulate when discussing food security of a country. One is self-sufficiency. This is a term which describes how much of the food we consume, in energy, is produced in Norway. In Norway this was at 47% in 2014. If we discount the meat

which was produced using imported feed, this number drops to 38% (Rognstad et al. 2016). Even though this seems to be very low, the degree of self-sufficiency is not a very useful metric for measuring how prepared a country is in case import of food becomes difficult. In such a case the degree of self-sustainability is more relevant. This is a number from 0 to 1 that informs about how much of the country's food needs in energy which could be produced domestically. If agriculture transitioned towards more energy-intensive crops and energy-effective livestock, meaning a lot of energy per unit of productive inputs, as well as no exports to other countries, this number would be a lot higher than 38% or 47%, especially since Norway exports more than 2,4 million tons of fish each year (SSB, 2021).
Norway's degree of self-sustainability was on average 90% in 2000-2014 (Rognstad et al. 2016). In the years 2000 to 2014, the population in Norway was on average 4,73 million (SSB, 2021). The projected population in Norway in 2050 is 6 million (SSB, 2020). By using simple mathematics, we can calculate that if this projection is true, and agricultural production stays at the same level, the degree of self-sustainability in Norway will be approximately 71% in 2050. If Norway follows the path for high population growth, leading to 6,65 million inhabitants in 2050, this number will be 64% if food production remains at 2000-2014 levels.

3.1.2 Agriculture across the country

The government of Norway believes there are many advantages to maintaining agriculture in all parts of the country. It is crucial for food production, as we have very little growth area, 3,5% of total land area (SSB, 2020). It also is an important part of Norway's cultural heritage. Much of the Norwegian culture is well preserved on the countryside, and without agricultural support to rural farms, centralization would increase, and preservation of the Norwegian cultural heritage suffer as a result.

An active countryside is also positive for Norwegian tourism. Some agricultural areas in Norway would not be farmed if not for the policies which help the small farmers, such as differentiating the subsidies for milk farmers such that farmers in different areas of Norway get differing subsidies for production (Jordbruksavtale, 2020-2021). An example is the milk production subsidies which ranges from 0 NOK to 1,89 NOK per produced liter of milk depending on which of the ten differentiated production zones applies. Where the areas with the most favorable conditions receiving 0.

As the climate becomes more unstable, a diversification of where production takes place can be even more valuable than it is today.

About 52% of all agricultural area is currently located in the districts of Norway(Mittenzwei, 2021).

3.1.3 Increased value creation

The Norwegian government has targeted an increase in the market for locally produced agricultural goods from 4,8 billion NOK in 2016 to 10 billion NOK in 2025 (Meld. St. 11, 2016/2017). This is part of the green shift, where locally produced, sustainable food is important. The government wants to help facilitate this through policies which affect cost effective and sustainable production (Meld. St. 11, 2016-2017).

An objective of the government is to design policy to give farmers more freedom to utilize each farms resources in an effective way. In some cases, the production subsidies can be too important for what is profitable, and keep a farmer from maximizing the potential of the farm.

3.1.4 Sustainable agriculture

Sustainability can mean many things. In Meld. St. 11 (2016-2017), they address what sustainability in Norwegian agriculture entails. Food security and increased value creation are amongst them, which are also their own objectives and are the economic and social aspects. An environmentally sustainable agriculture means maintaining the diversity in nature, and keeping it open to the public. To reduce emission of greenhouse gases, water contamination and increased carbon capture are important aspects of environmentally sustainable agriculture.

A lot of areas will overgrow if it’s not used in agriculture, such as grazing fields, and therefore productive assets lost. With it, biodiversity will be affected.

3.2 Agricultural policy and subsidies

The aim of policy is to influence the actors in the economy such that the optimal behavior of the actors align with the optimal behavior for the economy. In the agricultural sector in Norway, these desired behavior is to maintain a large area of agricultural land across the country, provide food security, value creation, sustainability in agriculture, and increase economic welfare in Norway. In Norway, the agricultural policy is largely focused on correcting a market failure. In Norway, agriculture is not economically profitable enough for farmers had it not been for support from the government, but the benefits agriculture provides, positive externalities, is grounds for subsidizing production.

Every year, the Norwegian government, the Norwegian Agrarian Association (Norges Bondelag), and the Norwegian Farmers and Smallholders Union (Norsk Bonde- og Småbrukarlag) meet in negotiations called the agricultural settlement (jordbruksoppgjøret). In these meetings, they negotiate prices for agricultural goods, subsidies for production, and regulation and organization of the market (Norwegian Agriculture Agency, 2021).

When all parties in the negotiation agree upon the outcome of these subjects, representatives of the three organizations sign what's known as the agricultural agreement (jordbruksavtalen).

The agricultural agreement does not include regulation on the import protection from foreign agricultural goods, these are for the main part in the General Agreement on Tariffs and Trade (GATT), an agreement ratified by the World Trade Organization. The toll on different agricultural goods can be raised and lowered by the Norwegian Agriculture Agency, depending on the production in Norway (Norwegian Agriculture Agency, 2021).

The content in the agricultural agreement for the period 2020-2021 can be categorized as: Rates and limits for subsidies for production and area, target prices for agricultural goods, the agricultural welfare fund, subsidies in case of crop failure, market regulation, price subsidies, subsidies for farm development and social insurance programs (Jordbruksavtale, 2020-2021). The production subsidies outline the base subsidy received by farmers for products such as meat, dairy and grains, based on the size of their farm. Norway is divided into different geographical zones based on climatic and other factors which can influence agricultural production, with a differentiated subsidy based on the location of the farm. These differentiated subsidies make it possible for farmers in other than the most productive parts of the country to derive a profit from their business, leading to agriculture around the country and preservation of the Norwegian cultural heritage, as well as increasing food production. This can however affect the value creation in agriculture, as relatively unproductive farms can remain profitable for the farmers.

3.3 Climate in 2050

Agriculture is dependent on the climate. Given our inability to control the weather to our desires, that means that we must take it into account when deciding which policies to enact. In conjunction with the fifth assessment report (2014) of the United Nations, the IPCC (Intergovernmental Panel on Climate Change) created something called representative concentration pathways, which is commonly abbreviated to RCP. The RCP's are used for making projections based on how population size, economic activity, energy use, lifestyle, land use, technology and climate policy affects greenhouse gas emissions (IPCC, 2014). The IPCC created four different RPCs, one for a low emission scenario, a second and third for a medium emission scenario and a third for a scenario with high emissions. These are labelled RCP2.6, RCP4.5, RCP6, RCP8.5, with the numbers representing the projected radiative forcing level in year 2100. (IPCC, 2019).

The RCP's are based on the possible development of the factors which affect the emission of greenhouse gases, such as population size, economic activity, technology, land use patterns, and climate policy. The RCP4.5 scenario is characterized by weakly increasing or stable emission towards 2040, then reductions to about 40% of 2012-levels by 2080. The projected global increase in temperature towards the end of the century is 2,5 Celsius degrees compared to the temperatures in 1850-1900.

The RCP8.5 scenario is commonly referred to as the business as usual scenario. Following this pathway, the increase in emission follows the current trajectory, while the world population increases to 12 billion by the end of this century. The projected increase in temperature is above 4 Celsius degrees compared to 1850-1900, with continued increase in temperatures after 2100.

The paper «Klima i Norge 2100» is a report published by Hanssen-Bauer et al. for Norsk Klimaservicesenter in 2015. This paper contains many predictions about the climate in Norway in the periods 2031-2060, “2045”, and 2071-2100, “2085”. I will base many of my beliefs about the future climate on this report. This report is based on the predictions from the IPCC report about climate change (IPCC, 2013 “Climate change 2013”), and downscaled to Norway. The report uses two of the pathways in its predictions: RCP4.5 and RCP8.5.

Following the RCP4.5, Oslo is projected to be an average of 1,9 Celsius degrees warmer in 2050 than the year 2000 (Andersen et al., 2018 “Met rapport”) , and the trend can be seen all over the country.

Location	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Year
Stavanger-Sola	1.3	1.7	1.6	1.4	1.4	1.3	1.3	1.4	1.4	1.5	1.8	1.7	1.5
Oslo-Blindern	2.1	2.4	2.4	2.2	2.0	1.4	1.5	1.6	1.7	1.7	2.1	2.3	1.9
Gardermoen	2.1	2.4	2.3	2.2	2.0	1.4	1.5	1.6	1.7	1.8	2.2	2.3	2.0

Table 1: Projected changes (Celsius) in monthly and annual mean temperatures from 2000 to 2050 under emission scenario RCP4.5. Source: Andersen et al. 2018

This temperature increase is likely to increase the length of the growth season, the area which can be used to grow, and the variety of seeds which can be used. In many cases, Norway can expect an increase in the growth of “grass” for livestock by 11-14% by 2050 (Höglind et al. 2013).

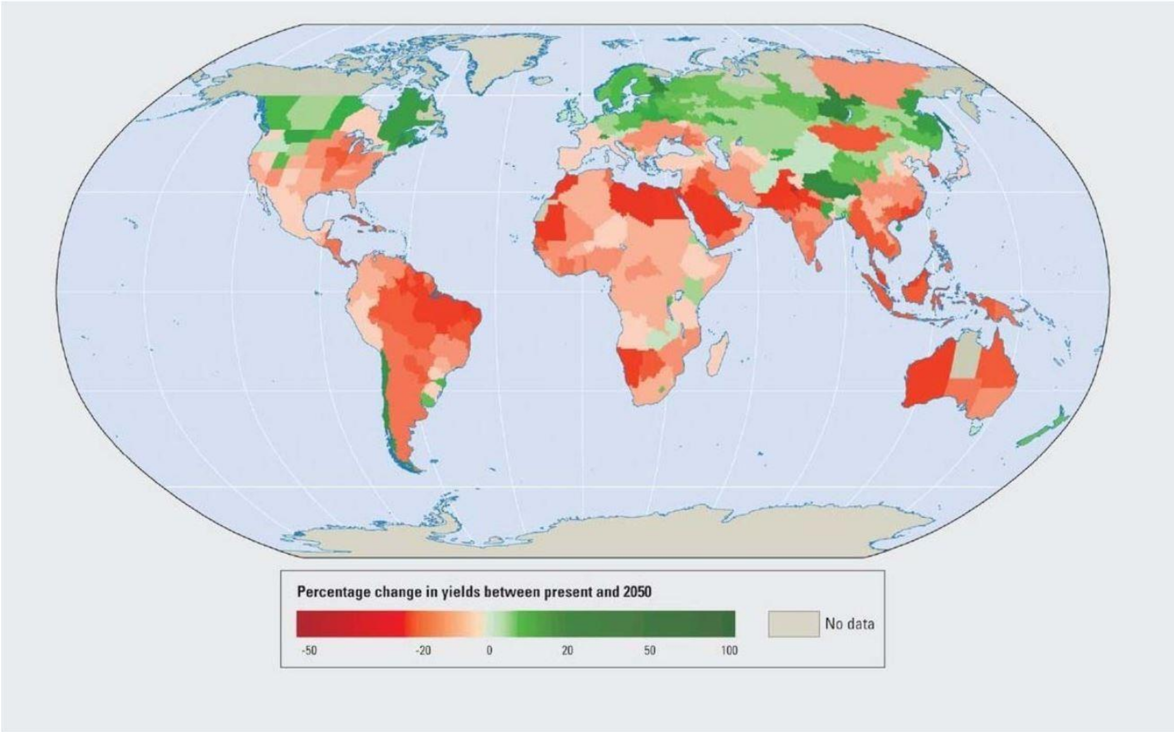

Figure 1: Projected percentage change in yields of 11 major crops. Source: Müller et al. 2009

As the map above shows, Norway will receive a boost in growth conditions, and be relatively better off compared to many parts of the world.

However, even though an increase in average temperatures can be beneficial for farming in Norway, this comes at a cost. The changes in climate isn't only related to an increase in temperature, but also an increased volatility in weather, which means that we will gradually experience more extreme weather. We will see an increase in precipitation, which will come more concentrated, at the same time as more frequent droughts.

Although an increase in the average yields in agriculture is a positive externality of climate change, the increased variability in yields will be a consequence of the increased climate volatility. And years such as 2018, where yields in grain was almost halved relative to a normal year, will become a more regular occurrence (SSB, 2021).

Following the RCP4.5 path, it can be expected a growth in precipitation of about 7% towards the period 2031-2061 in Eastern Norway, compared to the period 1971-2000, and over 10% increase in the RCP8.5 (Hanssen-Bauer et al., 2015).

The same study predicts that the amount of days with heavy rainfall, which is defined as a level of precipitation exceeded in 0,5% of days, will increase by somewhere between 35 to 45 percent, depending on which path is true, compared to 1971-2000 levels.

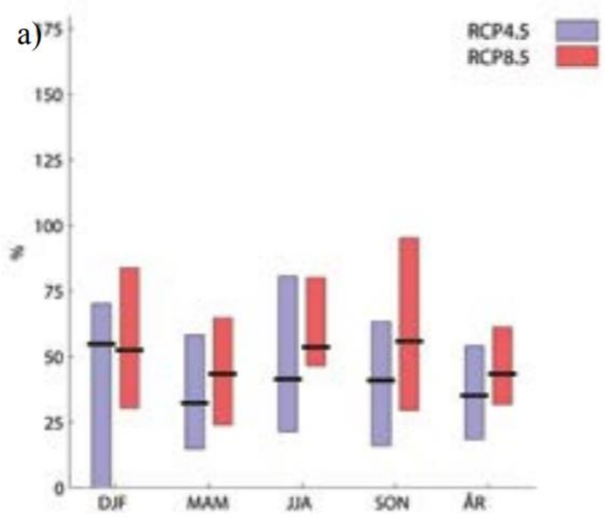

Figure 2: Relative change (%) in days with "heavy precipitation" from the period 1971-2000 to 2031-2060 for the emission scenarios RCP4.5 and RCP8.5. source: (Hanssen-Bauer et al., 2015)

The expected change in precipitation during days with heavy precipitation is expected to change by about 5-10% throughout the year (Hanssen-Bauer et al. 2015). This means that not only heavy precipitation becomes more likely, but when there is, it's more intense.

3.4 Agricultural models

In this thesis I will use the Jordmod model to analyze how the agricultural sector might have to change based on the predicted climate changes towards 2050 (2045). There aren't many models being used to analyze the agricultural sector in Norway, but other than Jordmod there are a few. Mainly SNOW and CAPRI. The use of economic models is popular in many different settings. They can provide valuable insight, and clarify difficult questions in a meaningful way.

However, when using models to analyze the real world, it's important to keep in mind that they are a simplification of a more complex and nuanced reality, and the results must not be taken at face value. Also, when the time horizon expands, so does the uncertainty of results. All models also have a limited life-span, and as the world changes, so does the validity of a model trying to replicate the same world, and this is why results from projections made many years ahead in time should be used with caution.

When analyzing something like the effect of climate change, it's common to use several models. This way, if all or most models lean in the same direction, there exists stronger evidence for a conclusion. When using a model, it's not always the exact output which are of the most interest, rather the overall directions of the results and to some degree the strength of them. In the report by IPCC on climate change in 2014 (AR5), they used up to 39 different models to analyze the expected change in climate, and divided the results of the models into three numbers for each RCP. Low, high, and medium.

3.4.1 CAPRI

CAPRI stands for Common Agricultural Policy Recreational Impact, and was at first created to analyze the effects of changes in economic and political conditions (Mittenzwei, 2018), as was Jordmod. When climate change became an important part of the political landscape, it was expanded to include emission in agriculture and to be able to assess the consequences of climate mitigation policies on agriculture.

The model uses inputs from FAOSTAT, and is specified for use in the EU.

The model is a comparative statics equilibrium model. This means that, given the inputs, it finds the equilibrium where actors in the agricultural sectors wouldn't want to change their behavior. Comparative statics mean that when the input is changed, the new equilibrium is achieved instantaneously, without any time for settling. It is not dynamic, in other words. This is obviously not very realistic, as some policies can take many years before the new equilibrium is reached, and should be interpreted as a long-term model.

The core of CAPRI is divided into two modules: A supply module and a market module.

The supply model contains approximately 50 different crop and animal activities for each of the around 280 different regions in the model (Mittenzwei, 2018).

The market module consists of 47 primary and secondary agricultural products.

3.4.2 SNOW

The name of the model is an acronym for Statistics Norway's World model. It is an equilibrium model, meaning that for given conditions, it finds the equilibrium (Rosnes et al. 2019). In SNOW, Norway is modelled as a small, open economy. And what happens in the rest of the world is given as exogenous variables, meaning that Norway has no effect on what happens in other countries. The model is used for projections on the Norwegian economy and its emissions.

The model contains 46 different economic sectors, with one representative, profit maximizing business in each sector.

3.5 Food security

As stated earlier in the thesis, the self-sufficiency of food in Norway is at 38% when correcting for meat with imported feed (Rognstad et al., 2016). And it is quite a bit higher when adding exported food. When implementing a carbon tax on agriculture, food security can possibly drop, as Norway has a comparative advantage in producing ruminant meat, as the environment is relatively suitable for growing roughage, and we have large areas suitable for grazing. However, as ruminants can eat grass, animals such as pigs and chickens aren't as suited, and are dependent on feed concentrate. And the Norwegian environment is also not particularly well suited for growing fruits and vegetables. However, livestock production is relatively less energy efficient, as livestock consumes more energy than is produced through meat.

This graph is from the Norwegian Directorate of Health (2015):

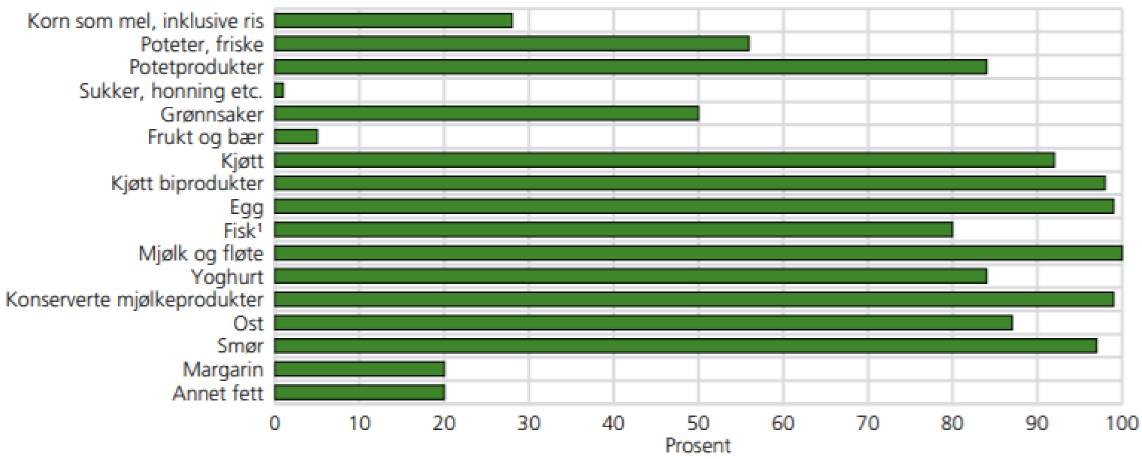

Figure 3: Norway-produced share of consumption for different foods on energy basis, Source: The Norwegian Directorate of Health (2015)

As this graph shows, the percentage of agriculture goods by category is consistently higher for animal products than fruits and vegetables. The percentage of animal feed produced in Norway is also higher for ruminants, cows, and goats, than for chickens and pigs. The percentage of animal feed from Norway is 82% for milk producing cattle, 97% for cows giving milk to calves and 86% for bulls for slaughter. The same number for pigs is 71%, 40% for slaughter chicken and 54% for chickens producing eggs (Animalia, 2020).

As chicken and pig meat are substitutes for cow and goat meat, an increase in price in cattle and goat meat relative to pig and chicken, is probable to lead to a shift in consumption to more pig and chicken consumption. In such a case, the food security in Norway is likely to decrease.

As stated earlier, the difference between ruminants and other animals is that they can consume roughage exclusively, as opposed to other animals. However, to increase efficiency in production, Norwegian ruminants consume a considerable amount of feed concentrate. The percentage of feed concentrate in the diet for milk cows, cows for slaughter and sheep is 45%, 39% and 12%, respectively. Pigs and chickens only consume feed concentrate (Animalia, 2021).

The amount of feed concentrate produced in Norway varies from around 60-63% for ruminants, 71% for pigs and 40% for chicken.

The degree of utilization of energy per kilogram meat vary greatly for the different livestock animals, where the ruminants utilize the energy from their feed less efficiently.

3.6 Technology and productivity in agriculture

In 1998, the average milk yield per year for a cow in Norway was 6200 kilograms, and in 2020 this number had risen to 8204 (Tine, 2020). This is a 32,3% increase in little over 20 years. And yields per decare in Norway in the period 2015-2020 was higher for wheat, barley, and oats than in the period 1995-2000)(SSB, 2021). This is even more significant when taking into consideration that 2018 was a statistical outlier. The last year with lower yields of grain than 2018 was in 1969 (SSB, 2019).

There may be many reasons for larger yields in grain and milk such as better growth conditions, new technology, and better animal feed.

A NIBIO report by Pettersen et al. (2015) studied productivity in agriculture. They define productivity in labor productivity for fixed prices as:

$$\frac{\text{Output}}{\text{Price index for sold goods}} - \frac{\text{Cost of bought goods and services}}{\text{Price index for bought goods and services}} = \text{Fixed prices productivity of labor}$$

Formula 1: Productivity of labor in fixed prices. Source: Ivar Pettersen et.al. (2015)

This graph shows the change in productivity for the food industry (green), industry (blue) and other industries (grey).

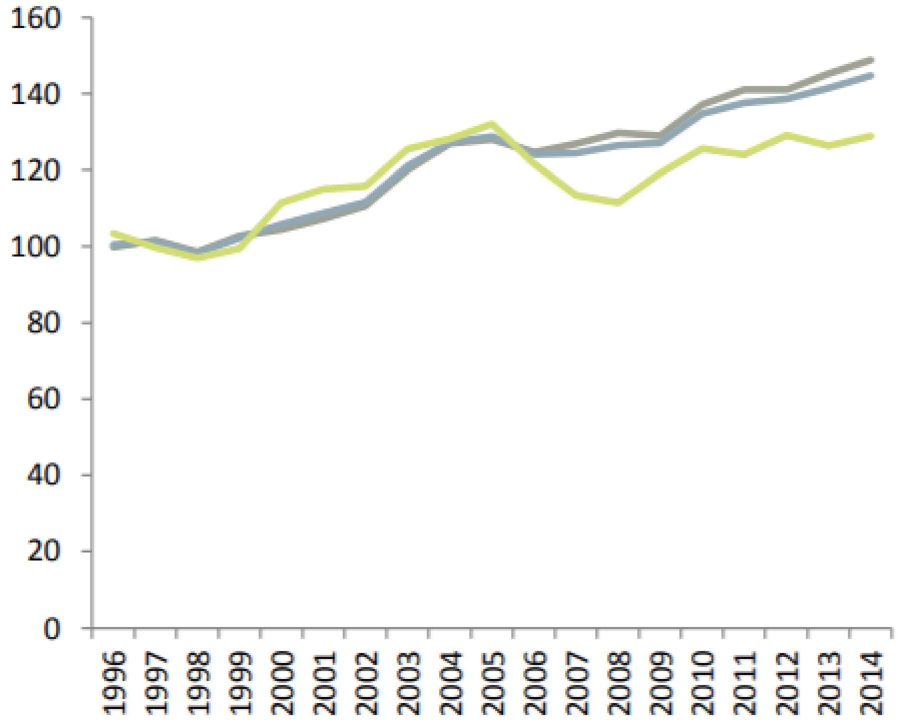

Figure 4: Change in productivity for different industries. Source: Ivar Pettersen et.al. (2015)

3.6.1 Productivity

The balance of productivity in agriculture is a problem of conflicting agricultural objectives. On the one hand, increasing productivity allows for greater value creation and higher food security. It also is an explanation for why livestock production is far more carbon intensive per kilogram meat produced in developing countries than in developed countries.

However, increasing productivity also comes at a cost.

One of the main four agricultural policy objectives is to maintain agricultural production all over the country. Another is for agriculture to be sustainable. One dimension of sustainability is to reduce the greenhouse gas emissions related to agriculture, in particular livestock production, which accounts for about 71% of total agricultural emission in Norway (Oort & Holmelin, 2019). In Klimakur 2030, they recommend, as well as the Norwegian directorate of health, reducing consumption of meat to maximum 750 grams of red meat per week. A study on the eating habits for Norwegian men and women in the ages 18-70, performed by Norkost 3(Totland et al., 2012), found that men on average consumed more than 1 kg per week.

But as stated earlier, as Norway has a comparative advantage in livestock production, and a

big percentage of agricultural area is only suitable for producing animal feed, reducing production of livestock can have negative effects on the objective to maintain agricultural production all over Norway. In the districts, a lot of the only production possibilities is livestock. For grains, 99,6% of production happened in Eastern Norway, Rogaland and and Trøndelag (SSB, 2021). While the same number for cattle, sheep and meadows was 69,7%, 59,4% and 67,3%, respectively (SSB, 2021). One way to reduce emission from agriculture, while at the same time maintaining agricultural production all over Norway, is to lower the productivity in agriculture, and reduce the degree of feed concentrate given to ruminants, such that production requires more active farmland per animal.
A report by Mittenzwei (2021) analyzed how to combine lower emission from the agricultural sector while at the same time maintaining farming all over the country.
The report analyzed how different policies could be used to achieve this goal. The report concluded that switching from livestock subsidies to an area subsidy is effective at reducing emission while at the same time maintain agricultural land across the country.

3.6.2 Technology and investments

The expected changes in climate are expected to have some positive effects on Norwegian agriculture, but also some negative. Some of these negative outcomes requires an increase in research on new technology, and increased investments.
The increase in precipitation can cause higher risk of soil compaction, which can cause decreased yields and quality (Ministry of Agriculture and Food, 2016). The increase in precipitation can also reduce the period for when farmers can harvest their fields. Apart from increased investment in soil, trenches and water systems, which is parameterized in the model, farmers might also be required to invest in new lightweight tractors to reduce the pressure on the soil, hence reducing the risk of soil compaction (Ministry of Agriculture and Food, 2016). The reduced period for harvest can result in an increase in farm equipment relative to farmers, as sharing equipment can get riskier when the time period is shorter.

4 Theory

In this chapter, I present theory which is relevant to my thesis.

4.1 Welfare

Economic welfare is a term used to define the standard of living in an economy. It is a broad term, that is measured in different ways. It can be measured using health of the population, literacy, and Gross domestic product, amongst others. However, as this thesis focuses on the agricultural sector, the best measure for the contribution to welfare from the sector is through its contribution to the gross domestic product (GDP). This is because it is difficult to measure the contribution of a single sector to the health of a population, but the contribution to GDP from the agricultural sector can be measured. Gross domestic product is often used as a measure of economic welfare in a society, as GDP measures all services and goods sold in the economy. The utility function of agents in the economy are increasing in consumption, therefore a large GDP per capita, adjusted for purchasing power parity (PPP), provides an insight in the consumption of the inhabitants in a country, and therefore a useful approximation of welfare. There are other factors that are relevant to the welfare of a country as well, such as inequality of income. This is because the marginal utility of consumption is falling, due to satiation, which means that the marginal utility from consuming one more of a good is lower than the good before. This is relevant, because to maximize utility in a country, there are a greater total utility when most actors in the economy gets a fair share. For example, in an economy with three actors, if one is more endowed than the others, and gets to consume 10 goods, while the two others can only afford to consume 1 good each, the marginal utility for the tenth good is lower than it would have been for one of the others if they were to consume it. However, there is a clear correlation between GDP and welfare, shown by Jones and Klenow (2016).

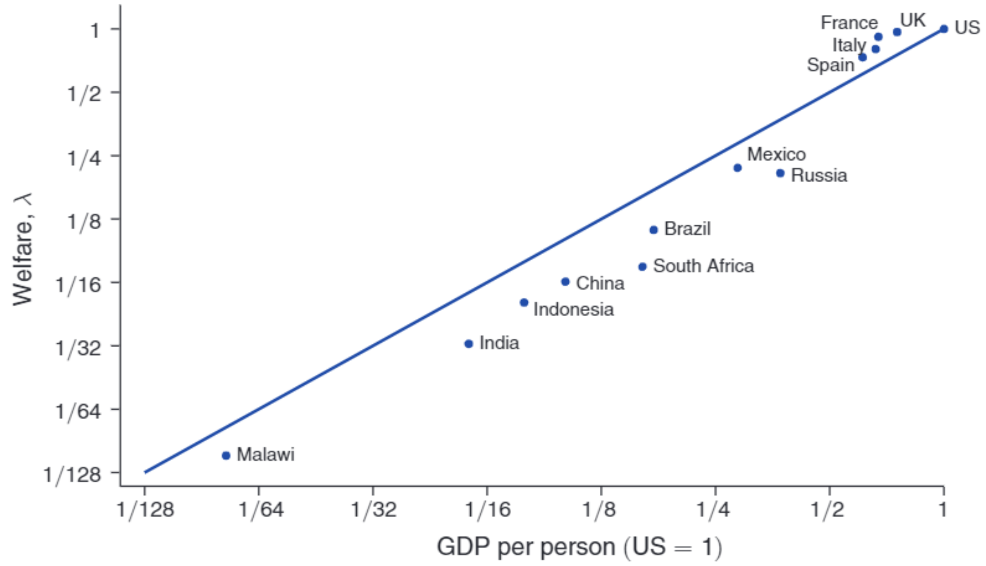

Figure 5: Relationship between welfare and GDP per person. Source: Jones & Klenow (2016)

As stated earlier, the contribution of the agricultural sector to GDP in Norway was 0,5% in 2005, while the share of total workforce employed through the agricultural sector at the same time was 2,5% (Ladstein & Skoglund, 2008). This shows that the contribution to GDP from the agricultural sector is lower than the average contribution of other sectors.

In a market with perfect competition, and no externalities, economic theory states that actors in the economy will act such that the equilibrium is found without any intervention. But in the agricultural sector, as well as other sectors, there are externalities and competition isn't perfect.

4.1.1 Externalities

Even though the agricultural sector doesn't contribute a lot to GDP in Norway per hour of labor, it does include several effects on the welfare in a country apart from the contribution to domestic GDP. These are called externalities, and arise when an activity imposes a cost or benefit on a third party.

In a market without externalities, economic theory suggests that the goods sold in that market should not be taxed or subsidized in order to maximize utility. However, if there's an externality which is not addressed through tax or subsidies, there will be a market failure.

If a factory pollutes the public drinking water, they inflict a negative externality upon those who will get worse drinking water in their homes, and possibly health problems as a result. If the factory isn't made to pay for the cost of this externality, it will pollute as if there was no

cost linked to the pollution, and there will be a market failure.
The effect of an externality which isn't taxed or subsidized can be shown in a simple graph of supply and demand.

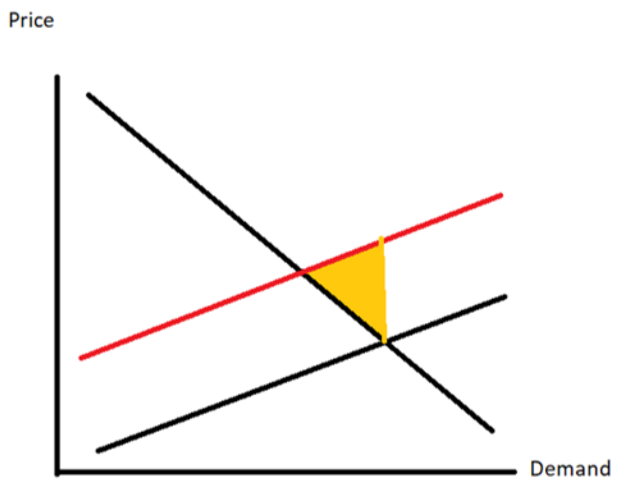

Figure 6: Welfare loss of an externality. Source: Own drawing.

Here, the downward sloping line is the demand of the customers for every given price, while the upward sloping line is the supply for the cost of production. The red line is the true cost of production, with the externality included. If the externality isn't addressed, the producer will supply too much for a given price, and there will be overconsumption of the good, which leads to a welfare loss, represented by the yellow triangle in the graph. To rectify the market failure of overconsumption or underconsumption as a result of an externality, there may be placed a tax on production or consumption of the good, equal to the cost/benefit of the externality (Pigou, 1924). The tax or subsidy makes the consumers or producers internalize the cost/benefit of the externality in their supply/demand. This is called a Pigouvian tax. The positive externalities of agriculture, which are addressed through subsidies, are active rural communities, and food security. The negative externality of agriculture, which isn't taxed, leading to a market failure, is damage because of greenhouse gas emission from production.
The positive and negative externalities is not a part of economic welfare, therefore, policymakers must consider whether the benefits of a policy which causes a reduction in GDP, and with benefits which can't be measured in economic welfare is efficient or not.

4.1.2 Taxes, subsidies, and legal regulation

As stated earlier, in order to reduce market failure as a result of externalities, the production or consumption of the good has to be subsidized or taxed according to the cost/benefit of the externality, and whether the externality is positive or negative.

The most important effect of the tax is not whether it is placed on the consumer, or the producer, but rather the elasticity of supply and demand. If consumers are sensitive to changes in price, horizontal demand curve, a small change in the price will have a large effect on the demand of the good. Therefore, supply will be reduced in the new equilibrium. If consumers have a low price sensitivity, consumers will not change their behavior much by an increase in price, and the producers will charge more for their goods, without a large change in demand.

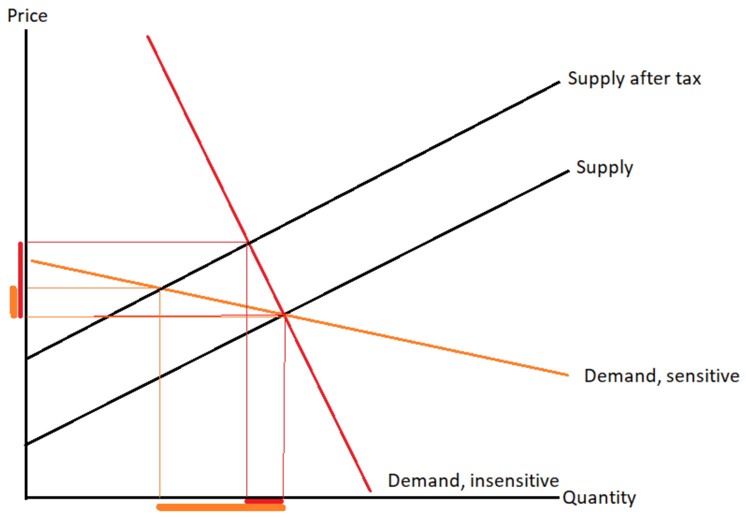

Figure 7: Change in price and quantity after tax with different price elasticities of demand. Source: Own drawing.

The graph above shows a scenario where a tax on emission is placed on the producer. The orange curve is the demand curve of a price sensitive consumer, while the red is the demand curve of a consumer that isn’t sensitive to changes in price. The red and orange lines below the x-axis, is the change in quantities after the tax for the two demand functions, while lines to the left of the y-axis is the change in price. The graph shows that when the demand curve is flat, quantity reduces a lot more than the case where the demand curve is steep. And in the case of low price sensitivity, prices increase more than if the consumers are sensitive for changes in price.

The elasticity of demand depends on several factors. One factor is the type of good, inferior good, luxury good, or necessary good. Agricultural goods are a necessity, as people need food to stay alive, but there are also many kinds of agricultural products. The availability of substitutes is important for the price elasticity of demand, and as ruminant meat increases relatively more in price from a tax on emission than chicken or legumes, it is likely that there will be a shift in consumption towards less carbon intensive agricultural goods.

However, taxes and subsidies must be agreed upon by politicians, and there is a lot of disagreement about taxing emission, even though it will lead to market efficiency. In a paper from Cherry et al. (2012), they discovered that more than 50% of voters opposed efficiency-enhancing environmental policies. One reason for the lack of support for taxes, is that it's seen as restrictive.

When placing a tax on emission, it is important to keep in mind the objective of the tax. By levying taxes on domestic production, without addressing emission from imported goods, emission from domestic production will be reduced, but since prices on imported goods are unchanged, there will be carbon leakage. If the aim of the tax is to reduce damage from greenhouse gas emission, placing a tax on domestic production of the good, without doing anything about imported goods, will not serve the purpose, as greenhouse gas emission has the same marginal damage independent on the location of emission. Therefore, to fix the market failure efficiently, the tax should be placed on the consumer and imported goods, or the consumers.

4.1.3 Carbon leakage

Carbon leakage is the phenomenon of reductions in emission one place causing an increase in emission somewhere else. The economy is very interlinked, and a shift in production one place is likely to have an effect somewhere else. In 2014, 53% of all food consumed in Norway was produced somewhere else, 62% when corrected for animal feed (Rognstad et al. 2016). When designing policy, the desired effect of the policy must be specified. If the objective is to reduce domestic emission, a tax on domestic production can have the desired effect. But if the ultimate objective is to reduce global emissions, which makes sense for greenhouse gas emissions which is spatially independent (emission has the same marginal damage independently on the location of emission) (Phaneuf & Requate, 2017, s.176), the taxation on domestic production alone might not have the desired effect.

Today, Norway protects the agricultural industry from foreign competition, as well as subsidizing production. The trade barrier is designed to protect the agricultural sector while at the same time maintaining a wide selection of goods. The goods that have a comparative advantage in production in the Norwegian climate are well protected through high toll, such as meat, dairy, grain, and eggs.

The goods that can be produced relatively efficiently have a moderate toll, such as potatoes, vegetables, fruits, and berries. And to maintain a wide variety of different food, the goods which cannot be produced in Norway are toll free, such as coffee, tea, rice and tropical fruit and vegetables (Ministry of Agriculture and Food, 2020).

If Norway introduces a carbon tax without changing taxing emission from imported goods as well, there will be an unbalance in the price relationship between domestic and foreign carbon intensive agricultural goods, such as meat. In a worst-case scenario, the entire reduction in domestically produced meat might be filled by cheaper meat from other countries.

The effect of a reduction in the domestic production of beef, for example, and an increase in imported beef consequently can have uncertain effects on the total emission of carbon equivalents. The carbon intensity in beef production can vary greatly, and while 1 kg of beef emits 17 kg co2-equivalents in Norway, the average emission of co2-equivalents in other countries are 46 kilograms (Animalia, 2019).

Even though the policymakers might increase the protection from foreign countries in response to a carbon tax, some leakage is impossible to prevent. Most studies on carbon leakage usually detects about 10-30% carbon leakage, such as Paltsev (2001), Böhringer and Löschel (2002), Babiker and Rutherford (2005), Fischer and Fox (2007), Ho et.al. (2008) and Böhringer et.al. (2010) (From Bye & Rosendahl, 2012). If Norway places a tax on emission in agriculture and imported food, it’s likely that more people will shop at the border, such as Sweden and similar countries, to buy cheaper goods. Therefore, to design policy, which is successful in reducing global emission, it’s important that reductions in domestic production isn’t replaced by similar imported products with higher carbon intensity. This can be done through placing a similar tax on imported goods.

However, as Sweden, Denmark and Finland are trying to mitigate their greenhouse gas emissions, as signaled by their contribution to the Paris agreement (United Nations, 2016), it’s not unlikely that some of these countries will increase their carbon tax as well within the next 30 years. For example, Jordbruksverket in Sweden made a report on sustainable meat consumption in 2013, where tax was discussed, on behalf of the Swedish government (Lööv

et al. 2013). Although whether our surrounding countries imposes a carbon tax on agriculture is an exogenous factor.
Carbon leakage can be stated mathematically like this:

$$Carbonleakage(\%) = \frac{Change\ in\ emission\ in\ the\ rest\ of\ the\ world\ (tonnes)}{Reduced\ emission\ in\ country/countries\ implementing\ policy\ (tonnes)} \times 100\%$$

Formula 2: Carbon leakage measured in percentage. Source: Karbonlekkasjer og årsaker, Bye & Rosendahl, 2012.

In a highly simplified scenario, where policy in Norway makes it too unprofitable for livestock farmers to produce cattle, such that all production of cattle meat drops to zero, but imports in cattle to Norway increases such that cattle meat consumption is 50% of today's level in Norway, it's possible that the carbon leakage completely erases the perceived gain from reducing production of cattle. This is simplified, as most western countries produce cattle more carbon efficient than 30kg per kilogram cattle, but it shows the complexity in reducing emission through policy in an open economy. This policy would also have another downside, which is the reduction in food security.

4.1.4 Economic surplus as measure of welfare contribution

As stated earlier, welfare contribution from the agricultural sector can be measured through GDP. However, another important aspect of welfare is consumer surplus. This is defined as the gain from purchasing a good at a lower cost than the consumers' willingness to pay.
In a market for a good, the equilibrium is the price and quantity where supply equals demand. The economic welfare can be shown with a simple diagram of supply and demand, with prices on the y-axis, and quantity on the x-axis.

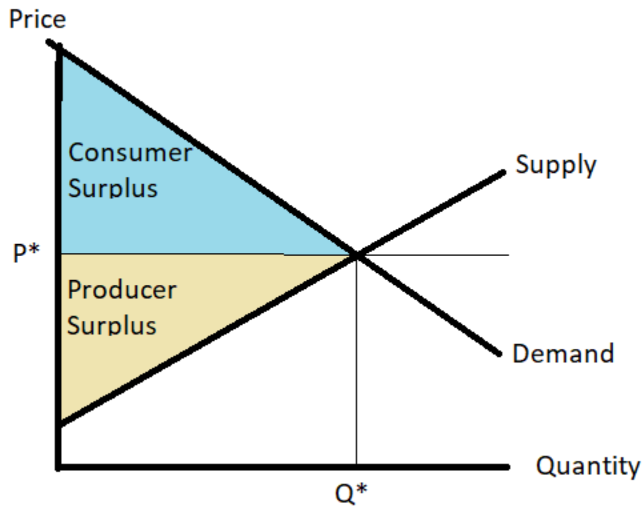

Figure 8: Graph of producer and consumer surplus. Source: Own drawing.

The supply curve is upward sloping in the price of the good, and the demand curve is downward sloping for the price. The equilibrium price and quantity are shown as P* and Q*. The area above the equilibrium price, and under the demand curve constitutes the consumer surplus, the difference between the total willingness to pay minus the price of the good. The area above the supply curve, and under the equilibrium price constitutes the producer surplus.

The Jordmod model calculates economic surplus the agricultural sector by maximizing the sum of consumer surplus, producer surplus, and importer surplus, and subtracting the support given through subsidies.

4.2 Impact of climate change on welfare contribution

The changes in climate is likely to cause changes in the production possibilities, as agriculture is dependent on the weather. As stated earlier, the increased precipitation can possibly shorten the period where harvest can be done. This may impose a need for investments in new equipment, and more equipment per farmer, as sharing tractors, for example can be risky when the harvesting period shrink. The warmer climate will also increase the growth period in many locations, and make new crops available in locations which previously was limited by the temperature.

4.2.1 Production

When the climate changes, the production function of agriculture changes as well. Using a standard Cobb-Douglas production function, I will show how climate can impact the production function of farmers as a result of changing climate.

$$Y = A*L^{\alpha}*K^{1-\alpha}$$

Formula 3: Cobb-Douglas production function

In this function, "Y" is output, "A" is productivity, "L" is labor input, and "K" is capital input. "α" and "1-α" combined is equal to one, and is the output elasticity for the two inputs. The size of "α" is the determines the returns for changes in the two input factors. If new, more efficient types of crops can be grown on a plot of land, this symbolizes a positive shift in productivity, which increases output for a given combination of input factors. This rases the production, hence utility for the farmer increases.

4.2.2 Risk and uncertainty

The utility function of an agent in the economy where time is not a factor, depends on the level of consumption. However, if time is included (intertemporal model), the increased uncertainty related to agricultural production, as a function of the climate, can reduce the utility. Take this simple model of two periods, where f is increasing and concave in income for a producer:

$$\sum_{t=1}^{T=2} U = f(y_t) + f(y_{t+1})$$

$$U^* = f(y_t) = f(y_{t+1})$$

$$y_t^* = y_{t+1}^* = y^*$$

In the function, "U" stands for utility, "f" is a function of income, "y". β is the rate of discounted utility. It is assumed that the function is similar for both periods, hereby making the utility of consumption equal in both periods. Since the marginal utility of income is concave, the allocation of lifetime income which maximizes utility is an equal amount of income in both periods. The concavity of the utility function implies risk aversion.

As the production of agricultural goods is dependent on the weather, uncertainty changes the production function, which has a negative effect on welfare for the producers in the economy. This can be shown in a graph of with income on the X-axis, and utility as a function of income on the Y-axis.

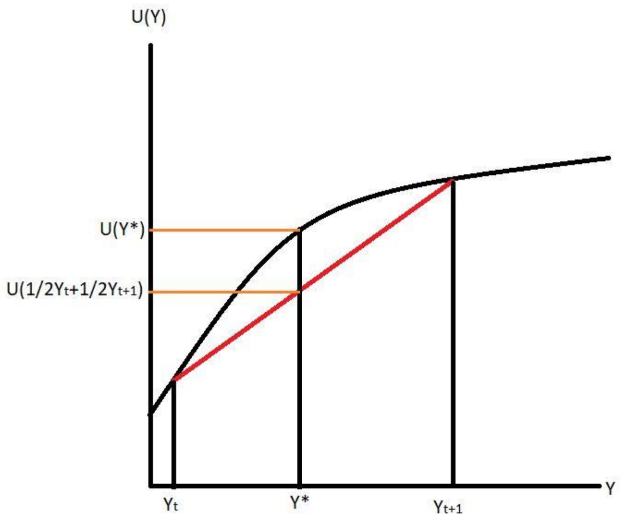

Figure 9: Utility with uncertainty. Source: Own drawing.

The graph shows that production in both periods combined are equal to the optimal C times 2. However, utility in the case with increased risk is lower than that of the optimal C.

This effect of risk is not captured in the model, but important, nonetheless.

5 The model, method, and data

In this chapter I will explain the method I use to answer my research question of how climate change and emission mitigation might affect which policy is best for the agricultural sector in Norway in the long run, and how the production of goods and success in achieving policy objectives might change. I will first explain the comparative statics model Jordmod. Then I will explain how I seek to use the knowledge of agronomic experts, coupled with predictions of the future climate in Norway to get a better understanding of how the climate might affect conditions for growth, and how this will change the sector.
Lastly, I will explain the data I use to answer my thesis question.

5.1 The Model

Jordmod is a model created by NILF in the 1980s (Norwegian Agricultural Economics Research Institute). The model is a comparative statics model, which means that it is not a dynamic model. When you run the model, it optimizes and the model finds the equilibrium instantly, without saying anything about how or when it adapts to the new equilibrium. Which means it can be interpreted as a long run model.
The model is useful for analyzing the effects on the agricultural sector in Norway when there is a change in the framework conditions such as policy, prices, and climate (Mittenzwei & Gaasland, 2008). The detail in which policy can be analyzed using this model makes it well suited for answering my thesis question.
The model is quite detailed and contains several parameters which can be changed to analyze different situations.
A typical simulation in Jordmod consists of changing exogenous variables, such as agricultural policy or international prices, and the model finds a new equilibrium.
The model is mainly constructed of two modules, the supply module, and the market module. The supply module consists of three modules, the farm module, meat module, and the dairy module (Mittenzwei & Gaasland, 2008).
The model is calibrated for year "2014", which is an average of 2013-2015.

5.1.1 Supply module

The model separates between 32 different production regions to consider the various climatic and topographical differences that exists in the different parts of Norway, which affects the yields. (Mittenzwei, 2018). Norway is a country that contains different climate zones and land types, therefore, changes in framework can impact the agricultural sector differently in some parts of Norway than others. For example, in 2019, 308,6 tons of grains were produced in Østfold, while no production took place in Finnmark (SSB, 2021).

There are 11 different modes of operation for farms, such as potatoes, fruits and berries and goats. There are 32 distinct input factors, which are divided between capital, fertilizer, energy, labor and spreading area for livestock manure.

The model also has variables for subsidies given to farmers, which are modelled after the rates from 2011 (Mittenzwei, 2018). Farmers are assumed to maximize profits in the model, which means maximizing income and subsidies minus costs.

Jordmod assumes free flow of capital and labor, which is a reasonable assumption in the long run, and if the farmer earns less per hour than a set amount, or the capital is less profitable than minimum, the farmer or capital relocates. The minimum wage and profitability of capital is exogenously given. The same is true for area, there is a regionally differentiated minimum return of NOK 0-150 per decare, and if the land can't achieve the demand, it goes out of production (Mittenzwei, 2018).

Emission from production are mainly calculated through a set coefficient. For example, there is one coefficient for the emission from greenhouse gases caused by digestion from different animals, and from livestock manure (Mittenzwei, 2018).

The model assumes that each farm can only produce one competing good, such that a small change in relative profitability in producing two goods will lead to the farmer only producing that competing good (Mittenzwei & Gaasland, 2008). The model does not consider aspects such as varying suitability for crops on one farm. Therefore, amongst other reasons, results from small changes can be drastic.

5.1.2 Market module

In the market module, equilibrium prices of 40 separate agricultural products are calculated by maximizing the sum of profits for producers, consumers, and importers (Mittenzwei & Gaasland, 2008).

The model assumes homogenous goods, which means that consumers have no preferences over where the good is produced. Therefore, the international prices in the model plus the import protection through toll on imported goods form a price ceiling for domestically produced goods, as consumers will rather buy imported goods if the prices for domestically produced goods exceed the imported goods.

Domestic demand of goods is calibrated using three parameters. Price and quantity in the base year, and elasticity of demand. There are no parameters for cross price elasticity in the model. Therefore, the relative price changes between goods does not affect demand other than through the direct effect of the price change.

5.1.3 Equilibrium

The model provides a reference scenario by keeping the exogenously given conditions unchanged, and projecting current trends in parameters such as productivity growth, inflation, and population growth.

The equilibrium is found through iterations between the market module and supply module until prices and quantities are equal in the two modules. The difference between the new equilibrium and the reference scenario is the effect of the change in framework conditions.

The results in the model can often be quite extreme in some cases, and should be interpreted with care. For example, the assumption that one farm can only produce one competing good, can have drastic consequences.

When the equilibrium is found, the model calculates a measure of economic welfare, which is calculated by adding producer surplus and consumer surplus, and subtracting subsidies given to the farmers(Mittenzwei, 2018). The value of import protection is not subtracted, because the consumers pay for this through higher domestic prices, and is therefore indirectly accounted for.

5.2 The data

To answer my thesis question, I need data as input in the Jordmod model in the form of projections of future climate. This data comes from a report by Norsk Klimaservicesenter (NKKS), and is published in a report called “Klima i Norge 2100” by Hanssen-Bauer et al. published in 2015. Some of the data is not published in the report, but found on the official website for NKKS.

The data from the website contains the same data used in the report, but also contains individual projections of a number of weather statistics for each of the 19 counties of Norway that existed in 2015, before the merging of several counties into the 11 counties in Norway today.

The report was made after the Norwegian environment agency requested it, and is the second of its kind. The first was published in 2009.

NKKS is a cooperation between the Norwegian meteorological institute, Norwegian Water Resources and Energy Directorate (NVE), and Uni Research.

The projections in the report are based on the results from the fifth assessment report (AR5) by the Intergovernmental Panel on Climate Change (2014), which is under the United Nations and the World Meteorological Organization. In the AR5, they give projections about the future climate, and present something called Representative Concentration Pathways (RCP’s). The RCP’s are pathways from different hypothetical developments in the mitigation of greenhouse gases. There are four different representative concentration pathways in the AR5 report, but only two of them are used in “Klima I Norge 2100”. RCP4.5 and RCP8.5.

The predictions are made by an ensemble of models, and the variation in the results are presented using low, medium, and high estimates. The low estimates represent the predictions of the model which predicted the 10^{th} percentile lowest estimates, while the high is the estimates of the 90^{th} percentile highest predictions (Hanssen-Bauer et al., 2015).

The RCP’s has a number in the end, which represents the level of radiative forcing in the atmosphere by the end of this century, which is a term defined by the IPCC.

The term radiative forcing is used to evaluate the mechanisms affecting the earths radiation balance, such as sunlight absorbed by the earth, and reflected back to the atmosphere, which cause climate change (IPCC, 2013). A larger extent of radiative forcing translates to more changes in the climate.

All pathways are calculated using several models, so the number represents the median value of these models. For all RCP's, there's also one low scenario, which represents the 10th percentile lowest radiative forcing of the models, and a high, which represents the 90th percentile highest. (Hanssen-Bauer et al., 2015)

The low scenario is called RCP2.6. This is a scenario with great success in reducing man-made emissions from 2020 onwards. In this scenario, greenhouse gas emissions are reduced to 0 by 2080, and the world population is around 9 billion by the end of the century (Hanssen-Bauer et al., 2015). This is a very optimistic scenario, and the only scenario where there's a good possibility of not breaching the significant 2 Celsius degree increase from the 1850-1900 period.

The medium scenario used in this report is the RCP4.5. This scenario is characterized by stable or weakly increasing emissions towards 2040, and by 2080 the emissions are about 40% compared to 2012-emission. Projected global increase in temperature is approximately 2,5 Celsius degrees hotter than the period 1850-1900.

The third scenario in the report, high, is the RCP8.5. This is usually referred to as the business as usual scenario. In this scenario, Co2 emission is expected to be tripled by the end of the century, compared to today, and population will increase to 12 billion. It's likely that the temperature increases approximately 4 Celsius degrees compared to 1859-1900-levels if the world follows this path. .

The projections of future climate are presented in the fifth chapter of the report.

Some important results in the report are predicted change in temperature, precipitation, occurrence of heavy precipitation, intensity of heavy precipitation, and change in agricultural drought.

This data contains rather detailed predictions on both temperature changes, and changes in precipitation. However, the occurrence of drought, which is expected to increase, is not well represented in this data. The best prediction we have is the Map over the expected change in agricultural drought towards 2031-2060, for RCP4.5 and RCP8.5.

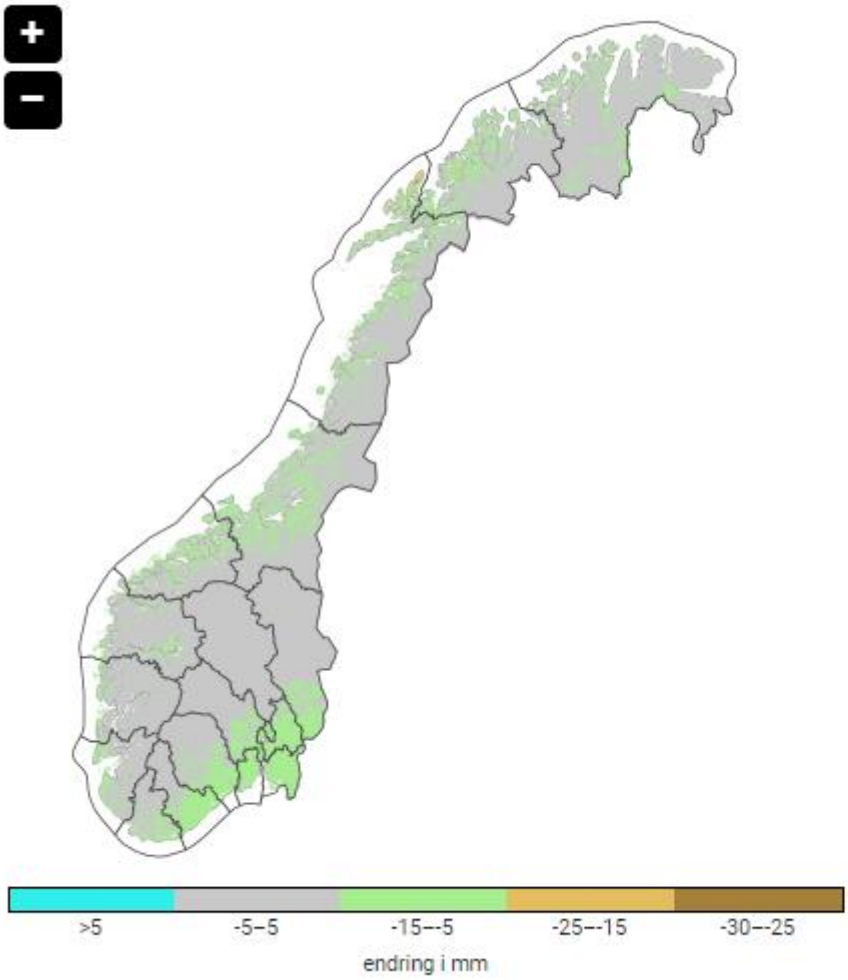

Figure 10: Change in soil moisture deficit towards "2045" in RCP4.5. Source: Norsk Klimaservicesenter, 2015.

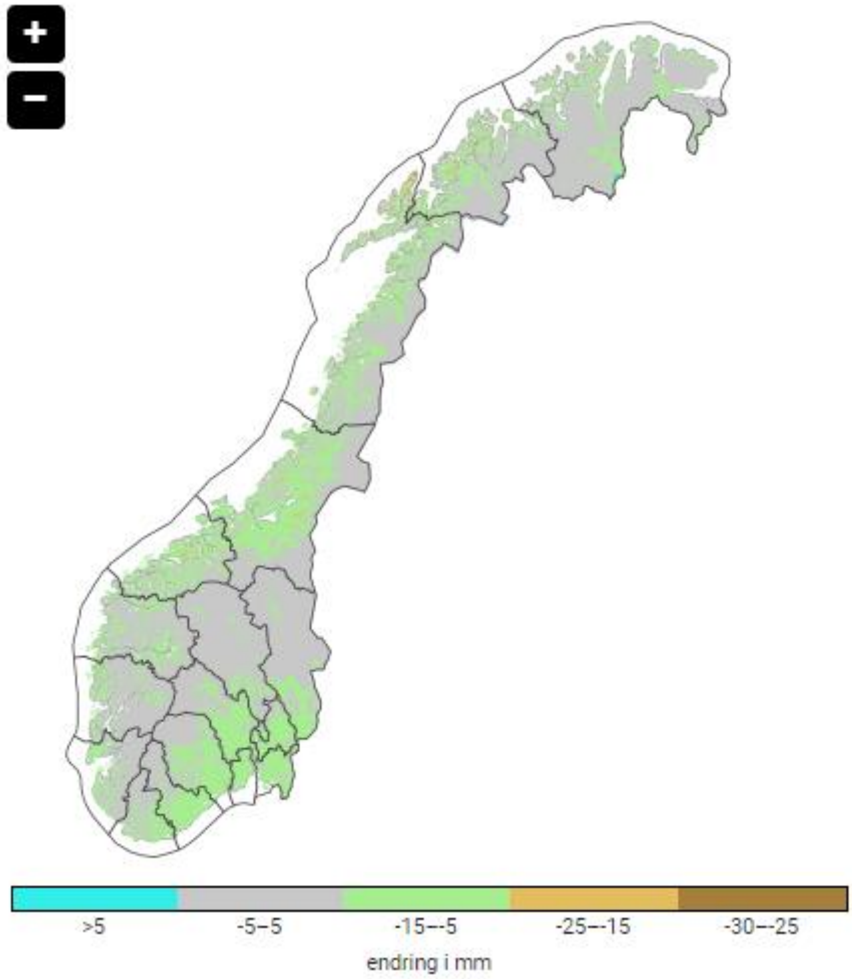

Figure 11: Change in soil moisture deficit towards "2045" in RCP8.5. Source: Norsk Klimaservicesenter, 2015.

From figure 3 and 4 we can see that in many places along the coast, and especially in the eastern Norway, the predicted change in soil moisture deficit is between -5 to -15, meaning that there will be less moisture in the soil. For the rest of the country, it is ambiguous if the soil moisture is expected to go up or down, but it is interesting that no places in the country is unequivocally expected to see an increase in soil moisture.

This soil moisture is expected to go even lower towards 2071-2100, with many places reducing its soil moisture by 15 to 25 percent, and some few places by 25 to 30 percent.

To use this as data in the model, I made a table of the various counties, measured what percentage of the county was affected by increased drought, and to what extent. For example, if Østfold is affected by drought all over the county, with a change in drought between 5-15 mm, I took the median value of the change, 10 mm, and multiplied this by the percentage of the county affected.

5.3 Method

To model the change in weather as a result of climate change, we had to construct a scenario for how the changes affected yields, and growth opportunities in the regions Eastern Norway, Western Norway, Central Norway, and Northern Norway. These scenarios are based on the medium RCP4.5 predictions from the data.

To get input for Jordmod on how the expected climate change can affect the Norwegian agricultural sector, new numbers for expected crop potential must be put in the model. There is little data on this currently, so through interviews with agronomic experts, and reviews of literature, such as (Ministry of Agriculture and Food, 2016), we made an approximation of how the data from Hanssen-Bauer et.al (2015) could affect agriculture in the four regions with differing climate.

The model separates areal into six different classes, based on the quality and possibilities for growth. The first and second class can be used to grow all types of crops, but are the only to grow grains for human consumption. Class two is marginal(Uleberg & Dalmannsdottir, 2018). These crops are wheat and oats, although, quality is important, not the type of crop for whether it's used for human consumption. But the model assumes homogenous goods. Class 1-4 can be used to produce crops for feed concentrate for livestock. Feed concentrate is barley and rye in the model. It can also be utilized for growing grass for the animals. Class 4 is marginal.

Class 5 can be used for cultivated grass, and regular grass for grazing for livestock. While class 6 is only suitable for grass for grazing. There is also a term for potatoes, fruits, legumes, and vegetables, which are referred to as other plants. These can be cultivated in class 1-5.

Based on the changes in climate for RCP4.5, we transferred some land from a lower class to a higher class(Uleberg & Dalmansdottir, 2018). Central Norway is limited by temperature today, but the 1,8 Celsius degrees increase in temperature can make it possible in the most suitable places to grow crops for human consumption where it wasn't in "2014". Troms, which is located in Northern Norway, is expected to be able to grow vegetables, grains etc. (Martin et al., 2017) , when 98% of all agricultural areas are used for producing roughage today (Uleberg & Dalmannsdottir, 2018)

The increased temperature is beneficial for agriculture in Norway, as well as increased $Co2$ in the atmosphere (Ministry of Agriculture and Food, 2016), but the increased precipitation can have a negative effect. To negate this effect, we increased the investment on soil, trenches, and water systems by 100% in Northern- and Central Norway, and 50% in Western- and Eastern Norway per decare from NOK 23-24 per decare (NIBIO, 2021). The investments are assumed to cancel the effect of the increased precipitation. The investments are only made on land from class 1 to 5, as class 6 can only be used for grazing, and are not managed actively. Below is a chart of areas for the 6 different zones, in percentages, for Norway.

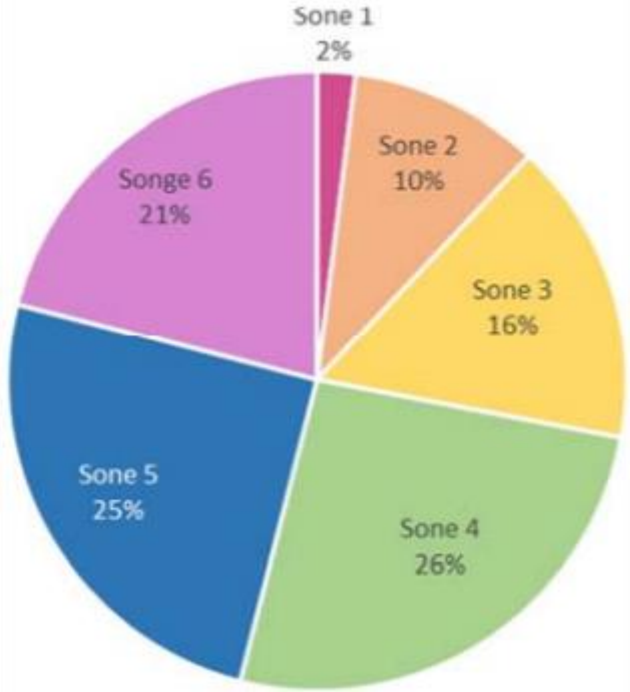

Figure 12: Distribution of total agricultural land in production classes. Source: Uleberg & Dalmannsdottir (2018).

As well as increased productivity per decare, increased temperatures are also likely to have a positive quality on some of the grains, cultivated grass, and other plants in some regions, but the fertilization of nitrogen has to be increased proportionally (Simonsen, 2014), which causes cost to increase.

One thing we had to keep in mind when preparing the scenarios for how the changes in climate could affect agricultural production, was that the reference period in Hanssen-Bauer et.al (2015) is 1971-2000, while the "base year" in Jordmod is "2014". Some of the changes has already happened. For example, the average summer temperature at Blindern was 15,8 Celsius degrees in the reference period, and 16,5 Celsius degrees in 2013-2015 (NKKS, 2021). As the period "2014" is a short interval, results can be outliers, but the temperatures are consistently higher in recent years compared to the reference period. This change in temperature is considered when preparing the data for Jordmod.

Höglind et.al (2013) found that grass yields were expected to increase in Norway by 11-14% towards 2050. Although these results were not differentiated by location, rather non-irrigated versus irrigated land, we used 14% increase in grass yields in regions which are more constrained by temperature today, and 11% for regions which are not. This is because the regions that is constrained more by temperature in Norway can grow different strains of grass, and the growth season, days with average temperatures equal to or above 5 Celsius degrees, is expected to increase more (Ministry of Agriculture and Food, 2016).

As stated earlier, all goods are assumed homogenous, so to parameterize this in the model, we adjusted the price subsidy received by farmers growing the the crop which received a higher quality. The price increase we used in the model is 10%.

6 Results and discussion

The results from Jordmod is divided into four different columns. The first is “Ref”, which Stands for reference path. This is how Jordmod anticipates the agricultural sector will look if the current and projected changes in inflation, population, wage growth and so on continues, without any changes in agricultural policy, climate etc. The second column is “RefGhg”. This is how Jordmod predicts the agricultural sector will look if the politicians reduce the greenhouse gas emission by about 5 million tons CO2-equiv., according to the suggestion by the Norwegian environment agency. The third column, “KliGhg”, is the agricultural sector with changed climate, and reduced greenhouse gas emissions from the agricultural sector. And lastly, “LndKliGhg” is the same as “KliGhg”, but with an added subsidy of NOK 200 per decare in production.

Production	Ref	RefGhg	KliGhg	LndKliGhg
Food production (GJ)	13 126	13 967	14 035	13 957
Food grain (million kg)	341	431	435	434
Feed grain (million kg)	663	728	714	754
Potato (million kg)	266	266	266	266
Fruit & vegetables (million kg)	592	592	592	592
Cow milk (million ltr)	1 578	1 536	1 542	1 523
Meat (million kg)	364	344	345	344
Cattle (million kg)	81	55	57	56
Sheep (million kg)	22,9	24,2	24,5	23,7
Pig (million kg)	141	145	145	146
Poultry (million kg)	119	119	119	119
Egg (million kg)	77	76	76	76

Table 2: Production. Source: Mittenzwei (2021).

All three scenarios for food production are larger than the Ref scenario, which suggests that taxing greenhouse gas emission increases production measured in energy. It is interesting to see that the effect of climate change towards 2050 has marginal effects on food production, based on the increase of less than 0,5% from RefGhg to KliGhg It is also clear that the tax affected the relative profitability between producing meat and grain, as production of grain for human consumption and feed has increased by 15,4% from Ref to RefGhg, while meat production decreases. This is because producing meat is carbon intensive. Production of cattle is reduced by a third. This is likely because cattle production is the most carbon-intensive per kilogram meat produced of all livestock production.

Food grain production is increased relatively more in the scenarios with climate change included, as new areas can grow food grain as a result. The shift in production possibilities for the farmers had little effect, which is seen by the small changes from RefGhg to the two scenarios with climate change included.

Imports	Ref	RefGhg	KliGhg	LndKliGhg
Food grain (million kg)	641	539	536	533
Feed grain (million kg)	136	10	18	-
Soy (million kg)	278	273	273	269
Dairy goods (million kg)	52	53	52	53
Meat (million kg)	18	29	27	26
Cattle and sheep (million kg)	14	23	22	21
Pig and poultry (million kg)	3	6	5	5
Egg (million kg)	1	1	1	1

Table 3: Imports. Source: Mittenzwei (2021).

Imports on grain for livestock is reduced by 93% by placing a tax on greenhouse gas emission in agriculture. This is in parts because the increased production of grains. The reduction in import of grain is about the same size as the increased production. The reduction in production of meat is around the twice the size of the increased imports. This suggests that there has been a change in relative profitability in production, and as a result, some farmers shifts in their production. The increase in imports of meat is likely not because the tax on emission, as the tax is levied on imported goods as well, however the new framework does change the relative profitability between different meat products, and meat and plant products, which can result in an increased import.

Consumption	Ref	RefGhg	KliGhg	LndKliGhg
Food consumption (GJ)	17 605	17 339	17 343	17 262
Plant products (million kg)	2 089	2 075	2 075	2 070
Cattle and sheep (million kg)	74	64	64	63
Pig and poultry (million kg)	205	210	210	210
Dairy goods (million kg)	839	833	834	831
Egg (million kg)	78	78	78	77

Table 4: Consumption. Source: Mittenzwei (2021).

Consumption hasn't changed a lot, but there is some substitution from ruminant meat, which are more carbon intensive, to pig and poultry. There is also a trend of lower food consumption for all scenarios with a tax on emission, which can be a result of increased food expenditure for consumers, which increase by 4-5,6% in the scenarios with a tax on emission (table 10).

Intensity in livestock production	Ref	RefGhg	KliGhg	LndKliGhg
Milk yield per cow (liters)	8 410	8 408	8 409	8 406
Roughage percentage milk production (%)	41,6	41,8	41,8	38,5
Roughage area cattle (daa per cow)	19	18	18	19
Roughage area milk cow (daa per cow)	17	18	18	19
Roughage area beef (daa per nursing cow unit)	19	21	20	21
Beef intensity (kg per cow)	270	284	287	290
Roughage percentage cattle excluding milk cows (%)	11	9	9	9
Sheep meat intensity (kg per sheep)	28,0	27,8	27,8	27,9
Roughage area sheep (daa per sheep)	1,3	1,3	1,4	1,4
Outlying fields (daa per sheep)	2,5	2,5	2,4	2,4
Yields roughage (kg feed unit, milk, per daa)	387	391	396	394

Table 5: Source: Intensity in livestock production. Source: Mittenzwei (2021).

The milk yield per cow is unchanged, but considering the changes in quality of grain and grass in some parts of Norway as a result of climate change, an analysis of how this changes milk yields and/or roughage percentage in cattle and milk cows is something that maybe should be studied more closely. The roughage percentage marginally increased, though. The model assumes a yearly increase in milk yields per cow of 0,62% (Mittenzwei, 2018), which seems to be the reason for the increase in yields towards 2050. It is also interesting to see that the roughage percentage for cattle excluding milk cows has been reduced. This can possibly be explained by the increased cost of production, which causes intensification in production to be more profitable. More feed concentrate increases productivity, hence reduces emission, which is taxed.

Factor input	Ref	RefGhg	KliGhg	LndKliGhg
Agricultural area (1000 daa)	9 805	8 046	8 129	8 373
Grain area (1000 daa)	2 623	2 970	2 941	3 056
Potato, fruit & vegetable (1000 daa)	330	329	329	328
Roughage area (1000 daa)	6 852	4 747	4 860	4 989
Milk cows (1000)	188	183	183	181
Nursing cows (1000)	112	12	13	10
Sheep (1000)	819	868	880	851
Pigs (1000)	49	50	50	50
Hens (million)	4	4	4	4
Chickens (million)	73	73	73	73
Share of calves (%)	18	10	7	3
Years of work (1000)	33	31	31	31

Table 6: Factor input. Source: Mittenzwei (2021).

From table 5, it is clear that the tax on emission causes a lot of land to go out of production. The reduction in land area is 18%, 17%, and 14,6%, in order. This can in part be because production of cattle, which requires a lot of roughage area. The years of work also decreases. This is not surprising considering there is less agricultural land in production. The shift in production can also explain why the Ref scenario produces less food, measured in gigajoule, even though agricultural area is larger than the three scenarios with a tax on emission from the agricultural sector. Some areas are also only suited for producing feed for livestock, and as livestock production is costlier, some area goes out of production.
The amount of nursing cows in Norway is reduced drastically for all scenarios with a tax on emission. This is likely due to nursing cows being more carbon intensive than other cows. The coefficient for emission related to digestion is 94,8 kilograms of methane per nursing cow. The corresponding number for cattle for slaughter is 58,1 kilograms of methane (Mittenzwei, 2018). The reduction in cattle production reduces the demand for nursing cows. Nursing cows also has a significantly higher percentage of roughage in its diet. While milk producing cattle and bulls get between 55 and 61% of their energy intake from roughage, the corresponding number for nursing cows is 93% (Animalia, 2021).

Rural share	Ref	RefGhg	KliGhg	LndKliGhg
Total area	57	56	56	57
Grain area	1	8	8	10
Roughage area	81	87	87	86
Dairy cows	59	80	79	78
Feeding cows	94	100	100	100
Sheep	100	99	100	99
Pigs	44	49	49	48
Hens	-	-	-	-
Broiler chickens	65	65	65	65
Labor	61	65	65	64

Table 7: Source: Rural share. Mittenzwei (2021).

The share of rural agriculture is not significantly changed from the reference scenario, which is positive. Agricultural land in more central locations are often more productive than agricultural land in rural locations. Therefore, one might assume that most of the land that went out of production came from rural land. This is not the case and can be explained by milk production quotas in rural locations, which can be seen by the increase in the rural share of dairy cows from 59% to 78-80%. Producing milk is relatively labor intensive, which explains why rural share of labor increases from 61% to 64-65%. However, since the total agricultural land is reduced, total rural area in production is also lower. This is a negative result in terms of the agricultural policy objective of agriculture all over the country. Rural share of roughage area is increased. This might be a result of total area for roughage decreasing a lot, but relatively more in central locations, as some rural parts of the country have less suitable land for producing other products. Also, the share of cows increases, and as ruminants consume roughage, this seems natural.

Producer prices (2014-NOK/kg)	Ref	RefGhg	KliGhg	LndKliGhg
Grain	3,95	4,16	4,17	4,37
Potato	3,47	3,44	3,45	3,48
Horticulture	13,63	13,67	13,67	13,68
Milk	6,33	7,65	7,48	8,09
Cattle	60,65	77,61	77,76	80,92
Sheep	64,03	89,80	87,14	93,94
Pig	30,43	33,89	33,75	34,97
Poultry	23,20	24,04	24,04	24,53
Egg	17,98	19,12	19,13	19,60

Table 8: Source: Producer prices. Mittenzwei (2021).

Most producer prices increase from the reference scenario. The tax on emission affects livestock the most, as production is more carbon intensive. The prices increase by 28-33,4%. Prices is higher for the scenario with increased land subsidy, which hints at the policy not being the most effective in terms of efficiency of production. However, agricultural area used is larger for this scenario, which is a policy objective. Production of grain is costlier for the scenarios with climate change than without, which is surprising considering the increased yield potential in some regions, but this might be a result of changes in the structure of the agricultural sector.

Consumer prices (2014-NOK/kg)	Ref	RefGhg	KliGhg	LndKliGhg
Grain	8,70	9,44	9,46	9,64
Potato	6,05	6,01	6,02	6,08
Horticulture	22,60	22,65	22,65	22,66
Dairy goods	27,73	30,13	29,82	29,93
Cattle and sheep	103,89	132,91	131,51	134,49
Pig and poultry	58,74	66,09	65,54	65,79
Egg	27,16	28,16	28,15	28,62
Food expenditure (million 2014-NOK)	81 295	84 823	84 578	85 827
Sum greenhouse gas emission (million t CO2-equiv.)	5 374	4 645	4 624	4 585
Greenhouse gas emission production (million t CO2-equiv.)	4 385	3 500	3 500	3 500
Greenhouse gas emission import (million t CO2-equiv.)	989	1 145	1 124	1 085
Food production (energy) GJ	13 126	13 967	14 035	13 957
Net budget support (million 2014-NOK)	27 421	22 392	22 560	23 079
Budget support (million 2014-NOK)	27 421	23 815	23 999	24 751
CO2-tax (million 2014-NOK)	-	1 423	1 439	1 672
Operating profit (2014-NOK/year of work)	797 409	916 543	910 518	979 674
Welfare (million 2014-NOK)	293 765	291 538	291 592	291 872

Table 9: Source: Consumer prices. Mittenzwei (2021).

Table 9 shows an increase in consumer prices for grain in the scenarios with a tax on emission, which can be explained by the increase in producer prices. Greenhouse gas emissions from domestic production are reduced by 20% for all scenarios with an emission tax. But as shown by the greenhouse gas emissions from imported goods, there is some carbon leakage to other countries. Using the formula for measuring carbon leakage, the percentage of leakage is 17,6, 15,3, and 10,8 for RefGhg, KliGhg, and LndKliGhg, respectively. This percentage of carbon leakage falls within the observed carbon leakage from other studies.

Profits for farmers increase for all scenarios relative to the reference scenario, most in the scenario with land subsidy. This is positive for the agricultural policy objective of higher value creation.

The reference scenario has the highest economic welfare, marginally, but this number does not reflect many of the aspects which can be argued causes welfare. For example, the value of reduced emission is not included in welfare, but it can be argued that reduced emission increases welfare. Policymakers will have to balance whether the welfare loss from the climate policy outweighs the benefit of reduced greenhouse gas emission

Land usage is also significantly higher for the land subsidy scenario, which is an agricultural

policy objective.
The increase in consumer price in the scenarios with a tax on emission ranges from 26,6% to 29,5% for cattle and sheep, while the price increase in pig and poultry ranges from 11,6% to 12,5%. This is as expected due to the carbon intensity of ruminants, and explains the substitution from ruminants to pigs and poultry. Even though prices increase, the closest substitute increases more, which makes the relative price lower in relation to ruminant meat.
The economic welfare, measured as producer and consumer surplus, minus subsidies to farmers decreases by 0,76% in all scenarios with a tax on emission. However, the operating profit for farmers increases by 14,9% in RefGhg, 14,2% in KliGhg, and 22,9% in the LndKliGhg scenario.
Consumer prices increase in all scenarios with a tax on emission, the most in the LndKliGhg scenario. Therefore, consumer surplus is likely to decrease. But total welfare is larger for LndKliGhg than RefGhg, and KliGhg, which is because producer surplus increases.

The difference in results for scenarios with and without a tax on emission are consistently larger than the difference in results between scenarios which takes climate change into account and scenarios that doesn’t. This means that policy changes, here a tax on carbon specifically, has a larger effect on the agricultural sector than climate change towards 2050.

7 Conclusion

The changes in climate does not impact the agricultural sector significantly, when modelled in Jordmod. The largest changes predicted by the model was a result of the tax on emission, which reduced emission in the agricultural sector, as well as agricultural area in production- It is, however, important to keep in mind that Jordmod is not a model for analyzing risk, which can increase because of climate change.

The welfare in the scenarios with a tax on emission is reduced by less than 0,8%. Out of the scenarios with a tax on emission, the scenario with an increased subsidy on land use stands out as the preferable. This is because it has more agricultural land in production, operating profit for the farmers is larger, and there is less carbon leakage.

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