UNIVERSITÄT FÜR BODENKULTUR WIEN
University of Natural Resources
and Life Sciences, Vienna

Master Thesis

Bioeconomic simulation of a change in maximum plot size in the Znojmo region

submitted by

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in the framework of the Master programme

Agrar- und Ernährungswirtschaft

in partial fulfilment of the requirements for the academic degree

Diplom-Ingenieur

Vienna, December 2023

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Affidavit

I hereby declare that I have authored this master thesis independently, and that I have not used any assistance other than that which is permitted. The work contained herein is my own except where explicitly stated otherwise. All ideas taken in wording or in basic content from unpublished sources or from published literature are duly identified and cited, and the precise references included.

I further declare that this master thesis has not been submitted, in whole or in part, in the same or a similar form, to any other educational institution as part of the requirements for an academic degree.

I hereby confirm that I am familiar with the standards of Scientific Integrity and with the guidelines of Good Scientific Practice, and that this work fully complies with these standards and guidelines.

Vienna, December 2023 Petr ILGNER *(manu propria)*

Acknowledgements

I would like to express my sincere gratitude to my dedicated supervisor, Andreas Niedermayr, whose unwavering patience, guidance, and support were instrumental throughout the extended three-year writing process of this thesis. I also extend my thanks to the supervising professor Jochen Kantelhardt, whose oversight and expertise were crucial to the success of this work.

Special appreciation goes to Stefan Kirchweger for generously allowing me to work with his model, which significantly contributed to the research in this thesis.

Last but not least, my heartfelt appreciation goes to my wife, Lenka, whose enduring support and understanding during my long journey of studies made this achievement possible.

Table of content

Abstract

Czech Republic has one of the largest average agricultural field sizes in Europe. This is largely due to the historic development of the landscape. From the farmer's point of view, large fields are a source of cost savings and efficiency gains. Yet, research suggests that the ecosystem services provided by farmland biodiversity are negatively affected by this. Czech agricultural policymakers have thus decided to limit the single-crop field to a maximum of 30 ha, first on erosion-prone fields and then on all arable land. This decision is a compromise between farmers and nature conservation organisations. However, the 30 ha aren't based on scientific research, and the impact of this policy on agricultural productivity and ecosystem services hasn't been modelled yet. The aim of this thesis is to provide some first insights towards modelling the economic and environmental effects of this policy at landscape level. For this I carried out a bio-economic simulation of land use change on spatial data of a selected region in the Czech Republic. The environmental results show an improvement of biodiversity and pollination services of the landscape on oilseed rape crop when the field size decreases. The economic results indicate a decrease in yield and gross margin, even if positive pollination effects are considered. The economic results also suggest a potential change in the size of machinery used by farmers in the long run. Further incentives would be needed to compensate farmers for including biodiversity enhancing areas in their fields. I conclude that more concrete research on biodiversity and pollination effects would need to be conducted in order to better calibrate model parameters to Czech agriculture. A similar simulation should be carried out prior any further policy changes, so that policy makers can make a better informed decision.

Kurzfassung

In Tschechien haben landwirtschaftliche Betriebe aufgrund historischer Entwicklungen eine große durchschnittliche Schlaggröße, die Kosteneinsparungen und Effizienzgewinne ermöglicht. Jüngste Forschungsergebnisse deuten allerdings darauf hin, dass Ökosystemleistungen, die von der biologischen Vielfalt der landwirtschaftlichen Flächen erbracht werden, durch größere Felder negativ beeinflusst werden. Die tschechische Agrarpolitik hat daher beschlossen, die maximale Schlaggröße auf 30 Hektar zu begrenzen, zunächst auf erosionsgefährdeten Flächen und dann auf allen Ackerflächen. Diese Entscheidung war ein Kompromiss zwischen Landwirtschaft und Naturschutzorganisationen. Die Auswirkungen auf die landwirtschaftliche Produktivität und Ökosystemleistungen wurden im Vorfeld jedoch nicht untersucht. Das Ziel der vorliegenden Arbeit ist es, einen ersten Beitrag zur Modellierung der wirtschaftlichen und ökologischen Auswirkungen dieser Politikmaßnahme zu leisten. Dazu habe ich eine bioökonomische Simulation der Landnutzungsänderung auf der Grundlage räumlicher Daten einer ausgewählten Region in der Tschechischen Republik durchgeführt. Die Ergebnisse zeigen, dass sich die biologische Vielfalt und die Bestäubungsleistungen der Landschaft für Winterraps verbessern, wenn die Größe der Schläge abnimmt. Die ökonomischen Ergebnisse zeigen einen Rückgang des Ertrags und des Deckungsbeitrags, selbst unter Berücksichtigung positiver Bestäubungseffekte. Darüber hinaus könnte sich bei geringerer Schlaggröße langfristig die optimale Maschinengröße ändern. Zusätzliche monetäre Anreize wären erforderlich, um Landwirt*innen für die Schaffung biodiversitätsfördernder Flächen zu kompensieren. Weitere Untersuchungen sind notwendig, um die Modellparameter besser für die tschechische Situation zu kalibrieren. Vor weiteren politischen Entscheidungen sollten ähnliche Simulationen durchgeführt werden, um besser informierte Entscheidungen zu treffen.

1. Introduction

"Velké širé rodné lány, jak jste krásny na vše strany." – J.V. Sládek (1889)

"Big wide birth fields, how beautiful you are in all directions."

When the Czech poet Josef Václav Sládek wrote these words, he had no idea how controversial they would become a century later. The structure of the Czech landscape today is very different from the one Sládek was referring to. Large open fields, sometimes hundreds of ha in size, are now a common feature of the Czech landscape. Growing public interest in the landscape around them and the increasing focus on environmentally friendly agriculture raised the question of spatial change in the Czech landscape, perhaps the most significant change since forced collectivisation in the 1950s. The effects of implementing simple greening rules to ensure the soil protection and to implement at least some crop rotations were not effective (Vermouzek et al., 2018) so, the government was forced to act and did it with a policy that de facto caps the size of a single crop field to a maximum of 30 ha. The explanatory memorandum states that the 30 ha lies in the field size optimum between 20 and 40 ha. Other effects of this policy would be a reduction of wind erosion, mitigation of drought effects and slowing the water runoff due to wider crop rotations (ČTK, 2018).

This policy has been criticised for being too prescriptive and not allowing for a regional differentiation. Also, no economic analysis was carried out before the policy was announced. Stakeholder organisations are arguing whether this policy is too strict or too soft, and whether it is just a smoke screen to maintain the status quo in agriculture. The measure aims to reduce soil erosion caused by water and wind and to increase biodiversity in the landscape (Žalud et al., 2019). The leading group of opponents consists of some associations of agricultural companies, who proclaim that international competitiveness of Czech agriculture will be impeded by this measure, edge effects will increase the use of pesticides and herbicides, and there will be more frequent rodent outbreaks (Jandejsek, 2019). The Ministry of Agriculture of the Czech Republic argues for the cap of maximum field size with erosion protection (Žalud et al., 2019).

In the present thesis, I will try to address some of these claims. The first thing to be said about this thesis is that similar research should have been carried out before this policy measure was issued. Such a far-reaching policy, the biggest visual change in the Czech landscape in decades, is an example of armchair politics. This thesis attempts to provide provide some first insights towards modelling the economic and environmental effects of this policy at landscape level. Based on recent research dealing with a similar issue, I adapt and extend an existing bioeconomic model to emulate the effects of the policy, offering different strategies, how farmers might react and how this policy might affect them. This model is based on Kirchweger et al. (2020), who analysed the problem of field enlargement in Germany and developed a simulation model to compare the trade-off between the cost savings within large fields and a reduction of ecosystem services. The thesis looks at how the Czech policy affects the economics of crops, the effects of extended edges and headlands on yields, the effects on ecosystem services (mainly pollination) and the effects on the biodiversity at landscape level.

Larger fields have a positive effect on production costs per ha and are easy to manage (Kirchweger et al. 2020). Moreover, in countries where fields are traditionally smaller, there is a trend towards field enlargement. Therefore, some studies analyse the effects of field enlargement (Kirchweger et al., 2020; Sklenička et al., 2014; Kapička and Brant, 2017). A larger field size is not only associated with potential economic benefits, but may also reduce biodiversity. For example, Fahrig et al. (2015) show that an increase in field size reduces resources for wild pollinators. Larger fields are also associated with lower crop diversity, preventing beneficial organisms from moving to complementary resources, for example after harvest. Field size can be expected to have a significant effect on biodiversity, particularly in landscapes dominated by arable farming. It has been suggested that smaller fields may be a way to conserve biodiversity on agricultural land without the need to take land out of production (Fahrig et al., 2011). There are recent studies on the importance of field size, some of which I directly build on. However, these studies only address the issue of possible field enlargement, a tendency observed in countries with more traditional agricultural practices.

The main aim of the thesis is to assess the possible impact of subdividing fields to comply with the 30 ha maximum rule to ensure the crop diversification specified by the rules of the common agricultural policy (CAP) of the European Union (EU). This is done based on a bioeconomic simulation for a study landscape in the South Moravian region near Znojmo. What are the opportunity costs of this policy? Will increased pollination effects compensate for the loss caused by subdivision? Will the change in landscape structure affect biodiversity? Will the effectiveness of mechanisation be affected? Which adaptation strategy to comply with the policy is most likely to be adopted by farmers? And which adaptation strategy is most desirable for policy makers?

This thesis proceeds as follows. The next chapter first describes the current structure of agriculture in the Czech Republic and discusses the differences compared to other countries. Then I summarise the available information on the economic effects and the effects on biodiversity as well as ecosystem services of a change in field size. Chapter 3 mainly concerns the description of the model, the response variables as well as adaptations and extensions compared to the original model developed by Kirchweger et al. (2020). Chapter 4 presents and critically discusses the results. Finally, in the last chapter I provide some concluding remarks.

2. Theoretical framework

2.1. *Background on Czech agriculture*

The current status of agriculture in the Czech Republic reflects the effects of the forced socialist collectivisation initiated in 1948, agricultural industrialisation between 1975 and 1989, extensification and privatisation during 1990-2004, and the Common Agricultural Policy period after 2004.

Prior to 1990, the agricultural structure in Czechoslovakia was dominated by state-owned farms or large cooperatives (Chloupkova, 2002). The state farms had an average area of 9,200 ha, while cooperatives had an average area of 2561 ha (Chloupkova, 2002). Following the Velvet Revolution, it was commonly believed that large and inefficient structures would be eliminated, paving the way for Western-style family farms to take root (Bezemer, 2004). During the economic transition, land was returned to its pre-communist owners, resulting in land ownership structures reverting to those of the 1940s or 1950s. The land register included long and narrow plots intended for cultivation using horse power. This led to a common practice of exchanging land with other farms to create larger and optimally shaped field blocks, as noted in Jelínek et al. (2018). The number of farms increased drastically after private farming was allowed again, as pointed out by Bezemer (2004). Farmers who entered the sector were optimistic about its future, as they were aware that agriculture was favoured in the previous regime. Despite this, the new regime did not provide adequate support to the sector and reduced most subsidies. The lack of state support, coupled with the opening of trade with other countries that typically offer agricultural subsidies, resulted in a decrease in the number of farmers and a widespread shift towards extensive agricultural production, as noted in Grešlová Kušková (2013). There was a decrease in the number of livestock, particularly in the case of pig rearing and fattening. In the mountain and highland regions, a substantial portion of fields covering nearly 13.8% or 115,000 ha was transformed into less-intensive, permanent grasslands between 1990 and 1999 (Grešlová Kušková, 2013). The total agricultural land, including permanent grassland, witnessed a decrease. In contrast, the forest area showed an increase during the same period (Grešlová Kušková, 2013). The period up until EU accession was mostly characterized by a shift in production towards more fertile areas. According to the research of Grešlová Kušková (2013), there was evidence of a rise in agricultural efficiency during the same period.

The net value added per worker rose by 60% after joining the EU, comparing the years 2003 and 2006 (Doucha and Foltýn, 2008). After accession, the structure of the economy became more similar to that of the initial member states (EU 15), and the percentage of agriculture in GDP dropped. Furthermore, the overall number of workers in agriculture continued to decrease. The entire production levels of several commodities, including pork, sugar, and vegetables, fell. However, despite the overall reduction in production levels, the agriculture sector managed to increase output, owing primarily to other agricultural products. There was also a significant increase in the total area managed under organic production measures, from 235,136 ha in 2003 (representing 8% of all agricultural land) to 506,106 ha in 2015 (representing 17% of all agricultural land) (Zelená zpráva, 2017).

The structure of farms in the Czech Republic, according to the 2016 Green Report (Zelená zpráva, 2017), is as follows: There are a total of 45,855 farms. Of these, 51.6% are farms with an area of less than 5 ha, which occupy only 1.1% of the total agricultural area. 38% of the farms are in the segment of 5-100 ha, which occupies 12.3% of the total agricultural area. 6.5% of the farmers fall into the medium segment of 100-500 ha, which uses 18.8% of the total agricultural area. However, only 3.8% of the total agricultural area was used by the remaining portion, which is a significant contrast to the 67.6% used by the other portions. According to Zelená zpráva (2017), the segment of the largest farms in the Czech Republic possesses 76% of all the livestock. Nevertheless, when we focus on the total number of utilised agricultural area, the disparity between the land and livestock kept by the biggest farms (67.6% versus 76%) is insignificant.

In the last decade, a trend of decreasing number and area of farms in the segment of largest farms can be observed, as shown in Figure 1. The segment of farms over 2,000 ha has lost more than 158 thousand ha of land between 2007 and 2016, farms between 1,000 and 2,000 ha have lost almost 100 thousand ha of land. The segment of agricultural farms between 100 and 500 ha has grown the fastest. This segment gained a total of 115,202 ha. The other two segments (less than 100 ha and 500 to 1,000 ha) gained moderately, both by about 10 thousand ha. Comparing the trends shown in Figure 1, it can be assumed that the fastest growing segment is that of farms between 100 and 500 ha. An important fact as a side note apart from the official statistics is the existence of large groups of individual farms - holdings. Eleven holdings use more than 10,000 ha each. In these holdings there are 175 farms, which means that 8% of agricultural land is used by eleven owners (Jelínek et al., 2018).

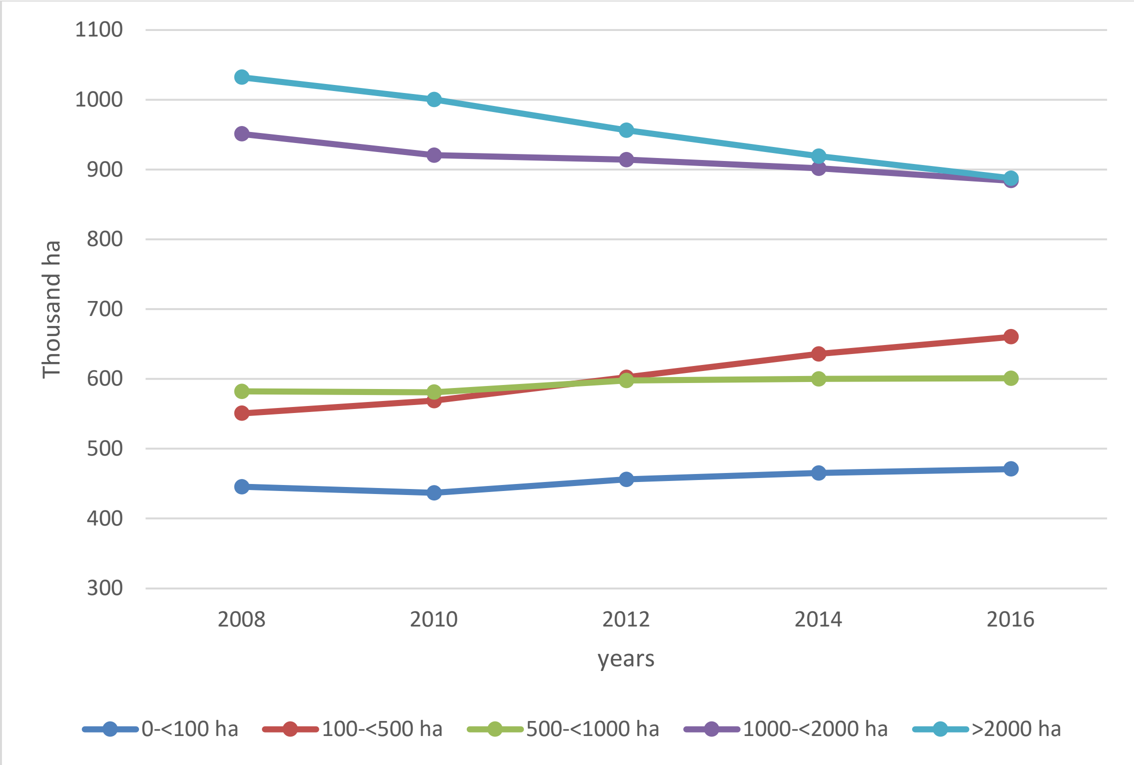


Figure 1. Total aggregate acreage of farm segments by farm size Source: Zelená Zpráva (2017)

The aforementioned structure gives rise to a phenomenon known as the dual structure, a term utilized for the Central and Eastern European transition countries (Tamáš, 2010). This implies that enterprises are categorized into two primary groups. The composition of said groups includes a minority of considerably large farms, primarily legal entities originating from state enterprises and cooperatives, and a comparatively larger number of small farms with limited land. Bezemer (2004) suggested a grouping that consists of three categories, which includes the very small farms (< 5 ha of land), the recently formed farmer class (mostly comprising individual full-time farms), and then the big farms. This phenomenon explains differences in agriculture compared to other nations. The European Commission (2019) has reported that the Czech Republic and Slovakia utilise a significantly larger proportion of hired labour compared to the old Member States. This is consistent with the prevailing structure, where large industrial farms need to employ workers while small farms primarily rely on unpaid family labour.

The significance of the relationship between landowners, farms (individual or corporate), and the state of agriculture on its current structure cannot be overstated. Due to the privatisation that occurred in the 1990s (Sklenička and Šálek, 2008), land ownership in the Czech Republic is notably fragmented, with 3 million landowners and only 70,000 land users. On average, a single owner possesses 3.23 ha of land divided into roughly 6.3 plots (ČUZK, 2014). According to Jelínek et al. (2018), a quarter of landowners have land that is partially or completely inaccessible, as it is contained within a larger field. This is in sharp contrast to the above-described agricultural structure. Jelínek et al. (2018) revealed that farms operating as legal entities have an average of 489 land lease contracts. Medonos et al. (2011) has observed that these enterprises are sensitive to sale and rental prices of agricultural land. The "farmland rental paradox" was described by Sklenička et al. (2014). The authors discussed the correlation between the real allocation of land among landowners and another allocation among land users. The key discovery is that smaller plots owned by many different landowners result in larger fields being formed. Small plots are often rented to nearby large farmers.

Kellermann et al. (2006) investigated the impact of land use and land tenure fragmentation on one another. Their key finding related to the expenses incurred in modifying land tenure within a large field blocks context. Strong evidence was found indicating that large fields impede the transformation of agriculture in the short term. According to their model, smaller subjects (using smaller field blocks) must pay market rent prices, while the land within a larger field block is typically rented below market price. This assertion is supported by Doucha and Divila's (2005) statement that farms displaying dynamic behaviour are more prone to pay higher rents than those abiding by the status quo.

The field roads' situation is one of the final topics to be addressed in this part of the thesis. Countries like Austria or Bavaria feature web-like structures of field roads connecting the land blocks within the landscape. These roads are subject to continuous management and modifications to meet the evolving agricultural needs over time. However, this is not the case in the Czech Republic. In the Znojmo region, a basic field road rationalization occurred shortly after the end of World War II. (Veselá, 2008). From 1948 to 1990, the majority of field roads were demolished due to their hindrance to agricultural industrialisation (Vlasák and Bartošková, 2007). Large fields were perceived as a symbol of collectivisation, and field roads were viewed as an obstruction towards achieving this ideal. Following the compulsory collectivisation completed in the 1960s, the importance of physical access to fields diminished as farms utilised all land and took responsibility for managing roads, regardless of land ownership. Legal attention to the matter of physical accessibility was only given in the 1990s following economic transformation (Vlasák and Bartošková, 2007). The socialist landscape planning methodology, enforced from 1974 to 1991, prioritised erosion prevention and soil conservation over environmental and biodiversity concerns (Dumbrovský, 2004). The extensive fields devoid of natural or semi-natural habitats in the landscape are a result of this period and have not yet been restored. According to Vlasák and Bartošková (2007), the field road network reduced by 55%-74% compared to the pre-collectivisation era. Despite the economic transformation in the 1990s, the previous roads continued to be a constituent of the vast fields. In 1948, the ownership of the roads devolved to the state, and the ownership arrangements varied among different villages. In case of land consolidation before 1948 or after 1991, the road plots are owned by either the municipality or the state. As per the status quo in Czech agriculture (Jonáš, 1990), most of the farms lease these old roads. This makes it possible to renew them and provide access to all plots.

Chloupkova and Bjornskov (2002) identified another significant difference between Czech and Austrian agriculture. According to them, social capital is an integral aspect of agriculture. Today, bank loans availability, peer pressure for good practices, and punishment of immoral behaviour are significant factors of social capital, but they do not work efficiently in rural Czech Republic. This is because large farms often operate in distant areas from the headquarters or hire workforce who does not have any knowledge about the local interests.

In total, the primary distinctions between agriculture in the Czech Republic and the EU-15 areas can be summarised with the following three points:

- Czech Republic has a vast average utilized area per farm, non-family farming is prominent, and variable inputs efficiency is 30% lower.
- The primary comparative advantages of Czech agriculture are lower prices for labour and land.
- Agricultural subsidies are crucial in the Czech Republic, as they account for up to 70% of the value added in the industry, making it strongly reliant on the future of the Common Agricultural Policy (CAP) and other related payments.

2.2. *The 30-hectare policy*

The Czech government made a swift decision in 2019 to alter the configuration of the agricultural landscape. Since 1948, the average plot size in the Czech Republic has risen from 0.23 ha to its current size of 20 ha. (ÚZEI, 2012). This poses a threat to various aspects, primarily to the safeguarding of the landscape, soil and water resources (ÚZEI, 2012). Furthermore, the magnitude of field blocks is recognised as a potential contributor to issues in the Czech government's plans for 2030. Given these circumstances, a decision was made to restrict the maximum size of one-field block for a crop to 30 ha.

The structure of Czech Republic's agriculture makes it uniquely reliant on national and European policies for its sustainability (Sklenička et al., 2014). The prospect of losing subsidies is the primary driving force for sustainable agriculture. Thus, the measure aligns with existing policies. In the context of cross-compliance, Good Agricultural and Environmental Conditions (GAEC) are precisely defined. Minimum requirements must be defined by EU Member States according to Annex II of Council Regulation (EC) No 1306/2013. These minimum requirements should be defined in relation to specific areas, climate and soil conditions, farming systems, land use, crop rotation, farming practices, and farm structures. The GAEC framework varies in different regions of Europe, and sometimes even at a regional level (GAEC, n.d.). Adherence to GAEC is a necessary condition for farms to be eligible for direct payments. In the upcoming CAP (2023+), the conditions are further strengthened, partly through the implementation of the enhanced conditionality rule, which obligates farms to use some parts of the land for non-productive purposes.

In GAEC 7, a measure has been implemented to divide fields in order to limit them to a maximum size of 30 ha. The primary focus of GAEC 7 is on the landscape and maintaining a minimum level of upkeep. This measure was a part of NV 48/2017 Sb. and applied to all plots of land larger than 30 ha that were under threat of erosion, effective from 1st January 2020. As per the Ministry of Agriculture (Ministry of Agriculture of the Czech Republic, 2019), the measure was extended to apply to all plots starting from 1st January 2021.

The determination of the maximum size of field blocks in the regulation was a compromise between lobby groups involved in agriculture and nature protection. While the Chamber of Agriculture of the Czech Republic (Agrární komora České republiky) advocated for maintaining the status quo with no regulation on field block sizes (Agrární komora, 2020), the Czech chapter of Birdlife International (Česká společnost ornitologická) suggested that the government should limit field sizes to a maximum of 20 ha with the aim of preserving biodiversity. In 2019, a petition signed by 56,602 individuals calling for an decrease in the maximum field block size was submitted to the Czech Ministry of Agriculture (ČSO, 2020).

To comply with these regulations, farmers have the following options:

1. Planting multiple crops
2. Crop divided by a parcel of another crop, at least 100 m wide
3. Crop divided by a protective strip at least 22 m wide
4. Permanent road renewal

This thesis examines the alteration in the maximum field size as of January 2021. The 4 options outlined above are elaborated in detail in the methodological part of this work.

2.3. Literature review

The topic of field size in the Czech Republic can be seen from different angles. The following three sections describe the current research on this issue.

2.3.1. The economics of field size

One of the main arguments against the 30 ha policy is the positive economic impact that large fields have on farms. Various authors have approached this issue differently. Upon reviewing the literature, I found that there is a bias towards authors from fragmented landscapes who do not consider large fields, mechanisation and different approaches to work organization (Rodriguez and Wiegand, 2009). Their theories fail to consider the effects of field block sizes above a certain number of ha. The most reliable sources for this thesis were found in Germany. German sources and calculations take into account both small farm structures in Bavaria and large farms in Eastern Germany (KTBL, 2020).

A variety of factors is related to the economics of field size. Working time is a significant factor associated with field size and has been analysed by Auernhammer et al. (2001) and Degner (1999). These studies found that as field size increased, working time decreased, up to a field size of 40 ha. The working time encompasses the duration spent during actual agricultural operations as well as the time taken to reach the field, turn around, and adjust machinery, among other operations. With larger fields one spends less time on these latter work and more time on the actual agricultural operations. Brunotte and Fröba (2007) carried out a study that explored the relationship between plot size and fuel consumption. Fuel consumption per ha decreases significantly from 2.5 ha to 60 ha according to the research. However, above this threshold, fuel savings aren't substantial. Moreover, by optimizing the trajectory of agricultural machines on fields between 10 and 40 ha, significant time savings can be achieved (Fechner, 2014). Furthermore, transport of the final product from larger fields can result in considerable work time savings. (Demmel et al., 2014; Streicher et al., 2014). In their practical research on agricultural productivity, Ženka et al. (2016) found that the regions in the Czech Republic with large and regularly shaped fields have the highest labour productivity, which supports the aforementioned effects.

The abovementioned authors mentioned the maximal optimum field block size where costs can be minimised. Conversely, some authors consider the minimal optimum field block size to be effective. The concept of the farmland rental paradox was developed by Sklenička (2014). The authors analysed the current state of field blocks and actual land ownership to establish the minimum threshold size of a block of arable land that is economically viable for its owner to use. In the Czech Republic, this threshold was calculated to be 1.07 ha. Parcels with an average size smaller than 1.07 ha commonly get rented and are thus incorporated into large field blocks. Beyond this threshold, the land plots are mainly utilized either by the owner or as a single block rental. This result indicates the minimum suitable size for a field. Kellerman et al. (2006) also noted that the conjunction of fragmented land ownership and limited access to land parcels leads to increased transaction costs for landowners. The transaction costs increased with the field block size. Transaction costs have the potential to negatively impact land markets by decreasing the prices and rents of the plots included in large field blocks. Some agricultural lobby groups argue for maintaining the status quo due to the presence of transaction costs.

In a recent study Clough et al. (2020) raise doubts about the actual economic impact of smaller fields. Figure 2 illustrates the potential influence of ecosystem services when incorporated into the calculation, as shown by the shift from the grey line to the dashed line in the graph. The causes of field enlargement are identified, mainly including the cost-efficient use of large machinery, structural change, land consolidation, and the minimum field size required to receive subsidies. Factors contributing to the reduction in field size include technical innovations that are suitable for smaller fields, higher subsidies for smaller fields, and successful substitution of inputs with ecosystem services based on biodiversity.

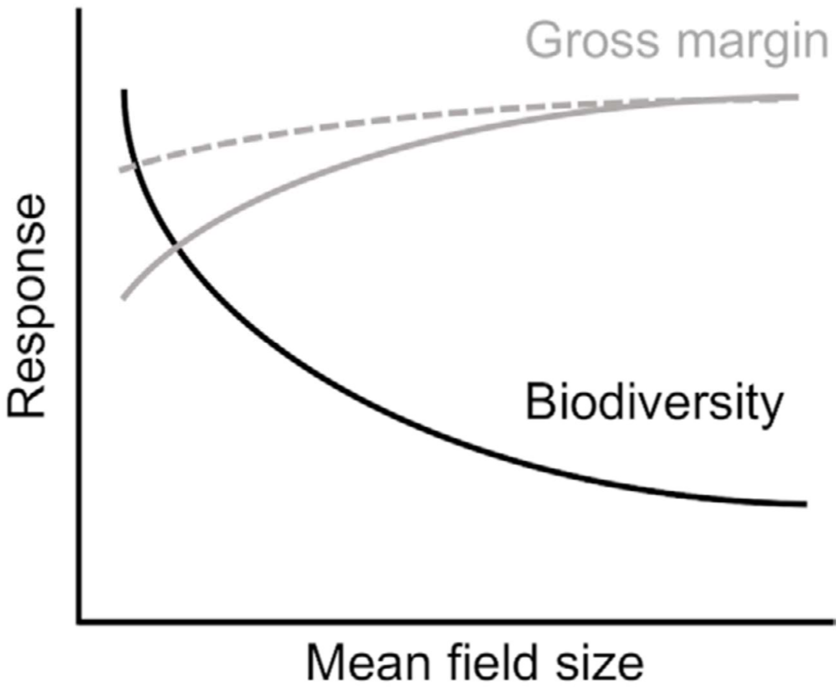


Figure 2 Gross margin and mean field size relation explained in the text, the dashed grey line represents the lessening of ecological-economic trade-offs (Clough, Kirchweger, Kantelhardt; 2020)

When considering field size and efficiency, the size of available machinery is often deemed a crucial factor. Mechanisation in the Czech Republic is dependent on the current structure of extensive fields and large agricultural enterprises (Kapička and Brant, 2017). The size of machinery has been increasing since the late 1990s, with an annual investment rate of 5.5%, the third highest in the EU. This increase is determined by the structure of the Czech landscape (European Commission, 2019). Investing in machinery deepens the dichotomy between large enterprises and small farms, as large enterprises are usually more competitive and can allocate more funds to modernisation (Mazouch, Vltavská, Krejčí, Kvasnička; 2015). Today, with large farms operating machinery suitable for large fields, maintaining these large fields may be essential for economic viability.

Figure 3 shows the gross margin per ha of winter wheat for different machine size categories and different average plot sizes. This comparison is based on three selected size categories. The most prominent feature of the graph is the reduction in gross margin when large machinery is applied on small fields. The gross margin likewise decreases when the field's shape deviates from a rectangle (Kapička and Brant, 2017).

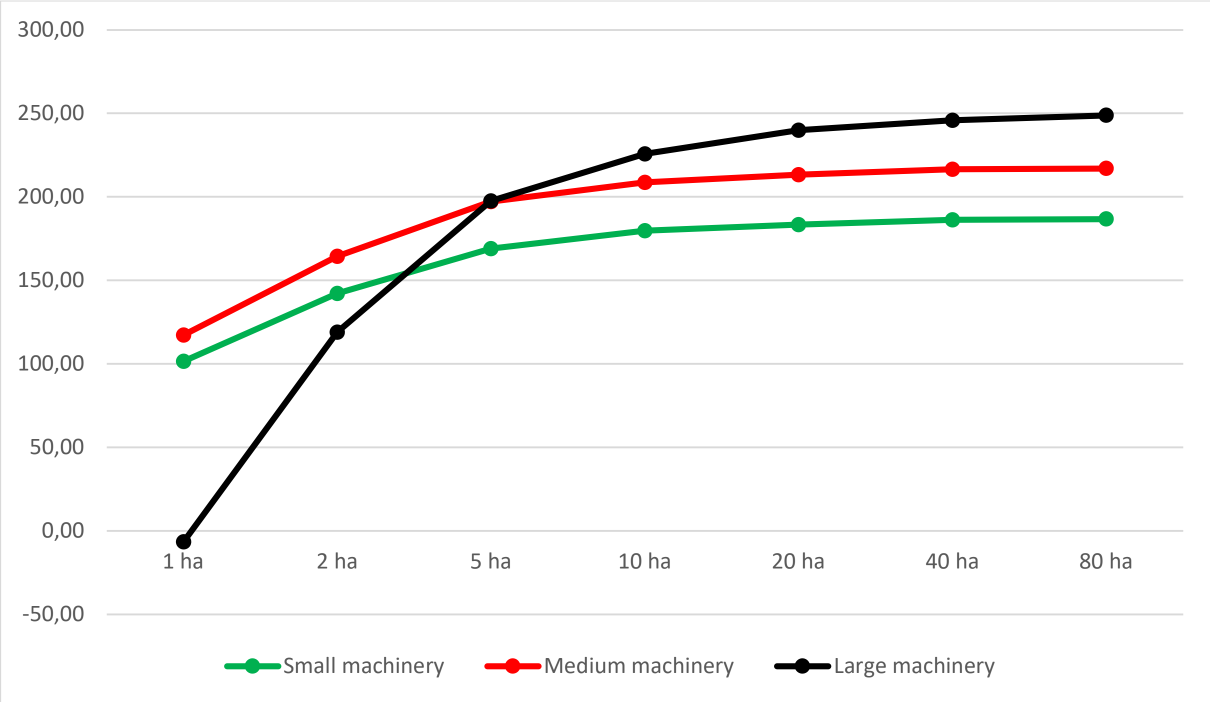


Figure 3 Absolute gross margin (in EUR) per ha (Winter Wheat) in comparison with the size of the machinery and the field size (Data from KTBL Deckungsbeitragskalkulation, 2020)

However, large fields do not always correspond with large farms, though these two factors are closely correlated and mutually support each other in the Czech Republic. In spite of that, when assessing productivity from a landscape perspective instead of the farm level, it appears that small and diversified farms yield higher productivity per ha than large monocultures. The inverse relationship between farm size and productivity or the paradox of scale (Tscharntke et al., 2012) is a well-known phenomenon. In conclusion, these factors can have an impact on the modelled situation and the eventual results.

2.3.2. Biodiversity and field size

Another issue frequently associated with field size in the Central European region is biodiversity. Although agricultural production and biodiversity may appear to be complete opposites, literature suggests a more complex relationship. Central European ecosystems have peculiarities such as "farmland species". These species have adapted to living in open agricultural landscapes, and in some parts of the Old Continent, they would not even exist without the presence of arable land, as stated by Reif and Vermouzek (2019). The agricultural landscape has been the most significant anthropogenic change to nature in Europe since the last ice age. Nevertheless, it has resulted in enhanced diversity of plants and birds due to the disruption and diversification of land use; an outcome that would be more uniform in human absence (Nátr, 2011). The open landscapes offer shelter to nearly 120 bird species in Europe's endangered list of fauna (SPECs), which is the highest concentration of such species inhabiting a single ecosystem. Recent research by Bezemer (2004), Reif and Vermouzek (2019), Stjernman et al. (2019), and Redlich et al. (2018) has shown that the scale of reduction in the population of these species is only comparable to the decline in the number of endemic species on islands after the introduction of non-indigenous predators (Donald et al., 2001). This work considers two of the nine prime reasons for the reduction of farmland species:

- The reduction in habitat diversity and the growing size of fields, along with mechanisation.
- The disappearance of hedgerows and other unproductive areas.

Various authors have described the influence of field size on biodiversity with examples from various landscapes around the world. Frühauf (2005) identified the factors that have the greatest impact on the most common species in farmland. One of these factors is the width of the field. They also hypothesised that field size plays a crucial role when combined with mechanised field operations.

Field size is included among the indicators of high nature value farmland (Bartel, Schwarzl and Süßenbacher, 2015). Small fields and connected grasslands or field margins contribute to landscapes with greater structural diversity. In addition, landscapes with finer structures have a significantly higher number of landscape elements. The variety of crops between field blocks enhances the structural diversity of agricultural landscapes, primarily through usage limits and varying temporal rhythms. The positive effects mainly result from the unused field margins and various crop rotation management periods, thereby influencing the abundance of farmland birds.

Stjernman (2019) discovered that interventions focused on land under production could be beneficial for farmland birds. Additionally, it was discovered that crop diversity positively impacted farmland birds, especially in uniform landscapes that lack interstitial semi-natural habitats. Redlich et al. (2018) discovered no advantages of crop diversity on the abundance of farmland birds, but they did incorporate field size in landscape heterogeneity, and as a result, found favourable effects on farmland birds. Fahrig et al. (2015) found that a reduction in average field size had a consistently beneficial effect on farmland biodiversity. The researchers emphasise that this effect is not a consequence of an increase in natural and semi-natural habitats. It is suggested that this effect is due to easier access to habitats at the field boundaries. Little evidence was found to suggest that farmland with higher crop diversity has higher biodiversity than simpler landscapes.

To accurately describe the differences between Central European landscapes, which are similar in some aspects such as climate, soil, and native vegetation, but different in others, such as landscape heterogeneity and diversity, a brief analysis of the known dissimilarities between Czech and Austrian agricultural landscapes was undertaken. Upon examining the yields, which indicates the agricultural intensity in both regions (refer to Figure 4), the similarities between both border regions becomes apparent. Therefore, agricultural intensity does not seem to be the major contributing factor to the biodiversity in the border region, despite the research conducted by Reif and Vermouzek (2019) who discovered that the intensification of agriculture in the Czech Republic, following its accession to the EU, had a negative impact on the number of farmland birds.

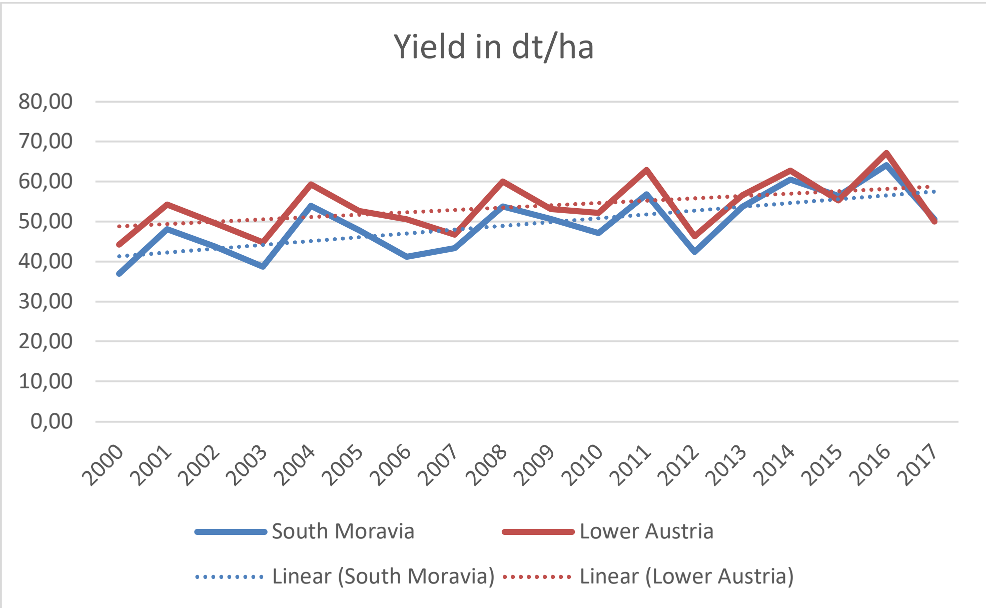


Figure 4 Winter wheat yield comparison between neighbouring regions in Austria and Czech Republic (Eurostat, 2019)

Upon comparing the most commonly used measure to assess the state of biodiversity, the Farmland Bird Index (FBI), represented by farmland birds, between Austria and the Czech Republic, one can see that the decline in Austria has been more pronounced than in the Czech Republic (see Figure 5). Nevertheless, the FBI merely represents the relative abundance of birds. Šálek et al. (2018) conducted a survey directly on the border that separates the two countries and identified significant differences in the absolute abundance of farmland species. Austria had 44%-59% higher bird abundance, 15% higher butterfly abundance, and 303% higher European hare abundance on its side of the border in comparison to the Czech Republic. Šálek et al. (2018) found that the species' abundance was highly correlated with the patch size or non-crop elements between fields. It was also discovered that practices linked with large fields, such as full-field mowing or coordinated harvesting, have a detrimental impact on the abundance of farmland birds and mammals. Smaller fields that are managed differently offer a safe haven for animals in the neighbouring alternative crop or non-crop areas.

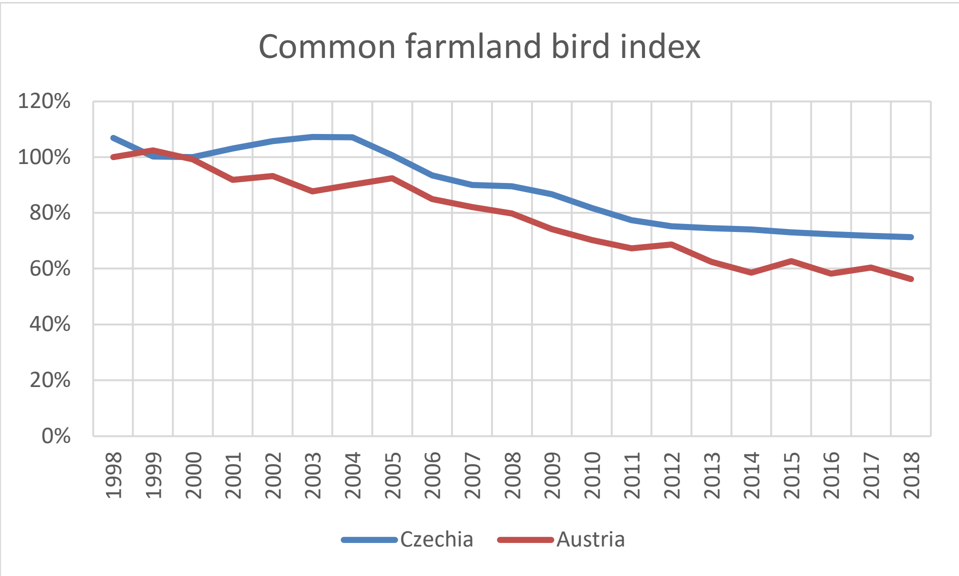


Figure 5 Common farmland bird index compared between Austria and Czech Republic (Eurostat, 2020)

In the context of agriculture in Central Europe, field size emerges as a vital factor that influences biodiversity. "Farmland species," which have adapted to these environments, highlight the impact of agriculture on ecosystems. Interestingly, human activities contribute to the increase in the variety of plants and birds, some of which are endangered avian species. Amidst this delicate balance, the interaction between field size and biodiversity provides a harmonious perspective that highlights the complex and mutually beneficial relationship that thrives in these landscapes.

2.3.3. Ecosystem service valuation and field size

Assessing the value of natural systems is of paramount significance in understanding ecosystem services. Biodiversity assessment and economic valuation directly linked to agricultural production are two fundamental approaches for evaluating these services. Although the public widely accepts economic instruments, ecological knowledge remains rudimentary. Therefore, a comprehensive strategy is necessary to address the challenges posed by dwindling ecosystem services (Nátr, 2011). Studies such as from Costanza et al. (2007) reveal the intricate relationship between biodiversity and agricultural production, demonstrating the cascading effects of even minor biodiversity reduction on primary production and overall ecosystem services.

The introduction of policies, like the 30 ha policy, creates a twofold challenge. On the one hand, it can act as a framework for scientific decision-making by accurately assessing the services that directly benefit agricultural production. On the other hand, applying such policies uniformly across diverse regions lacks the important regional adaptation required to achieve sustainable agricultural landscapes (Phalan et al., 2011; Tschartnke et al., 2012). Achieving harmony between production and conservation, which represent diverse interests, becomes an important necessity (Phalan et al., 2011).

The correlation between agricultural intensity and biodiversity appears in Figure 6 as a complex curve (Tscharntke et al., 2012). This essential correlation implies that small-scale variations in agricultural intensity can significantly affect the thriving of biodiversity and, therefore, agricultural production. This connection has been extensively documented in European landscapes. In contrast, systems such as tropical agroforestry manifest resilience, where biodiversity decline doesn't correlate with agricultural intensity (Tscharntke et al., 2012). The primary policy objective is to surpass the unfavourable curve by shifting towards a more positive one, which demonstrates the real association between agricultural intensity and biodiversity.

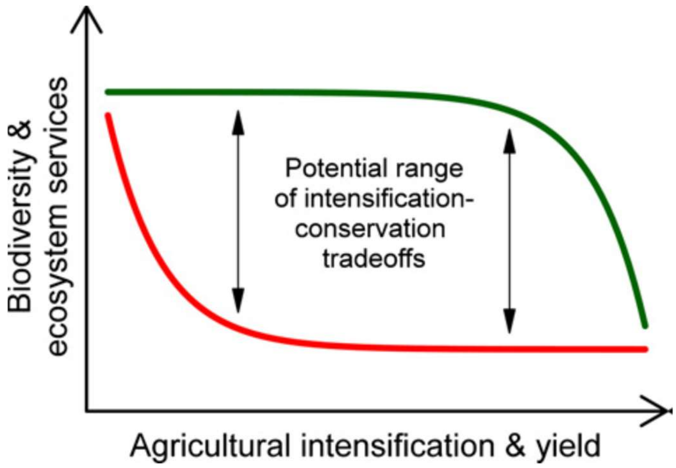


Figure 6 The relationship between intensified agriculture and biodiversity. (Tscharntke et al. 2012)

The size of fields is crucial in shaping ecosystem services, particularly in relation to pest control and pollination. Studies confirm that smaller fields promote higher levels of pest control and pollination, and landscapes with higher field edge densities exhibit significant increases in these services (Martin et al., 2019). However, challenges arise as farmers may not immediately observe these effects, unlike the immediately observable variations in variable costs (see again Figure 2). The use of managed pollinators and pesticides further complicates the delicate balance between ecosystem services and agricultural production (Kirchweger et al., 2020).

Limiting field block sizes is emerging as a strategy to increase biodiversity without compromising crop yield. However, there are broader implications that go beyond immediate outcomes. The significance of landscape fragmentation and erosion risks is increasing (Brázdil, Trnka, et al., 2015; Kapička et al., 2017). Visual aesthetics, which are a key component of rural landscapes, hold cultural value and diversify across regions such as Austria and the Czech Republic (Stotten, 2015; Pospěch, 2015). The public's perception of habitat destruction and landscape simplification highlights the importance of policy designs that balance ecological and social factors (Tscharntke et al., 2012).

The way forward requires a comprehensive strategy that combines economic instruments and ecological insights to reconcile the objectives of production and conservation. The 30 ha policy serves as an illustration but should cover regional variations. The sensitive balance between field size, ecosystem services, and agricultural productivity underscores the complex nature of viable agricultural landscapes. A comprehensive evaluation of the ecological, economic, and societal elements is critical for informed policy-making.

3. Materials and methods

To model the overall effects of the 30 ha policy, one must consider the effects on pollination services, while evaluating the economic impact and biodiversity effects. In order to accomplish this, the present thesis draws on a model created by Kirchweger et al. (2020), which I modified to suit the Czech context. The initial model was created to evaluate the simplification of the landscape which is happening in some areas of Europe. The model must be adjusted to simulate the inverse processes in the extensive cereal landscape of the Czech Republic. The adapted model is then applied to a landscape in the South Moravian region near Znojmo

The model comprises three modules, which are shown in Figure 7: the input data module, the bio-economic simulation module, and the response variables module. The following three sub-sections describe how each of these modules were implemented in Kirchweger et al. and modified for the Czech context in the present thesis. The remaining two sub-sections of this chapter then describe the study region and the implemented model scenarios.

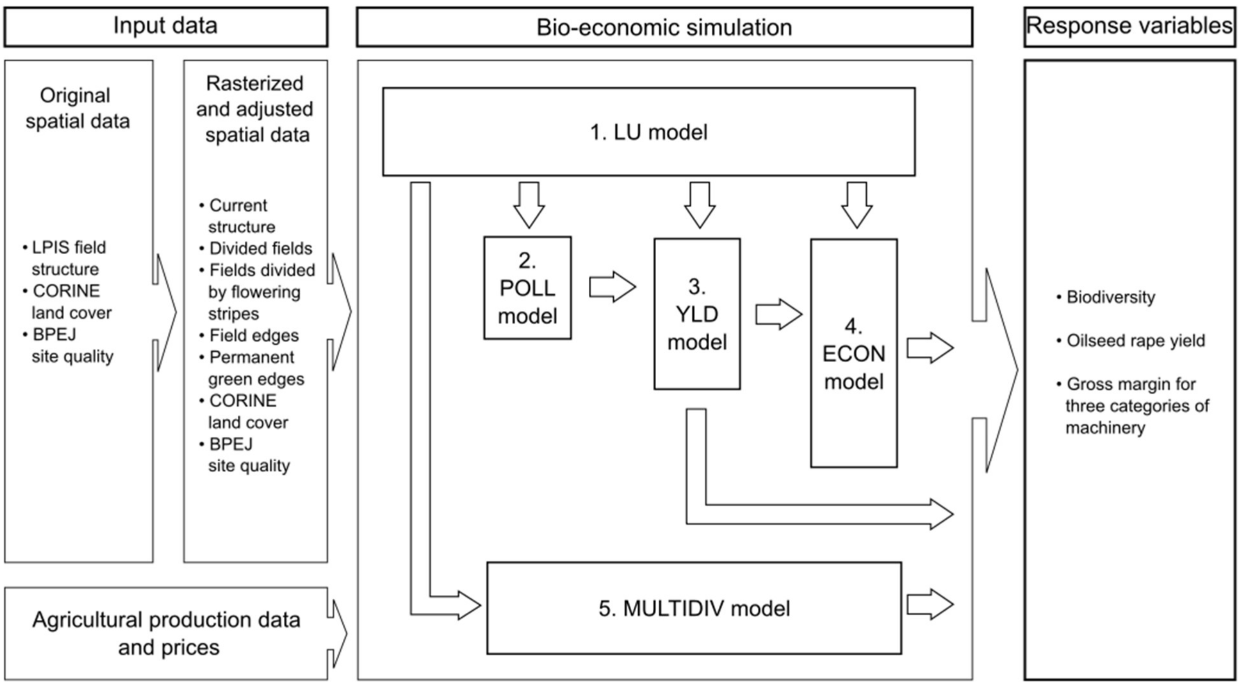


Figure 7 Overall modelling framework[1] (Own illustration based on: Kirchweger et al. 2020)

[1] The abbreviations used in the table are:
LPIS – Land Parcel Identification System, the system used for governmental evidence of agricultural land
CORINE – European landuse classification system

3.1. Input data

The bioeconomic model uses two primary dataset types: spatial data and production as well as price data. The spatial data comprises several datasets, including the Czech Republic LPIS (Land Parcel Information System), which covers the years 2016 to 2019, the CORINE land use cover layer (CLC2018), and the BPEJ, the land evaluation system used in the Czech Republic. Apart from the original model, the modified spatial data is used based on LPIS, where the landscape structure is changed based on the scenarios presented in section 3.6. These sources are used to generate explicit GIS layers that represent the landscapes. The layers are rasterised into grid cells of 25 x 25 m. It is assumed that every cell is homogeneous and uniform concerning site conditions, soil type, land use, and field edge information.

The GIS data obtained from LPIS were processed using ArcGIS software. In defining the division lines in the landscape structure, the assumption made was that farmers would divide their fields to reduce edge effects. Farmers might decide differently and divide their fields in another way based on their experience.

Two types of field edges are identified by the model. Normal field edges are defined by field boundaries and used for crop cultivation, whereas permanent edges contain permanent vegetation and have a total width of 4 meters for permanent green edges, as stated by Kirchweger et al. (2020). In my model, permanent field edges exist only on specific physical boundaries or in Scenario 3 to represent the renewed field roads. Normal field edges are used for agricultural purposes, but with lower yields and higher inputs due to the edge effects. The LPIS data was used to locate the edges and arable fields. I identified grid cells with overlaps and categorised them as normal or permanent green edges. Datasets for every scenario were adjusted manually to suit the modelled hypotheses using LPIS data. The first dataset contained status information, the second represented the simple field division scenario, and the third included flowering strips that were 22m wide.

BPEJ – soil quality classification system
LU – land use part of the model used to prepare the data
POLL – pollination model
YLD – yield model
ECON – gross margin calculation model
MULTIDIV – biodiversity evaluation model

Current land use is produced by combining the LPIS and CORINE layers. Land use is classified into four categories: arable land, permanent agricultural land, flower strips, and non-agricultural land. Arable land is subcategorized into eleven categories: winter wheat, maize, rape, lucerne, peas, summer barley, sunflower, sugar beet, winter barley, winter rye, and oil pumpkin. Arable land usage shifts over time. There is no available data on the specific varieties of crops grown in a particular Czech Republic region. The available data is solely from the governmental agency responsible for distributing state and EU subsidies to the farmers (SZIF, 2020). The data provides only averages for the entire Znojmo district. Consequently, it can be assumed that the field blocks in the selected area are proportionally used for the average crop shares from this data. Therefore, the actual crop grown in a specific field is determined based on the crop distribution in the whole district. Permanent crops are insignificant in the area of interest, and therefore, this class did not contribute to the calculations of agricultural output. The non-agricultural land use from the CORINE dataset considers the following land uses: The areas of settlement, forest, and green infrastructure are considered.

The CORINE data had to be adjusted to the appropriate coordinate system. This was accomplished using ArcGIS software to change the coordinates to the Czech JTSK-Krovak system. This issue emerged in the model as some of the exterior grid cells were without the CORINE land cover details. To resolve it, 198 grid cells were manually added and defined as arable land.

I used data from the BPEJ to add information about site conditions to the model. These four letters stand for the Czech "bonitovaná půdně-ekologická jednotka" - bonified soil-ecological units. The aim of the BPEJ is to assess the absolute and relative production potential of agricultural land. The BPEJ is characterised by a five-digit code representing climate, soil type, exposition and slope, soil depth and soil texture (VÚMOP, 2018). For the purpose of this paper, I only work with the relative production potential number. This number tries to evaluate the production potential for each soil type on a scale from 0 to 100, where 0 is the least productive land and 100 is the most productive soil in the Czech Republic. In case of missing values, I generate the missing data based on the adjacent grid cell.

The non-spatial data sources vary as I used different sources. The variable costs of machinery were obtained from KTBL (2020). Nutrient prices were obtained from Shaufler (2018). The prices of agricultural products, variable costs such as seeds, pest control and other costs were obtained from ÚZEI (2020). Labour costs were taken from Cook (2020). The exchange rate used is 25.2 Česká koruna per 1 euro, already in 2020 (ČNB, 2020).

3.2. *Bioeconomic simulation model*

The primary aim of the bioeconomic model is to convert input data into randomized land-use structures to simulate pollination, yields, economic and biodiversity effects. The model's results are subsequently presented through the response variables in the results chapter. The bio-economic simulation model is partitioned into five sub-models.

3.2.1. Land use model

The initial stage of the model combines the gathered data into grid cells measuring 25 x 25 metres. Each of these cells contains the information collected during the data preparation process.

To model the varying machine size categories alongside the differences in machine costs (outlined in the Economic Model chapter), the field blocks are categorised into seven groups sourced from KTBL (2020), for both the divided field block landscape and the original landscape, as shown in Table 1. The size range corresponds to the average size of the category. The category's value is utilised in the ECON model.

Table 1 The field size categories, Source: Own elaboration based on KTBL (2020)

Category	Field size (ha)	Size range (ha)	
1	1	0	<=1.5
2	2	>1.5	<=3.5
3	5	>3.5	<=7.5
4	10	>7.5	<=15
5	20	>15	<=30
6	40	>30	<=60
7	80	>60	

To simulate the landscape, four types of edges have been identified. The first is the perimeter of the field block, which I have regarded as permanent. The second is the physical field boundaries. The third type is the edges of fields in the simulated landscape and the fourth type of edges are the edges of the simulated landscape that has flowering strips.

Permanent crops and grassland are unaffected, whereas non-permanent agricultural land is simulated with a four-year harvest rotation. The crop for each year is assigned probabilistically, based on the observed proportion of each crop in the Znojmo district. To simulate crop rotation, a sampling function in R (function name 'sample') was utilized. The newly generated probabilities were used to replace the original values for arable land.

This process was conducted four times prior to the randomized four-year crop rotation simulation, as described in Kirchweger et al. (2020). Since there were variations in the results of the simulation as the model landscape is larger in size than the original model, the repetitions of the simulation were increased from 20 to 40.

The results of the LU model calculations are directly used in the POLL and MULTIDIV models, as shown in Figure 7. To calculate the YLD and ECON models, an average proportion of all crops is determined for each grid cell, as outlined in Kirchweger et al. (2020).

3.2.2. Pollination model

A spatially explicit, process-based approach is used to model insect-dependent crop pollination (Kirchweger et al. 2020). The focus is on winter-sown oilseed rape. Oilseed rape is grown on one tenth of the study landscape and is the primary insect-pollinated crop in the study region. Other insect-pollinated crops such as sunflower and oil pumpkin are marginal in this area (sunflower 2.62%; oil pumpkin 0.82%). An entirely new professional modelling framework would be required to include the pollination effects of these crops additionally to those of oilseed rape. Therefore, I do not include these crops in the POLL model.

Crop pollination depends on the pollinators, the amount and spatial arrangement of nesting and foraging habitat, and the seasonal dynamics of pollinator populations in response to land use. Permanent grassy field margins can provide nesting sites for solitary bees and bumblebees. Field margins also provide wild bees with pollen and nectar from the wildflowers they contain. In my scenarios, significant changes in the landscape lead to an increase in the density of field margins, which means an increase in nesting and foraging opportunities for wild pollinators. Changes in crop distribution affect pollinators in the short run, and changes in permanent structures affect wild pollinators in the long run. Here, I use a pollination model published by Häussler et al. (2017) and modified by Kirchweger et al. (2020). The POLL model was run 240 times by repeating the crop rotation sequence from 2016 to 2019 for 40 times. The simulation is run without resource manipulation over a cycle of seven land use maps as a burn-in period to level the wild bee population after initialisation (Häussler et al., 2017). The model integrates the number of bee colonies per ha, the average number of bee queens produced at the end of the season, the visitation rate to flower cover per ha and the average visitation rate to oilseed rape per ha (Häussler et al., 2017). I used the same parameters for the pollination model as in Kirchweger et al. (2020).

The impact of pollination on different crops does not include an assessment of the impact of the density of domestic beehives in rural areas. It only calculates the support of natural pollinators. This could be an issue because of the different socio-economic environments of beekeepers, which may be related to a different density of hives per square kilometre compared to the original pollination model. This could also alter the effects of natural pollinators (De La Rua et al., 2009). The original pollination model came from Sweden (beehive density <1 per km²) and was then applied to Germany (beehive density 1-3 per km²) and Austria (beehive density 3-5 per km²), and this work should apply it to the Czech Republic (5-7 per km²). Beekeeping could threaten natural pollinators by competing for resources (De La Rua et al., 2009). Some European countries have even banned commercially kept bees from protected landscapes (De La Rua et al., 2009). Therefore, the impact of beekeeping has been neglected in this model, but could be considered an important factor that masks the actual deprivation of natural pollinators in the study landscape.

The inputs to the POLL model are the randomised land use grid and the green edge grid for each scenario. The output is a spatially explicit share of pollination for oilseed rape, which is used for the YLD model if oilseed rape is grown at that location.

3.2.3. Yield model

The yield model emulates the grid cell specific yield for the crops. I assumed that agricultural yield in the study landscape was independent of farm specification, as the model simulates changes at a landscape level, not farm level. I considered the following aspects affecting yield: pollination effects, site quality and field edge effects (Kirchweger et al., 2020).

In the first step I estimated the yield (Y_c) for all crops (where C can have the following values 1 = winter wheat, 2 = maize, 3 = rape, 4 = lucerne, 5 = pea, 6 = summer barley, 7 = sunflower, 8 = sugar beet, 9 = winter barley, 10 = winter rye, 11 = oil pumpkin, 14 = flowering strips, numbers 12 and 13 are reserved for non-agricultural use and permanent crops). A regression is performed to model the correlation between the raster-specific site quality D and the crop-specific minimum and maximum yield: $Y_C = f(D)$. To estimate the yield, I asked a member of a local agricultural company (21,000 ha) to set these variables according to the yield achieved in this part of the Znojmo region. Using the coefficients $\widehat{\alpha}$ and $\widehat{\beta}$ and the grid specific site quality d_i, I predicted the yields in each of the grid cells ($y_{i,c}$):

$$\hat{y}_{i,c} = \widehat{\alpha} + \widehat{\beta} * d_i \qquad \textit{Equation 1}$$

This regression was based on the yield data from ČSU (2019). The source for the minimum and maximum yield values is based on expert consultation and the site quality data based on the BPEJ units.

In the next step, I evaluated the pollination effects on pollinated crops. The only pollinated crop for which I have sufficient data is oilseed rape (C=3).

$$y^*_{i,c} = y_{i,c} + y_{i,cp} * \left(\delta_{i,cp} - \bar{\delta}_{cp}\right)/\bar{\delta}_{cp} \qquad \textit{Equation 2}$$

Where $y^*_{i,c}$ is the grid-cell-specific pollination-effect-adjusted yield vector, which is made by conjuring the $y_{i,c}$ and $y_{i,cp}$ vectors. In the equation above $y_{i,c}$ is a grid-cell-specific yield vector calculated for all crops, $y_{i,cp}$ the original grid-cell-specific site-condition-based yield for insect pollination sensitive crops, $\delta_{i,cp}$ the grid-cell-specific pollination ratio for the crops calculated in the POLL model and the $\bar{\delta}_{cp}$ the average pollination ratio for the crops. To estimate the average pollination ratio, I researched the topic of rapeseed pollination. Several studies were conducted on this topic illustrated in Table 2. The studies most relevant to the geographical location and the spatial configuration are the studies from Austria and the new member states of Germany, suggesting an assumption that the yield of non-pollinated oilseed rape reaches 70 % of the yield of pollinated crop. I consequently assumed the non-pollinated oilseed rape yield level δ^o to be 0,7. The average pollination rate on the regionwide data was estimated to $\bar{\delta}$ (0,8).

Table 2 Studies about the oilseed rape pollination dependent yield

Yield increase	Area	Source
13 – 46 %	Canada	Gavloski, 2012
16 – 34 %	France	Mesquida et al., 1988
30 %	Eastern Germany	Radtke, 2013
5 – 20 %	Canada	Glen, 2017
30 %	Ireland	Stanley et al., 2013

19 %	Germany	Hudewenz et al., 2014
1000 kg/ha	Austria	Mandl, 2007

To be able to calculate the pure pollination effect, I needed to first calculate the scenario with no pollinators $y^o_{i,c}$. I do this by replacing the actual simulated pollination ratio $\delta_{i,cp}$ with hypothetical ratio without pollination $\delta^o{}_{i,cp}$.

$$y^o_{i,c} = y_{i,c} + y_{i,cp} * (\delta^o{}_{i,cp} - \bar{\delta}_{cp})/\bar{\delta}_{cp}$$ *Equation 3*

Field edge effects are the last thing to add to the YLD model. Empirical literature (Kapička, Brant et al., 2017) suggests significant yield depressions along the field edges, especially on the headlands where the machinery turns, causing soil compaction, and the inputs are applied unevenly because of the overlaps in the machinery trajectories. I, therefore, reduced the grid-cell-specific site-condition-based yield $y^*_{i,c}$ to consider this effect. The reduction was calculated by multiplying the yield with field edge yield depression factor εy_i (it can only lie between 0 and 1). This variable is included for the cells affected by the edge effects. The reduction factor is assumed to be 0.952, based on Kirchweger et al. (2020). The outcome is $y^{**}_{i,c}$ which is the field-edge-adapted grid-cell-specific site-condition-based yield. It can be illustrated like this:

$$y^{**}_{i,c} = y^*_{i,c} * \varepsilon y_i$$ *Equation 4*

The same was applied to the yield with no-pollination:

$$y^{oo}_{i,c} = y^o_{i,c} * \varepsilon y_i$$ *Equation 5*

There is a wide range of yield reductions at field edges and headlands, depending mainly on the crop grown, the block shape of the field, the topography and the size and age of the machinery. Precision farming practices, which are relatively common on large fields, could also change the edge effects. I followed the same assumptions as made in Kirchweger et al. (2020) based on Kapfer (2007). Yield depression was set to 30% on headlands and 15% on field edges. The negatively affected area was set at 8 m on the headlands and 4 m on the edges. I didn't have the information to identify the headlands, so I assumed that all edges included normal edges and headlands. Based on the prevalence of rectangular fields in the study area and the tendency to minimise headlands, the ratio of headlands to normal edges was set at two to one, as shown in Figure 8.

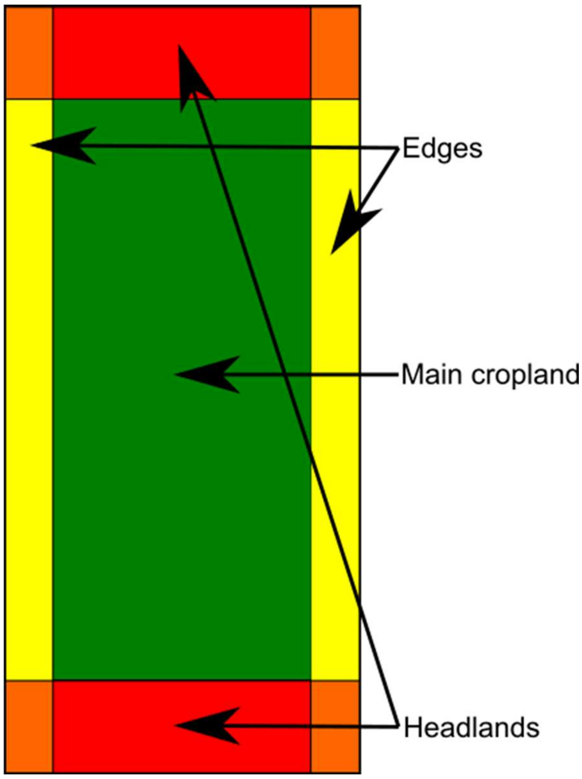


Figure 8 Headland and edges on the fields Source: Own illustration based on Kapfer (2007)

3.2.4. Economic model

The economic part of the model (ECON module) calculates the economic consequences of landscape changes for farmers at the landscape level. I used gross margin as an economic indicator because of its wide acceptance in economic landscape modelling (Parra-López et al., 2008). The gross margin excludes fixed costs, which are data intensive and were not needed for this model because I was trying to explain landscape changes, not changes in farmers' production structures. I split the ECON model into three categories, each calculated separately and representing different size categories of mechanisation. The splitting aims to evaluate the landscape changes from different points of view. From the perspective of small, medium and large farmers, each own different types of machinery and are therefore affected differently by changes in landscape structure. I separated three different sizes of machinery for the model: 'small', representing the category of machinery with a power of 67 kW, 'medium' - 102 kW or 'large' - 240 kW. The calculations in the model and the results were then carried out for these three categories separately. The field size categories are also considered in the ECON part of the model.

To calculate the gross margin of each machinery category, I subtracted the variable costs from revenue. The gross margin (π_{ix}) where x represents the category of the mechanisation and can take on a value of S for small machinery, M form medium machinery and L for large machinery, is calculated for each grid cell i as follows:

$$\pi_{ix} = r_i - c_{ix} = r_i - (cf_i + cy_i + co_i + cm_{ix}), \qquad \textit{Equation 6}$$

where π_{ix} is the gross margin per grid cell and per machinery size category, r_i are the revenues per grid cell and c_{ix} the variable costs per grid cell and machine size category. The variable costs are subdivided into fertilizer costs (cf_i), yield depending variable cost (cy_i), other costs (co_i) and the field size category depending variable costs (cm_{ix}).

For zero pollination calculations differ slightly and can be expressed as follows:

$$\pi_{ix}^{00} = r_i^{00} - c_{ix} = r_i^{00} - (cf_i + cy_i + co_i + cm_{ix}), \qquad \textit{Equation 7}$$

where: π_{ix}^{00} is the zero pollination gross margin per cell and per machinery size category, r_i^{00} are the zero pollination revenues per grid cell and c_{ix} the total variable cost. The costs are calculated the same way as for the pollinated crops.

Revenues are calculated by multiplying the crop yields ($y_{i,c}^{**}$) with respective sales prices (yp_c). Multiplying these values with grid-cell-specific crop rotation shares ($s_{i,c}$) and summing the results, I can get the grid-cell-specific revenues. Revenues for the model without pollination are done in the same way but use the zero pollination crop yields $\left(y_{i,c}^{oo}\right)$. The difference to the Kirchweger et al. (2020) model is that I didn't include public payments into the revenue calculation. The revenue calculation is illustrated as:

$$r_i = \sum_{c=1}^{C}\left(y_{i,c}^{**} * yp_c\right) * s_{i,c}, \qquad \textit{Equation 8}$$

and for zero pollination as:

$$r_i^{00} = \sum_{c=1}^{C}\left(y_{i,c}^{oo} * yp_c\right) * s_{i,c}. \qquad \textit{Equation 9}$$

The fertilizer costs part is taken unchanged from Kirchweger et al. (2020). The fertilizer prices were adjusted for Czech context based on prices from Schaufler (2018). Firstly the 75 % quantile of the previous yield based on the YLD model is calculated. The quantile was based on the assumption that the farmers tend to expect higher than median yields and orient their fertilization strategy at the 75 % quantile of the observed yields ($y_{i,c}^{*}$) within each single field (j), which determines the amount of the fertilizers the farmers use. The calculation can be depicted a follows:

$$y_{j.c}^{Q75} = Q_{0.75}\left(y_{i,c}^{*}\right). \qquad \textit{Equation 10}$$

Furthermore, rhizobia nitrogen fixation is considered. In addition to Kirchweger et al. (2020), who calculated the nitrogen fixation for peas only, I added the alfalfa crop to the calculation because it is also a nitrogen fixating crop.

The next step is the fertilizer demand in the field edges, which was calculated similarly to the yield depressions in the YLD model. Using the same approach as the yield depression on the field edges, the edge effect factor εx_i was assumed to be 1.048 based on Kirchweger et al. (2020) and was applied in each grid cell with field edge effects. The grid-cell specific fertilizer calculation ($f_{i,n}^{*}$) for each nutrient is depicted as:

$$f_{i,n}^{*} = \sum_{c=1}^{C} y_{j,c}^{Q75} * m_{n,c} * \varepsilon x_i * s_{i,c}, \qquad \textit{Equation 11}$$

where $y_{j,c}^{Q7}$ is the estimated expected yield for each crop c and field j, $m_{n,c}$ the nutrient removal for crop c and nutrient n. This is further multiplied with the edge factor εx_i and the share of each crop within a grid-cell $\left(s_{i,c}\right)$.

In the next step, I add the biologically fixated nitrogen ($n = 1$). The yield of each crop fixating nitrogen ($y_{i,cn}^{**}$) of each crop which fixes nitrogen (cn) is multiplied with the nitrogen surplus rate ($sur_{n=1,cn}$) and the grid-specific share of the crop for the field ($s_{i,cn}$). The surpluses are then summed and subtracted from the fertilizer amount ($f_{i,n}^{*}$) from the previous calculation. The biological nitrogen fixation occurs in my case with two crops. These are peas ($cn = 4$) and alfalfa ($cn = 5$). The calculation is depicted as follows:

$$f_{i,n}^{**} = f_{i,n}^{*} - \sum_{cn=1}^{CN} y_{i,cn}^{**} * sur_{n=1,cn} * s_{i,cn}. \qquad \textit{Equation 12}$$

The last step is the multiplication of nutrient-specific fertilizer quantities ($f_{i,n}^{**}$) with the nutrient-specific prices (fp_n) per unit to retrieve the total fertilizer costs for each crop. This is depicted as

$$cf_i = \sum_{n=1}^{N} f_{i,n}^{**} * fp_n. \qquad \textit{Equation 13}$$

Next is the yield dependent variable cost (cy_c), containing mainly transportation, drying, and cleaning costs. It was not possible to obtain specific data for the Czech situation. Thus, these costs were assumed to be identical to those used in Kirchweger et al. (2020). The data are multiplied with the yield data from the YLD model and the crop rotation data from the LU model.

The other costs (co_i) include the costs independent of the field size and the sizes of the machinery. Namely, it considers the costs of seeds, pesticides, and further costs such as insurance (ÚZEI,2020).

In the next part I developed a whole new part of the model where landscape changes could be assessed not only in terms of changes in edge density and changes in pollination, but also in terms of working time and machinery costs associated with changing field block sizes. These changes could have a significant impact depending on the mechanisation of farms The calculation works with the categorisation from the LU part of the model and the categorised variable costs of machinery and labour obtained from KTBL (2020). I decided to include labour costs in the model because the indicators from Cook (2020) show that the number of hired workers on Czech farms is much higher than in Austria or Germany. For example in 2012 only 13.6 % of agricultural labour was salaried in Austria, compared to 75.6 % of directly salaried workforce in Czech Republic. It is common practice in Czech agriculture to add labour costs directly to the calculation of gross margins (e.g. Poláčková, 2010). The only part that is added as fixed is holiday pay, which is difficult to allocate directly to labour. The change in the amount of work is crucial to the argument for the large field blocks, as they consider many machine operations unnecessary and therefore save a considerable amount of time at the landscape level. For traditional family farms in older member states, time spent in the field is an aspect that does not need to be included in the calculation, as usually most work is carried out by unpaid family labour and thus the associated costs are not part of the gross margin.

The calculation for the field size category dependent on variable costs (cm_{ix}) was done as follows. First, the variable costs for each field size and machinery category (cm_g) for field size category (g) are loaded into the model. The values are multiplied by the field size category from the LU model (pc_g). This variable has a value of 0 or 1, so the multiplication returns the values for the right field size category only. Obtained values are then multiplied by grid-specific crop shares ($s_{i,c}$). This calculation is done for three categories of mechanisation separately. This can be illustrated by the following formula:

$$cm_{ix} = \sum_{g=1}^{G} (cm_g * pc_g) * s_{i,c} \qquad \textit{Equation 14}$$

3.2.5. Multiple diversity model

The MULTIDIV module is used to assess the impact of different scenarios on biodiversity. The underlying model is based on the Multitrophic Diversity Index developed by Sirami et al. (2019) to identify the effects of semi-natural habitats and the spatial diversity of semi-natural habitats in the landscape, as well as the effects of reducing the average plot size on overall biodiversity. The study was carried out in eight agricultural landscapes in the northern hemisphere. Seven different taxonomic groups of organisms were sampled and a synthetic Multitrophic Diversity Index was calculated. The effects assessed are shown in Figure 9.

Since Sirami et al. (2019) described and modelled the effect of decreasing mean field size, I decided to use it in my study, as it is the best index available so far, but with some inconsistencies.

I use the same method as Kirchweger et al. (2020) to generate the multi-diversity model. I use three explanatory variables calculated from the landscape and edge raster, similar to the original study by Sirami et al. (2019). The variables are: crop diversity, mean field size in ha, and the proportion of semi-natural habitats in the landscape. I intentionally left the three covariates set to the same values as chosen in Kirchweger et al. (2020), because the study area of their study is the closest to my study area and no specific data for the Czech study landscape was available.

For this thesis, the data obtained from the MULTIDIV part of the model must be considered carefully. The spatial heterogeneity of the study area is very low, and there is little information on biodiversity in landscapes with such low spatial heterogeneity. In Sirami et al. (2019), the maximum mean-field size they mapped was slightly larger than 12 ha. In the first scenario of the present thesis, the mean field size was more than 19 ha, which decreased to 11 ha in the last scenario.

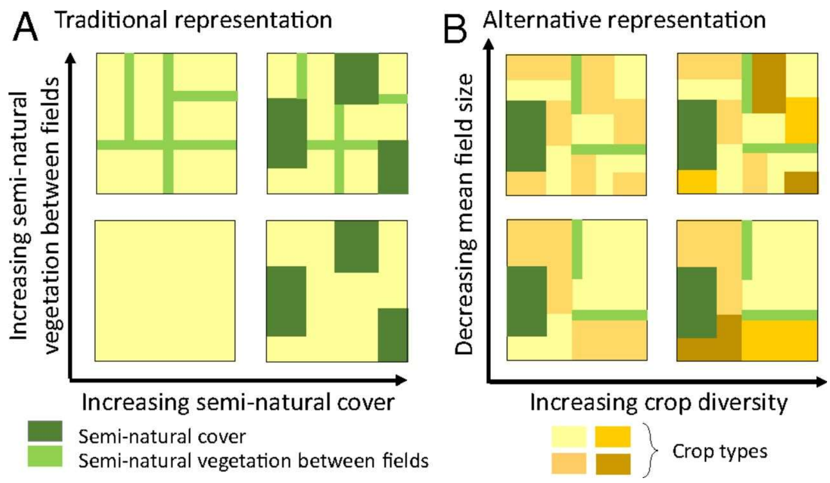


Figure 9 The MULTIDIV model representation Source: Sirami et al. (2019)

3.3. Response variables

An overview of the response variables of the model is presented in Table 3. Ecological changes in the modelled landscapes are described using the multi-diversity indicator. The impact of landscape changes on the biophysical production of crops is described using oilseed rape yield as a response variable. The agronomic description of the result is yield per ha. The following three response variables are similar and represent the gross margin at the landscape level and per ha of arable land. Each of these response variables is calculated for different machine size categories and can assist in explaining the effect of landscape changes on various machinery sizes.

Table 3 Description of response variables

Response variable	Unit	Description
Multi-diversity	Z-score	Average standardized species richness
Oilseed rape yield	dt/ha	Average yield of oilseed rape per ha
Gross margin small machinery	€/landscape €/ha	The sum (or average) of grid cell-specific gross margins of the landscape with small (67 kW) machinery
Gross margin medium machinery	€/landscape €/ha	The sum (or average) of grid cell-specific gross margins of the landscape with medium (102 kW) machinery
Gross margin large machinery	€/landscape €/ha	The sum (or average) of grid cell-specific gross margins of the landscape with large (240 kW) machinery
Pollination contribution to oilseed rape yield	dt/landscape dt/ha	The difference of simulated oilseed rape yield between simulated landscape with and without pollination
Pollination contribution to gross margin	€/landscape €/ha	The difference of simulated oilseed rape contribution to the gross margin between simulated landscape with and without pollination

To assess the economic (income) and agronomic (yield) effect of field subdivision, I compute the last two response variables that represent the contribution of pollinators to yield. The calculation pertains to the agronomic and economic variables. I estimated the impact of pollinators on the yield and gross margin of oilseed rape for the whole landscape of the study region and per ha in these response variables.

3.4. Study region and landscape

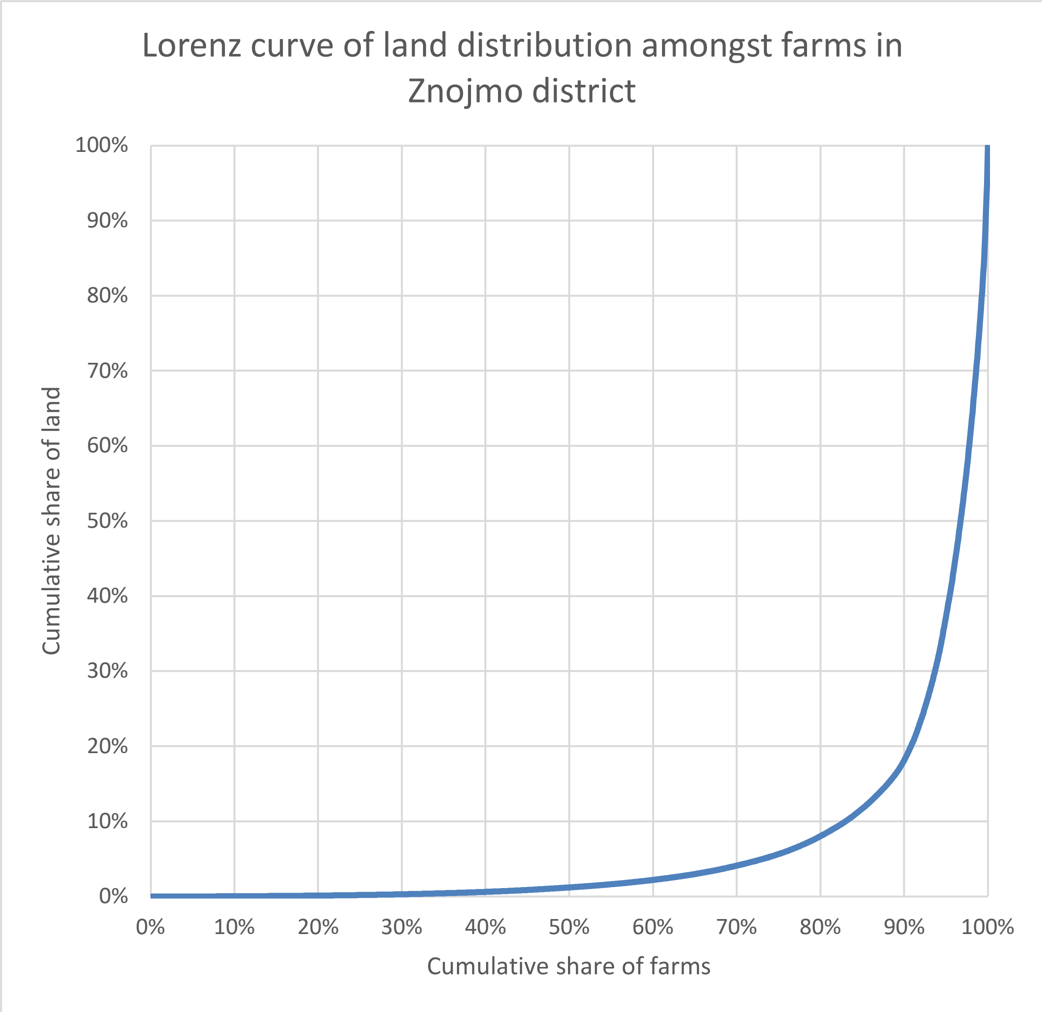
In this work, the area I describe is evenly distributed around the town of Znojmo, the former district of Znojmo. This region is located in the plain around the Dyje River and is about 200-250 m above sea level. According to the Ministry of Agriculture of the Czech Republic (2019), this region is the warmest part of the country, with an average temperature of 9.3°C. The main crops grown are winter wheat (about 30%), maize (about 20%), rape (about 10%), alfalfa (about 9%), peas (about 6%) and summer barley (about 5%) (SZIF,2020). Various vegetables are grown on irrigated land. Vineyards and orchards are also important in this area. (ČSU, 2017)

The average plot size of arable land is 9.75 ha. In the Znojmo district, 44.5% of the arable land is cultivated in a field block larger than 30 ha (LPIS 1.6.2016, own calculation). In addition, 25% of the arable land is cultivated in plots larger than 60 ha. The distribution of land between farms is shown in Figure 2.

One possible flaw in these figures is the relationship between farms. Some giant farms have the same owner or are members of a holding (Medonos et al., 2011). If I'd taken this information into account, the duality of land division would have been even more significant.

The proximity of the border has some other influences on the structure of the Znojmo district. Sklenička et al. (2014) discovered the differences between the nationwide structure of the landscape and the structure of the border region due to its special regime during the Iron Curtain period. In recent years, the value of land has increased. Austrian farmers buying land on the other side of the border could have a significant influence on its price. Therefore, land prices are around 26-30 Kč/m2, one of the highest in the Czech Republic (FARMY.CZ, 2019).

I chose this landscape because it represents a landscape without villages, is generally flat, and is ideal for the creation of large field blocks. It lacks extensive semi-natural habitats and contains only rectangular fields, which are easy to divide manually and use for the model. The locals call it "America" because of its flatness and wide fields. I will use this name for



further reference.

Figure 10 The land distribution amongst farms in the Znojmo district (own processed data from LPIS, 2020)

The main characteristics of my study landscape "America" are the following The average soil quality is 80.2 points. It is an area with one of the best soils in the Czech Republic. The average field size is 19.5 ha, the field size structure is shown in detail in Figure 11. The share of arable land in the total area is 85%. The total length of field boundaries is 116 km. Permanent crops account for 0.5 % of the study area and semi-natural areas for 5.4 %. The semi-natural habitats consist mainly of windbreaks, abandoned sand pits, small field woodlands or decaying dung pits.

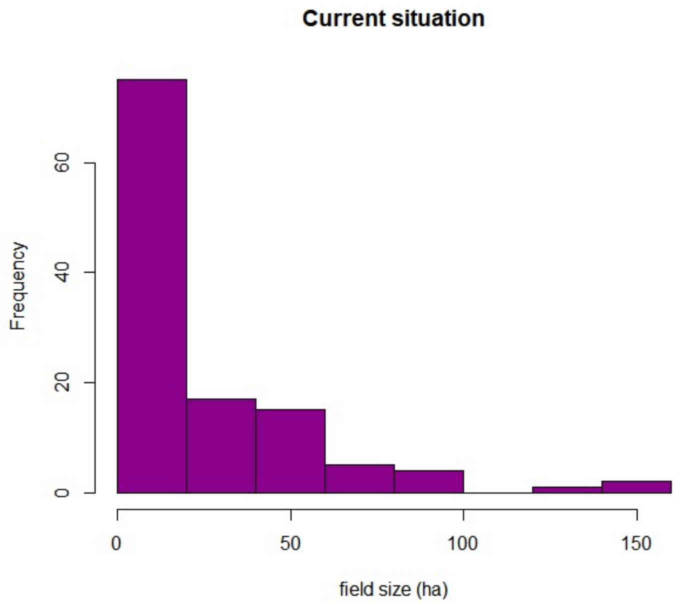


Figure 11 The current field size distribution in "America"

3.5. Model scenarios

I develop four scenarios. The first scenario models current land use, while each of the remaining 3 scenarios represents a different strategy for complying with the new policy. Each scenario contains a different structure of field edges, permanent edges and flowering strips, depending on the strategy adopted. Each scenario is described in detail in what follows.

Scenario 1 – Landscape unchanged

The first scenario represents the landscape as it was assumed to be on 1.6.2019. The landscape structure of this scenario is shown in Figure 12. The average field size in this scenario is 19.5 ha, with fields as large as 150 ha. The total number of fields in the landscape was 119. The crop composition was simulated in the LU model chapter. The edges between the fields are not considered as green, as it is common to use the fields up to the edge, mainly due to the direct payment policy (Marada, 2011). However, I consider the outer edges of the large field blocks as green because the field boundaries are often adjacent to unpaved field tracks, windbreaks and other landscape structures. I carried out an aggregation of the field, ignoring the inner boundaries but identifying the outer edges shown in Figure 12. These edges were considered green for each of the following scenarios.

Figure 12 The landscape structure in Scenario 1 Source: Own processing, based on LPIS

Scenario 2 – Multiple cropping

The first hypothesised response strategy of farmers in the landscape and the most straightforward is to grow multiple crops adjacent to each other in such a way that the field blocks with a single crop larger than 30 ha would be divided into several field blocks with different crops, each with a maximum size of 30 ha.

For this scenario, I took the raw landscape structure data from 1.6.2019 and manually divided the fields in ArcGIS software. To make the division as simple as possible, I tried to reduce the length of the field edges. It is possible that farmers would decide otherwise to minimise headlands or to simplify harvest logistics. Other motivations depend on the accessibility of the plots, the existence of infrastructure, the optimal trajectories to the fields, the size of the machinery and its trajectories or the optimal constitution of the fields also depends on the terrain configuration (the general flatness of the study landscape supports the theory of simple division for this model). However, as this model is mainly concerned with the edge effects on yield, I have tried to minimise edge effects. The resulting landscape is shown in Figure 13. The characteristics of the landscape then changed compared to Scenario 1. The average field size decreased to 14.02 ha and the number of fields increased from 119 to 190.

Figure 13 Landscape structure after the 30-ha division Source: Own processing based on LPIS

Scenario 3 – Field roads renewal

The Czech landscape is one of large fields. However, the field structure often doesn't respect the structure of the landowners. To illustrate the situation, I have created an example. I use the cadastre of the South Moravian villages of Nový Šaldorf and Znojmo - Louka (Figure 14). Figure 15 shows all the plots of land that were intended to be used as country roads but are currently in use. The land is owned by the state or the municipality. A comparison is made between the current situation and the possible use of old field roads as field dividers. If all roads were renewed, the maximum size of a field block in this example would change from 99.6 ha to 23 ha, and the total length of roads (permanent green edges) would increase from 9.65 km to 24.3 km. Therefore, the maximum plot size in that case would be even smaller than 30 ha and the field roads would have the effect of a permanent green edge. The benefit of this measure would be the presence of a permanent line structure in the landscape, without the need to grow multiple crops on adjacent field blocks. This could mean the reduction of costs associated with harvest logistics. As the policy is already being applied as I write these lines, I can already say that this solution is widely used by farmers.

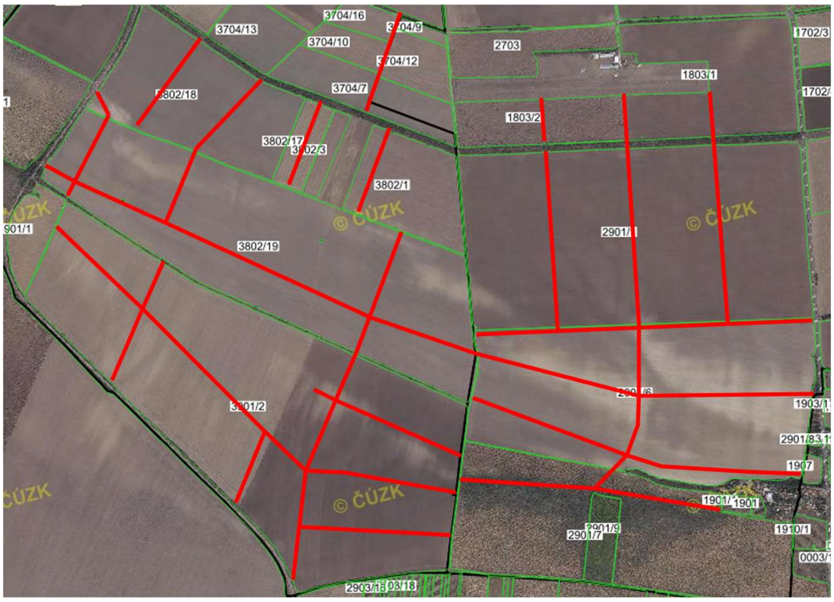


Figure 14 Currently unavailable field roads as present in the land registry (Own processing based on: LPIS, 2020; ČUZK,2020)

Figure 15 Current state of land use with field roads utilised as arable land (Own processing based on: LPIS, 2020; ČUZK,2020)

This scenario is applied to the model in the following way. Since only some of the field roads are suitable for the farmers, and it would be counterproductive to renew them, I assume that the subdivision lines in the landscape used in scenario 2 are the same as those used for the field roads in Scenario 3. This assumption also serves to simplify the model and leads to better comparability. The difference is that I consider these edges to be green and permanent compared to Scenario 2. The proportion of semi-natural habitats increases from 5.32% to 5.45% and the length of semi-natural edges increases from 116,450 metres to 184,025 metres. The size of the arable fields stays the same as in Scenario 2. The resulting landscape structure is shown in Figure 16.

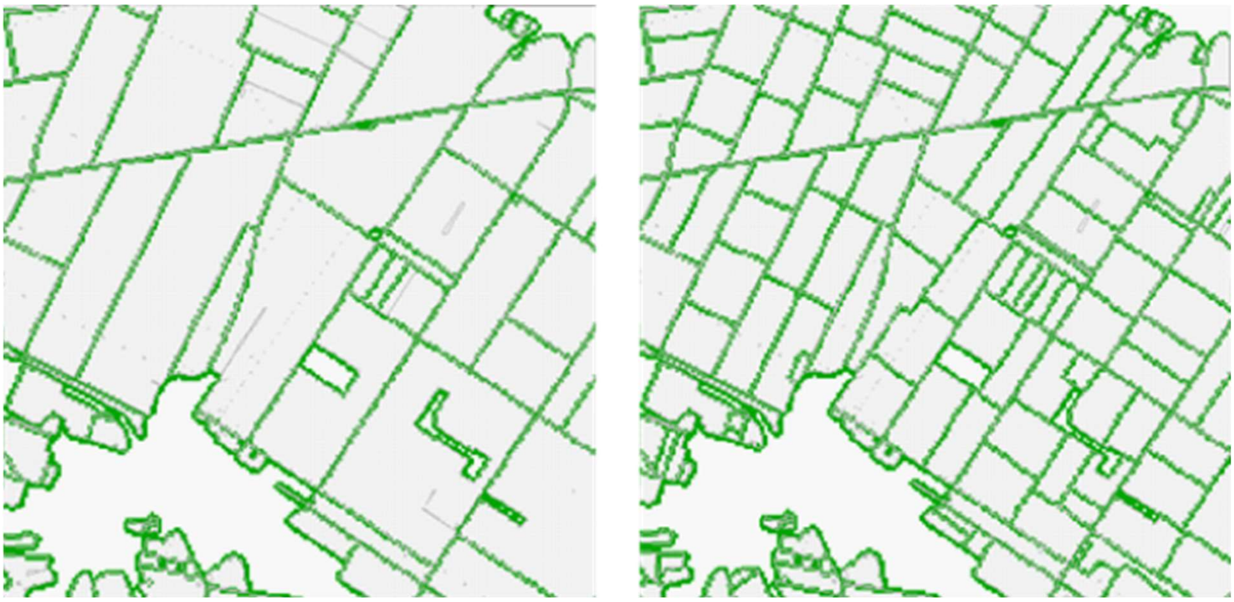


Figure 16 The green edges infrastructure in Scenario 1 compared to Scenario 3 Source: Own processing

Scenario 4 – Flowering strips

The hypothesis for this scenario is that fields with single crops larger than 30 ha would be divided by strips of flowering plants. The minimum width of a strip is 22 m and the crops that can be used for the protective strips are defined in § 14 odst. 4 NV 50/2015 Sb. namely: white mustard (Sinapis alba), peas (Pisum sativum subsp. sativum, Pisum sativum subsp. elatium), clover (Trifolium), melilot (Melilotus), buckwheat (Fagopyrum esculentum), proso millet (Panicum miliaceum), radish (Raphanus sativus), lacy phacelia (Phacelia tanacetifolia), eggs and bacon (Lotus corniculatus), plants of the genus Medicago (including alfalfa), vetch (Vicia), dill (Anethum graveolens), coriander (Coriandrum sativum), flax (Linum usitatissimum), cress (Lepidium sativum), grasses of the genus Poaceae, excluding cereals, or a mixture of the above.

The model for this scenario is again made with the same division lines as in scenario 2. The difference is in the division boundaries. Using ArcGIS, I manually created new fields, 22 metres wide, containing flowering strips as a predefined crop. There are two ways to approach the problem for the model. The first is to model the inclusion of multivarietal flowering strips with a long flowering period, which are optimal for supporting pollinators and are addressed by the pollination model developed by Kirchweger et al. (2020). The other possibility is to assume that farmers use the cheapest and most common variety, such as lacy phacelia. I considered the widely grown white mustard, but the seed, drilling and machinery costs for these two crops were almost identical. In modelling the multi-variety mix, there could be an inaccuracy in the price paid by the farmer for the seeds (multi-variety mixes are more expensive to grow), or there could be an inaccuracy in the pollination model due to the limited flowering period of these single-variety crops. I tried to model both possibilities and the results of the model didn't change the overall result. I therefore chose the single-crop variant of the model to present the results. The edges were considered to be non-green and non-permanent. Compared to Scenario 1, the average field size decreased to 11.92 ha. The structure is shown in Figure 17.

Figure 17 Landscape structure with flowering stripes (red) Source: Own processing based on LPIS

4. Results

This section displays the findings of the landscape model analysis, which is presented in Figures 18-24. The analysis indicates results at both landscape and ha levels. At the landscape level, the results depict the cumulative impacts across the entire landscape of the study region. At ha level, the outcomes have been determined by dividing the cumulative results by the utilised agricultural area. In addition, figures 19-24 differentiate between effects caused by non-pollination factors (blue) and those induced by pollination (yellow). To provide greater clarity on the variations in scenarios, a comparison graph is provided for each result chart. The outcomes are divided into three main sections. The first section illustrates the biodiversity score calculated for the entire landscape. The second section shows the oilseed rape yield at both landscape and ha levels. This section demonstrates pollination effects, as oilseed rape is the only crop in the simulation that is pollinated by insects. The last section presents the results of the gross margin calculation at the landscape and ha level. The outcomes are split into three machinery categories to simulate different mechanisation size categories. For more comprehensive results, please refer to the tables in the appendix.

In Figure 18, the modified biodiversity scores are shown and how they changed in the simulated landscapes. At first, the model results were negative because it was created to simulate biodiversity scores in landscapes that exhibited higher spatial diversity. (Sirami et al. (2019) reported the largest average field size landscape as 12 ha.) For this reason, the biodiversity score of the unchanged landscape (S1) was adjusted to a value of one, and all other scenarios were modified accordingly. If the blocks were divided simply (from S1 -> S2), the biodiversity increased by 0.11, achieving 1.11. Incorporating a structural element (S1 -> S3) in the basic division shows a rise of 0.12 in biodiversity. This translates to an increase of 0.005 compared to the S2 scenario. On the other hand, the existence of flower strips (S4) triggers changes in both the biodiversity and landscape, resulting in an increase of 0.19 in biodiversity when contrasted to the primary S1 scenario. The acquired results establish the hypothesis that augmenting the landscape heterogeneity will lead to an increase in the biodiversity index.

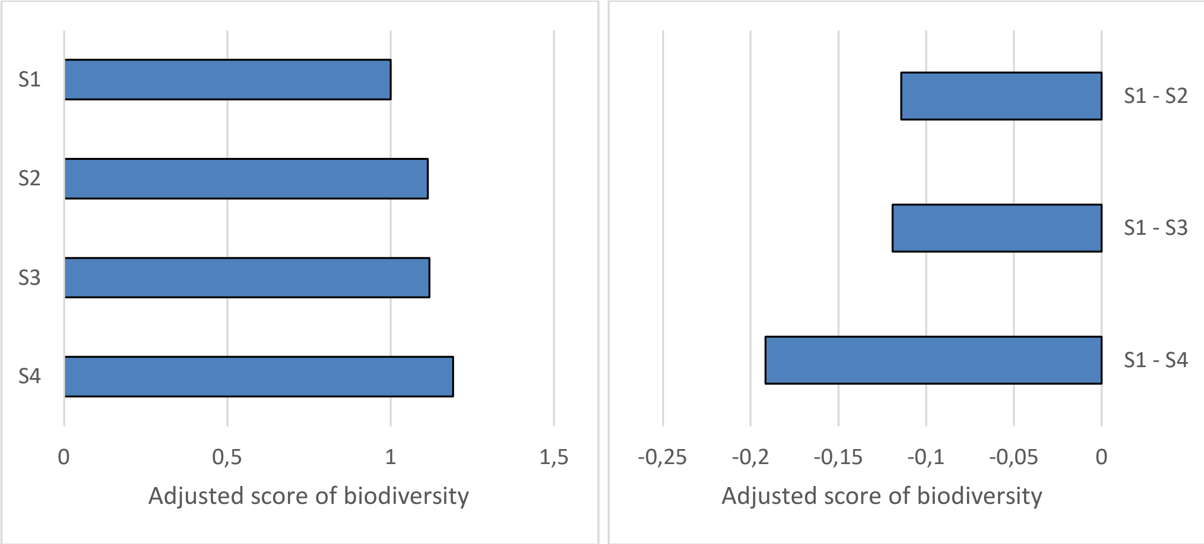


Figure 18 Adjusted biodiversity score results in different landscapes and the effects of landscape changes (left) and the comparison between the scenarios (right).

Source: Own calculation

Figure 19 presents the yield of oilseed rape in dt/ha. In the status quo scenario (S1), the yield of oilseed rape is estimated to be 33.51 dt/ha, with a contribution of 2.19 dt/ha from pollination. An average yield of 33.69 dt/ha is observed with pollination contributing 2.44 dt/ha in the scenario with simple subdivision (S2). The yield of oilseed rape is 33.71 dt/ha with a contribution of 2.46 dt/ha from pollination when field roads are present. The scenario with flowering strips shows the highest yield per ha at 33.77 dt/ha with a contribution of 2.55 dt/ha from pollination. The data suggests that pollination compensates for the loss caused by edge effects on a per ha basis.

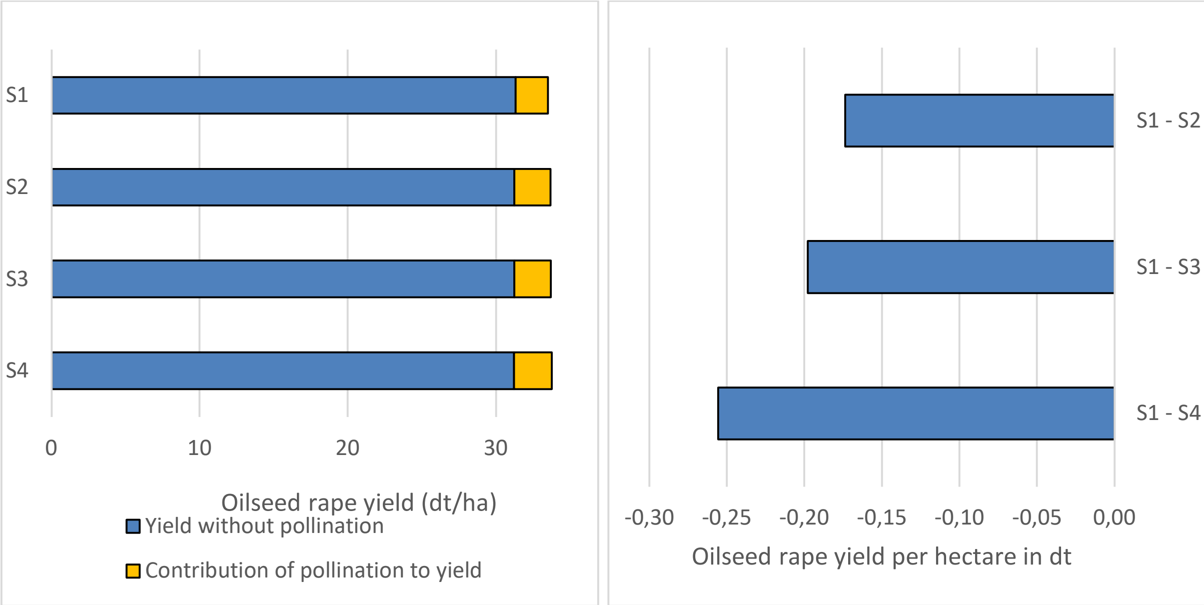


Figure 19 Mean results of oilseed rape yield in dt per ha for various simulation scenarios (left) and the comparison between the scenarios (right). Source: Own calculation.

Figure 20 displays oilseed rape yield results in dt at the landscape level. S1 has a yield of 6739 dt/landscape, while S2, S3 and S4 have yields of 6670 dt/landscape, 6664 dt/landscape, and 6347 dt/landscape, respectively. Contrary to the average yield, the landscape results demonstrate that the pollination at the landscape level does not compensate for the loss caused by edge effects.

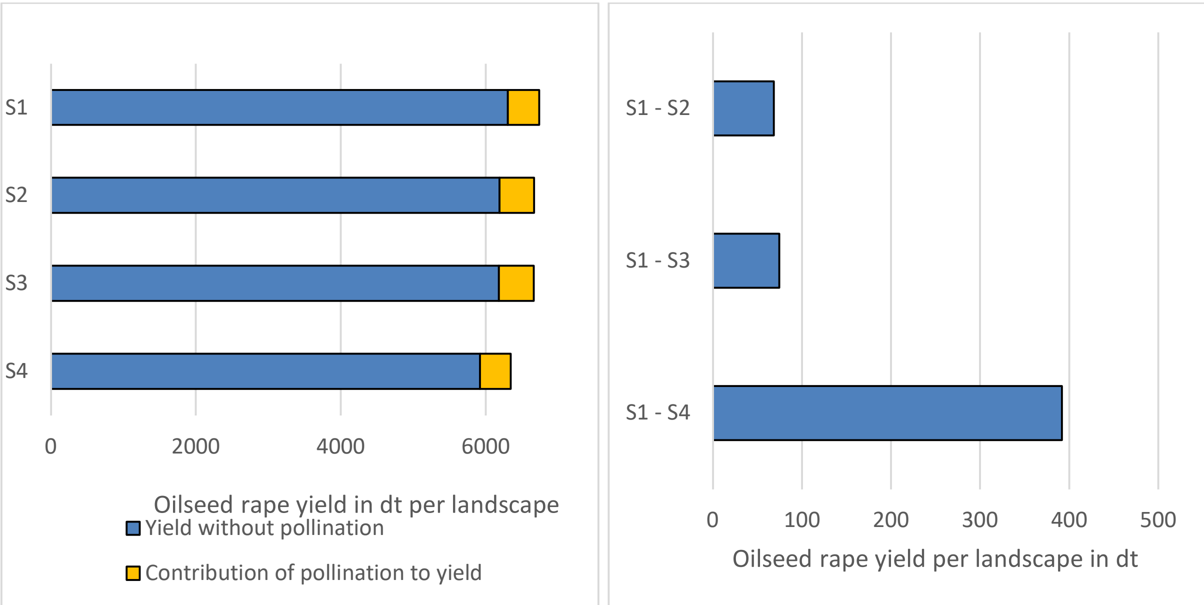


Figure 20 Landscape results of oilseed rape yield in dt for various simulation scenarios (left) and the comparison between the scenarios (right). Source: Own calculation.

In Figure 21, the gross margin per ha is presented, including the changes when comparing the scenarios based on their machinery size categories. The outcome exhibits the extent of alterations in gross margin per ha. Within the status quo scenario, the large machinery category obtains the highest gross margin (426.9 euro/ha). The smaller-sized machines (medium and small machines) yield lower gross margins in the current situation. Specifically, medium-sized machines generate 417 euro/ha, while small machines result in 370.8 euro/ha. This outcome indicates the consistency with the hypothesis that the employment of large machinery results in the highest gross margins. Nevertheless, in order to identify the optimal machinery size category, a farm level perspective would be required and the fixed costs for machinery as well as farm size would have to be taken into account as well. The results for the other scenarios differ. The medium machine category yields the best gross margin results for S2, S3, and S4. This result might suggest that there would be a shift in the most efficient machinery size category, but whether such shift would occur a farm level research would be necessary. The gross margin is lower for both S2 and S3 compared to S1, and the pollination does not offset the losses in any of the machine size categories. In the absence of pollination, the simple subdivision scenario (S2) performs slightly better than the field renewal scenario (S3) due to the unproductive land (roads). However, with the help of pollination, per ha results are levelled out across both scenarios.

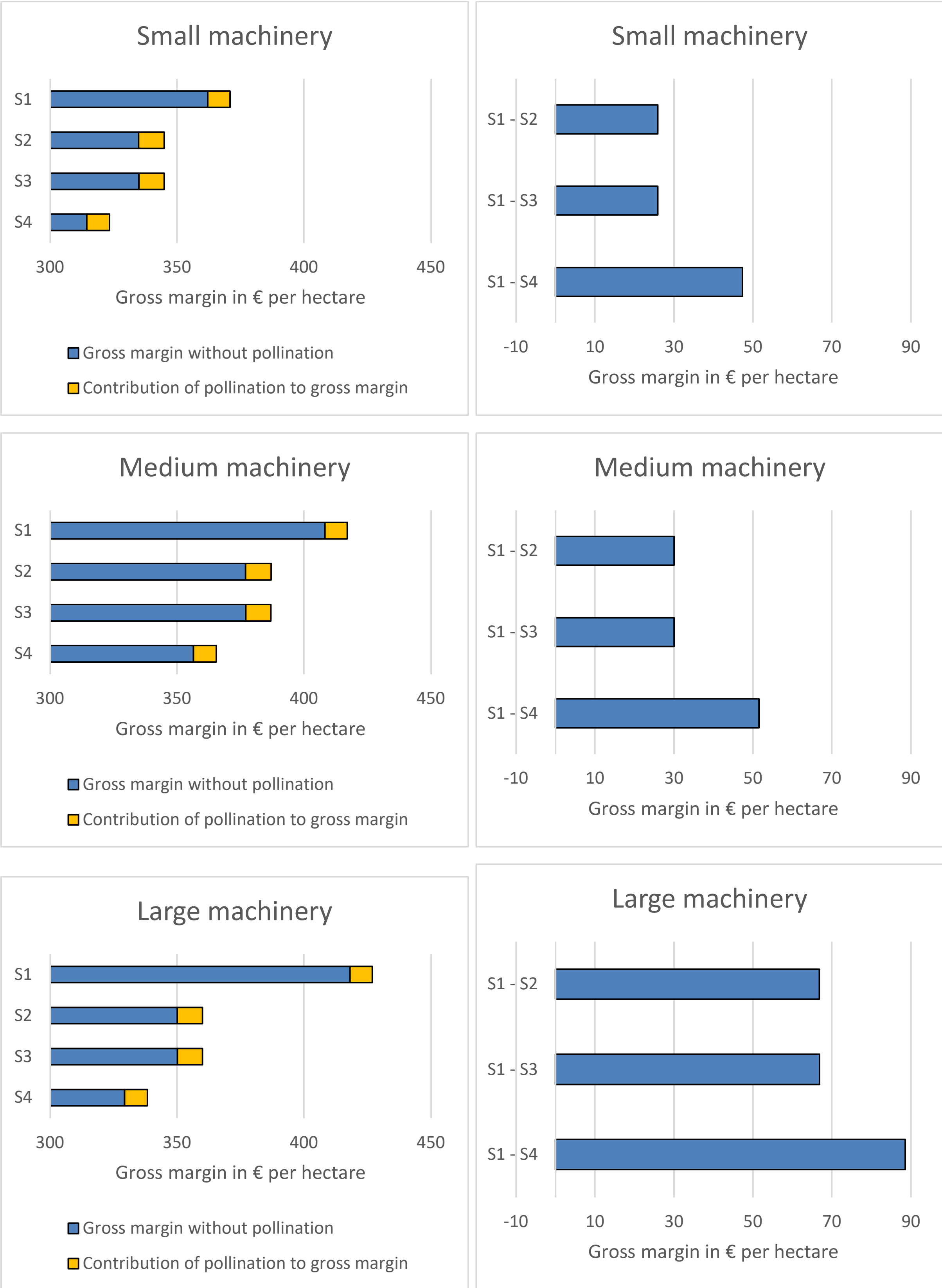


Figure 21 Mean results per ha of all scenarios for three different machinery size categories (left) ant the comparison between the scenarios (right). Source: Own calculation.

The economic impact of landscape change on each category is captured in Figure 22. The most significant impact is on large machinery, and the gross margin reduces by €88.5 in the transition from S1 to S4. Medium machinery is impacted by €30, and small machinery's gross margin goes down by €25.9. In relative numbers, the gross margin in large machinery goes down by 20.8%, 12.4% for the medium category, and 12.8% for the small machinery category. The smaller machinery categories being less economically impacted by the landscape changes is confirmed by this result. For every mechanisation category, the economic change observed between S2 and S3 is insignificant (0.01 euro).

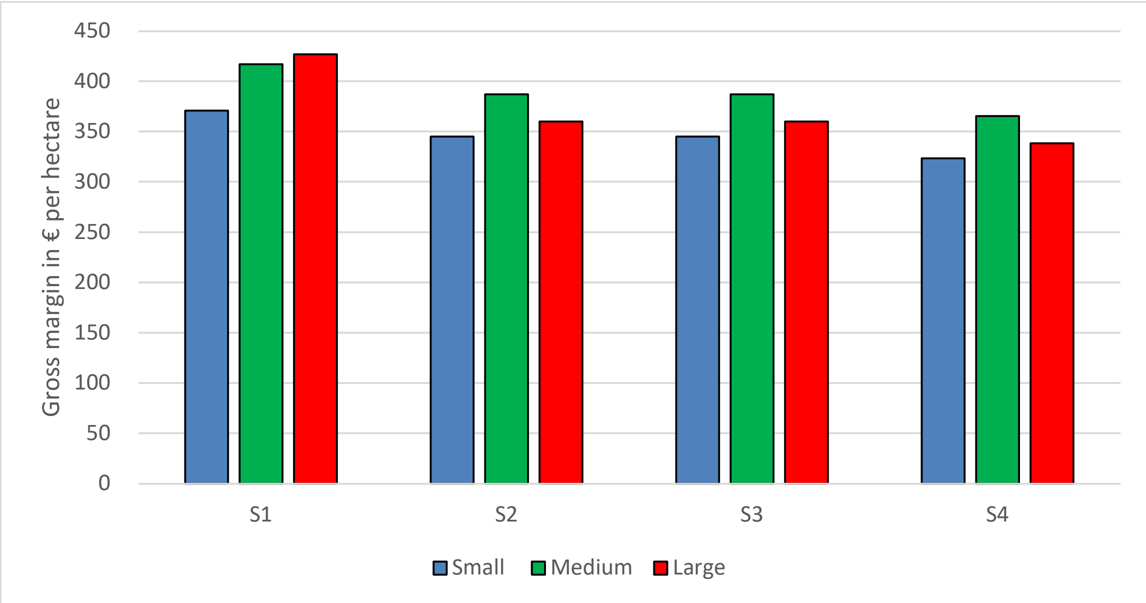


Figure 22 Comparison of average gross margin for different Scenarios and different machinery size categories. Source: Own calculation.

The landscape simulation results for the machine categories are presented in Figure 23. It is evident from the chart that the effects of pollination do not make up for the losses at the landscape level.

Figure 23 Landscape results of all scenarios for three different machinery size categories (left) and the comparison between the scenarios (right). Source: Own calculation.

Similar to Figure 22, Figure 24 illustrates the impact of landscape change on the economic results for each category, but at a landscape level. The suggestions are similar to the per-ha results. In each scenario, the large machinery category experiences the largest reduction in gross margin per landscape. For each simulated change scenario, the medium machinery category shows the highest gross margin.

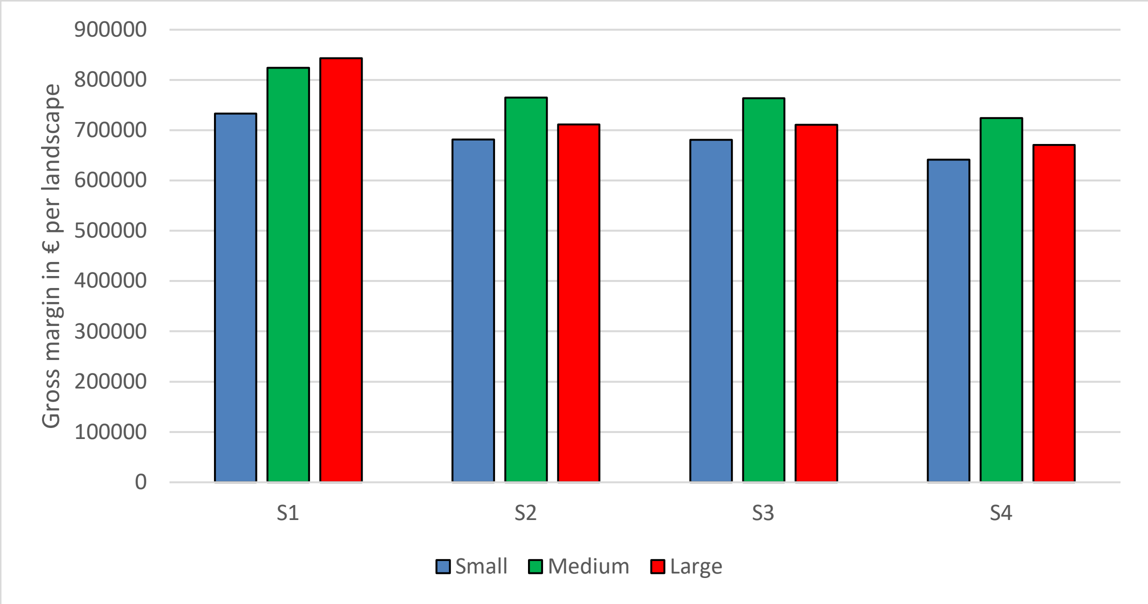


Figure 24 Comparison of landscape gross margin for different Scenarios and different machinery size categories. Source: Own calculation.

5. Discussion

The results align with previous studies on field size, which were reviewed in the theoretical part. Auernhammer et al. (2001), Degner (1999), Brunotte and Fröba (2007), and Fechner (2014) reveal that the economic benefits of field size increase with a size greater than 30 ha. Based on the KTBL (2020) data and Figure 3 observations, machines' cost for mechanization size categories has small cost differences above 20-ha field size category. Machines lose their efficiency on bigger fields while still maintaining an operational disadvantage on smaller fields, which helps to explain these cost trends. Sklenička (2014) calculated the economically sustainable field size threshold to be 1.707 ha. However, none of the scenarios show outcomes close to this threshold.

Another political aim of the 30-ha measure is to improve biodiversity of the landscape (Žalud et al., 2019). According to Fahrig et al. (2011), the model results demonstrate that without requiring any land to be used for production, biodiversity would improve. Likewise, Šálek et al. (2018) provided strong evidence that biodiversity improves with a more structured landscape, with the same production yield. This discovery could suggest that regulating the field size could be a standard land-sharing approach (Phalan et al., 2011). Frühauf (2005) suggests that the field width, which decreases in each scenario, is a function of biodiversity, and the modelled biodiversity increases accordingly. The result of a higher landscape heterogeneity resulting in an increase in biodiversity is consistent with the findings of Redlich et al. (2018) and Fahrig et al. (2015). The results of the present thesis reveal an increase in biodiversity in each situation. Smaller fields are also supportive of bigger populations of untamed pollinators that influence the yield of insect-pollinated crops. Despite its ecological benefits, the economic costs of pollination, including loss from fragmentation of large fields, yield loss caused by expansive field margins, and increased machinery costs in smaller field blocks do not justify its continued implementation. The policy designers' intention to increase biodiversity has been successfully realised in each scenario, with an evident increase in biodiversity.

According to my model, the contribution of pollination to the oilseed rape yield level lies between 6.5% (S1) and 7.55% (S4) per ha. The change in the landscape alone led to an increase of 0.77% in the oilseed rape yield that depends on pollination. The contribution would be higher if the landscape was more varied in its composition. Nevertheless, the contribution of pollination across the entire landscape is unable to compensate for the decline in oilseed rape yield at the landscape level. At the landscape level, the pollination-induced yield gain is less than the production decrease as a result of UAA loss. This is primarily due to edge effects, particularly in S2 and S4, and loss of productive area in S4.

Additionally, there are notable findings when comparing S2 and S3. In terms of landscape economic outcomes, S3 experiences a loss in gross margin owing to the loss of UAA. However, the gross margin at the hectare level is greater in S3 than in S2 as a result of a higher pollination rate of oilseed rape.

For fields smaller than 30 ha, the gross margin per ha (or the opportunity costs of a 30-ha policy) range from 25.9 to 88.5 euros per ha. The wide range of opportunity costs arises from the machinery size category used in the landscape and the target scenario chosen by each farmer. According to the findings of Kirchweger et al. (2020), the cost of maintaining a small structured landscape was 19 euros per ha. In contrast, while my model simulates an average field size reduction from 19.5 ha (S1) to 14.02 ha (S2 and S3) and 11.92 ha (S4) respectively, the simulated landscape of Kirchweger et al. (2020) changed from an average field size of 1.54 ha to 2.93 ha.

One significant finding relates to the size of the machinery. The model classifies the machinery into three different size categories, since this could be the crucial economic factor for farmers. The model illustrates a change in the most lucrative machinery size category in terms of gross margin from the large (240 kW) to the medium (102 kW) category in all three proposed scenarios (see Figures 22-24). In case the medium-sized machinery category is linked to higher gross margins, farms might also adjust their machinery size in the mid- to long term. However, as mentioned previously, whether this is the case would require calculations at farm level, taking into account farm size and also fixed costs of the machinery. Additionally, any such adaptations in terms of machinery would most likely not occur immediately but would rather be implemented in the mid- to long-run.

Another significant finding pertains to the scenario of renewing the field roads. Some of the arable land would be taken up by the field roads. Nevertheless, according to the model, this is significantly mitigated by the pollination effect, which implies that the effect of fields divided by field roads is nearly equivalent to that of fields divided crop-to-crop. Another advantage of renewing the field roads could be to cultivate the same crop on neighbouring fields. This could lead to better organisation for the harvest, and the field roads may be utilised as compressed tracks for the harvest logistics in order to reduce soil compaction on adjacent blocks. Another benefit of this measure would be that the farm could avoid the expenses linked to renting the land, as the field roads are presently owned by the municipality or the state. The main drawback of this scenario is outlined in the theory section. The restoration of field roads might provide access to separate plots that are presently clumped together in substantial blocs. This situation is a form of monopoly that maintains lower rents and precludes competition by other farms. Nevertheless, this market imperfection benefits the present users of the fields, and changing the structure could result in unknown impacts on the future landscape.

The model has several limitations that require consideration. For instance, the model developed by Sirami et al. (2019) may not be the most suitable for measuring biodiversity in the Czech context since it was implemented in an environment with significantly greater spatial heterogeneity than the Znojmo research region. Thus, while the biodiversity indicator in the model imparts only general information regarding shifts in biodiversity, it remains the most fitting simulation available.

The model is rooted in the 2020 scenery, which was intended to align with the highest field size of 30 ha. It deserves emphasis that a corresponding inquiry, like this one, should have been conducted by the government to evaluate the probable effect of the policy before enforcing it on farmers. The study endeavours to model the changing structure of the landscape while holding other variables constant. The outcomes rely on the assumed mix of crops, prices, and inputs that remain constant. The model could for example be significantly altered in the future by an increase in pollinated crops, as stated earlier.

The study by Kirchweger et al. (2020), on which the model in this thesis is based, centred on the effects of pollination and the presence of natural refuges for wild pollinators that are of considerable economic significance to crops that rely entirely or partially on insect pollination. According to Kirchweger et al. (2020), the shortage of measurements and modelling of pollination impacts is because of the small proportion (around 10%) of insect-pollinated crops within the agricultural area. In the same way, the oilseed rape crop in my model is pollinated by insects and only covers about 10-12 per cent of the agricultural area. This implies that the pollination effects are limited to only a small part of the area while the costs of the large field divisions, green edges, and flower strips apply to the entire landscape.

A lack of data limits my model, particularly in relation to systematic crop rotation. However, a farm could use different machinery sizes for different plot sizes to minimise the effects, which my model's assumption of all farms using certain machinery sizes, may not account for and could be a limitation. To conclude, my model assumes one machine class on the whole landscape, which can impact machine profitability. Moreover, the decisions made by farmers are surrounded by uncertainty. It's unlikely that a single scenario would be adopted throughout the entire landscape. Furthermore, the Czech agro-economic calculation has a limitation: it lacks the necessary information, which is either outdated or insufficient. As an illustration, the data gathered by the KTBL isn't tailored to Czech agriculture. This could result in variations in the calculated gross margin, which may differ among countries due to higher or lower costs.

It is noted in (Kirchweger et al., 2020) that pollination effects might be underestimated. I consider mechanisation as a given and create a model for the three categories. Nevertheless, I am aware that changes in technology could shift towards different machines, leading to a higher economic viability of small fields.

6. Conclusion

This thesis simulated effects of an agricultural policy that imposes a 30-ha limit on field sizes in the Czech Republic with a bioeconomic model applied to a study region near Znojmo. The model assesses the influence of the policy on biodiversity, pollination, crop yield (including pollinated crops) and gross margin at the landscape and ha level. Starting with a scenario of land use before implementation of the policy (S1), three further scenarios were simulated, which all comply with the 30-ha policy (S2-S4).

The main research question of this thesis was to investigate the impact of reducing the field size to a maximum of 30 ha. The bio-economic model has three main outcomes. These are biodiversity, yield at the landscape and ha level, particularly focusing on the effects of pollination, and the gross margin generated from both landscape and ha. The gross margin results are classified into three categories of mechanisation levels. Biodiversity rises as predicted for every alteration scenario. Pollination increases the yield per ha of oilseed rape. However, it decreases at the landscape level due to the high edge effects and the loss of arable land, which cannot be compensated by higher yields due to pollination on remaining land. The final outcome of the model yields intriguing results, describing the influence of landscape alterations on gross margin for three different machinery size categories (small, medium and large). While before implementation of the policy the large machinery shows the highest gross margin, after the anticipated landscape adjustments it falls behind the medium sized machinery.

This thesis centres on the bio-economic model, which simulates how Czech agriculture will change and the potential impact of the 30-ha policy on yield and economic performance. The model simulates four possible scenarios of landscape change for the three machinery categories. This model is founded on a landscape section located in the Southern Moravia region.

According to the results, the policy can enhance the biodiversity and pollination, yet the effect on yield and income hinges on the particular scenario. This study offers policy makers and farmers valuable perspectives on the policy's potential benefits and trade-offs.

According to the modelled effects of the 30 ha policy, specific costs at both the ha and landscape levels can be expected. The cost per ha, suggested by the model, is at least 25.9 euros. Making a direct recommendation to farmers or policy makers is not straightforward.

A simple subdivision or field renewal would be the most likely scenario from a farmer's perspective, depending on the organisation and logistics of individual farms. In case policy makers want to support biodiversity, introducing further payments per ha to compensate farmers for the loss would be necessary. The policy ought to take into account the various approaches and increase the payment for farms that implement the flower strips scheme (opportunity cost ranging from €47.4 to €88.5 per ha) in contrast to the simple subdivision or renewal of field tracks scenarios (opportunity cost ranging from €25.9 to €66.8 per ha). It is necessary to introduce a policy to fill the gap. This model proposes that landscape simplification incurs a cost. Policy makers in other countries could consider preserving a small field structure as a recommendation due to the significance of conservation. According to the outcomes of the second and third scenarios, farmers should endeavour to renovate field roads in areas where field accessibility could be improved. Nevertheless, this implies relinquishing some arable land. Such field roads would not be exclusive and could result in an increase in land usage by owners or opening up to other farmers, which, in turn, could lead to higher land rental prices.

Based on the model results, the straightforward subdivision scenario, perhaps combined with the field road improvement programme to enhance field accessibility, would be the most viable alternative for farmers. The flowering stripes scenario, which would primarily promote biodiversity and modify the landscape composition, would be the most suitable option and could be put forward to policymakers if boosting biodiversity is the main aim. Nonetheless, it would necessitate increased government incentives for farmers, given that the opportunity costs for this scenario are the greatest.

Farmers would incur specific costs, primarily related to variable and innovation costs in the long run. The findings indicate partial effects on pollination and biodiversity enhancement. Field size is an underestimated intermediary between biodiversity and gross margin. A monetary valuation would yield further insight and could support other policy decisions.

Landscape change's long-term effect could be a gradual change in the size of machinery, potentially enhancing the competitiveness of smaller farms. The changes in landscape, although not economically effective, demonstrate an increase in biodiversity. The smaller fields may be vital from a social perspective, potentially reducing the significant decline in biodiversity observed in the past. Supporting biodiversity is one of the primary goals of the policy and is in the interest of the public.

The future assessment of policy-induced landscape change effects could result from further model development. Initial improvement should be the addition of relevant data which was not available during the current analysis. One example could be the usage of Sentinel 2 probe's data to obtain crop rotation data. Adapting the biodiversity model of Sirami et al. (2019) to new landscapes would be another aspect to consider. Even though the research could be expensive and time-consuming, it could offer valuable insights into biodiversity for future modelling. To improve understanding on this topic, it is suggested that further research on biodiversity and agricultural economics should be conducted specifically in the Czech setting. Conducting research on wild pollinators in landscapes where bee hives have a high density could yield additional insights. Collecting larger data sets for agricultural payment purposes would lead to improved model methodology. Better understanding of the trade-offs between economic and natural indicators could further improve the model.

To ideally account for public goods, the calculation should include their effect in the model. Inclusion would change the results to a more desirable outcome. It demonstrates the extension of the model beyond private concerns. The support for farmers is not strong, but it does indicate the public trade-off when smaller blocks are compensated. The model confirms that the improved cost of pollination services alone cannot offset the expenses of this measure for farmers.

A future government proposal intends to increase the field size to 10 ha in erosion-prone regions. The thesis's developed model might aid in assessing policy impact before its implementation. The repercussions entail informed decisions, eradication of conjectures and promotion of evidence-based policies.

7. Literature

Agrární komora (2020), Usnesení 29. sněmu Agrární komory České republiky konaného dne 16. června 2020 v Olomouci online: http://www.akcr.cz/txt/usneseni-29-snemu-agrarni-komory-ceske-republiky-konaneho-dne-16-cervna-2020-v-olomouci?hlasuj=261

Auernhammer H., Demmel M., Rothmund M. (2001). Gewannebewirtschaftung im Projekt Zeilitzheim. In: Landtechnik. 56: 136 – 137.

Bartel A., Schwarzl B., Süßenbacher E. (2015). „High Nature Value Farmland“ in Österreich 2007-2013. Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft.

Bezemer D. J. (2004). Risk and agricultural de-collectivisation, with evidence from the Czech Republic. Economic Systems, 28(1), 13-33. doi:10.1016/j.ecosys.2003.11.003

Brázdil R., Trnka M. et al. (2015): Historie počasí a podnebí v českých zemích XI: Sucho v českých zemích: minulost, současnost a budoucnost. Centrum výzkumu globální změny Akademie věd České republiky, v.v.i., Brno, 402 pages. ISBN 978-80-87902-11-0.

Brunotte J., Fröba N. (2007). Schlaggestaltung – kostensenkend und bodenschonend. KTBL-Schrift 460. Darmstadt. 178 pages.

Chloupková J. (2002). Czech Agricultural Sector: Organisational Structure and Its Transformation. Royal Veterinary and Agricultural University, Food and Resource Economic Institute, Unit of Economics Working papers. DOI: 10.22004/ag.econ.24195

Chloupková J., Bjornskov C. (2002). Could social capital help Czech agriculture?. ZEMEDELSKA EKONOMIKA-PRAHA-, 48(6), 245-250.

Clough Y., Kirchweger S., Kantelhardt J. (2020). Field sizes and the future of farmland biodiversity in European landscapes. Conservation letters, 13(6)

ČNB. (2020). Kurzy Devizového Trhu. Retrieved February 1, 2020, from https://www.cnb.cz/cs/financni-trhy/devizovy-trh/kurzy-devizoveho-trhu/kurzy-devizoveho-trhu/

Cook E., European Union. European Commission, European Commission. Statistical Office of the European Union, European Union. Eurostat. (2020). Agriculture, Forestry and Fishery Statistics. Publications Office of the European Union. https://doi.org/10.2785/143455

Costanza R., Fisher B., Mulder K., Liu S., Christopher T. (2007). Biodiversity and ecosystem services: A multi-scale empirical study of the relationship between species richness and net primary production. Ecological economics, 61(2-3), 478-491.

ČSO (2020) Petice Vraťme život do krajiny online at:https://www.birdlife.cz/petice-za-krajinu/

ČSU (2017) Sklizeň zemědělských plodin v Jihomoravském kraji v roce 2017. Retrieved November 18, 2019, from https://www.czso.cz/csu/xb/sklizen-zemedelskych-plodin-v-jihomoravskem-kraji-v-roce-2017.

ČTK. (2018, December 3). Nová pravidla pro zemědělce. Vláda nařídí zmenšit pole tam, kde hrozí eroze. *Seznam Zprávy*. https://www.seznamzpravy.cz/clanek/nova-pravidla-pro-zemedelce-vlada-naridi-zmensit-pole-tam-kde-hrozi-eroze-61758

ČUZK. (2014). Souhrnné přehledy o půdním fondu z údajů katastru nemovitostí České republiky. Available at: https://www.cuzk.cz/Periodika-a-publikace/Statisticke-udaje/Souhrne-prehledy-pudniho-fondu/Rocenka_pudniho_fondu_2015.aspx

ČUZK (2020) Katastrální mapa. Retrieved June 10, 2020, from https://sgi-nahlizenidokn.cuzk.cz/marushka/default.aspx?themeid=3&&MarQueryId=6D2BCEB5&MarQParam0=707988&MarQParamCount=1&MarWindowName=Marushka

De la Rúa P., Jaffé R., Dall'Olio R., Muñoz I., Serrano J. (2009). Biodiversity, conservation and current threats to European honeybees. Apidologie, 40(3), 263-284.

Degner J. (1999). Einfluss der Schlaggröße auf die Verfahrenskosten. In: Landwirtschaft und Landschaftspflege in Thüringen Heft – Jahrestagung Landwirtschaft 1999. Hrsg. Thüringer Landesanstalt für Landwirtschaft. Jena. 10: 66 – 71.

Demmel M., Rothmund M., Auernhammer H., Feldmann J., Rademacher T. (2014). Infrastrukturplanung zur Optimierung des Zuckerrübenanbaues in einer Gewanneflur. Landtechnik. 59: 36 – 37.

Donald P. F., Green R. E., Heath M. F. (2001). Agricultural intensification and the collapse of Europe's farmland bird populations. Proceedings of the Royal Society of London. Series B: Biological Sciences, 268(1462), 25-29.

Doucha T., Divila E. (2005). Possible impacts of the Czech agricultural policy after the EU accession on the land market and land usage. Agricultural Economics–Czech, 51(5), 185-193.

Doucha T., Foltýn I. (2008): Czech agriculture after the accession to the European Union – impacts on the development of its multifunctionality. Agric. Econ. – Czech, 54: 150-157.

Dumbrovský M. (2004): Pozemkové úpravy. Brno, VUT, 263 pages

European Commission. Statistical Office of the European Union. (2019). Agriculture, forestry and fishery statistics :2019 edition. Publications Office. https://doi.org/10.2785/743056

Eurostat. (2019). Crop Production. Retrieved November 1, 2019, from https://ec.europa.eu/eurostat/cache/metadata/en/apro_cp_esms.htm

Eurostat. (2020). Common Bird Index. Retrieved February 1, 2020, from https://ec.europa.eu/eurostat/cache/metadata/en/t2020_rn130_esmsip2.htm

Fahrig L., Baudry J., Brotons L., Burel F. G., Crist T. O., Fuller R. J., Sirami C., Siriwardena G. M., Martin J. L. (2011). Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. Ecology Letters, 14(2), 101–112. https://doi.org/10.1111/j.1461-0248.2010.01559.x

Fahrig L., Girard J., Duro D., Pasher J., Smith A., Javorek S., King D., Freemark Lindsay K., Mitchell S., Tischendorf L., (2015). Farmlands with smaller crop fields have higher within-field biodiversity, Agriculture, Ecosystems & Environment,Volume 200, 219-234, ISSN 0167-8809, https://doi.org/10.1016/j.agee.2014.11.018.

FARMY.CZ (2019). Retrieved October 20, 2019, from http://www.cenova-mapa-pudy.cz

Fechner W. (2014). Einfluss der Hauptbearbeitung auf die Arbeitszeit im Feldbau am Beispiel eines mitteldeutschen Großbetriebes. 19. Arbeitswissenschaftliches Kolloquium des VDI-MEG Arbeitskreises Arbeitswissenschaften im Landbau. Bornimer Agrartechnische Berichte. Heft 83. Potsdam-Bornim. Dresden. 22 – 34.

Frison E., Jeremy C., Hodgkin T. (2011). Agricultural Biodiversity Is Essential for a Sustainable Improvement in Food and Nutrition Security. Sustainability. 3. Doi:10.3390/su3010238.

Frühauf J. (2005). Raumbezogener Einfluss von Flächennutzung, Bewirtschaftung und ÖPUL auf Feldhase, Rebhuhn, Wachtel, Feldlerche sowie die Vogelartenvielfalt. Distelverein, Wien.

Gavloski J. (2012) Bees on Canola – what are the Benefits-In : Pest Management Facts. (2012)7.

Glen B. (2017) Honeybees Play Role in Boosting Canola Yields http:///www.producer.com/2013/08/honeybeesplay-role-in-boosting-canola-yields

Good Agricultural and Environmental Conditions (GAEC). (2019). Retrieved October 15, 2019, from https://marswiki.jrc.ec.europa.eu/wikicap/index.php/Good_Agricultural_and_Environmental_Conditions_(GAEC).

Grešlová Kušková, P. (2013). case study of the Czech agriculture since 1918 in a socio-metabolic perspective–From land reform through nationalisation to privatisation. Land Use Policy.

Häussler J., Sahlin U., Baey C., Smith H. G., Clough Y. (2017). Pollinator population size and pollination ecosystem service responses to enhancing floral and nesting resources. Ecology and Evolution, 7(6), 1898-1908.

Hudewenz A., Pufal G., Bögeholz A. L., Klein A. M. (2014). Cross-pollination benefits differ among oilseed rape varieties. The Journal of Agricultural Science, 152(5), 770-778.

IUCN. (2013). Food security policies: making the ecosystem connections. Gland, Switzerland: IUCN

Jandejsek, Z. (2019, February 22). Agrární komora České republiky. Retrieved from https://www.akcr.cz/data_ak/19/jc/dopisy/DZES_7_190222.pdf.

Jelínek L., Medonos T., Foltýn I., Humpál J., Boyinová S. (2018). Social and economic consequences of direct payments capping and redistribution on the Czech large-scale farms (No. 2038-2018-3067).

Jonáš F., et al. (1990): Pozemkové úpravy. Praha, Státní zemědělské nakladatelství, 512 pages

Kapfer M. (2007). Ökonomische Auswirkungen ausgewählter Verfahren der Flurneuordnung (Doctoral dissertation, Technische Universität München).

Kapička J., Brant V., Lang J., Petrus D., Novotný I., Kroulík M. (2017). Metodický Postup Pro Optimalizaci Velikosti Zemědělských Pozemků (Vol. 1). Prague: Ministry of Agricultur Czech Republic. Retrieved from https://kalkulacka.vumop.cz/docs/Metodika_Kapicka_Brant_Optimalizace_publikace.pdf

Kellermann K., Sahrbacher C., Jelinek L., Happe K. (2006): Impacts of an increasing land mobility in NMS – a case study of the Czech region Vysočina. EAAE Seminar 28-29.06.2006, Praha

Kirchweger S., Clough Y., Kapfer M., Steffan-Dewenter I., Kantelhardt J. (2020). Do Improved Pollination Services Outweigh Farm-Economic Disadvantages of Working in Small-Structured Agricultural Landscapes? – Development and Application of a Bio-Economic Model. Ecological Economics 169(January 2019): 106535. https://doi.org/10.1016/j.ecolecon.2019.106535.

KTBL (2020). Leistungs-Kostenrechnung Pflanzenbau. KTBL (Kuratorium für Technik und Bauwesen in der Landwirtschaft e. V.). https://daten.ktbl.de/dslkrpflanze/postHv.html

LPIS (2020) Veřejný registr půdy. Retrieved June 10, 2020 from: https://eagri.cz/public/app/lpisext/lpis/verejny2/plpis/

LPIS (2020) Veřejný export dat LPIS Retrieved March 8, 2020 from https://eagri.cz/public/app/eagriapp/lpisdata/

Mandl S. (2007) Ertragssteigerung durch Honigbienen bei Raps-In : bienen und natur – Verl. DLV München 12.- S. 7

Marada P. (2011). Zvyšování přírodní hodnoty polních honiteb (Vol. 1). Grada. ISBN: 978-80-247-3885-7

Martin E. A., Dainese M., Clough Y., Báldi A., Bommarco R., Gagic V., Steffan-Dewenter I. (2019). The interplay of landscape composition and configuration: new pathways to manage functional biodiversity and agroecosystem services across Europe. Ecology letters, 22(7), 1083-1094.

Mazouch P., Krejčí I., Vltavská K., Kvasnicka R. (2015). Age of machinery and equipment in the Czech agriculture. Agricultural Economics. 61. 356-366. 10.17221/238/2014-AGRICECON.

Medonos T. et al. (2011). Nájemní vztahy k půdě a kapitalizace podpor v cenách nájemného. Výzkumná zpráva z Výzkumného záměru Mze za rok 2009, (MZE 0002725101)

Mesquida J., Renard M., Pierre J.-S. (1988) Rapeseed (Brassica napus L.) Productivity: The Effect of Honeybees (Apis mellifera l.) and Differnet Pollination Conditions in Cage and Field Tests -In Apidiologei 19(1988)1. 51 – 72

Ministry of Agriculture Czech Republic. (2019). Česká pole se zásadně změní. Podle nových pravidel už nebude možné pěstovat jednu plodinu na ploše větší než 30 hektarů. Retrieved October 10, 2019, from http://eagri.cz/public/web/mze/tiskovy-servis/tiskove-zpravy/x2019_ceska-pole-se-zasadne-zmeni-podle-novych.html.

Nátr L., (2011) Příroda, nebo člověk?: služby ekosystémů. 1. vyd. Praha : Karolinum, 349 pages ISBN 9788024618883.

Parra-López C., Groot J.C.J., Carmona-Torres C., Rossing W.A.H. (2008) Integrating public demands into model-based design for multifunctional agriculture: An application to intensive Dutch dairy landscapes, Ecological Economics, Volume 67, Issue 4, 2008, Pages 538-551, ISSN 0921-8009, https://doi.org/10.1016/j.ecolecon.2008.01.007.

Phalan B., Balmford A., Green R. E., Scharlemann J. P. W. (2011). Minimising the harm to biodiversity of producing more food globally q. Food Policy, 36, S62–S71. https://doi.org/10.1016/j.foodpol.2010.11.008

Poláčková, J. (2010). Metodika kalkulací nákladů a výnosů v zemědělství. Praha: Ústav zemědělské ekonomiky a informací. ISBN 978-80-86671-75-8.

Pospěch P., Spěšná D., Staveník A. (2015). Images of a good village: A visual analysis of the rural idyll in the “Village Of The Year” Competition In The Czech Republic. European Countryside, 7(2), 68–86. doi: 10.1515/euco-2015-0005

Radtke J. (2013) Bienen als natürlichen Ertagsfaktor nutzen-In : LIB – Mitteilungsblatt des Länderinstituts für Bienenkunde Hohen Neuendorf e. V.

Reif J., Vermouzek Z. (2019) Collapse of farmland bird populations in an Eastern European country following its EU accession. Conservation Letters.; 12:e12585. https://doi.org/10.1111/conl.12585

Redlich S., Martin EA., Wende B., Steffan-Dewenter I. (2018) Landscape heterogeneity rather than crop diversity mediates bird diversity in agricultural landscapes. PLoS ONE 13(8): e0200438. https://doi.org/10.1371/journal.pone.0200438

Rodríguez C., Wiegand K. (2009). Evaluating the trade-off between machinery efficiency and loss of biodiversity-friendly habitats in arable landscapes: The role of field size. Agriculture, Ecosystems and Environment, 129(4), 361–366. https://doi.org/10.1016/j.agee.2008.10.010

Schaufler V. (2018). Ceny minerálních hnojiv. Retrieved February 29, 2020, from http://www.agronormativy.cz/docs/rpttab2040008

Sirami C., Gross N., Baillod A.B., Bertrand C., Carrié R., Hass A., Henckel L., Miguet P., Vuillot C., Alignier A., Girard J., Batáry P., Clough Y., Violle C., Giralt D., Bota G., Badenhausser I., Lefebvre G., Gauffre B., Fahrig L. (2019). Increasing crop heterogeneity enhances multitrophic diversity across agricultural regions. Proceedings of the National Academy of Sciences of the United States of America, 116(33), 16442–16447. https://doi.org/10.1073/pnas.1906419116

Sklenička P., Janovská V., Šálek M., Vlasák J., Molnárova K. (2014). The Farmland Rental Paradox: extreme land ownership fragmentation as a new form of land degradation. Land use policy, 38, 587-593.

Sklenička P., Šímová P., Hrdinová K., Šálek M. (2014) Changing rural landscapes along the border of Austria and the Czech Republic between 1952 and 2009: Roles of political, socioeconomic and environmental factors, Applied Geography, Volume 47, 2014, Pages 89-98, ISSN 0143-6228, https://doi.org/10.1016/j.apgeog.2013.12.006.

Sklenička P., Šálek M. (2008). Ownership and soil quality as sources of agricultural land fragmentation in highly fragmented ownership patterns Landscape Ecol 23: 299. https://doi.org/10.1007/s10980-007-9185-4.

Stanley D.A., Gunning D., Stout J.C. (2013). Pollinators and pollination of oilseed rape crops (Brassica napus L.) in Ireland: ecological and economic incentives for pollinator conservation. Journal of Insect Conservation, 17(6), 1181-1189.

Stjernman M., Sahlin U., Olsson O., Smith H.G (2019). Estimating effects of arable land use intensity on farmland birds using joint species modeling. Ecological Applications 29(4):e01875. 10.1002/eap.1875

Stotten R. (2015). Das Konstrukt der bäuerlichen Kulturlandschaft: Perspektiven von Landwirten im Schweizerischen Alpenraum (p. 290). innsbruck university press.

Streicher G., Heizinger V., Bernhardt H. (2014). Optimierungsansätze der Infield-Logistik im Mähdruschprozess. 19. Arbeitswissenschaftliches Kolloquium des VDI-MEG Arbeitskreises Arbeitswissenschaften im Landbau. Dresden. Bornimer Agrartechnische Berichte. 83: 146 – 157.

SZIF. (2020) Internal data about the crop percentage in Znojmo region, obtained after personal enquiry from Ing. Skopal on January 30, 2020

Šálek M., Hula V., Kipson M., Daňková R., Niedobová J., Gamero A. (2018). Bringing diversity back to agriculture: Smaller fields and non-crop elements enhance biodiversity in intensively managed arable farmlands. Ecological Indicators. 90. 10.1016/j.ecolind.2018.03.001.

Tamáš V. (2010). Problem of the dual structure of farms in European transition economies. Acta univ. agric. et silvic. Mendel. Brun., 2010, LVIII, No. 6, pp. 571–578

Tscharntke T., Tylianakis J. M., Rand T. A., Didham R. K., Fahrig L., Batáry P., Westphal C. (2012). Landscape moderation of biodiversity patterns and processes‐eight hypotheses. Biological reviews, 87(3), 661-685.

ÚZEI. (2012). Souhrn z podkladových analýz za skupinu: Přírodní zdroje Priority: 4 a 5. Retrieved October 15, 2019, from http://www.spov.org/data/files/analyza-prirodni-zdroje.pdf.

ÚZEI. (2020). Náklady a výnosy vybraných rostlinných a živočišných výrobků. https://www.uzei.cz/data/usr_001_cz_soubory/210105_naklady2019.pdf

Vermouzek, Z., Zámečník, V., Janota, J., & Fišer, M. (2018, November 27). *Vraťme život do krajiny! - petice za krajinu*. Česká Společnost Ornitologická. https://www.birdlife.cz/petice-za-krajinu/

Veselá M. (2008) Osídlování českého pohraničí po druhé světové válce na stránkách Rovnosti. (Master Thesis.) Brno, PdF MU 2008.

Vlasák J., Bartošková K. (2007): Pozemkové úpravy. Praha, ČVUT, 168 pages

VÚMOP. (2018). eKatalog BPEJ. Retrieved February 1, 2020, from https://bpej.vumop.cz

Žalud Z., Trnka M., Hlavinka P. (2019) Zemědělské sucho v České republice - vývoj, dopady a adaptace. Praha: Agrární komora České republiky, s. [1a]. ISBN 978-80-88351-02-3. Available at: http://www.digitalniknihovna.cz/mzk/uuid/uuid:42e88978-44e5-40ba-a76e-60f34ce8d010

Ženka J., Slach O., Krtička L., Žufan P. (2016). Determinants of microregional agricultural labour productivity–Evidence from Czechia. Applied Geography, 71, 83-94.

Zelená zpráva (2017) Zpráva o stavu zemědělství ČR za rok 2016. Retrieved November 19, 2018, from http://eagri.cz/public/web/file/569334/ZZ16_V3.pdf

List of abbreviations

AKČR - Agrární komora české republiky (Czech Chamber of Agriculture)
BPEJ - Bonitovaná půdně ekologická jednotka (Estimated pedologic-ecological unit)
CAP - Common Agricultural Policy
CLC - Corine Land Cover
ČNB - Česká národní banka (Czech National Bank)
ČSO - Česká společnost ornitologická (Czech Society for Ornithology)
ČSU - Český statistický úřad (Czech Statistical Office)
ČTK - Česká tisková kancelář (Czech News Agency)
ČUZK - Český úřad zeměměřičský a katastrální (Czech Office for Surveying, Mapping and Cadastre)
EC - European Commission
FBI - Farmland Bird Index
GAEC - Good Agricultural and Environmental Conditions
GIS - Geographical Information System
KTBL - Kuratorium für Technik und Bauwesen in der Landwirtschaft (German non-profit research organisation)
LPIS - Land Parcel Identification System
SZIF - Státní zemědělský a intervenční fond (The State Agricultural Intervention Fund)
UAA - Utilized Agricultural Area
ÚZEI - Ústav zemědělské ekonomiky a informací (Czech state research organisation)
VÚMOP - Výzkumný ústav meliorací a ochrany půdy (Czech public research institute)

Appendix: Result tables

Table A-1 Results and descriptive variables of the multidiversity model for different scenarios. Source: Own calculations

	Average Z-score	Crop_SHDI	Crop_MFS	Seminatural habitat (% of total landscape area)	Lenght of permanent green edges (m)
Scenario S1	-1,142	1,629	19,62	0,927	116450
Scenario S2	-1,006	1,684	14,10	0,927	116450
Scenario S3	-1,000	1,684	14,10	1,061	184025
Scenario S4	-0,921	1,684	11,92	0,927	116450

Table A-2 Average oilseed rape yield per landscape and ha arable land model for different scenarios (decitons) Source: Own calculations.

	Total		Contribution of insect pollination	
	Per landscape	Per hectare oilseed rape	Per landscape	Per hectare oilseed rape
Scenario S1	8713,505	32,54903	296,221	0,99
Scenario S2	9407,798	32,41336	362,409	1,24
Scenario S3	9408,475	32,4634	377,653	1,29
Scenario S4	9036,165	32,73407	435,405	1,57

Table A-3 Average economic results per landscape model for different scenarios and for different machinery size categories´(euro) Source: Own calculations.

	Revenue	Fertilizer costs	Yield depending variable costs	Other variable costs	Gross margin
Small machinery					
Scenario S1	2173750	177253	24668	1245104	726725
Scenario S2	2179307	125836	25772	1338646	689053
Scenario S3	2176522	125652	25736	1336562	688572
Scenario S4	2138071	121261	25078	1344826	646906
Medium machinery					
Scenario S1	2173750	177253	24668	1153202	818627
Scenario S2	2179307	125836	25772	1261368	766331
Scenario S3	2176522	125652	25736	1259403	765731
Scenario S4	2138071	121261	25078	1267534	724198
Large Machinery					
Scenario S1	2173750	177253	24668	1084515	887314
Scenario S2	2179307	125836	25772	1329692	698007
Scenario S3	2176522	125652	25736	1327619	697515
Scenario S4	2138071	121261	25078	1336052	655680

Table A-4 Average economic results per ha arable land for different scenarios and for different machinery size categories´(euro) Source: Own calculations.

	Revenue	Fertilizer costs	Yield depending variable costs	Other variable costs	Gross margin
Small machinery					
Scenario S1	1017,9	83	11,5	583,7	339,7
Scenario S2	1020,5	59	12,2	627,5	322,0
Scenario S3	1020,8	59	12,1	627,5	322,2
Scenario S4	1001,3	57	11,7	630,4	302,4
Medium machinery					
Scenario S1	1017,9	83	11,5	540,6	382,8
Scenario S2	1020,5	59	12,2	591,3	358,2
Scenario S3	1020,8	59	12,1	591,3	358,4
Scenario S4	1001,3	57	11,7	594,1	338,7
Large Machinery					
Scenario S1	1017,9	83	11,5	508,4	415,0
Scenario S2	1020,5	59	12,2	623,3	326,2
Scenario S3	1020,8	59	12,1	623,3	326,4
Scenario S4	1001,3	57	11,7	626,2	306,6

Table A-5 Contribution of insect pollination to the average economic results per landscape for different scenarios (euro) Source: Own calculations.

	Revenue	Fertilizer costs	Yield depending variable costs	Other variable costs	Gross margin
Scenario S1	12314	197	127	0	11989
Scenario S2	15065	96	156	0	14814
Scenario S3	15699	99	162	0	15438
Scenario S4	18100	105	187	0	17808

Table A-6 Contribution of insect pollination to the average economic results per ha arable land for different scenarios (euro). Source: Own calculations.

	Revenue	Fertilizer costs	Yield depending variable costs	Other variable costs	Gross margin
Scenario S1	6	0,09	0,06	0,00	6
Scenario S2	7	0,05	0,17	0,00	7
Scenario S3	7	0,05	0,08	0,00	7
Scenario S4	8	0,05	0,09	0,00	8

Table A-7 Estimation of the effects of simulated landuse change on biodiversity, oilseed rape yield, and machinery category specific gross margin per landscape and ha arable land. Source: Own calculations.

	Oilseed rape (in decitons)			Gross margin Small machinery (in euro)		Gross margin Medium machinery (in euro)		Gross margin (in euro) Large machinery	
	Z-Score	Per landscape	Per hectare oilseed rape	Per landscape	Per hectare arable land	Per landscape	Per hectare arable land	Per landscape	Per hectare arable land
Comparing S1 with S2	-0,14	-694,29	0,14	37672	17,7	52296	24,6	189307	88,8
Comparing S1 with S3	-0,14	-694,97	0,09	38153	17,5	52896	24,4	189799	88,6
Comparing S1 with S4	-0,22	-322,66	-0,19	79819	37,3	94429	44,2	231634	108,5
Comparing S2 with S3	-0,01	-0,68	-0,05	481	-0,2	600	-0,2	492	-0,2
Comparing S2 with S4	-0,09	371,63	-0,32	42147	19,6	42133	19,6	42327	19,7
Comparing S3 with S4	-0,08	372,31	-0,27	41666	19,8	41533	19,8	41835	19,8