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Changes in the use of agricultural land in an urban municipality

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Abstract

Agricultural land is exposed to pressure for other purposes than agriculture in urban areas, because of population growth and urbanization. This is due to increased demand for area for housing, infrastructure, industry and so on. But we have few studies that see actual land use changes in peri- urban areas over longer periods of time, and what can possibly explain these changes. In this study we examined agricultural land use changes, in Trondheim municipality, Sør- Trøndelag county, and at national level (in the period 1969- 2019), overall land use changes in Trondheim (period 2003- 2019), changes in use of fully cultivated land and factors explaining this, verification of map data. Future plans for reallocation of fully cultivated land in the municipality was examined, and four interviews of active farmers who lost agricultural area due to development (between 2003 and 2019), were conducted, to look into their experiences of farming in an expanding city.

We found that the amount of agricultural land in operation and fully cultivated land has decreased the most in the municipality, with respectively 22,6 % and 18,9 %. Compared to Sør- Trøndelag (3,7 % and 8,9%) and Norway (9,5 % and 11,1 %), in the period 1969 to 2019. In the period 2003 to 2019 the amount of built-up area increased with 27,9 % and transport and communication (infrastructure) increased with 29,4 %. Fully cultivated land decreased with 5,6 %.

38 % of the fully cultivated land has in the period 2003 to 2019 changed to built-up area (and open firm ground). Possible connections that may explain changes in the use of fully cultivated land are population density, distance to road and distance to the city center. Most of the future plans for reallocation of fully cultivated land is for built-up area, with 48,6 %. Farmers who lose land for development, all experience a burden of this, depending on how large an intervention this is for the individual farmer. This will determine whether, and what adjustments the farmer must make, by renting land, downscaling operation, etc.

The result of this study implies that loss of agricultural area is a highly relevant challenge in other urban areas as well as Trondheim, and the focus of decision makers, on the reduction of agricultural land, and how to manage this, should be in cities and urban municipalities, where the loss of agricultural land is greatest.

Keywords: land use changes, agricultural area, urbanization, reallocation (demolishing)

Sammendrag

Jordbruksareal er utsatt for press til andre formål enn jordbruk i urbane områder, på grunn av populasjonsvekst og urbanisering. Dette skyldes økt etterspørsel etter areal til boliger, infrastruktur, industri også videre. Men vi har få studier som ser på endringer i arealbruken i bynære områder over lengre perioder, og hva som muligens kan forklare disse endringene. I denne studien undersøkte vi endringer i bruk av jordbruksareal i Trondheim kommune, Sør-Trøndelag fylke og på nasjonalt nivå, i perioden 1969- 2019. Generelle endringer i arealbruk i Trondheim, i perioden 2003- 2019, endringer i bruk av fulldyrka areal og faktorer som kan forklare dette og verifisering av kartdata. Fremtidige planer for omdisponering av fulldyrka jord i kommunen ble undersøkt, og intervjuer av fire aktive bønder som har mista jordbruksareal til forskjellige typer andre formål (mellom 2003 og 2019) ble gjennomført, for å se på deres erfaringer med å drive jordbruk i en voksende by.

Vi fant at mengden jordbruksareal i drift og fulldyrka jord har blitt redusert med mest i kommunen, med henholdvis 22,6 % og 18,9 %. Sammenligna med Sør- Trøndelag (3,7 % og 8,9 %) og Norge (9,5 % og 11,1 %), i perioden 1969 til 2019. I perioden 2003 til 2019 økte mengden bebygd areal med 27,9 % og transport og kommunikasjon (infrastruktur) økte med 29,4 %. Fulldyrka jord gikk ned med 5,6 %.

38 % av den fulldyrka jord har i perioden 2003 til 2019 endret seg til, bebygd areal (og åpen fastmark). Mulige sammenhenger som kan forklare endringer i bruk av fulldyrka jord er befolkningstetthet, avstand til vei og avstand til sentrum. Det meste av den fulldyrka jorda som er planlagt omdisponert, er til bebygd areal, med 48,6 %.

Bønder som mister areal til nedbygging, opplever alle en byrde på grunn av dette, avhengig av hvor stort inngrep dette er for den enkelte bonde. Dette vil avgjøre om, og hvilke justeringer bonden må gjøre, ved å leie jord, nedskalere driften også videre.

Resultatet av denne studien indikerer at tap av jordbruksareal er en svært relevant utfordring i andre byområder så vel som Trondheim, og beslutningstakernes søkelys på tap av jordbruksareal, og hvordan forvalte dette, bør være i byer og urbane kommuner, hvor tapet av jordbruksareal er størst.

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1. Introduction

Change in land use is a process that is constantly going on and is induced by human, and will be a phenomenon for all time to come, as long as there are humans on earth (Lambin and Meyfroidt, 2011). The need for area to produce food, build homes and produce energy makes people dependent on land. Human use has changed more than 70 % of the global, ice- free land surface (Song et al., 2018, IPCC, 2019). Intergovernmental Panel on Climate Change (IPCC) (2003) suggested six categories of land representation to assess land use changes and classify the different types of land use, which are forest, cropland, grassland, wetlands, settlements and other land cover.

1.1. Effects on biodiversity and ecosystem services

Despite the fact that human land use has been modified to provide livelihoods and other essential elements for thousands of years, the intensity, extent and rate of land use changes are far greater now than they were in the past (Hassan et al., 2016). In recent decades, the increasing and more intense human use of land has resulted in significant changes in biodiversity (Hansen et al., 2004), and change in land use presents the greatest immediate threat to biodiversity (UN, 2014). Land use changes that lead to e.g., habitat loss can reduce population sizes, and lead to reduced genetic variation. A more extreme consequence of land use change is that it can lead to a more homogeneous landscape and therefore reduced ecosystem diversity (Jung et al., 2019).

Species diversity is key to a rich and diverse set of ecosystem services (Mace et al., 2012, Fu et al., 2015a). A loss of biodiversity as a result of changes in human land use affects the functions of ecosystems and ecosystem services (Isbell et al., 2015). The International Union for Conservation of Nature (IUCN) defines ecosystem services as *"the benefits people derive from ecosystems"* (IUCN, 2016). Ecosystem services, like biodiversity and ecosystems, will get negatively affected by human induced activities (Tolessa et al., 2017).

The Millennium Ecosystem Assessment (MEA) identified four overall types of services, which are provisioning, supporting, cultural and regulating services (MEA, 2005). The ecosystem services vary with different land use types and change in response to land use changes. The provisioning services e.g. are affected by land use changes in form of urban development and urbanization, where population growth requires more resources to produce food and fiber, but also land for housing etc. (Hasan et al., 2020). Fu et al. (2015b) found that natural ecosystems with minimal human disturbance have weaker provisioning services but stronger supporting and regulating services. In those systems with moderate human disturbance, provisioning services are stronger while their regulating and supporting services are weaker. However, when human disturbance is large enough to result in the destruction of land, the function of all ecosystem services will be threatened (Braat et al., 2008).

1.2. Changes in the use of agricultural land

A trend in land use change, both at global and local level, is the loss of agricultural land (European Environment Agency, 2012, Seto and Ramankutty, 2016, FAO, 2018, Öhlund et al., 2020). Agricultural land covers about 40 % of land surface (Power, 2010), and one main factor contributing to the decline is the rapid urbanization (Chen, 2007, Jaradat and Boody, 2011). Urbanization is when people change their rural lifestyle into an urban lifestyle, and can be defined as "*a complex process that transforms the rural or natural landscape into urban and industrial ones(…)*" (Antrop, 2004). According to United Nations and data from the World Bank, over 50 % of the total world's population live in cities around the world (United Nations, 2019, The World Bank, 2019b). At the same time, the total world population is growing. The overall population increase and the upward shift in the percentage living in urban areas are driving growth in the urban population (United Nations, 2019).

Cities have arisen in the vicinity of productive agricultural land, because people have settled down to be able to produce food (Satterthwaite et al., 2010). This means that these productive areas are easily accessed and exposed to pressure to be used for purposes other than agriculture, when the city expands. In western Europe most of the settlements due to urban growth have happened on agricultural land (Zasada, 2011). The major land changes in Europe are not just about loss of agricultural land, but a general redistribution of land and a net loss of agricultural land (Huang et al., 2019).

Loss of agricultural land is not without consequences. Agricultural land provides and receives numerous ecosystem services, and supplies three of the main ecosystem services groups, providing, regulating and cultural services (Swinton et al., 2007, van Vliet et al., 2015). Among the ecosystem services associated with agriculture, the provisioning services meeting peoples' needs for food, fiber and biofuels are the main goals. Nevertheless, agriculture has many more important roles when it comes to ecosystem services. Such as the regulating services flood control, regulate the population dynamics of pollinators and carbon sequestration. Cultural ecosystem services include agricultural landscape as recreation, tourism, and conservation of biodiversity. In addition to provisioning food and fiber, agricultural production can be forage and pharmaceuticals (Zhang et al., 2007, Power, 2010). As agricultural land is one of the most important provisioning services it must be managed sustainably to both protect the environment, but also to feed people.

1.2.1. Change in agricultural land in Norway

In the last 50 years, about 100 000 hectares of agricultural land (sum of fully cultivated land, surface cultivated land and infield pasture area) and arable land have been reallocated to other purposes than agriculture in Norway. Annually around 1000 hectares of land is reallocated. This is a high number considering that only three percent of the area in Norway is agricultural land, and that only three percent is suitable for growing food grains (Statistisk sentralbyrå, 2017b). It is especially the highly productive agricultural areas near cities and towns that are exposed to development pressure.

Areas suitable for grain cultivation are among the most valuable food production areas. With today's global population growth and climate challenges, it is becoming increasingly important to consider food and food production as a global matter. Secure food supply for an ever- increasing population in Norway, as well as in the world, is dependent on the areas being taken care off (Statistisk sentralbyrå, 2017b).

1.3. Management of cultivated land

1.3.1. Soil protection and Master Municipal Plan

Norway has, seen in an international context, strict national protection of agricultural land. Using the land suitable for food production, for something other than agriculture, is primarily prohibited by law. Land Act (Jordloven, 1995) §9 states that cultivated land cannot be used for purposes that are not aimed at agricultural production. The Norwegian Land Act allows for exceptions "if after a collection assessment of the conditions finds that other land uses are of more vital importance than agriculture".

The Planning and Building Act (Plan- og bygningsloven, 2008) regulates land use and planning and is thus somewhat related to the Land Act. The law requires all municipalities to prepare an area part in the Master Municipal Plan, where future area needs must be accounted for. The different types of area are classified into six categories, and arable land belong to the category "agricultural, nature, outdoor life and reindeer husbandry areas" (LNF-R). The term reallocation of cultivated land is used when an area changes land use category from LNFR, to one of the other categories. The most common reallocation of agricultural land is to the category built-up area, or infrastructure (Vinge, 2020).

1.4. Farmers' perspectives on agricultural land use changes

Changes in the use of agricultural land will naturally affect many people, and especially landowners and farmers who make a living from operating the agricultural land. Loss of agricultural land mainly takes place in favor of activities other than agriculture, such as buildings, infrastructure, or parks and gardens. Lack of land caused by population growth and urbanization has been reported as a problem for farmers in peri- urban areas (Vandermeulen et al., 2005), mainly due to the location of the areas. Nevertheless, there is little research to be found which is directly relevant to this issue. The impact of changes in agriculture land on farmers is examined in this study.

1.5. Study objectives

The main purpose of the study was to examine changes in the use of agricultural land in the municipality of Trondheim. This has been done in three parts.

The first part has been general with a broad scope. The objectives are to (1) examine long term changes for agricultural land area on a national, regional (Sør- Trøndelag county) and local scale (Trondheim municipality) in the period 1969 to 2019. (2) examine the land use changes for the 8 main land use categories in AR5 in the period 2003 and 2019, and how the changes have been within each land use category (increase or decrease).

The second part of the study has examined more detailed possible changes in the use of "fully cultivated land". Part of this has been done in a limited area of the municipality, which has been based on the area investigated by Kleppe (2019). The objectives are to (3) examine the land use changes that has happen to the fully cultivated land for the whole municipality and explain these changes. (4) Examine the actual land use changes within the category "fully cultivated land" in a delimited area, in relation to registered land use changes. (5) Examine future plans the municipality has for re- regulation of fully cultivated land.

The third part of the study has been social science oriented. It has been conducted small interviews of four landowners who are active farmers and their view on farming in a growing city has been examined. Also, their experience with pressure on their areas, losing land and how it has affected their motivation for future farming has been examined.

1.5.1. Research questions

Research questions that have been investigated, related to the objectives above are: (1) What are the agricultural land area changes for the urban dominated municipality of Trondheim in relation to the changes at larger regional and national levels? (2) What are the changes in the main land use categories in Trondheim, in the period 2003 to 2019? (3) To what extent has fully cultivated area changed in the period 2003 to 2019, to which land use categories have changes entailed, and what can explain these changes? (4) To what extent is map data on available fully cultivated area in the municipality updated? (5) What plans do the municipality have for re- distribution of fully cultivated land? (6) What are the landowners view on doing agriculture in a growing city, and experience with pressure on their areas?

We expected that (1) there has been a decline in agricultural land in the period 2003 to 2019, at the municipal level, the regional and national level, due to development (re- allocation) or area gone out of production. (2) There has been an increase in built-up area and area for transport and communication . (3) Most of the fully cultivated land between 2003 and 2019 is lost due to housing or area for infrastructure (roads). Changes happen close to built-up area and roads . (4) The municipality has updated map data. (5) Decline in demolition of fully cultivated land, based on political goals.

2. Materials and Methods

2.1. Study area

The study was performed in the municipality of Trondheim in Trøndelag county, in Norway (63°26’N 10°24’Ø), showed in figure 1. Trondheim is the third largest city in Norway, with about 200 000 citizens (Statistisk sentralbyrå, 2019b), and a total land area of 32 200 hectares (Statistisk sentralbyrå, 2019a). It is important to note that these are numbers from before the merger with former Klæbu municipality, i.e., the numbers are from 2019.

Figure 6 Map of the study site Trondheim municipality.

Trondheim is a large agricultural municipality with 6 422 hectares (Ha) of agricultural area (in 2018), which consist of the agricultural land use categories fully cultivated land, surface cultivated land and infield pasture area. This is approximately 20 % of the municipality’s total land area. 5 801 Ha of this is fully cultivated land (NIBIO, 2018b). (Definitions on the categories can be found in chapter 2.2).

The agricultural landscape in Trondheim is characterized by large grain areas in the west and south. In several places, there are farms right up to the city limits, and these agricultural areas play an important role as a framework around the city. These are important for identity and well-being and connect the city and village (Bondelaga i Trondheim, 2016).

Reallocation of agricultural land has been practiced extensively in Trondheim through the years. In 2018, Trondheim was the municipality in Norway that reallocated the second most agricultural area for purposes other than agriculture, with 150 hectares (Statistisk sentralbyrå, 2019e).

2.1.1. Management of cultivated land in Trondheim municipality

Two Master Municipal plan reports form the basis of the management of cultivated land in Trondheim,

In 2005, a Master Municipal Plan report on long- term urban development and soil protection was adopted (Trondheim kommune, 2005). The background for this was to facilitate continued population growth and business activity, at the same time as highly productive and cohesive agricultural land is given priority. This message should facilitate the work by knowing guidelines and which areas should be focused on, and which agricultural areas should not be developed (Trondheim kommune, 2005).

The municipality is working on a new strategy called The Green line ("Grønn strek"). This strategy shall state how and what agricultural area is to be used for, which areas are important, and shall be a framework for urban expansion (Trondheim kommune, 2020b). After the agricultural part of the Master Municipal Plan for the current period has laid out new agricultural areas for development purposes, the municipality now wants to define which cultivated areas are to be secured in a long-term perspective. This will make it predictable and simple, which agricultural area that is going to be developed in the future and will form the basis for the area part of the Master Municipal Plans. The Green line will form the basis for the long-term urban development strategy for Trondheim, until 2050 (Trondheim kommune, 2020a).

2.2. Data collection

2.2.1. Changes in agricultural area

Data on land cover changes (1969- 2019) of "fully cultivated land" and "agricultural land in operation" at the national, regional (Sør- Trøndelag county) and municipality scale was provided by Statistics Norway (Statistisk sentralbyrå, 2019c, Statistisk sentralbyrå, 2019d). The categories were the basis for the graphs made.

2.2.2. Overall land use changes

To examine spatial data and temporal land use and land cover changes in Trondheim municipality different sources of land cover data were used.

The area resource map from 2003, DMK (Digitalt markslagskart), and the last updated one from 2019, AR5 (Area resource map) provided by the municipality were used as a basis of the analysis identifying land use and land cover changes. Both maps give information about land use, tree species, forest quality and basic environmental conditions (NIBIO, 2018a), of which information on land use is most important in this assignment. DMK 2003 has been replaced by AR5, so the categories for land use in DMK 2003 were adapted to match the categories in AR5 to make it possible to compare the maps (by co- supervisor Tanja K. Petersen). The definitions of the land use categories examined in this study is shown below in table 2. Both DMK 2003 and AR5 are designed at a scale of 1: 5000. Note that the maps show the area status (condition) not necessarily current usage (NIBIO, 2018a). These two maps were processed in ArcMap, version 10.8 (ESRI, 2020).

A digital terrain model (DTM) and data on population density were also used in ArcMap as a basis for the regression analysis done in part 2.

Table 1 gives an overview of the data sources used in ArcMap to prepare data for statistical analysis done in R, version 1.3.959 (R Studio, 2020).

Table 1 Description of data sources used in ArcMap and further in the statistical analysis in R.

Data source	Description
DMK 2003	Area resource map from 2003
AR5	Area resource map from 2019
Digital elevation model (DTM)	Provides information about elevation
Population density	Population density at the basic district level

To get an overview of future development plans in Trondheim municipality, map data on the area part in the current Municipal Master Plan was provided by the Map and Surveying Office in the municipality. This was presented in ArcMap.

Definitions of the land use categories in the area resource map

Table 2 shows definitions of the various land use categories included in the area resource map AR5, and which ones are used in the thesis. The definitions are taken from NIBIO (Bjørkelo et al., 2018). There are a total of 11 categories, of which 8 are relevant for examining the objectives in this thesis. Some of these categories can be compared with the IPCC’s land use categories, and function as an assessment and classification of land use.

Table 2 Definitions of the eight land use categories from AR5 (Bjørkelo et al., 2018) used in the thesis.

Land use category	**Definition**
Built-up area	Developed or significantly developed area, as well as adjacent areas that in function are closely linked to the settlement.
Transport and communication	Area used for transport and communication.
Fully cultivated land	Agricultural area cultivated to normal plowing depth, and which can be used for arable crops or meadows, and which can be renewed by plowing.
Surface cultivated land	Agricultural area which is mostly cleared and evened out on the surface, so that mechanical harvesting is possible.
Infield pasture area	Agricultural area which can be used as pasture but cannot be harvested mechanically. At least 50 % of the area must be covered with grass species.
Forest land	Area with at least six trees per 0,10 hectare which are or can be five meters high, and evenly distributed on the area.
Open firm ground	Land that is not agricultural land, forest, built-up or area used for transport and communication.
Wetlands	Area with bog vegetation and at least 30 cm thick peat layer.

Validation of map data

To see how well the map data on area resources used in this study match reality, a validation of data in a limited area in the municipality (restricted by Kleppe (2019)) was performed. The verification process was done for polygons which were classified as fully cultivated land.

Figure 7 The limited area where fully cultivated polygons were verified. The red line marks the demolition of the area, the red areas marks the polygons which were verified. Image exported from Google Earth.

All AR5 fully cultivated polygons within this area (figure 2) were filtered. There were 4 489 polygons consisting of raster cells. The file was imported to Google Earth (Google, 2020). An iPad with the file was used in the field, to have a good overview of where the polygons were located. This verification of the limited area serves as an estimate for the entire municipality.

2.2.3. Interviews

Four active farmers were interviewed. The farmers were active farmers who had experienced changes in the use of agricultural land in the period 2003 to 2019. Their views on running a farm in a growing city was investigated. Also, their experiences with pressure on their areas from developers, municipality, The Norwegian Public Roads Administration etc., and how it was losing land. How it affected their motivation for further farming and how they looked at an eventually future farming.

An interview guide consisting of three blocks and seven questions was formed (appendix B). The Agricultural office in the municipality proposed and provided contact information for six people, of which four were contacted for interviews. All the interviews were conducted face-to- face and transcribed.

2.3. Data analyses

2.3.1. Preparation of data

DMK- and AR5 data were converted from vector format to raster format. The process converts the vector data into pixels or cells, all with the same size. Raster data makes different analysis less demanding to carry out and contains only necessary information about the land use types.

Before the data was rasterized, the land use category water was removed. The two map layers were rasterized, using the function "*polygon to raster*" in ArcMap. The cell size was set to 1 m. The two raster layers were used to make a new raster layer, which shows how much area (measured in raster cells) there were of different land use categories in 2003, and how much and what the different land use categories have changed to in 2019. The new raster layer was created using the Spatial Analysis- tool "*combine*". Data material resulting from this operation is presented in Appendix A, and later used in the thesis.

To investigate what factors can affect changes in fully cultivated land, a linear regression was performed. The preparation of the data for the regression was done in ArcMap.
Seven independent variables were chosen as the starting point for the regression predicting the probability of a fully cultivated polygon changing category between 2003 and 2019. The different variables, and unit of measurements are listed in table 3.

Table 3 The variables in the regression model, and unit of measurements.

Variables		**Unit of measurement**
Dependent variable:	Probability of a fully cultivated polygon changing category	Nr from 0- 1.
Independent variables:	Distance to built-up area	Meters
	Distance to road	Meters
	Distance to city center (defined as Torget)	Meters
	Area of the fully cultivated polygons	M^2
	Population density	Nr of people per m^2
	Altitude	Meters above sea level
	Slope	Degrees

The variables were derived from different map layers and data sources (table 1). The independent variables were derived from the map layers DMK 2003, a map layer containing information about population density and the DTM- model (map layers mentioned in "Data collection"). The dependent variable was derived from the raster model, which shows the amount (in m^2) of the different land use categories in 2003, and to what and how much of the land use categories that has changed to another land use category in 2019. The variables were derived as described below.

To calculate and derive the different variables containing distance (distance to built-up area, road, and city center) the tool "*near*" from the Analysis toolbox in ArcMap was used.

Figure 8 Illustration of where the shortest distance between two polygons is being calculated. Esri, 2019.

The two variables "distance to built-up area" and "distance to road" were presented as polygons. The shortest distance is being calculated between the two corners on the polygons that is closest (figure 3) (Esri, 2019).

Distance to city center in Trondheim, is defined as a single point. The shortest distance is the perpendicular distance from the point to the line segment in the polygon (figure 4) (Esri, 2019).

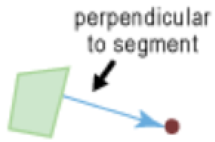


Figure 9 Illustration of how the shortest distance between a point and a polygon is calculated. The area where the arrow starts, is the line segment in the polygon. Esri, 2019.

«Altitude» and «slope» had both the DTM as base. Whereas "slope" was further calculated by using the tool "*slope*" in the Spatial analyst toolbox. The tool identifies the slope, for each raster cell, which here is the raster cells telling if a fully cultivated polygon has changed or not. Slope is measured in the degrees.

Then the dependent variable, probability of change of a fully cultivated polygon (between 2003 and 2019) was calculated by using the tool *"con*" also from the Spatial analyst toolbox. The tool performs an if/ else evaluation in each of the input cells of an input raster, which in this case calculated if the raster cell has changed from a fully cultivated (given the value 1) or not (given the value 0).

To further derive these variables to be used in a regression model, some other steps were required. The three variables mentioned above were all derived further by the same principle. They were all presented in raster cells. One fully cultivated polygon may consist of several raster cells, dependent on the size of the polygon. To be able to calculate the values of these three variables (e.g., numbers of meters above sea level or slope, measured in degrees) for a fully cultivated polygon, one needed to consider the value of all the raster cells within the polygon. One way to do this is to aggregate data from each of the raster cells and calculate f. ex. the mean of all these individual data, which was done in this case. To do this the tool "*zonal statistics as table*" from the Spatial analyst toolbox was used. The result of this was a table with average values for each fully cultivated polygon, in this case values for altitude, slope (in degrees) and the probability that a polygon changes from fully cultivated (numbers between 0 and 1).

The last two variables, "size of fully cultivated polygons" and "population density" required less preparation. "Size of fully cultivated polygons" was already included as a value in the map layer containing information about all the fully cultivated polygons in 2003, which was shown on the DMK 2003.

“Population density” was derived from a map layer that contained different information about the population, such as age composition, gender composition and further. The value containing information about total population density was derived as an own layer and used as a variable.

All the seven variables were joined to the DMK 2003- layer containing information about the fully cultivated polygons in 2003. The data could now be exported to R and be used in a multiple linear regression.

2.3.2. Statistical analysis

To assess any pattern in the changes, as where they happen and why, a multiple linear regression model on the data was performed in R, version 1.3.959. Prior to the regression analysis, a correlation analysis was performed to see if any of the variables were correlated. There was no correlation between the variables (Pearson's correlation coefficient < 0.32).

The dependent variable (the probability of a fully cultivated polygon changing) was log-transformed (log+ 0.0002) to change the distribution of the values to normal distribution prior to the analysis. To find the constant that gave a normal distribution closest to zero, the function skewness() from the package “moments” was used (R Core Team, 2021).

At the beginning all the seven independent variables were included in the function lm() from the package “stat”. To choose the best suited model of all the variables, the function step() also from the package “stat” was used (R Core Team, 2021). This function chooses a model by AIC in a stepwise algorithm. The output from the step function must be tested manually by removing one and one variable, until the difference in AIC for the remaining variables was > 2. When the difference was >2, the ideal linear model for fitting is picked.

To be able to interpret the coefficients in the linear model when the dependent variable is log transformed, both dependent and independent variables must me transformed back, by using equation 1. One must exponentiate the coefficient (X), subtract by one and multiply by 100:

$$(\exp(X) - 1) * 100 \qquad (1)$$

This will give a percentage. As an example, the intercept will thus be back transformed as follows:

$\log (X + 0.0002) = -3.041$

$10^{-(3.041)} – 0.002 = X$

$-0.001 \quad = X$

The intercept- coefficient (α) is – 0,001. The mean of the possibility for a fully cultivated polygon to change or not, when distance to built-up area, population density, distance to Torget and distance to road (the independent variables) are set to zero.

3. Results

3.1. Long term changes in agricultural land use

Figure 5 a- c show the changes in the amount of area (ha) in the categories agricultural area in operation and fully cultivated land, for Norway, Sør- Trøndelag and Trondheim. Norway and Trondheim in the period 1969 to 2019. Sør- Trøndelag in the period from 1969 to 2017[1]. For all the three it is in a ten- year interval (except between 2009 to 2017 for Sør- Trøndelag).

On a national level (figure 5 a) both agricultural land in operation and fully cultivated land have decreased, between the years 1999 and 2019, with respectively 9,5 % and 11,1 % of the total area in 1999. From the years 1969 to 1999 there was a slight increase in total amount of area for the two categories.

At county level (figure 5 b), there is an increase in the area in both the categories between 1969 and 1999, while there was a decrease from the years 1999 to 2017, with 3,7 % of agricultural land in operation and 8,9 % of fully cultivated land (of the top of amount of area in 1999).

In Trondheim (figure 5 c), the trend, on various scales, has been a decline from 1979 to 2019, with a more marked decline from 1999 to 2019, where the loss of both fully cultivated land and agricultural land in operation has been 15,4 % and 14,6 %. The total loss in this period (1969 to 2019) has been 22,6 % in the category agricultural land in operation, and 18,9 % in the fully cultivated land category.

[1] In January 2018, Nord-Trøndelag and Sør-Trøndelag were merged into Trøndelag county, i.e., figures up to and including 2017.

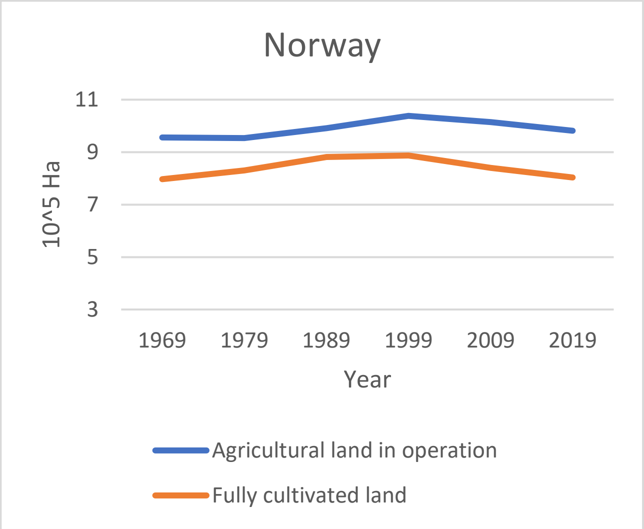


Figure 5 a) Change in agricultural land in operation and fully cultivated land in Norway, in the time period 1969 to 2019, in a ten- year interval. Measured in hectare.

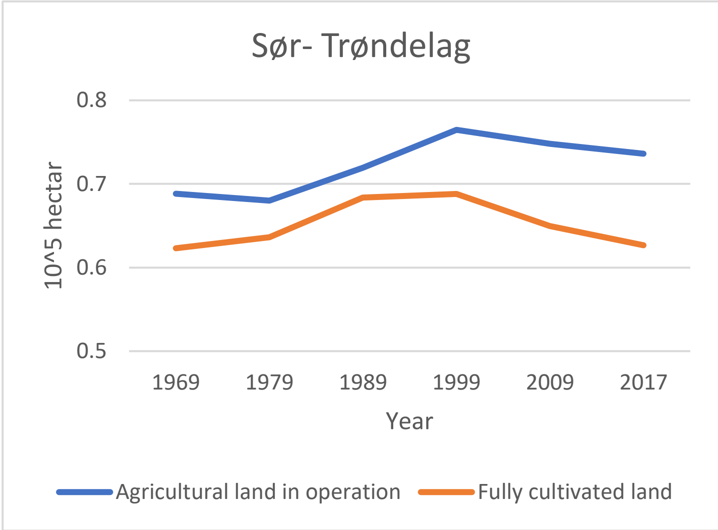


Figure 5 b) Change in agricultural land in operation and fully cultivated land in the county Sør- Trøndelag, in the time period 1969 to 2019, in a ten- year interval. Measured in hectare.

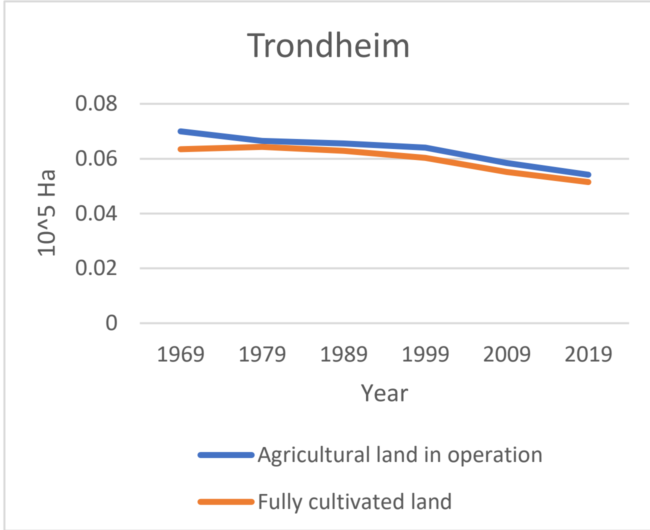


Figure 10 c) Agricultural land in operation and fully cultivated land in Trondheim municipality, in hectare. Between 1969 and 2019 in a ten- year interval. Measured in hectare.

3.2. Overall land use changes in Trondheim

Figure 6 shows the changes in the eight different land use categories (described in table 2) in Trondheim between year 2003 and 2019. The figure is based on data presented in appendix A. As seen from the nodes in the figure the amount of the land use categories built-up area and transport and communication have increased, with respectively 27,9 % and 29,4 %. Fully cultivated land has in the period decreased with 5,6 %. There has also been a decrease in the agricultural land use categories surface cultivated land, and infield pasture area.

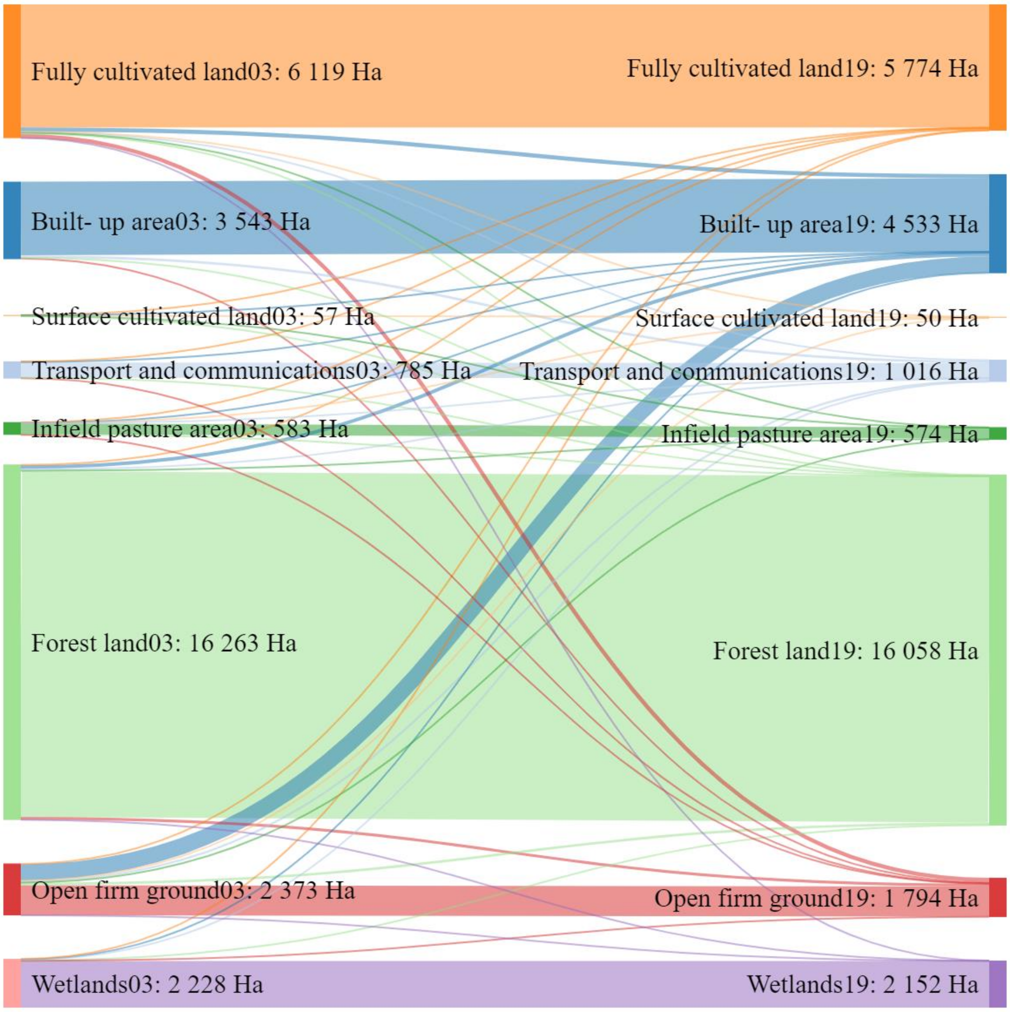


Figure 6 Sankey diagram showing changes in land use from 2003 to 2019.

3.3. Change in the use of fully cultivated land in Trondheim

As shown in figure 5 c the use of fully cultivated land has changed during the period, and the total amount of fully cultivated land has decreased. Figure 7 details which categories fully cultivated land has changed to from 2003 to 2019. Most of the fully cultivated land has changed to built-up area (38 %) or open firm ground (37 %) (see table 2 for explanations on the different land use categories). Some fully cultivated land has been used for forest (11 %) and transport and communication (9 %).

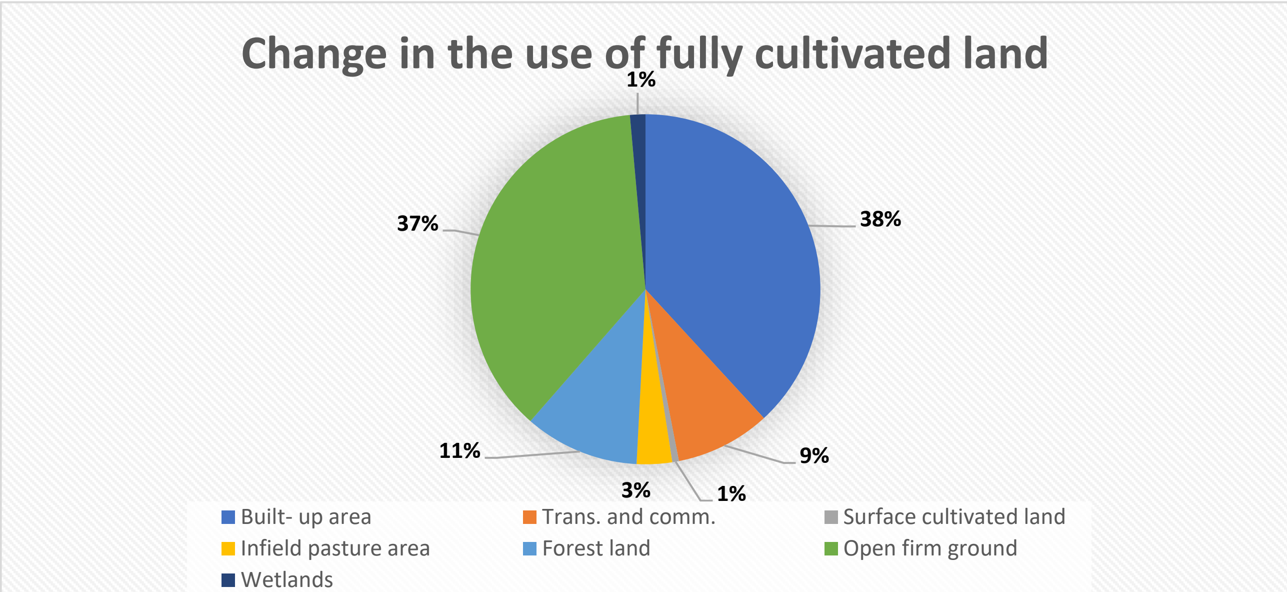


Figure 7 The diagram shows to what categories fully cultivated land has changed to in the period 2003 to 2019.

The changes mentioned above is present at different places in the municipality. Figure 8 shows that the changes in use of fully cultivated land, which are marked in red, are concentrated in the more urban areas in the municipality. The urban areas, including the city center, is the dark area on the map through which the river flows (in the middle of the map).

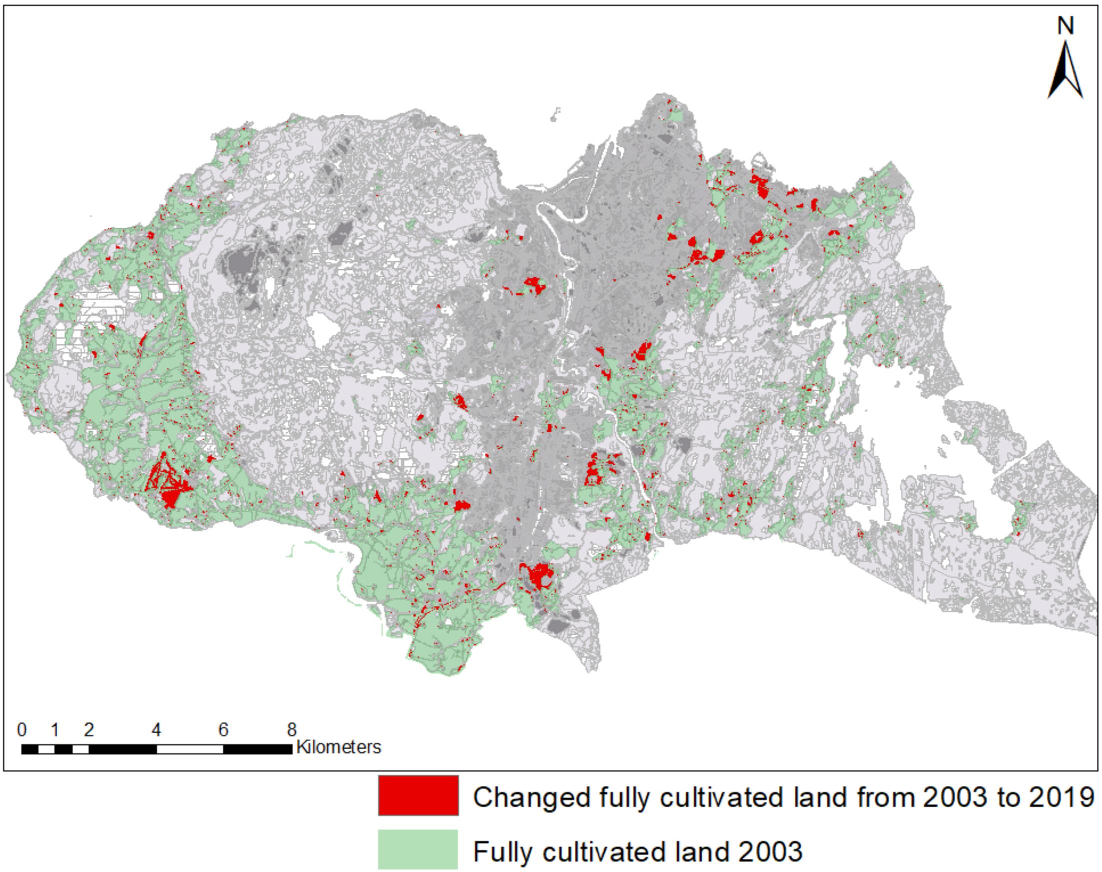


Figure 8 Changes in fully cultivated land from 2003 to 2019. The red areas are the ones being changed, while the green area is still fully cultivated land in 2019.

3.3.1. Factors affecting changes in use of fully cultivated land

In the process finding the best suited linear regression model, four variables were removed. First altitude, then slope, size of fully cultivated polygon and then distance to road. The best suited model to explain the probability of a fully cultivated polygon changing is with the variables distance to built-up area, population density, distance to city center and distance to road. Table 4 shows the coefficients for each variable derived from the model to explain the changes to fully cultivated polygons. How the coefficient is interpreted is shown in appendix B.

Table 4 Results from the best suited model in linear regression.

	Estimate	Std.Error	T value	Pr(>|t|)
(Intercept)	-3. 041	0.16	-19.40	<0.001
distance_builtup	0.00011	<0.001	2.55	0.01
pop_density	0.00079	<0.001	5.07	<0.001
distance_citycenter (Torget)	-0.0000901	<0.001	-5.81	<0.001
distance_road	-0.00403	<0.001	-6.04	<0.001

Figure 9 show response curves of each of the four independent variables in the model. The y-axis shows the probability of a fully cultivated polygon to change, in relation to each of the different independent variables.

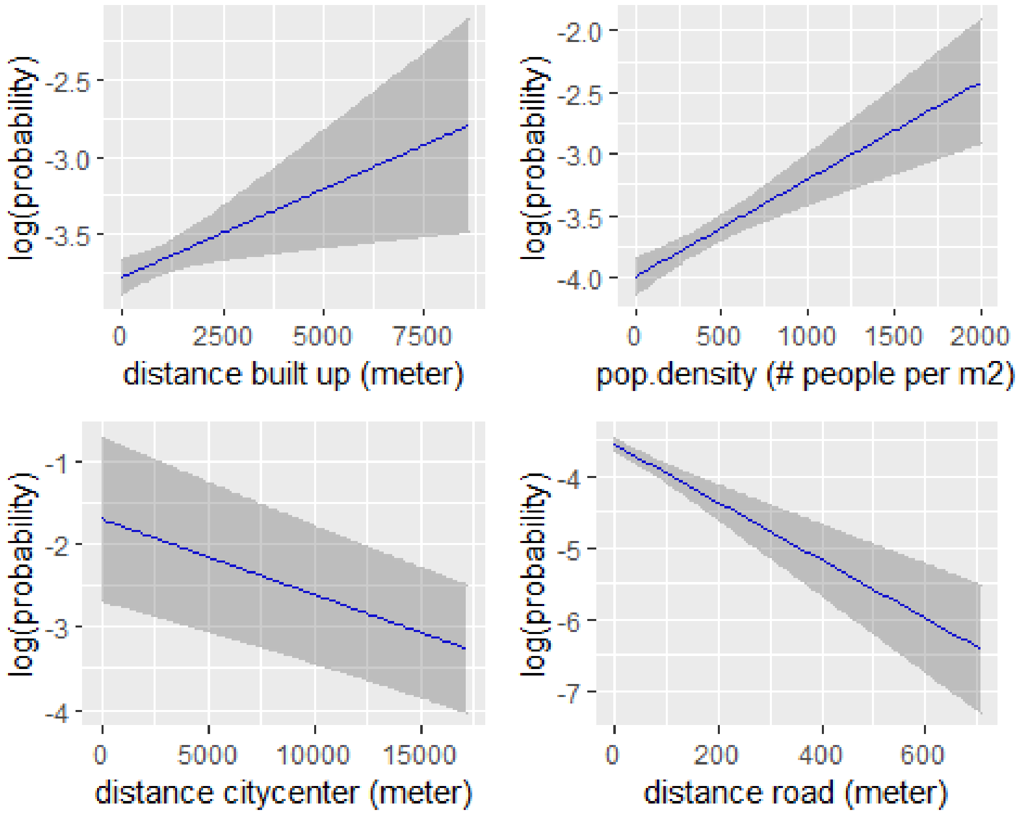


Figure 9 Plot showing response curves for the four variables in the regression model. The y- axis shows the probability of a fully cultivated polygon to change.

3.3.2. Verification of map data for fully cultivated land

A total of 4 489 polygons of fully cultivated land was checked, and 24 polygons showed another land use category than the mapped fully cultivated land, which is shown in figure 10. The green area (which are many small polygons) shows the fully cultivated areas where the map gave the correct description. The red area mark fully cultivated polygons that did not match with the map. The discrepancies make up 0,54 % of the total amount of polygons.

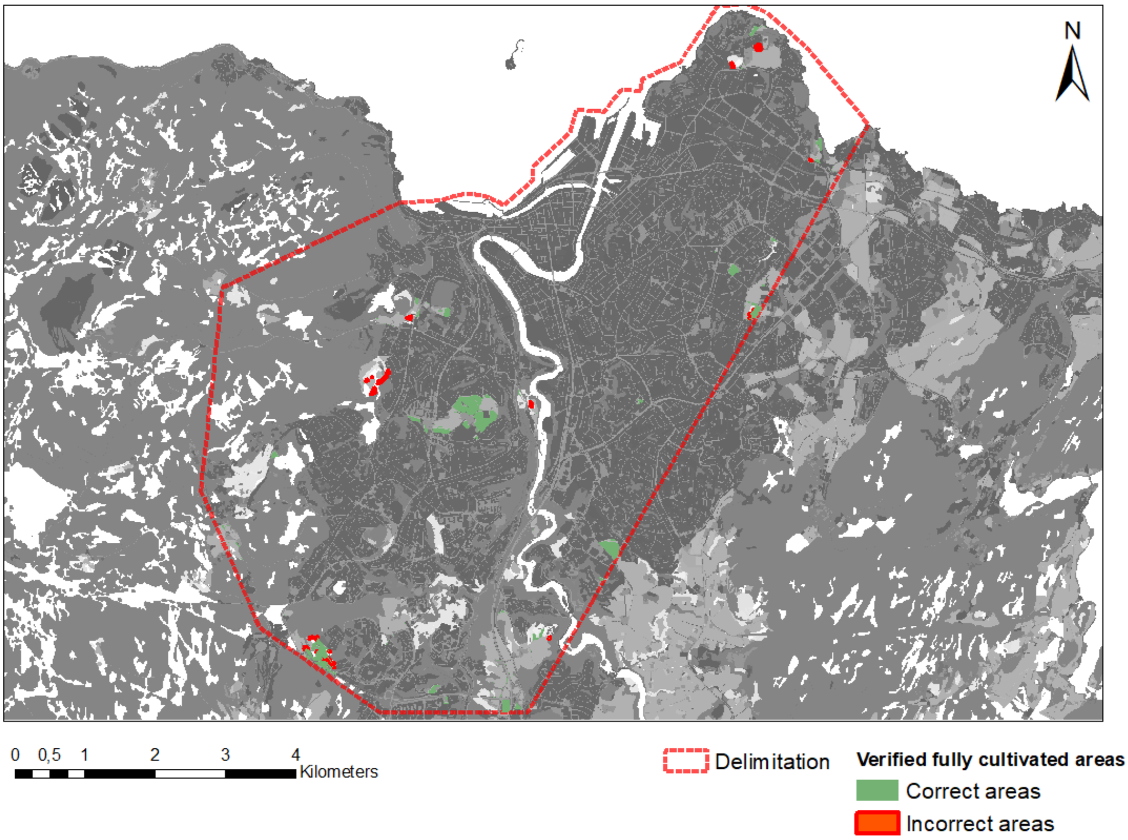


Figure 10 The green and red areas (many small polygons) show all the fully cultivated polygons given on the map, in the restricted area. The green area showed fully cultivated land when verifying, and where correct, while the red area showed another land use than fully cultivated.

3.3.3. Reallocation of fully cultivated land in the future

Figure 11 a-c show what plans the municipality have for future development for fully cultivated land in the current Municipal Master Plan (for the period 2012- 2024[2]), and where the plans will be put into action. The yellow area shows fully cultivated land. While the small map with the red square shows where in the municipality the larger map is taken from. Most of the plans for development on fully cultivated land take place in the city center and suburban areas (the dark grey area about in the middle of the map), in the most densely populated areas. Most of the area is being developed for the area purpose "green structure", "built-up area", "buildings and construction purposes" and for "business activity", which is

[2] Adopted before Klæbu municipality became a part of Trondheim municipality, i.e., figures for Klæbu are not included.

explained in the legend[3]. Also, area used for roads is present. The total area of fully cultivated land that is planned to be developed is 366 Ha. The category built-up area constitutes the largest category of future plans on fully cultivated land, with 48, 6 % (178 Ha) of the total area. This is followed by the categories business activity with 13 % (48 Ha) and green structure with 12,3 % (45 Ha).

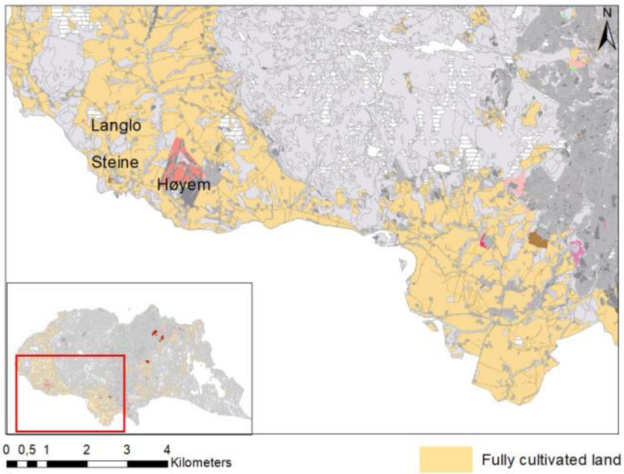


Figure 11 a) The map shows future redistribution/ re-regulating plans in the current municipal plan, on fully cultivated land, south east of the municipality.

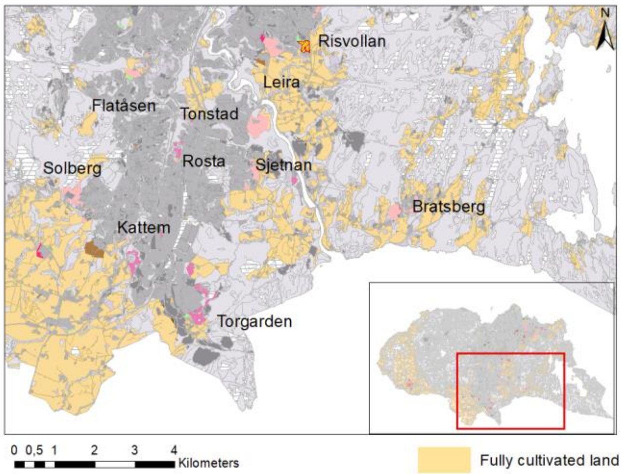


Figure 11 b) The map shows future redistribution/ re-regulating plans in the current municipal plan, on fully cultivated land, south and south west of the municipality.

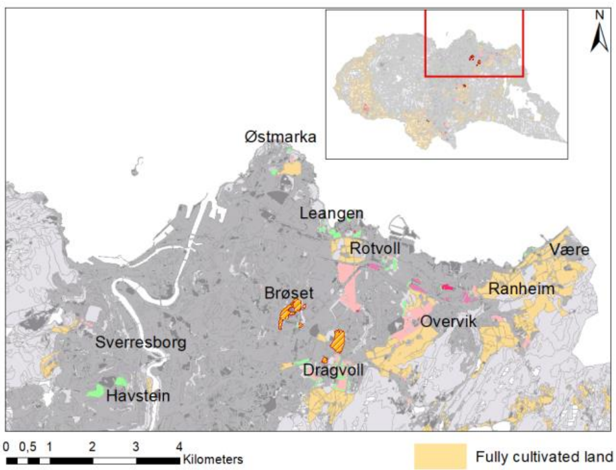
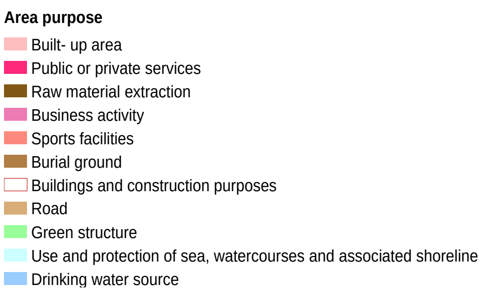


Figure 11 c) The map shows future redistribution/ re-regulating plans in the current municipal plan, north of the municipality.



Legend

[3] The categories are taken from the Ministry of Culture and Modernization's guide (2009) for maps and planning regulations and indicate area purposes.

3.4. Interviews with the farmers

The main points of the four landowners' views on the various questions in the interview guide (appendix C) is summarized in table 5. These points will be discussed in chapter 4.4, without referring to each specific point. Some nuances of what emerged during the interviews have not been included in the table. Some of these nuances that are left out from the table will be discussed. There are also aspects mentioned in the table that are not discussed.

Table 5 Summary of the four landowners' main points during the interviews.

Landowner	Production	Land use changes (03-19)	Challenges/ possibilities of being a farmer in a growing city	Future farming	Decisive/ important for further agricultural operations	Degradation of agricultural areas
1	Grain production	Road development	Major challenges related to E6. And logistics around driving in E39 with equipment. Expand the road might need more area from me. Will continue farming. The land I rent is further away from the city- easier.	My oldest daughter might take over. Sees the value in the area, and probably rents out the land. I am very interested in farming.	Not necessarily crucial but would rent more land to continue what I want to do.	Not easy for people because there is a lot of money involved. If I could sell land where there is the greatest interest in it and buy land elsewhere- would have been fine.
2	Milk production and grain	School, kindergarten, and a shop has been built	People walk through the property. Releasing dogs. Opportunity for further farming is to build a new barn. Relatively irrelevant due to costliness.	Bleak future for the cows. The road will possibly be expanded with another field. Area to triple production but will not buy me more work. Probably will not have cows in 3- 5 years.	More profitability.	Tells the municipality that they are not allowed to expropriate cultivated land for residential purposes. I am all for selling forests and outfields.
3	Milk production and gran production (contracts)		Great interest in the area. Also, people walking in the fields, people always close. Possibilities: urban agriculture and cooperative farming.	Future: pedestrian and bicycle path on my property. Also, and extra field on the road. Motivation/ interest is huge. If I could have rented more land, I would have. Not a bright future for the cow. No one to take over.	Ordered grain dryer. Store more grain and thresh grain for others.	Against demolition of agricultural area. I cannot say no if my land is needed for f ex roads. Understand that something is needed, like schools, road etc. Expropriation for hobbies is not good.
4	Beef cattle	Metro bus and stop, roads and three shops.	Due to all the traffic much of the tractor driving must take place at night/ early Sunday. Cannot drive whenever you want. Garbage along the road. Possibilities: rent out house and grazing area for horses.	One year at a time. If I lose more area, think about whether I have enough. Future changes: footbridge.	Cannot have more animals. Hope that they do not take any more of the area that is left. Dividing the area affects the recruitment.	I do not sell anything voluntary. Do not like that the municipality is demolishing cultivated land. Would rent more land if possible but much is used for roads. I have said no to housing developers several times. Do not come running to sell, just to sell!

4. Discussion

Land use changes have had a strong impact on area, distribution of agricultural land and associated ecosystem services, especially in urban areas during recent decades (Zasada, 2011, van Vliet et al., 2015, FAO, 2018). This study examined long term changes in agricultural land use in Trondheim municipality. Overall land use changes in Trondheim are also examined, changes in use of agricultural land and what affects these changes and plans for future re- regulation of fully cultivated land in the municipality. In addition, landowners view on change in the use of their agricultural areas is examined.

4.1. Long term changes in agricultural land use

The use of fully cultivated land and agricultural land in operation has both increased and decreased on a national level between the years 1969 and 2019, as well as in Sør- Trøndelag and in Trondheim municipality.

Both on national and county level (figure 5 a and b) there has been a slight increase in the amount of both fully cultivated land and agricultural land in operation, from 1969 to 1999. While there has been a decrease in both categories (more marked decline at the national level), from 1999 to 2019. For Trondheim municipality (figure 5 c), the trend is a decline in both categories for the entire period, 1969 to 2019. The percentage reduction is much larger for Trondheim than at county and national level.

Trondheim is an urban municipality, which can explain the marked decline of agricultural land, in comparison to the county and at a national level, which naturally consists of several rural (outlying) municipalities. People move from rural to urban areas, and the need for land to housing, infrastructure etc., in the cities increases. Cities have from ancient times often arisen in the vicinity of highly productive agricultural land, and these areas easily accessible for development when the need for area to other purposes grows (Langemeyer et al., 2021). These areas are cheap to develop compared to areas which are steeper and needs more plowing. Literature shows that urban expansion often comes at the expense of agricultural land (Satterthwaite et al., 2010, Bren d'Amour et al., 2017).

Reallocation of agricultural land is a major cause of degradation, both in Europe (Meyer and Früh-Müller, 2020) and in Norway (Statistisk sentralbyrå, 2017a). Trondheim is the municipality in Norway which reallocated the second most cultivated land in 2018, with 150 hectares (Statistisk sentralbyrå, 2019e). From 1994 to 2003, the annual average amount of redistributed cultivated land at a national level was 1 140 hectares, while in the period 2004 to 2013 it was 760 hectares. Today, a goal has been set not to reallocate more than 400 hectare of cultivated land annually (Regjeringen, 2015).

There are several other reasons that affect the total decline in agricultural area. A change in the use structure in agriculture, which means more agricultural area on fewer and larger farms might lead to decline (Eldby and Fjellhammer, 2014, Neuenfeldt et al., 2019). Some of the areas might be too far away so that areas are no longer profitable to operate. If the area is of medium quality, it might not necessarily be needed, and it is a natural reason for it goes out of production (Landbruksdirektoratet, 2020, Zhou et al., 2020). This might in turn lead to forest succession of the area (Statistisk sentralbyrå, 2019g, Nationen, 2019).

There may be reason to believe that the amount of agricultural land in operation, at all three levels, is at a lower level than what emerges from the graphs. In an analysis conducted by Statistics Norway (2019f) it shows that 22 % of all actual demolition of cultivated land in Norway, is due to agriculture itself. This can be in the form of a new operating building or expansion of an existing building. When constructing new buildings or extensions, cultivated land will often be the best available area. Registration of construction activities on cultivated and arable land in connection with agricultural activities are not registered in the database KOSTRA (municipal- state reporting) (Kommunal rapport, 2005). This is because this type of measures does not require dispensation under the Land Act or under the Planning and Building Act. Since the amount of agricultural land in operation is based on the material reported by KOSTRA, one might expect the figures to be lower.

4.2. Overall land use changes

Changes in land use categories have been present in the municipality of Trondheim during the period 2003 and 2019. Fully cultivated land, surface cultivated land, infield pasture area, forest land, open firm ground and wetlands have had a decrease in area. Built-up area and transport and communication are the only two categories which have increased in the period, which was expected.

An increase in the two categories reflects the development of Trondheim as a city, where urbanization and population growth have been marked (Statistisk sentralbyrå, 2020a).

Trondheim is now the third most populous municipality in Norway (Statistisk sentralbyrå, 2020b). Population growth because of urbanization is shown to have an effect on the loss of agricultural land (Pandey and Seto, 2015).

This follow the same trend globally, and in Europe (The world bank, 2019a, United Nations, 2019). Agricultural land is being developed due to the need for housing, schools, improved infrastructure and so on (Ambros and Granvik, 2020, Langemeyer et al., 2021). One of the key reasons for a decline in agricultural land (forest or grass) in EU and globally is land use changes characterized by the expansion of construction land (Ji et al., 2006, European comission, 2012, Tsutsumida et al., 2015, Wang et al., 2018). Which agrees well with the results in this study.

4.3. Changes in the use of fully cultivated land in Trondheim

Fully cultivated land in Trondheim has in the period 2003 to 2019 been converted to other land use categories. Most of the fully cultivated land in the period has changed to built-up area (38 %), or open firm ground (37 %). Some of the fully cultivated land has been changed to forest and transport and communication (11 % and 9 % respectively).

The category that makes up most of the changes is built-up area. Which discussed in the previous two paragraphs, the population growth in Trondheim (Statistisk sentralbyrå, 2019b), requires more homes, and thus area. There are three applicable Municipal Master Plans during the period, which address the need for housing. In the Municipal Master Plan that covers the period 2002 to 2012, it was decided that enough area should be set aside to build a minimum of 1 000 homes each year (Trondheim kommune, 2003). In the plan covering the next period, 2006 to 2018, it was estimated, that the long- term housing construction needed for Trondheim was approximately 1 100 homes per year (Trondheim kommune, 2007). In the current plan (Trondheim kommune, 2013), it is assumed that it is possible to realize 28 000 homes within the Municipal Master Plan period 2012-2024. For the first four-year period, until the next roll-out of the area part, a need for 6 400 homes has been calculated. Figure 12 shows an area

Figure 12 The area inside the fence is previously fully cultivated land and is now re- regulated to built-up area.

previously fully cultivated which is now re- regulated to built-up area. The development policy that the municipality is pursuing calls for a densification of already existing built-up area, and densification inside the city, rather than an expansion (Trondheim kommune, 2020a).


Figure 13 Previously fully cultivated land which has been re- regulated to other purposes.

The second largest category fully cultivated land has changed to, is open firm ground (37 % of the total area). Open firm ground can be considered a "collective term" and includes several different types of land use. Examples that fall into this category are border zones, public parks and gardens, outdoor sports facilities, random open green areas and random areas with asphalt, gravel and stones (NIBIO, 2019). In all three Master Municipal Plans, there is a goal of preserving the green structure, and develop green structure areas in new areas where housing is to be build. Green structure is parks, gardens, playgrounds, open green areas, border zones and so on, which thus falls into the category open firm ground. Figure 13 illustrated a previously fully cultivated area which are now set aside for another land use category, in connection with the establishment of a new built-up area.

Open firm ground is a comprehensive category. There are different types of area that do not differentiate between biologically productive, vegetation-free, and built-up areas. Degraded areas occur in both the open firm ground area and the built-up area type which stated in a report from Skog og Landskap (2013) (today, NIBIO). This may be one of the reasons why a large proportion of fully cultivated land has been re- regulated to open firm ground.

A land use category that has also required fully cultivated land during the period is roads (9 % of the total area). There have been several road projects during the period, one of which is the construction of a motorway, with an extension to the four- lane highway (The Norwegian Public Roads Administration, 2015), in addition two- level crossing were also built. The entry of metro buses in 2019 also occupied agricultural land, because of development of new junctions and transfer points.

4.3.1. Factors affecting changes in use of fully cultivated land

The regression analysis shows that the possibility of fully cultivated polygons being developed in any way increases the closer to the city center the areas are located. Also, the closer one gets roads, and the more people there are in the area, the greater the probability of change. This is according to the expectation.

According to the model, the chance of change in relation to built-up area is greater, the further away from built-up area the fully cultivated areas that are being changed are located. This does not agree with expectation.

Literature shows that rapid population growth because of urbanization often means expansion of existing built-up areas (Azadi et al., 2011). There is also shown that expansion happens near urban zones, which in many cases means areas where it is a high density of existing built-up areas (Zhong et al., 2011). The Municipal Master Plans for Trondheim states that housing development will take place as an extension of already existing housing estates (Trondheim kommune, 2012, Trondheim kommune, 2003, Trondheim kommune, 2007). Therefore, one might expect that the result for change in relation to built-up areas would be the opposite, that the closer the fully cultivated polygons is to built-up area, the greater the chance for a change in the polygon to another land use category.

According to the analysis the chance for a fully cultivated polygon to change for every meter further away from built-up area is 0,01 % (appendix B), so it is marginal. Therefore, one can possibly assume that the analysis and figures can affect the result, and that the result could just as well have been the opposite.

The variable population density shows a more logical result in relation to the expansion of housing areas that are included in the Municipal Master Plan, where a higher population density will lead to a greater probability of change in fully cultivated areas, by 0,08 % for each additional person per m^2. In areas with already existing housing estates which are developed, there are also more people. This is a natural conclusion to draw if the change to, for example, living space takes place near already existing residential areas. Areas of high population is shown to act as catalysts for further urban expansion, which can support the finding that the more people in an area the greater the chance that a fully cultivated polygon will change (Radwan et al., 2019).

Change of fully cultivated land for every meter further away from road it gets, decrease by 0,4 %, which is in line with expectations. It is easier and more natural to develop new housing areas, shops, business area and so on in the vicinity to already existing road networks. This is also shown in literature, that urban expansion takes place along main roads/ already existing road network and highly developed infrastructure (Fazal, 2000, Li and Yeh, 2004, Benayas et al., 2007).

In the analysis, the variable, distance to Trondheim Torg was included. Trondheim Torg is defined as the center of the city. Based on the results, it appears that the probability of a fully cultivated polygon changing decreases by 0,09% for each meter further away from Trondheim Torg the polygon is located. Urban expansion happens where population density is high, as mentioned. In city center, the population is at a high density, compared to further away from the center. Urban expansion also happens close to roads and developed infrastructure, which there is obviously in city center, and urban expansion often goes at the expense of agricultural area (Fazal, 2000, Benayas et al., 2007, Radwan et al., 2019). Then it may seem logical that agricultural areas that are in or close to the city center itself have a greater chance of being developed for purposes other than agriculture, than areas that are further away. This is also reflected in the model in the Municipal Master Plan from 2001 to 2012 (Trondheim kommune, 2003), where densification of already existing housing estates should take place in the city center, and be at the expense of a lot of agricultural area.

4.3.2. Verification of map data for fully cultivated land

Of the 4 489 surveyed polygons, 24 polygons showed another land use category than the registered fully cultivated land. This equals 0,54 % of all the polygons.

Fully cultivated land given on the map, will give an indication of the amount of fully cultivated land that is present in the municipality. But it can be misleading, as AR5, which is the basis for the verification, shows the status of the area and not actual use (NIBIO, 2018a). This means that a polygon initially has the status of fully cultivated, but which in fact is used for other purposes. The polygons that show another land use category than fully cultivated land in the field, is unlikely to be cultivated as fully cultivated land due to location, size of area or other factors that make the area impractical to run and uneconomical and inconvenient to use (Landbruksdirektoratet, 2020, Zhou et al., 2020). This was the case for several of the polygons when they were verified. Some were parts of the construction site, park, edge zones for housing estates and more. Several of them were also small and wedged and would not have been used as a fully cultivated area, as the disadvantages of operating the area are most likely greater than the advantages.

To be able to say something about land use changes and the accuracy of them, good and updated map data is convenient. The more locally one look and the smaller amount of data one use, small errors and incorrect information in the map data will have greater effect. In this case, the discrepancies were only 0, 54%, and will by no means amount to much, as most of the fully cultivated polygons match the map, which was as expected.

4.3.3. Reallocation of fully cultivated land in the future

For the current planning period, 366 Ha of fully cultivated land is planned to be developed in this twelve-year period, 2012 to 2024. This overview contains areas regulated for development, but also areas that have already been developed, for the period 2012 to 2024, which means that some of the area has already been developed.

Downsizing of agricultural land has almost been a trend in Trondheim, where 150 Ha of cultivated land was reduced, only in 2018. However, it may seem as if Trondheim is on its way to a change of direction (NTNU and Adresseavisen, 2020), with an abrupt brake on the demolition of cultivated land, following a proposal from the municipal director. An important point is that this is currently just talk, nothing has been decided yet.
Also in Europe (EU), the need for better protection of farmland, and a brake on the development of agricultural land for other purposes is being stressed (Ambros and Granvik, 2020). And the European Green Deal that was launched in 2019, will change the EU into a modern, competitive economy with net zero emissions by 2050, where economic growth is linked to the extraction of natural resources, has an overriding goal of sustainable land management for long-term soil protection (European Comission, 2019).

In the current Municipal Master Plan for Trondheim, large agricultural areas (LNF- areas) have been re- regulated for residential purposes (Trondheim kommune, 2012). Increased focus on protection of agricultural area, and the necessity for more attractive and climatefriendly city has led to a need to reassess the use of these areas (Trondheim kommune, 2020c). Previously re- regulated LNF- areas for housing and other purposes, will be returned to the LNF- category.

In accordance with Green Line and a new knowledge base for the development order in the area part of the Municipal Master Plan (Trondheim kommune, 2020b, Trondheim kommune, 2020c), a decrease in the reallocation and development of agricultural land can be expected.

4.4. Interview with farmers

The four landowners who were interviewed does all run active farms with grain and production animals, and all of them have areas that have been developed for purposes other than agriculture. During the interviews it turned out that they all had done, or thought about making significant adjustments in their farming, because of the developments that had taken place, and as an adaptation for future developments. They all have in common farming in a city that is constantly growing, and experience pressure on their areas, where developers, municipality, the Norwegian Public Roads Administration, and others wants to use the areas for purposes other than agriculture.

All the landowners experienced disadvantages as a direct result of the developments, and the burden because of these have varied in scope and affected the landowners to varying degrees. It is worth mentioning that none of the farmers do not (obviously) like the degradation of their agricultural area. And that from their side it is basically a question of expropriation, where they sell the area on "coercion" and have no choice.

The adaptations that the landowners have been forced to make, or plan to make, have been depended on how large interventions a development of agricultural land has had for the operation of the farm. It can therefore be useful to include the concepts of “total load” and “adaptation” within land use management, to which the landowners’ answers can be linked and discussed.

4.4.1. Total load

"Total load" originates in the Convention on Biological Diversity, which obliges the parties to ensure biological diversity, i.e., the variety of life, including the diversity of species, genetic diversity, and diversity of ecosystems (Naturmangfoldloven, 2009). The term is based on assessing the impact a measure, intervention or activity has on ecosystems based on the total load to which the ecosystem is exposed.

The principle can also be discussed considering people's ability to and still drive an activity that depends on area and biological resources. An example of this is the concept's relevance to agricultural operations in areas exposed to pressure for urban expansion / expansion, which is the problem in the thesis.

To gain an understanding of how the term can be used in such contexts, it may be useful to look at how the term is used in land management in reindeer husbandry areas, where the total burden for maintaining reindeer husbandry in areas exposed to development can serve as a parallel to agricultural management.

Within the principle «total load" for the maintenance of reindeer husbandry, the terms direct, indirect, and cumulative effects are used (Worldbank, 1997). These three concepts explain the different types of effects that contribute to the overall burden, in this case on land management in reindeer husbandry areas. Direct effects are effects that affect individual animals. Indirect (regional) effects are effect on entire herds in the relevant area that is burdened by a development. Cumulative effects are the overall, long- term effects of development.

Parallels to the use of the principle "total load" in reindeer husbandry and development can be drawn to farming in suburban area, and the pressure on the areas. The effects of different development plans on land and resources for both the industries includes much of the same, thus parallels can be drawn. The four landowners interviewed all run farms in suburban areas, and experience pressure on the use of their land. Mostly in the form of development of roads, shops, and houses.

The direct effects of changes in the use of these agricultural areas by e.g., development, are effects at the individual farm level, where a possible development/ change of area will affect the individual farm and farmer to one degree or another, depending on the size of the development / severity of the intervention. Physical loss of land is such an effect. All four landowners have experienced loss of land. Landowner 1 in loss of area for road, landowner 2 for school, kindergarten, and a shop. In previous years, landowner 3 lost a lot of land for the construction of a motorway and will in the future have both a pedestrian and bicycle path on the property, in addition to an extension of the motorway. And landowner 4 has lost agricultural land for the development of bus stops, roads, and shops. The person in question will also in the future get a footbridge on their area.

Other direct effects of development are the motivation to continue farming after the development. Landowner 1, who operates with grain, will continue to operate for as long as possible. It is also mentioned that it has become more inconvenient to drive in the last four years due to driving heavy and large machines on one of the main roads. Landowner 3, who is a grain and dairy farmer, says that it takes a lot to not want to continue farming. With landowners 2 and 4, the motivation is affected more by area changes and other factors. Landowner 2 has always had an interest in agriculture but says that the motivation would have been greater if there had been more profitability in the industry. Because of this, the future for grain is bright. Landowner 4, who works with beef cattle, says that active farming is like a hobby and lifestyle. But due to loss of land, and personal reasons, the person in question takes one year at a time. If the person loses more soil, it must be considered whether there is enough area to produce feed and for maintained operation. If the landowner did not live close to the city, the person would have had more cattle. More animals near the city are not possible.

The motivation of each individual landowner for continued active farming is related to the cumulative effects, and how these are experienced by the individual. Cumulative effects are, as mentioned, overall (and long-term) effects of changes in the use of the peri-urban agricultural land, i.e., the land for the farmers. As land is reduced and used for other purposes, the landowner also loses the basis for producing grain or animal feed. In the event of a reduced production base, part of the income base will also be reduced. This can lead to more land having to be rented, if it is to be obtained, and more driving may have to be expected, which in turn can affect the cost level. Such a reduction in the production base can lead to the closure of farms, as mentioned as a consequence, by landowner 4. Seeing that areas are being demolished, and topsoil is disappearing, can affect the motivation for continued active operation of the farm. Landowner 3 mentions that it is difficult to see colleagues build down their land, and sell it for a lot of money, without specifically mentioning that it affects own motivation for further operation. Seeing what happens to surrounding areas, which do not necessarily affect one's own operations directly, can, however, indirectly affect, through weakened motivation. It is thus conceivable that the more effects, and the greater the effect these together constitute, the greater the load can be experienced, and affect the motivation for further operation.

4.4.2. Adaptation:

As a reaction to the total load to which landowners are exposed, adaptation of further operating arrangements on the farm may be necessary, to maintain production on the same or approximately the same scale. To what extent, and possibly whether adaptations will be necessary, depends on how large the total load of a development of agricultural land is for the individual landowner. The more area that disappears for e.g., the extension of a motorway, the more adaptation may have to be made to maintain agricultural production on the same scale.

A possible adaptation to loss of area ca be to rent more land if this is to be found at a reasonable distance from the farm. This is something landowner 1 sees as a current adaptation, for further operation. Landowners 3 and 4 would have rented more land if this had been an option.

If it is not relevant or possible to rent more land, landowner 4 finds himself forced to scale down operation at the farm, as a direct consequence of loss of land. Landowners 2 and 3 also envisage a downscaling of operations, due to economic factors such as the expansion of the operating building which might be necessary for a profitable farming. Landowner 2 has the area to triple production. Landowner 4 also points out that it can be challenging to know how long the person in question can run the farm, due to uncertainty about how much area will disappear in the future, for the development of e.g., roads. This can also have a negative effect on the recruitment of the next generation (takeover) to the job and had to deal with an uncertainty regarding whether one can keep all the area in the future, in addition to that existing area becomes fragmented, and then more difficult to operate so that continued operation on the area might no longer be profitable.

Adaptations of a more intrusive nature may be to close operations on the farm or change operations to a different form than the original one. Landowner 3 has thought that a possible adaptation could be to conduct more in the form of cooperative farming. Landowner 4 has envisioned that a possible adaptation in the slightly longer term could be to convert the farm building into a stable and rent out this and surrounding areas as pastures. For both landowners, this will require relatively large upheavals, and involve a different operation than the current operating plan, and it places great demands on their adaptability. One can reflect on what lies behind this willingness to adapt, and whether it can be perceived as a moral duty to operate the land. Landowner 4 states that it is not negative to run the farm, and that even with the land use changes that have taken place, the person in question envisages that it is possible to run. Then it may seem that the alternative of renting out stable space and grazing to horses is to maintain a type of operation on the farm (continued operation with animals), because for personal reasons it makes it difficult to operate the farm many years to come. In addition, landowner 4 has an interest in horses, which makes renting out stables and pasture areas a good solution.

Landowner 3, who has seen cooperative farming as a solution, has a genuine interest in agriculture and says it will take a long time before he does not want to continue operating the farm. The landowner has done adaptations that allow the person to do more rental driving and store more grain. There may therefore be a possibility that there will take some time for a possible conversion to cooperative farming in the future. There are also some concerns that a cooperative farm will lead to more people around the farm more often, which indicates that the person in question may not want to operate the land at any cost, and that this is a solution that is not taken lightly. The person in question does not like the degradation that takes place with agricultural land. The person has been asked to sell land and could have lived well with the sale. Selling is not something the person wants to do, but the person is aware that in a hundred years his farm and agricultural land may have been demolished. It is thus conceivable that moral obligations to maintain the land are the basis for the idea of a possible cooperative agriculture, but that it may to a greater extent seem as if there is a genuine interest in operating the areas as long and as well as possible. This is also a job the landowners have most likely chosen because there is an interest for it. It is thus natural to think that it is not so easy to "change" job and direction and lay down one's livelihood. It requires an upheaval that is most likely to be experienced as large, regardless of whether the areas are run by moral duty or by interest.

4.4.3. Conclusion- farmers' views

To gain more in- depth knowledge that did not emerge from any analyzes, of the basis for the land use changes of fully cultivated land, and who is affected by these changes, a round of interviews was conducted. The interviews gave insightful knowledge about farming in a growing city, and the pressure on agricultural land that this may entail. It turned out that dependent on the scope of the development on the farmers areas, and thus the total load, affected the adaptations they made as a response of the development. The farmers did not like the development of their areas, and they “had to” give up their areas for the developers.

There are some aspects that could have been interesting to examine. One of this aspect is the economy in selling land. Politicians and developers often point out that it is more rational and cost- effective to develop flat agricultural land. The economy in agriculture does not always compete with other professions. When a farmer is offered large sums for one of his areas, often by private interests, which may offset more than an entire working life, the idea of selling the area for other purposes is naturally tempting. If it is also possible to rent the corresponding amount of land elsewhere, the arguments for leaving the area untouched might be fewer and fewer. The municipality can be satisfied when private developers want to build new homes, which are needed. Gaining more knowledge of this dilemma, where principles and interest meet economic values, would have been interesting.

Another aspect that could have been interesting to examine, is the landowners' thought about the densification policy in the municipality. When developing the city, and thus also agricultural areas, the goal is to densify. As more and more agricultural area is being developed, farming can become inefficient and difficult to operate in the future, due to less area. Would it be better to develop the entire area if there is too little area left for efficient and profitable farming, rather than expand "new" areas outside the city? Expanding further out of the city leads to urban sprawl, and greater transport needs, and thus a less sustainable development of the city.

The knowledge and input of those who own and operate the areas which are to be developed for various reasons, might be beneficial in the assessment of management issues related to agricultural land. The farmers know how a development of the areas affects further operation of the area and the farm.

4.5. Challenges with data material

4.5.1. Differences between AR5 and Statistics Norway

The figures for the total area of fully cultivated land from the area resource map AR5 from NIBIO and the figures from the database to Statistics Norway do not match. The total fully cultivated area in Trondheim in 2019, according to AR5 is 5 774 Ha, while according to Statistics Norway it is 5 163 Ha. There may be several explanations for this.

The number published by Statistics Norway is linked to farms applying for production subsidies. If a farm applies for a production subsidy for a fully cultivated area located in another municipality, the area is nevertheless considered part of the statistics from Statistics

Norway, which apply to the municipality in which the agricultural holding is located. This can mean that the total area of fully cultivated land in a municipality is reported to be less than what is the reality, as someone outside the municipality rents the land, and thus the land is registered in this municipality instead of the municipality the area is located in.

Other explanations are based on the map. AR5 reports the status of the fully cultivated area, and not its use. The figures from Statistics Norway only state that fully cultivated area for which production subsidies are applied for, and which are thus used as fully cultivated area. This may lead to the total area of fully cultivated land reported in AR5 being higher than what emerges from Statistics Norway's data.

Age of map data, and when it is updated also plays a role. In Trondheim municipality, no periodic update has been carried out for two years, and figures from NIBIO show that 23 hectares of fully cultivated land (and surface cultivated) have been developed, which have not been updated in AR5 (NIBIO, 2020).

4.5.2. Challenges- regression dataset

One polygon in the analysis can potentially be considered an outlier. In this analysis, a fully cultivated polygon was classified as open firm ground in 2019. Due to a very large area (36,68 Ha) this could have significantly affected the results. The fact that the area is far from the city center itself, and in addition is surrounded by agricultural land, may strengthen the reasoning for it to be considered a potential outlier. After removal, the regression analysis showed a slightly different result, where coefficient and response curves can be found in appendix D. The independent variable, size of polygon, is now a part of the analysis. Interpretation of the coefficient of the variable shows that, there is a 0.000002% less chance that a fully cultivated polygon will change for every m^2 the larger the polygon becomes. This seems logical as small polygons can have more difficult operating conditions and perhaps provide less profitability during operation. Then it may be easier to develop the area for other purposes.

The basic unit in the analysis is fully cultivated polygons of different sizes. This creates challenges in that precisely the size will affect how much weight a change in parts of the polygon will have in the regression. That is, the larger the polygon that contains a land use change from fully cultivated land, the less weight this change will have in the analysis, even though the change itself can be large. Some parallels can be drawn to the modifiable area unit problem (Wong, 2004).

The variable "distance to road" did also have some limitations. Delimitation of transport area in AR5 shall follow the boundaries in the most accurate data sets for the relevant topics. The area type also includes developed and permanent operating roads in agricultural areas (NIBIO, 2019). This means that there can be many roads that are included in the analysis, e.g., forest roads, small roads and private roads that not necessarily is functional in the analysis. Which thus might give an insufficient picture of this variable explaining changes in fully cultivated land.

4.6. Management implications

Norway has one of the world's strictest legislation in the Land Act (Vinge, 2020), topsoil has to a large extent been reallocated in Norway, and in Trondheim. Most of the agricultural area goes to housing and roads, and a change of area takes place in areas close to road, and the city center and in areas with a high population density. This has also been seen elsewhere in Norway that the pressure on agricultural land is greater in urban areas (Statistisk sentralbyrå, 2017b). Therefore, the focus of politicians, on the reduction of agricultural land, and how to manage this, should be in cities and urban municipalities. When necessary, the farmers perceptions of losing land and their knowledge of the area could be used more actively in the management strategy, to hopefully attain a more functional management.

To get a better overview of the loss of agricultural land, agriculture's own reduction should be reported (in KOSTRA). To reduce this amount, support schemes for farmers not to build on agricultural land if possible, might be a part of the management.

Once the agricultural area has been reduced, one alternative to reduce the extent of damage is to move topsoil. It requires careful planning, as well as a number of measures and resources, and should therefore be seen as a last solution after other alternatives (Arnoldussen and Olsen, 2016). Moving topsoil is relatively new, and little is known about long-term effects.

Other measures to reduce loss of agricultural areas is to keep the speed limit on motorways low, where a possible increase in speed will require a lot of agricultural area in an extension of the road. To be restrictive when it comes to developing agricultural land for recreational purposes use, such as a trotting track (track for horse races) can be a sustainable management strategy when managing cultivated land.

The effects of only small changes of land are by Norwegian standards relatively large, since only 3 % of the total land area is agricultural land. This should perhaps indicate that stricter enforcement of the law is needed, as well as other solutions for development, such as expanding forests and other areas that are not agricultural land and building more in height.

Biodiversity loss is a consequence of both developing agricultural area and other land use types, such as forest. Habitats of different species disappear. And the value for people being surrounded by green and open areas also disappears. A total protection can be a solution, but this will also affect farmers who will build new farm buildings.

The chief municipal executive councilor's staff in the municipality has submitted proposals for development that limit the loss of cultivated land, even with a densification policy (Trondheim kommune, 2020c). Developers and politicians who disagree believe that housing construction will be more expensive, as it is cheap to build down flat agricultural land. The municipality needs housing. This shows the complexity of densification policy, soil protection, population growth and the need for housing, roads, etc. The pictures below (14 a-d) show agricultural land close to city, with houses, roads etc. The green, large, and often flat areas can from developers and some politicians point of view, be natural and simple to expand and develop for other purposes than agriculture.

Figure 14 a) Photo: Ajay Dhukuchhu

Figure 14 b)

Figure 14 c)

Figure 14 d) Photo: Hildegunn Heggøy

5. Conclusion

There has been significant changes in the use of agricultural area the recent years, in Norway, Sør- Trøndelag and Trondheim municipality. This study shows that loss of agricultural area in operation and fully cultivated land between the years 1999 to 2019 is more marked in Trondheim, with 22,6 % and 18,9 % respectively. Compared to Sør Trøndelag with 3,7 % and 8,9 %, and on a national level, with 9,5 % and 11,1 % respectively. Total for Trondheim shows that the amount of area of the land use categories built-up and transport and communication (infrastructure) has increased with 27,9 % and 29,4% respectively, while the category fully cultivated land has decreased with 5,6 %.

38 % of fully cultivated land has in the period 1969 to 2019 changed to built-up area, while 37 % has changed to open firm ground, that also covers some built-up area. The changes has happened in the urban parts of the municipality. These changes has taken place near roads, city center and in already densely populated areas. Future plans for reallocation of fully cultivated land will mainly be for built-up area, which amount to 48,6 % of the total fully cultivated area, and 13 % will be regulated for business activity.

In the interviews that were conducted, it emerged that none of the farmers (naturally) think anything about the development of their areas, and that they still "must" sell land if it is needed for e.g., road construction. The farmers adjusted the operation of the farm, depending on the total load of the development of their areas.

The fact that the loss of agricultural land is greatest in Trondheim in relation to county level and nationally, where most of the area is lost due to built-up area, may reflect the urbanization and population growth that the city experiences. This is also reflected in the future plans for reallocation of fully cultivated land, where most is reallocated for built-up area. It may indicate on a general level that loss of agricultural land in an urban municipality might be more significant, until today and in the future, due to urbanization. Solutions for the construction of built-up area in urban areas should be prioritized by decision makers, to avoid/ limit loss of agricultural area in the future.

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Appendix A- Land use matrix

2003	2019								2003 total
	Built up area	Trans. and comm.	Fully cultivated land	Surface cultivated land	Infield pasture area	Forest land	Open firm ground	Wetlands	
Built up area	3363	114	0,4	0,002	0,08	9	57	0,05	3543,53
Trans. and comm	44	694	7	0,07	0,84	16	24	0,64	786,55
Fully cultivated land	187	43	5629	3	16	52	182	7	6119
Surface cultivated land	2	0,2	13	40	0,98	1	0,23		57,41
Infield pasture area	11	3	37	5	500	21	7	0,05	583,05
Forest land	160	60	42	0,42	46	15817	127	11	16263,42
Open firm ground	736	93	37	2	11	112	1380	2	2373
Wetlands	30	9	9		0,012	30	18	2132	2228,01
2019 total	4533,00	1016,20	5774,40	50,49	574,91	16058,00	1794,23	2152,74	31953,97,97
Change (ha)	989,47	229,65	-344,60	-6,92	-8,14	-205,42	-578,77	-155,27	2518,24
Change (%)	27,92	29,2	-5,63	-12,05	-1,40	-1,26	-24,39	-6,73	7, 88

Appendix B- Interpretation of regression coefficients:

The interpretation of the other coefficients will, by using equation 1, give these results:

Every meter further away from built-up areas, the probability of a fully cultivated polygon changing will increase by 0,01 %.

For each additional person per m^2, the probability of a fully cultivated polygon changing increase by 0,08 %.

Every meter further away from the city center (Torget) (defined as city center in Trondheim), the probability of a fully cultivated polygon changing will decrease by 0,009 %.

Every meter further away from road, the probability of a fully cultivated polygon changing will decrease by 0,4 %.

Appendix C- interview guide

Interview Guide- farmers/ landowners in Trondheim municipality

Intervjuguide- grunneiere/ bønder i Trondheim kommune

Section 1/ seksjon 1: information about you (the farmer), the farm and the operation of the farm/ informasjon om deg (bonden), garden og drifta av garden

Tell us a little about yourself, the farm and the operation of the farm.

Fortell litt om deg selv, gården og driften av gården.

- Age/ alder
- Education/ utdanning
- Other work/ annet arbeid
- Information about the household/ opplysninger om husholdet (partner, barn/ kids etc)
- Childhood/ oppvekst
- Other/ anna…

Can you tell us a little about the operation of the farm? How big the farm is, type of production.

Kan du fortelle litt om bruket her? Hvor stort det er, type produksjon.

Usage information/ bruksopplysninger:

- Size/ størrelse
- Production/ produksjon (volume/ volum)

How do you envisage future farming? Do you want continued operation and in the same form as today, or as another production?

Hvordan ser du for deg fremtidig jordbruksdrift? Ønsker du fortsatt drift og i samme form som i dag, eller som en annen produksjon?

- Farm history/ gårdshistorikk, genealogy/ slektsbånd
- When and why did any expansion or downscaling of operations/ production takes place?
  Når og hvorfor skjedde en eventuell nedskalering av drift?
- When did you take over the farm? What is your ambitions with the farm, and was it as you thought when you took over?
  Når overtook du bruket? Hva er dine ambisjoner med drifta, og ble det sånn du hadde tenkt da du overtok?
- What future do you envision (same operation as today or other production?

Section 2/ seksjon 2: Land use changes in the period 2003 to 2019/ arealbruksendringer i perioden 2003 til 2019.

What land use changes have taken place here in the period 2003 to 2019?

Hvilke arealbruksendringer har skjedd her i perioden 2003 til 2019?

How has it been to run the farm/ area here during the period?

Hvordan har det vært å drive gård/ areal her i denne perioden?

Bolk 3: Challenges and opportunities regarding running a farm close to a growing city/ utfordringer og muligheter ved å drive gård i en voksende by.

What are the challenges and opportunities?

Hva er utfordringene og mulighetene?

What do you think about the municipality chooses to use agricultural land for purposes other than agriculture?

Hvordan ser du på det at kommunen velger å bruke jordbruksareal til andre formål enn jordbruk?

What will be crucial for you to maintain farming?

Hva vil være avgjørende for at du opprettholder jordbruksdriften?

Do you have any additional information you would like to share?

Har du noen tilleggsopplysninger du vil dele?

Appendix D- coefficients regression curves without outlier

Table 6 Results from the best suited model in linear regression, after removal of outlier polygon.

	Estimate	Std.Error	T value	Pr(>|t|)
(Intercept)	-3.029	0.156	-19. 385	<0.001
distance_builtup	0.0001	<0.001	2.288	0.0223
distance_road	-0.0042	<0.001	-6.362	<0.001
distance_citycenter (Torget)	-0.000085	<0.001	-5.395	<0.001
Size_ polygon	-0.0000022	<0.001	-4.328	<0.001
pop_density	0.00078	<0.001	5.067	<0.001

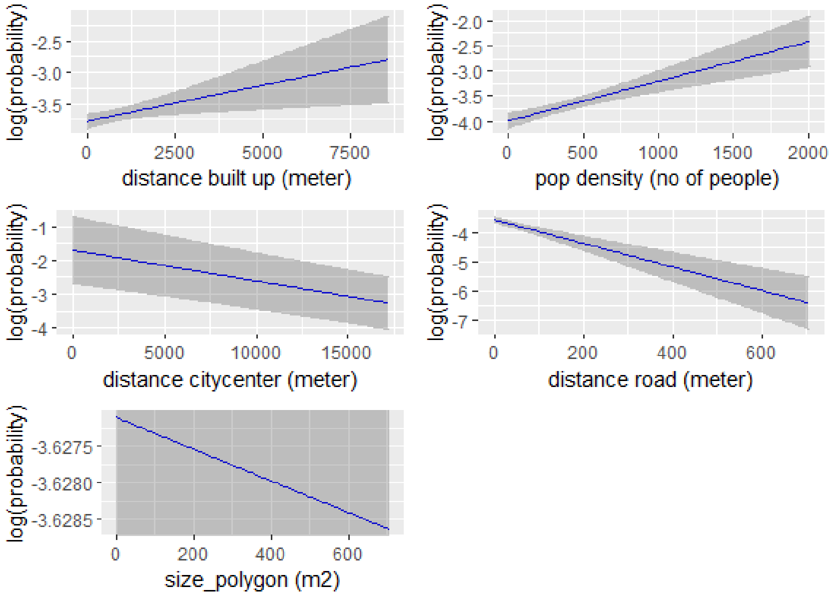

Figure 15 Response curves for the regression model without an outlier. The variable size_polygon is uncertain, with a large confidence interval (dark grey area).