MIXED

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Abstract

Aim
The aim of this deliverable is upscale efficiency and resilience analyses compared to the analyses in D6.2 – which focused on the farm-level, addressed efficiency purely from the economic perspective, and measured resilience through the resilience capacities of revealed robustness, adaptation, and transformation. In this deliverable, the upscaling of analyses occurs in three ways. First, by embracing other levels of analysis, i.e. cooperation between farms, and assessments at landscape and regional level. Second, by considering a wider set of performance indicators, i.e. next to efficiency, this deliverable also considers environmental performance indicators related to soil quality and nutrient balances. Third, by addressing resilience from the perspective of two core resilience attributes, i.e. diversity and connectedness. More specifically, the deliverable addresses the following questions: (i) How mixed are EU landscapes (Chapter 2)? What are the costs of developing towards more mixed regions (Chapter 3)? What is the effect on crop diversity if farmers optimize production as well as nutrient balances (Chapter 4)? and What are the economic and environmental gains if dairy and arable farmers collaborate (Chapter 5)?

Data and methods
Chapters 2-4 use top-down data (Farm Accountancy Data Network, Farm Business Survey, Eurostat), while Chapter 5 uses bottom-up data, which were collected in multiple MIXED data collection rounds and field workshops (WP1, WP2, WP5, WP6). Due to data intensity, Chapter 5 addresses one MIXED Network, i.e. the network in the Netherlands. Furthermore, due to the elaborate nature of the analyses on cost-effective scenarios to establish mixed regions (Chapter 3) and the joint consideration of profits and nutrient balances (Chapter 4), also these chapters zoom in on specific countries (Chapter 3: Denmark, Chapter 4: England and Wales). The analyses on factors contributing to mixed landscapes (Chapter 2) cover the entire EU. With regard to the methods used, Chapter 2 uses regression analyses, Chapters 3 and 4 are based on efficiency analyses, and Chapter 5 uses a bio-economic model.

Conclusions
Upscaling the analyses to different levels and perspectives consistently shows that synergies exist between efficiency and resilience:

- Multiple EU regions can be characterised as high in crop diversity, livestock diversity and circularity. (Chapter 2)
- Achieving mixed regions does not necessarily imply a lower profit potential for farms. Imposing mixedness at the regional level can even lead to a higher profit potential for farms compared to when maintaining current land uses. (Chapter 3)
- Simultaneous optimization of production and nutrient balances has the potential to increase crop diversity at farm and regional level. (Chapter 4)
- Collaboration (connectedness) between farmers in the region can improve income and soil quality. (Chapter 5)
- Even though scope and context differ, top-down and bottom-up analyses both point at synergies between efficiency and resilience. (Chapter 6)
- Extending efficiency to environmental indicators, and approaching resilience through diversity and connectedness enrich the insight into efficiency and resilience of MiFAS. (Chapters 1-6)

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Table of contents

Contents

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 862357

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 862357

1 Introduction

1.1 Performance of mixed systems

In understanding the performance of mixed farming and agroforestry systems (MiFAS), both sustainability and resilience need to be considered (Accatino et al., 2021). These concepts embrace multiple components (Figure 1.1). As part of assessing the performance of MiFAS, D6.2 and D6.3 focus on efficiency and resilience. In D6.2 we zoomed in on the **farm-level**, the economic perspective, and revealed farm-level resilience capacities of robustness, adaptability, and transformability (indicated with one asterisk in Figure 1.1). The aim of D6.3 is to **zoom out (scale up)** our analyses. We do this through embracing other levels (cooperation between farms, assessment of landscapes and regions), and other performance indicators. As indicated by the two asterisks in Figure 1.1., D6.3 indicators on sustainability also include soil quality and nutrient balance, while D6.3 resilience indicators relate to connectedness and diversity – as part of the systems' resilience attributes (Resilience Alliance, 2010; Meuwissen et al., 2019; Feindt et al., 2022). Efficiency has been part of both deliverables.

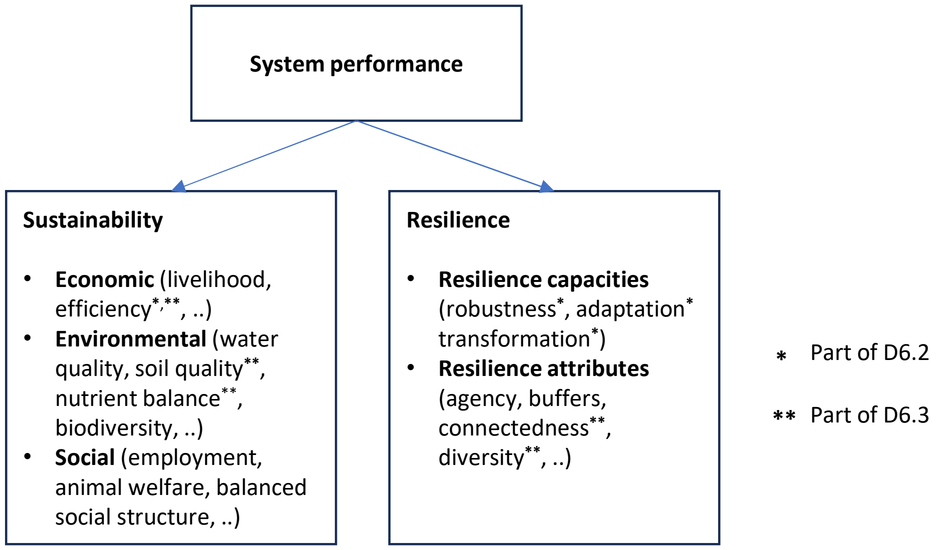

Figure 1.1: Positioning the deliverables D6.2 (farm-level efficiency and resilience) and D6.3 (upscaling efficiency and resilience analyses) in the domain of system performance.

Due to the large amount of data needed for some of the analyses in D6.3, only one chapter covers analyses for the entire EU. Also, most data are retrieved from the Farm Accountancy Data Network (FADN), Eurostat, and the Farm Business Survey (FBS). We were therefore not able to explicitly capture performance assessments related to agroforestry.

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1.2 Research questions and approaches

To scale up the efficiency and resilience analyses, this deliverable covers the following research questions: (i) How mixed are EU landscapes (Chapter 2)? What are the costs of developing towards more mixed regions (Chapter 3)? What is the effect on crop diversity if farms optimize production as well as the nutrient balance (Chapter 4)? and What are the economic and environmental gains if dairy and arable farmers would collaborate (Chapter 5)?

Chapters 2-4 use so-called 'top-down' data, whereas Chapter 5 uses detailed 'bottom-up' data (Table 1.1). Also, as each chapter addresses another perspective of the efficiency and resilience questions, also approaches, methods and scope differ across chapters, as elaborated in Table 1.1.

Table 1.1: Research chapters in D6.3, level of detail in data, approach with regard to efficiency and resilience, method, and scope of analyses. Core D6.3 performance indicators per chapter are in bold[1].

Chapters in D6.3 (core elements of upscaling are in bold)	Level of detail in data (top-down, bottom-up)	Approach with regard to efficiency and resilience	Method	Scope
Do mixed agricultural landscapes emerge from mixed farms? (Ch2)	Top-down farm and landscape data (Eurostat)[2]	- Efficiency: proxied through circularity as indicator for efficient use of resources. - Resilience: **diversity** (mixedness) of landscapes based on farm types (specialised, mixed).	Statistical analyses (regression) to assess factors contributing to mixed landscapes.	EU (NUTS2)
Cost-effective scenarios to increase mixedness of regions with a focus on DK (Ch3)	Top-down farm data (FADN)[3]	- **Efficiency**: farm-level profit optimization to identify cost-effective scenarios to increase mixedness in region. - Resilience: **diversity** at regional level (% arable, % livestock, % mixed farms).	Efficiency analysis	DK (NUTS2)
Production, environmental performance, and diversity: evidence from England and Wales (Ch4)	Top-down farm data (FBS)[4]	- **Efficiency**: farm-level optimization of production and **nutrient balance** - thereby also allowing for land reallocation, i.e. changing crops. - Resilience: effects on crop **diversity** at farm and regional level.	Efficiency analysis, followed by assessment of changed land allocation (number of crop species)	England, Wales (environmental zones)
Cooperation between arable and dairy farmers in NL-MIXED network (Ch5)	Bottom-up farm data[5]	- **Efficiency**: economic optimization of joint crop rotation schemes with specific requirements for **soil quality**. - Resilience: cooperation (**connectedness**) between arable and dairy farmers.	Bio-economic optimization	One community (NL-MIXED network)

[1]These are the indicators with two asterisks in Figure 1.1.
[2]Farm data with regard to diversity, and inferred proxy-data for farm circularity based on manure and crop land. Landscape data with regard to (i) travelling minutes to city – as proxy for opportunities for local selling of added value products, and (ii) agroecological context.
[3]Based on FADN (Farm Accountancy Data Network). These data do not inform about specific farm-level strategies.

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[4]Based on FBS (Farm Business Survey) data. These data do not inform about specific farm-level strategies.
[5]Based on detailed ('bottom-up') farm, plot and soil data of NL-MIXED network retrieved from farmers' management systems. Past, current, and future farm and collaboration strategies are identified through multiple individual and group discussions with the respective farmers during WP1 field workshops, WP2-handbook data collection rounds (i.e. to elaborate data from management systems), and the WP5 Dynamix serious game.

1.3 References

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2 Do mixed agricultural landscapes emerge from mixed farms?

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2.1 Context of this chapter

Mixed agricultural landscapes were defined in deliverable D3.3 focusing on the so-called top-down approach. This deliverable developed a framework to classify landscapes based on the diversity of agricultural production and its intensity. The framework was applied to European landscapes that were defined at second-level administrative boundaries, the so-called NUTS2 level. First, NUTS2 regions were grouped into regions with similar combinations of agricultural activities derived from agricultural statistics (EUROSTAT), and these regions were then classified into mixed or non-mixed regions based on production diversity and intensity using a decision tree. While this framework helped characterise European landscapes, the classification into mixed and non-mixed landscapes was not able to account for the heterogeneity within the regions. To address this limitation, a new approach to identifying mixed landscapes was developed, expanding on the database presented in D3.3, defining mixed landscapes as landscapes that are both diverse in terms of agricultural production and circularity. This chapter is based on this new definition of mixed landscapes.

2.2 Introduction

Agricultural landscapes, defined as areas where food production results from the interaction of human and biophysical elements (Burel and Baudry, 2003), play a critical role in our food supply. However, these landscapes face growing threats from climate change. As temperatures rise, extreme weather events, altered precipitation patterns, and shifting seasons are challenging the traditional methods of farming, putting the agricultural landscape under pressure and threatening the food supply (Vanbergen et al., 2020).

Efficiency and resilience are crucial concepts in the context of agricultural landscapes, especially in the face of climate change. While efficiency focuses on the optimal utilization of resources, minimizing waste, and enhancing productivity, resilience is about the capacity of the landscape to adapt and recover from disturbances. It's important to note, however, that these two aspects can sometimes be at odds. Increasing efficiency might lead to a reduction in the system's buffer capacity, thereby diminishing its ability to handle shocks (Bennett et al., 2021). Nonetheless, efficiency and resilience can also complement each other under certain conditions.

One way to achieve both efficiency and resilience in agricultural landscape is through the incorporation of diversity and circularity in agricultural practices. Diversity, which entails a mix of various crops and livestock allows coping with climate change and stabilizes yields. Different species have different tolerances and adaptabilities to changing conditions, reducing the risk of total crop failure due to specific pests or diseases (Dardonville et al., 2020; Egli et al., 2021). Circularity, another element, emphasizes the recycling of resources within the agricultural system, contributing to efficient use of resources (Szymczak et al., 2020).

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Circularity refers to reusing physical materials (Tanzer and Rechberger, 2020) and, in the context of an agricultural landscape, relates to the degree to which close cycles of key resources like nutrients, water, carbon, and energy are maintained at the landscape scale.

We refer to mixed agricultural landscapes as those characterized by greater circularity and diversity and, therefore are more adept at handling climate change challenges. However, the process of how these mixed landscapes develop remains unclear. Agricultural landscapes are a product of both biophysical conditions and human activity. The natural environment influences what farmers can do on the land, and these farming practices in turn shape the landscape. This dynamic is fundamentally path-dependent, meaning the history of land use and management strongly influences its current state and future possibilities.

While the emergence of mixed landscape is a complex issue, this chapter aims at investigating whether today's mixed landscapes are predominantly shaped by farms that incorporate a mix of activities or from the collective impact of specialized farms. Understanding the cross-scale interaction between different farm types and the characteristic of the agricultural landscapes is essential for policymakers. This understanding is key to devising effective policies aimed at boosting the resilience and sustainability of agricultural systems.

2.3 Material

2.3.1 New classification of mixed agricultural landscapes

To define what a mixed agricultural landscape is we build upon the foundations laid by D3.3. This previous work classified the second-level administrative areas of Europe (NUTS2) into areas with similar combinations of activities. These areas were then classified into mixed and non-mixed agricultural landscapes based on the diversity and intensity of agricultural production. We have since revisited this approach and expanded the database provided in D3.3 to include the concept of circularity and adapted the decision tree to classify landscapes into mixed and non-mixed.

The database developed for D3.3, bringing all data from Eurostat for crop and livestock together, making an average between 2011-2016, was used. The average over 5 years was used to mitigate the impact of any anomalies or atypical variations that might occur in a single year. This database was enhanced with a new circularity variable that was computed as a simplified gross nitrogen balance that assesses the extent to which nitrogen requirements for crop production can be met using locally available manures. To calculate the supply of manure, Eurostat's livestock numbers were used, applying extraction rates as provided by de Vries (2021). Furthermore, the nitrogen requirements of crops including the crop residues as well as the application of manures to grasslands were calculated following the methodological approach proposed by Einsarsson (2020). A limitation of this simplified gross nitrogen balance is that it does not account for the nitrogen losses nor the manure that is directly left on permanent grasslands. Nitrogen required for pastures and other planted fodder is accounted for in the database, suggesting that the circularity indicator might not reflect the circularity of areas shaped by permanent grassland well. Whereas Einsarsson (2020) provides data to compute nitrogen loss and the manures applied to grassland, this dataset is at national level, distorting results within countries. Also, it does not separate between permanent and temporary grasslands. The consequence of not accounting for manures applied to permanent grassland is that landscapes dominated by permanent grassland will overestimate the manure applied to

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cropland, and result in a nitrogen over-application, while in reality in terms of nitrogen balance and the resulting nitrogen leaching, this is not the case. Therefore, the circularity indicator used in this study should be interpreted as a measure of the crop-livestock interaction level representing the level of reuse of material within different agricultural practices and potential for independence from external input such as artificial fertilizer. It should not be interpreted as an environmental indicator, where non-circularity would represent or a nitrogen surplus with a likely water eutrophication problem or a nitrogen deficiency that leads to soil degradation.

The new decision tree is based on the diversity of crop, the diversity of livestock computed based on the Shannon Wearer index and the extent to which the simplified gross nitrogen balance is balanced. The individual maps for each of these variables is shown in Figure 2.2.

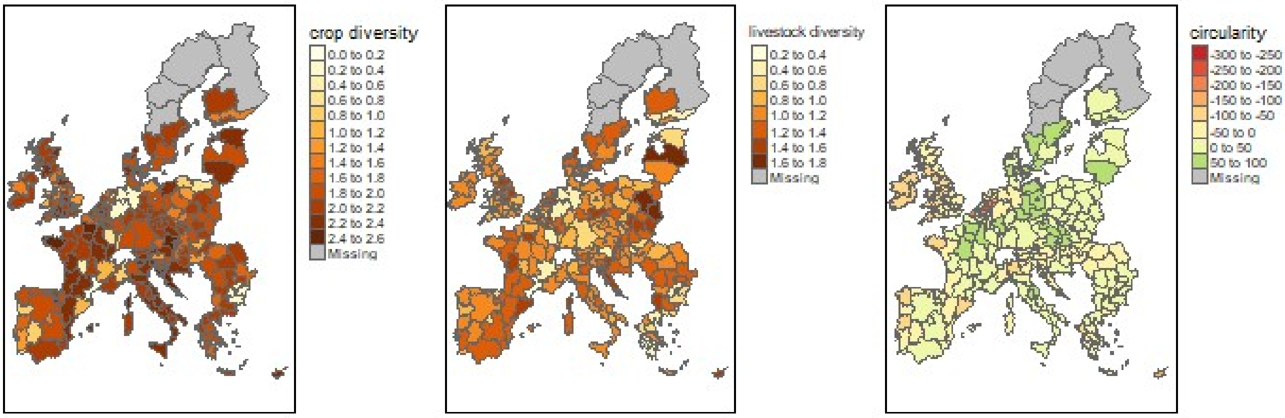

Figure 2.2: Input data for the classification, i.e. crop diversity based on the Shannon index (left), livestock diversity based on the Shannon index (middle), and circularity (right).

The diversity variables as well as the absolute value of the soil nitrogen balance have been grouped into tercile, where the highest tercile identifies the most crop diverse, the most livestock diverse and the most circular NUTS2 regions in Europe. When all three indicators are among the highest tercile for a landscape, then this landscape is considered as mixed. In Figure 3.2, these mixed landscapes are the dark blue ones with the point pattern. This tercile rule applied to NUTS2 region is more straightforward than the approach presented in D3.3, allowing a much finer resolution than the original classification in the areas with similar combination of agricultural activities, thus capturing better the variability between NUTS2 regions.

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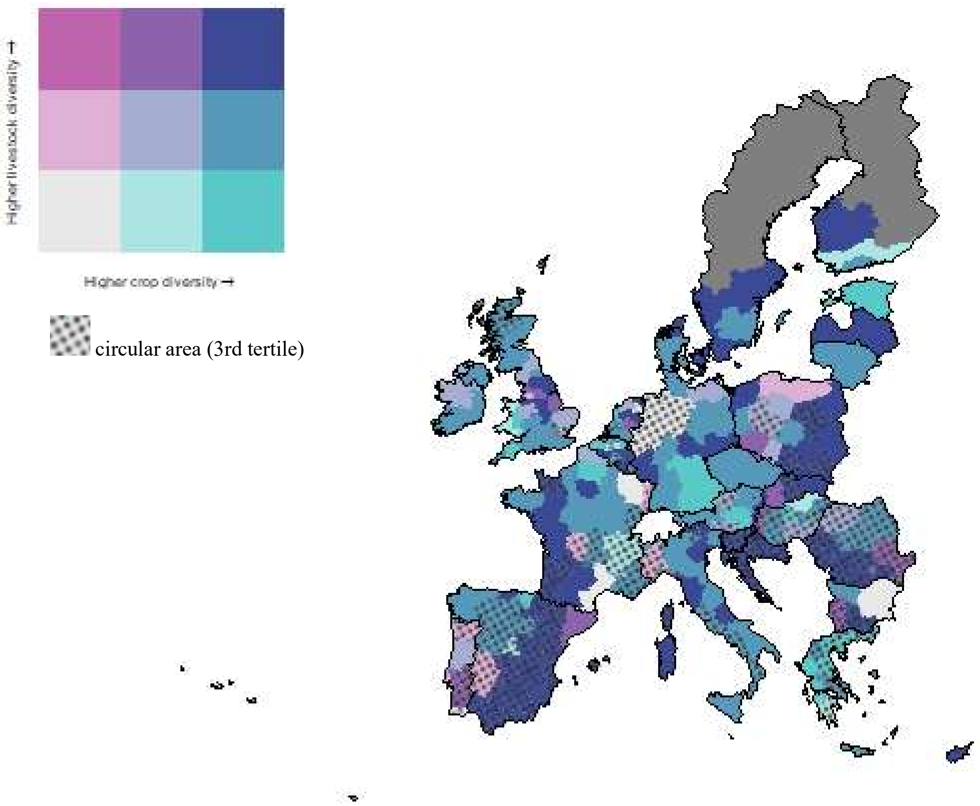

Figure 3.2: New classification of mixed landscapes, where dark blue zones with points are considered as high in crop diversity, livestock diversity and circularity.

2.3.2 Farm typology data

To evaluate the types of farms, present in each landscape, our study utilized the Eurostat farm typology, known as the "Classification of agricultural holdings by type of farming." This classification system organizes farms into nine distinct groups based on their economic characteristics, particularly focusing on the income generated by each farm rather than the volume of production. These groups are:

1. Specialist Cereal, Oilseed, and Protein Crop Farming: Farms primarily focused on cultivating cereals, oilseeds, and protein crops.
2. Specialist Horticulture Farming: Farms that concentrate on the cultivation of fruits, vegetables, and flowers.
3. Specialist Permanent Crop Farming: This category includes farms with a focus on permanent crops, such as orchards and olive groves.
4. Specialist Dairy Farming: Farms predominantly involved in milk production.
5. Specialist Livestock Farming (except Dairy and Granivores): Farms specializing in rearing livestock, excluding dairy cattle and granivores.
6. Specialist Granivore Farming: Farms primarily engaged in raising granivores, like pigs and poultry.
7. Mixed Cropping: Farms engaged in a variety of crop-growing activities without a specific focus.
8. Mixed Livestock: Farms that rear different types of livestock without specialization in one species.

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9. Mixed Crops-Livestock: Farms that combine crop growing and livestock rearing, without a clear specialization in either.

Eurostat provides the numbers of holding for each farm type allowing to derive the share of each farm type per NUTS2 region. Similarly to the other Eurostat data used, the average between 2011-2016 was used.

2.3.3 Additional data

In addition, additional potential drivers of mixed landscape were identified and processed, namely the agroecology capturing the context, as well as the travelling time to the nearest city, offering more options for farm diversification.

For each NUTS2 region, the dominant agroecology was extracted from the environmental stratification of Europe ecology (Metzger et al., 2005) shown in Figure 2.4. The environmental stratification map distinguishes 84 strata that are relatively homogeneous in environmental conditions and can be aggregated into 13 environmental zones, also known as agroecological zones. These zones are ALN (Alpine North), BOR (Boreal), NEM (Nemoral), ATN (Atlantic North), ALS (Alpine South), CON (Continental), ATC (Atlantic Central), PAN (Pannonian), LUS (Lusitanian), ANA (Anatolian), MSM (Mediterranean Mountain), MDN (Mediterranean North, MDS (Mediterranean South).

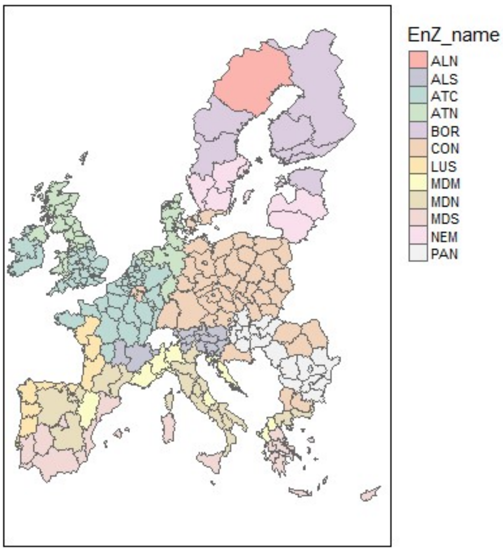

Figure 2.4: Agro-ecologies at NUTS2-level based on the environmental stratification map.

In addition, average travelling time to the nearest city with 50,000 inhabitant based on Weiss et al. (2018) was computed for each NUTS2 region shown in Figure 2.5. The travelling time is expressed in minutes.

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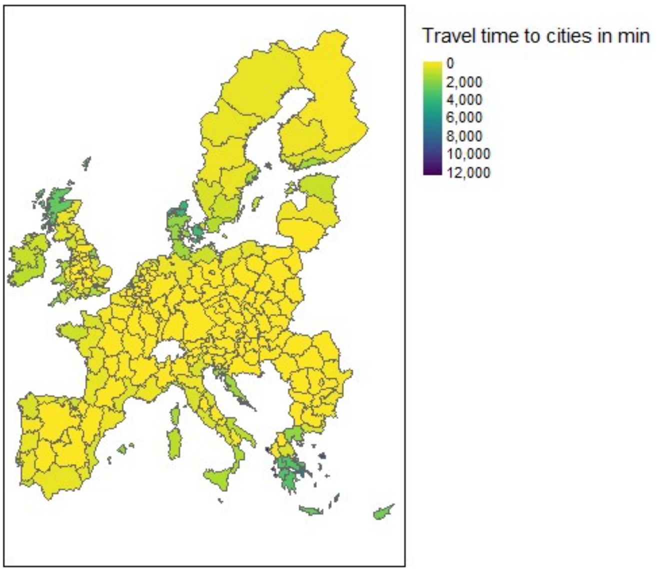

Figure 2.5: Average travel time to cities of 50,000 inhabitants or more in minutes.

2.4 Methods to assess the cross-scale linkage

To assess whether mixed landscapes emerge from economically mixed farms, our study primarily concentrated on mixed crop-livestock farms. These farms were chosen due to their inherent integration of both crop cultivation and livestock raising, which can potentially lead to circular agricultural practices. Furthermore, mixed crop-livestock farms are generally characterized by greater agricultural diversity compared to specialized farms, making them a suitable subject for investigating their potential contribution to mixed landscapes.
To investigate the prevalence of mixed crop-livestock farms in mixed landscapes and explore whether these farms play a role in shaping such landscapes two distinct analytical approaches were used: a descriptive analysis and a regression analysis.

2.4.1 The descriptive approach

The descriptive approach utilized box plots to make comparisons between the distribution of various farm types within each landscape category. Box plots were employed as a visual tool to aid in the interpretation of these comparisons. Interpreting the box plots involved examining several components:

1. Box Extent: The box in each plot represents the interquartile range (IQR), which includes the middle 50% of the data. It provides an indication of the spread of farm types within a given landscape category.
2. Median Line: The line within the box denotes the median, which is the central value of the data distribution. It offers insight into the central tendency of farm type distribution in a specific landscape.
3. Whiskers: The whiskers extend from the box, typically to the minimum and maximum values within a defined range (outliers may be depicted as individual points beyond the whiskers). These whiskers illustrate the range of farm type variation within each landscape.
4. Outliers: Individual data points beyond the whiskers may indicate extreme values or outliers in the distribution. These outliers could signify unusual cases or exceptions within the dataset.

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The extent of overlap between the boxes in the box plots is another crucial factor in interpretation. When comparing two variables, if the boxes (which represent the interquartile range) do not overlap, it indicates that the middle 50% of the data in each group is significantly different from the other. This implies that there is a substantial difference in the spread or variability of the two datasets. Conversely, if the boxes do overlap, it suggests that the middle 50% of the data in both groups is similar or not significantly different in terms of distribution.

The descriptive analysis was implemented in two ways: one for all of European Union and the other for specific agro-ecological zones. These zones have different biophysical context, so comparing all landscape together might distort the result for the whole of European Union. By focusing on each agro-ecological zone separately, landscapes that are similar in terms of their agro-ecological characteristics are compared.

2.4.2 Regression analysis

To assess whether mixed crop-livestock farms explain the mixed landscape, probit models were tested. A probit regression is a statistical modelling technique that can be used to analyse binary data, meaning with only two possible outcomes. In the context of this study, the dependent variable (y) represents whether a landscape is considered "mixed" or not, which is a binary outcome (either mixed or not mixed). The estimated coefficients of the explanatory variables in the probit regression estimate how these variables influence the probability of the landscape to be mixed. The explanatory factors considered in these models include the share of different farm types, agro-ecology zones, and traveling time to cities.

The share of farm type is the main hypothesis we explore, and the agro-ecological zone was added to control for the bio-physical context. Furthermore, we tested the hypothesis, adding the travelling time variable, that proximity to cities offers more opportunities for direct marketing, hence providing higher product prices, making it easier for landscapes to diversify and become mixed. In other words, we are testing whether the distance to cities has a significant impact on the probability of a landscape to be mixed. If the coefficient for traveling time is significant and positive, it would support the hypothesis, indicating that shorter traveling times to cities are associated with a higher likelihood of landscapes being mixed due to easier access to markets and potential for diversification.

2.5 Results

2.5.1 Descriptive approach

The box plot in Figure 2.6 compares the distribution of farm types for mixed and non-mixed landscapes. It shows that mixed landscapes have a higher share of mixed crop-livestock farms, and a lower share of specialist field crop and specialist grazing livestock farms. Also, mixed landscapes tend to have more mixed crop farms and mixed livestock farms. Yet, the difference between mixed and non-mixed landscape is not significant for any farm type.

Also, the share of specialized field crop and specialist grazing livestock farms is higher in mixed landscapes than the share of mixed crop-livestock farms, suggesting that even in mixed landscapes, the combination of specialized farms plays a more important role than mixed crop-livestock farms.

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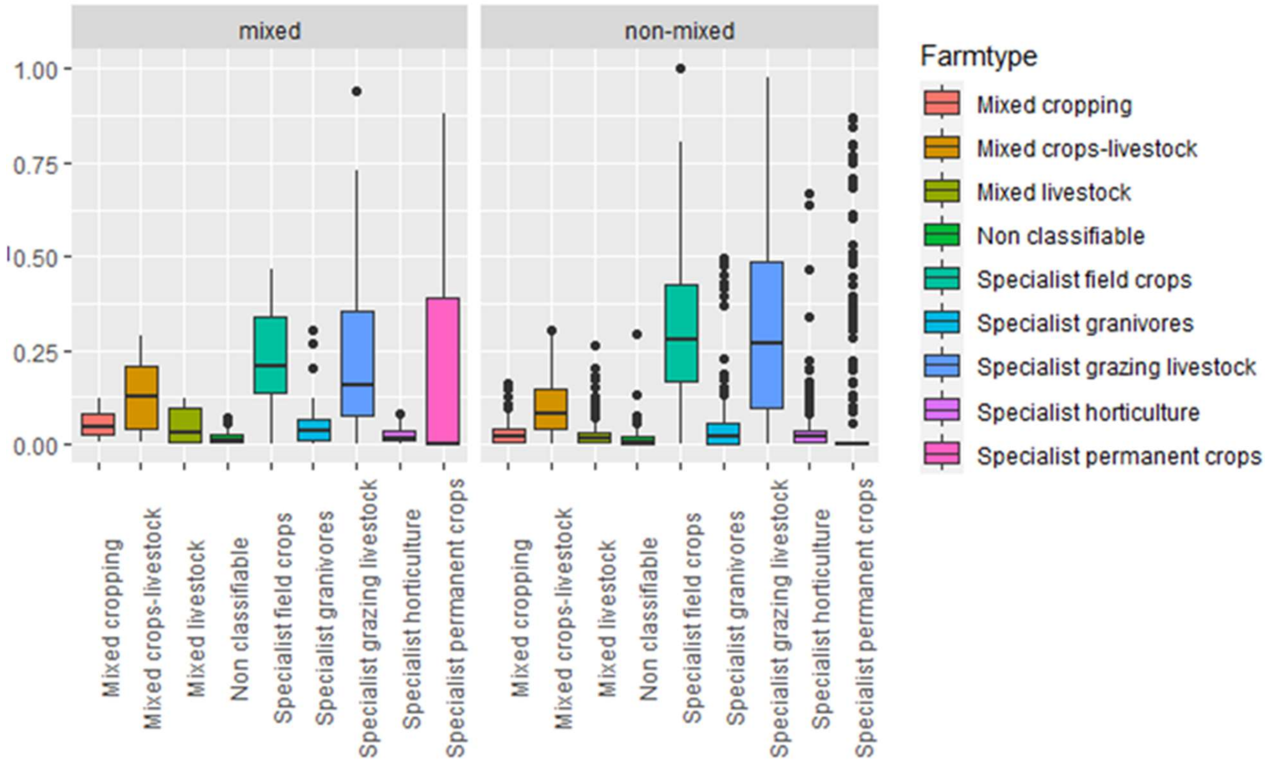

Figure 2.6: Comparison of share of farm type for mixed and non-mixed landscapes at European level.

The boxplot in Figure 2.7 shows the same as Figure 2.6, but split by agro-ecologies, showing only those agroecologies in which several mixed and non-mixed landscapes can be found, allowing to compare variability. The figure shows that the patterns identified at European level are consistent across all agroecologies with two exceptions. Firstly, the Mediterranean North, non-mixed landscape has a higher share of mixed crop-livestock farms than the mixed ones. Also, in both Mediterranean North and South the share of specialist permanent crops is higher in mixed landscapes than in non-mixed ones.

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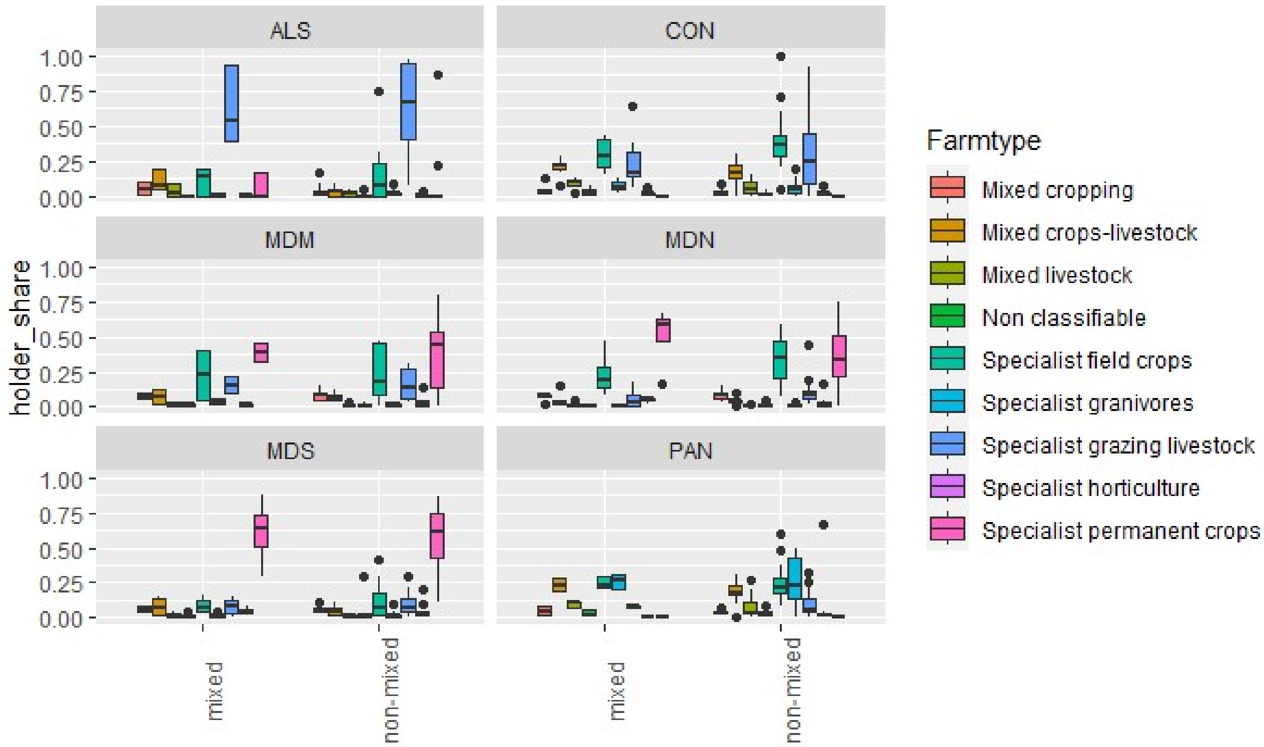

Figure 2.7: Comparison of share of farm type for mixed and non-mixed farms per agro-ecology with several landscapes classified as mixed and non-mixed.

The boxplot in Figure 2.8 focuses on those agro-ecologies that do not have any landscape classified as mixed. Both the Boreal (BOR) and the Nemoral (NEM) zone are shaped by higher share of specialist field crops than in the European average of non-mixed landscape, providing an explanation why these landscapes are non-mixed. This is the case even in the Nemoral (NEM) zone, i.e. there is a share of mixed crop-livestock farms comparable with the average share of mixed crop-livestock at landscape level.

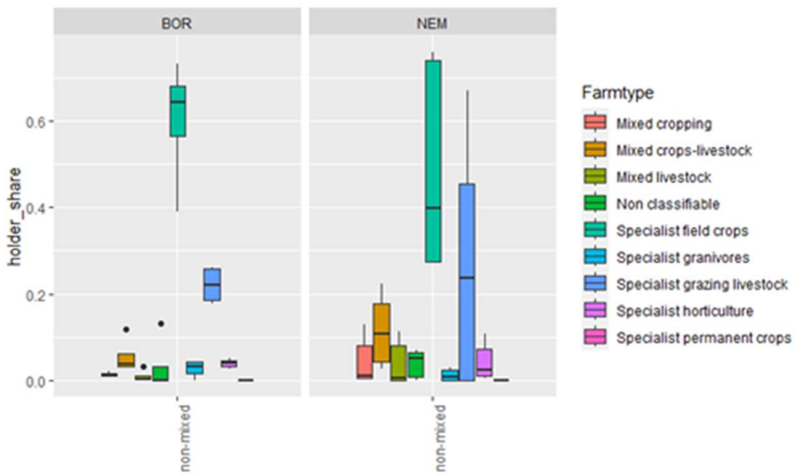

Figure 2.8: Share of farm type for agro-ecologies without mixed landscapes.

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2.5.2 Regression analysis: what explains mixed landscapes?

Table 2.1 shows several specifications for the regression models, in which only the variables that are significant were maintained for model 1. In Model 2, variables in model 1 were kept and other variables were added. Among these additional variables, only the variables that were significant were maintained.

In Model 1, results suggest that the share of mixed crop-livestock farms increases the probability of a landscape to be mixed while the share of specialized field crop reduces it significantly. Model 2 includes the agroecological zone as control variable. In that model the negative impact of the share of specialist field crop farms reduced and is not significant anymore, but the agro-ecological zone Atlantic Central intrinsically reduces the probability to find a mixed landscape (regardless of the other variables). This shows the importance of including the agro-ecological zone as a control variable.

Table 2.1: Results from regression analysis.

	Model 1	Model 2
(Intercept)	-1.09 ***	-1.37
	(0.23)	(0.74)
`Mixed crops-livestock`	3.64 *	10.06 *
	(1.45)	(4.11)
`Specialist field crops`	-1.94 **	-2.97
	(0.75)	(1.75)
EnZ_ATC		-2.68 *
		(1.27)
EnZ_ATN		-1.77
		(1.25)
EnZ_BOR		-15.19
		(1886.92)
EnZ_CON		-1.06
		(1.04)
EnZ_LUS		-1.56
		(1.35)
EnZ_MDM		0.00
		(1.09)
EnZ_MDN		0.31
		(0.93)
EnZ_MDS		-0.38
		(0.89)
EnZ_NEM		-16.23
		(1395.03)
EnZ_PAN		-1.71
		(1.14)
AIC	161.26	165.73
BIC	171.63	210.60
Log Likelihood	-77.63	-69.87
Deviance	155.26	139.73
Num. obs.	234	234
Mc Fadden Pseudo Rsq	0.07	0.16

*** p < 0.001; ** p < 0.01; * p < 0.05

Other variables, namely other share of farm type as well as travel time to cities were not significant. They were therefore excluded.

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2.6 Discussion

Both the descriptive and the regression-based approach suggest that there is a positive correlation between mixed landscapes and the share of mixed crop-livestock farms. Yet, this result is to be taken with caution. Firstly, the difference between mixed and non-mixed landscapes is not significant in the descriptive statistics. While the regression models suggest a correlation between share of mixed crop-livestock farm and mixed landscape, the Mc Fadden Pseudo R square suggests that only 7% of the variation observed in model 1 and 16% in model 2 explain the mixed landscapes.

While the regression model suggests that increasing the share of mixed crop-livestock farms could increase the probability of a landscape being mixed, it should not be overlooked that most mixed landscapes are dominated by specialised farms, which exact type of specialisation and in which combination depends on the agroecology. For example, in the Alpine South zone (ALS), specialized grazing livestock farms dominate the mixed landscape while in the Mediterranean zones (MDM, MDN, MDS) the mixed landscapes are dominated by specialist permanent crops. This suggests that already today the mixed landscape is not only shaped by mixed crop-livestock farms, but also by the combination of specialized farms.

It is interesting to notice that many mixed landscapes in the Mediterranean areas are shaped by specialist permanent crop farms. In the Mediterranean North (MDN) zone it is even the most found farm type and there are almost no farms that are specialized on livestock. Eurostat statistics however suggest that there is a relatively high livestock density is this area (in D3.3 the major part of the NUTS2 were classified as mixed combining permanent crop with sheet and goat). This suggests that the classification rules applied by Eurostat might overlook the livestock in the region. Indeed, the Eurostat classification is based on income. As a result, it could be that the landscape is shaped by farms that combine olives and vineyards with sheep, and are circular crop-livestock farm, but that the most important part of the income is generated from olives and vineyards, while sheep generate a limited share of the income. This hypothesis is further supported by the Eurostat statistics showing that sheep prices are lowest in Spain and Portugal compared to the rest of Europe and is about ¼ of the highest price in Europe. This shows the need to develop a new farm typology for Europe that is based on biophysical criteria, and accounts for the level of crop-livestock interaction at farm level through the amount of manure that is available for crops rather than on economic terms.

2.7 Conclusion

This chapter suggests a complex relationship between the presence of mixed crop-livestock farms and the development of mixed landscapes. While there is a positive correlation, the influence of specialized farms in shaping these landscapes cannot be overlooked. Policies should, therefore, focus on two key areas. Firstly, supporting individual farms in increasing their diversity and circularity. This involves encouraging practices that enhance resource recycling and diversification in crop and livestock farming, contributing to both efficiency and resilience. Secondly, there's a need to establish incentives for specialized farms to collaborate. Such collaboration can lead to a more integrated approach, leveraging the strengths of specialized production while fostering a broader landscape-level resilience. Moreover, future research should aim at developing a more nuanced farm typology. This typology should identify mixed farms based on tangible biophysical criteria, such as nitrogen surplus or deficiency, rather than solely on economic output. This approach will offer a more accurate reflection of the true nature of farm practices and their impact on the landscape.

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3 Achieving mixed regions in a cost-effective manner

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3.1 Introduction

D6.2 clarified that specialised farms tend to be more efficient yet less resilient than mixed farms. Nevertheless, mixedness may materialise not only at the farm level, but also at higher levels. Specialised livestock farms in the vicinity of specialised crop farms can be considered a mixed crop-livestock system at a higher level, yielding similar agroecological benefits as a region with mixed farms (Garrett et al., 2020; Low et al., 2023; Martin et al., 2016). European agriculture is characterised by increasing specialisation and scale over time. This trend is driven by economies of scale. Specialisation in differing farm activities may yield economic benefits at the farm level and agroecological benefits at a higher scale. Therefore, this chapter investigates the link between profitability and mixedness at higher scales, which allows for varying degrees of mixedness at the farm level. Focusing on three scenarios, we explore cost-effective pathways for achieving mixed regions.

Figure 3.1 illustrates the three scenarios under investigation. On the left, we have a hypothetical situation with one region with specialised crop farms and one region with specialised livestock farms. Both regions are thus specialised. How can these regions become mixed in a cost-effective manner? We sketch out three scenarios for achieving mixedness on the right. The first scenario allows for mixed farms, specialised crop farms and specialised livestock farms. The second scenario imposes that all farms should become mixed. The third scenario only permits specialised crop farms and specialised livestock farms. Each scenario has an associated cost. In our methodological proposal, we compute this cost as the forgone profit as compared to the *status quo* (on the left), using Data Envelopment Analysis (DEA). The empirical application focuses on Denmark.

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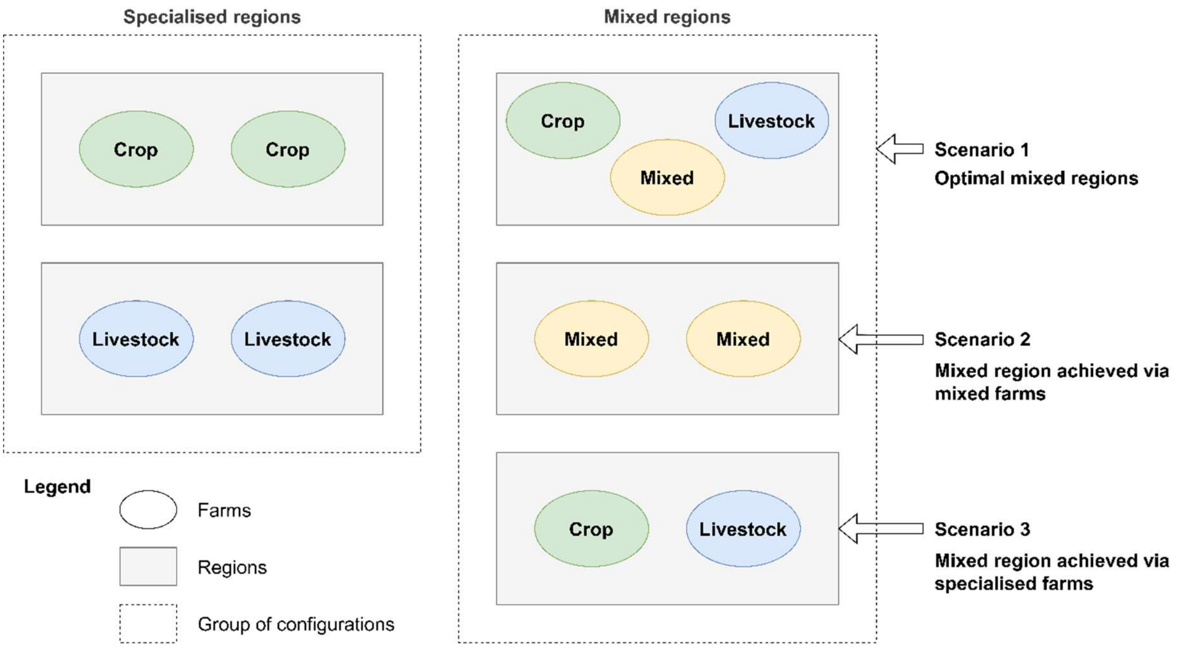

Figure 3.1: Three scenarios for achieving mixed regions.

A more elaborate description of the three scenarios can be found in table 3.1. In all scenarios, we assume that farms intend to maximise profits, and that farms are faced with the constraints of the production technology and their total utilised agricultural area that cannot be changed. Moreover, to obtain a conservative estimate, we assume that farms remain inefficient in their input use. As stated before, at the farm level, scenario 1 does not impose constraints on the mixedness, scenario 2 imposes mixedness, and scenario 3 imposes specialisation in crops or livestock. The mixedness (in terms of crop area and livestock units) is imposed at the regional NUTS2 level. Additionally, we assume that the total cost of feed and fertiliser cannot increase at the NUTS2 level. At the NUTS2 level, we investigate the profitability from the business-as-usual scenario.

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Table 3.1: Overview of approach.

Scenarios	Farm-level objective	Farm-level constraints	NUTS2-level constraints	Assessments at the NUTS2 level
Mixed and specialised farms	Profit maximisation	None on mixedness Production technology Input inefficiency remains constant Total land use remains constant	Mixedness in terms of crop area and livestock units Total cost of feed and fertilisers cannot increase	Profit difference from BAU[1] % mixed and specialised farms Impacts on costs, revenue, and capital depreciation
Mixed farms	Profit maximisation and mixedness maximisation	Mixed Production technology Input inefficiency remains constant Total land use remains constant	Mixedness in terms of crop area and livestock units Total cost of feed and fertilisers cannot increase	Profit difference from BAU[1] % mixed and specialised farms Impacts on costs, revenue, and capital depreciation
Specialised farms	Profit maximisation and specialisation maximisation	Specialisation in crops or livestock Production technology Input inefficiency remains constant Total land use remains constant	Mixedness in terms of crop area and livestock units Total cost of feed and fertilisers cannot increase	Profit difference from BAU[1] % mixed and specialised farms Impacts on costs, revenue, and capital depreciation

[1]:BAU: business as usual

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3.2 Methods

In all scenarios, the first step consists of measuring technical inefficiency. The inefficiency scores are later used in the calculation of mixed regions to be consistent with current farm managerial capabilities and micro-edaphoclimatic conditions. To calculate farm inefficiencies, we use Data Envelopment Analysis (DEA), which is a non-parametric method. In our application, the farm inefficiency scores indicate the extent to which the use of fertilisers, feed and other variable inputs could be proportionally and simultaneously reduced while maintaining all other inputs and outputs constant. For example, a technical inefficiency score of 0.3 indicates that the use of fertilisers, feed and other variable inputs could be simultaneously reduced by 30%, *ceteris paribus*.

In a second step, we calculate the maximum restricted profit, assuming that farms remain technically inefficient and keep the total land use constant. This second step is computed for the three scenarios shown in table 3.1. The first scenario does not contain a second objective besides profit maximisation. The second (third) scenario has a second objective of achieving mixedness (specialisation). By comparing the maximum profit for the three scenarios, we can identify the most cost-effective scenario and calculate the opportunity cost of each scenario.

Whether a farm is mixed or specialised is based on the definition of the Farm Accountancy Data Network (FADN). If more than two-third of the expected revenue comes from crops (livestock), we consider the farm a specialised crop (livestock) farm. If less than two-third of the expected revenue comes from crops or livestock, the farm is considered mixed.

3.3 Data

The farm characteristics, inputs, outputs are extracted from the Farm Accountancy Data Network (FADN). The FADN is the European Union's main effort to monitor the economic situation of agricultural markets and farms in the Community. The collection of FADN data is carried out by EU member states through interviews, management plans, and accounting records. The sample size and composition of the data are carefully determined to ensure representativeness in regions, economic sizes, and agricultural types (Commission implementing regulation (EU) 2015/220, 2015).

The empirical application focuses on Danish farms for the years 2004-2018. We do not consider farms that did not have utilisable available area (UAA), or greenhouse oriented farms (i.e. greenhouse area greater than 0.25 ha or 10% of the farm UAA), or farms where the turnover share coming from the other gainful activities was greater than 10%. We also removed some data inconsistencies, such as mismatches between UAA and the sum of land used for non-feed crops and land used for feed crops. For instance, we exclude farms where the land used for feed crops was larger than the UAA), and cases where livestock production was not linked with positive livestock units. After removing these farms we adapt the FADN sample weights to the remaining sample.

Our sample consists of 21,056 observations. Table 3.2 presents the descriptive statistics of the variables per Environmental Zone, The other fixed inputs are 'FAO ASI' and 'unpaid labour'; the other variable inputs are 'paid labour', 'other crop variable inputs', 'other livestock variable inputs', and 'other farm variable inputs', and the agricultural outputs are the 'crop output' and 'livestock output'. As indicated in Table X, some of these variables aggregate more than one variables from the FADN, for this aggregation we use the Törnqvist-price index (Balk, 2008: 72). The prices related to these variables are retrieved from EUROSTAT (2023). When prices where not available, we consider

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that the prices observed followed the European trend, calculated by the percentage change of weighted average prices based on total agricultural output.

Table 3.2: Descriptive statistics. Standard deviations are between brackets.

Variables	Units	Atlantic North (ATN)	Continental (CON)
Crop output	Euros [2018]	93,601.2 (3,006.6)	119,088.1 (6,936.5)
Livestock output	Euros [2018]	157,838.2 (4,935.0)	69,786.9 (7,223.9)
Non-feed land	Hectares	70.7 (1.6)	94.9 (4.2)
Feed land	Hectares	25.3 (0.8)	7.3 (0.8)
Livestock units	Livestock units	162.7 (5.6)	83.3 (8.5)
Feed costs	Euros [2018]	108,231.6 (3,359.4)	49,064.6 (4,633.0)
Fertiliser costs	Euros [2018]	8,325.2 (208.7)	12,335.4 (629.6)
Unpaid labour	Hours	1,644.4 (15.7)	1,404.6 (29.5)
Paid labour	Hours	1,369.0 (60.4)	1,050.0 (117.9)
Other crop variable costs	Euros [2018]	23,669.5 (959.7)	27,929.0 (1,869.7)
Other livestock variable costs	Euros [2018]	15,509.4 (495.4)	6,996.7 (733.1)
Other farm variable costs	Euros [2018]	64,391.5 (1,211.6)	58,088.6 (2,530.0)
Depreciation	Euros [2018]	34,900.8 (791.3)	25,917.1 (1,370.7)
FAO ASI	%	96.2	96.4

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Variables	Units	Atlantic North (ATN)	Continental (CON)
		(0.1)	(0.3)
Observations	Observations	1,188.8 (152.7)	214.9 (49.2)

3.4 Results

Our results show that allowing for a combination of specialised farms and mixed farms is the most cost-effective way to achieve mixed NUTS2 regions. They also demonstrate that especially imposing specialisation at farm level is a costly measure to achieve mixed NUTS2 regions.

When maintaining current land uses, the profitability, as defined by the ratio of revenues to variable costs, may on average increase from 0.972 to 1.301, and 0.959 to 1.244, for ATN and CON, respectively. Endogenising land use while imposing mixedness at the NUTS2 level does not necessarily lead to decreases in the profitability compared to the profitability under profit maximisation when maintaining current land uses. Allowing for specialisation and mixedness at farm level, as in scenario 1, seems in particular to be an attractive option, with an average profitability of 1.328 and 1.236 for ATN and CON, respectively. Scenario 2, which imposes mixedness at farm level to achieve mixed NUTS2 regions, is slightly less cost-effective. Here, the average profitability for ATN and CON are respectively 1.302 and 1.172 for ATN and CON. Scenario 3, which imposes specialisation at farm level to achieve mixed NUTS2 regions, is the least cost-effective option, as evidenced by an average profitability of 1.134 and 1.061 for ATN and CON, respectively.

Table 3.3: Average profitability ratio (revenue/variable costs) for (1) status quo, (2) profit maximisation without land use change, (3) scenario 1, (4) scenario 2, and (5) scenario 3. The values are shown for the Environmental Zones ATN and CON.

Environmental Zone	Status quo	Profit maximisation without land use change	Scenario 1	Scenario 2	Scenario 3
ATN	0.972	1.301	1.328	1.302	1.134
CON	0.959	1.244	1.236	1.172	1.061

These averages, however, mask substantial heterogeneity, as shown in figure 3.2. All scenarios under profit maximisation show a very large spread. In both Environmental Zones it is unclear whether profit maximisation under imposed specialisation of farms will dominate the current profit levels under *status quo*. The distributions of the profitability under profit maximisation for the current land uses, scenario 1 and scenario 2 are all in all similar.

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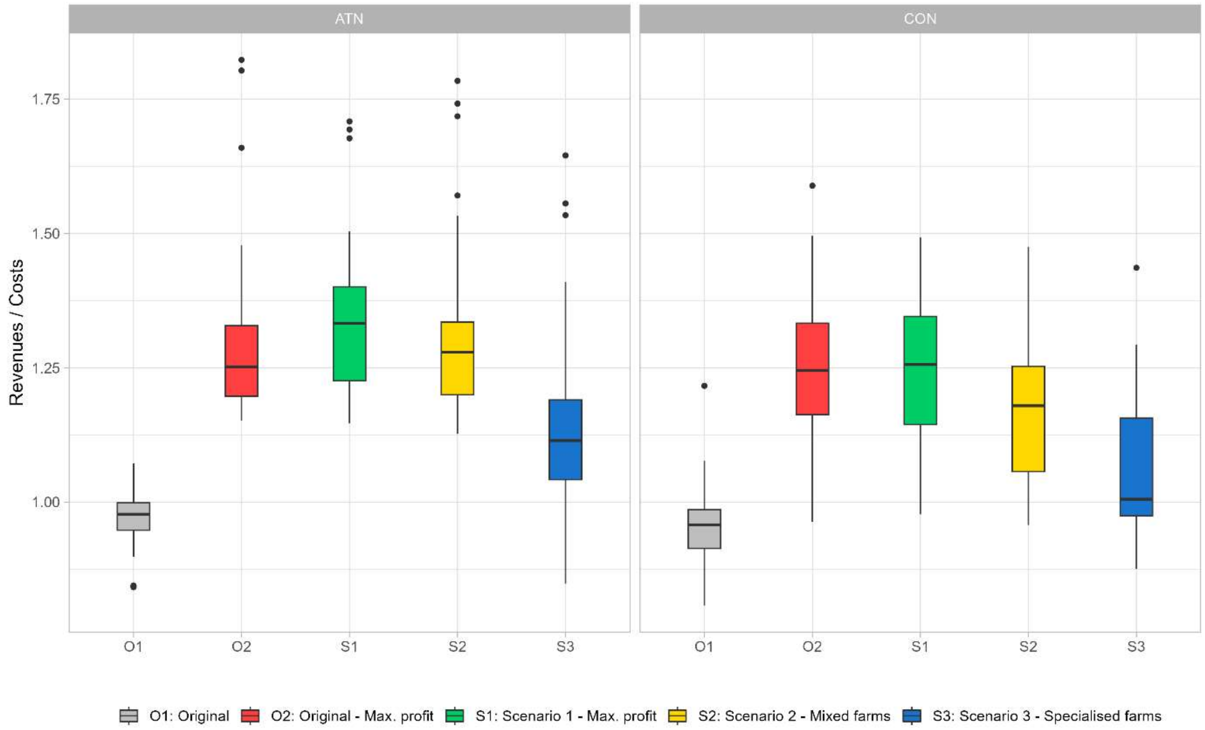

Figure 3.2: Three scenarios for achieving mixed regions: boxplots.

3.5 Conclusions

This chapter shows achieving mixed regions does not necessarily imply a lower profit potential for farms. Our analysis demonstrates that imposing mixedness at the regional level can even lead to a higher profit potential compared to the profit potential when maintaining current land uses. By construction of the DEA, allowing for mixed and specialised farms is the most cost-effective option to impose mixedness at the regional NUTS2 level. For policy makers, however, it may prove difficult to let farms within a NUTS2 region coordinate on the mixedness and specialisation at the individual farm level. Interestingly, imposing mixedness at farm level is not much less cost-effective than allowing for mixed and specialised farms. From this perspective, incentivizing farms to become more mixed in specialised NUTS2 regions should be further explored as a policy option.

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4 Production, environmental performance, and diversity: evidence from England and Wales

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4.1 Introduction

Agricultural production plays a crucial role in ensuring global food security. However, it also poses environmental challenges. For instance, agricultural production has been the main driver of nitrogen (N) pollution (Lamkowsky et al., 2021). At the same time, current agricultural and food system practices have led to a decline of cultivated biodiversity (De Ron, Bebeli, Negri, Vaz Patto, & Revilla, 2018; Jones et al., 2021; Negri, 2005). At the farm level, reduced diversity has been linked with increased vulnerability to extreme weather events, pests, and diseases, all of which are expected to increase under current climate change projections. Simultaneously, population growth and demand for food are increasing. As a result, increasing food production, reducing N pollution and promoting diversity have become major agricultural policy issues (Kanter et al., 2020; Pe'er et al., 2019).

Researchers found that reducing N pollution and increasing diversity can enhance economic performance from crop production (Gaudin et al., 2015; Nilsson et al., 2022; Renwick et al., 2019). These findings have led economists to investigate the economic reasoning behind the issue of N pollution and diversity losses. N pollution from agricultural activities is a typical downstream externality, while specialisation in agriculture is incentivised by economies of scale, streamlined processes, and competitive advantages. In addition, behavioural factors, such as risk and loss aversion, and opportunity costs, were found to further explain why farmers have been overusing fertilisers and specialising their activities. These behavioural factors linking N pollution and specialisation influence farmers' decision making. Among these decisions, the choice of which crops to grow carries substantial consequences for farm management and economic performance. Despite these links, to the best of our knowledge, no production economics studies have approached the issue of crop production, nitrogen surplus, and crop diversity from a land allocation perspective.

The aim of this chapter is to (i) assess the potential of simultaneously improving production while minimizing N pollution, and (ii) to analyse the related impact on crop diversity. Tackling the N issue from a land allocation perspective may lead to a synergy or a trade-off with crop diversity. If there are trade-offs, the optimal allocation that reduces N pollution may aggravate the diversity impoverishment. If there are synergies, the challenge lies in addressing the behavioural factors that prevent farmers from reducing nitrogen surpluses and diversifying their fields. This chapter focuses on England and Wales – as these countries collect and share detailed environmental Farm Business Survey (FBS) data and are rather exemplary for the environmental and diversity issues in other European countries.

4.2 Methods

This chapter looks at the combined problem of N and diversity in two steps. First, by maintaining current land uses we find how much efficiency improvements could simultaneously improve crop production and reduce N surpluses. Second, we introduce land reallocation through two scenarios,

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i.e. (i) a scenario focussing on maximizing production, and (ii) a scenario optimizing both the production and nitrogen objectives.

Following Murty et al. (2012) we distinguish between two types of sub-technologies, one for the production of good (intended) outputs, and another one for the production of bad (unintended) outputs. This approach recognises that there are differences in the functional relationships relating inputs used to produce good and bad outputs, while at the same time, acknowledging the links between both technologies. In our study, the sub-technology of good outputs models agricultural production, and the sub-technology of bad outputs models the N balance production.

Accounting for edaphoclimatical differences, the production technology is defined by environmental zone, see Figure 4.1 (Metzger et al., 2005). In addition, we control for interannual weather variability by only considering observations from the same year in the estimation.

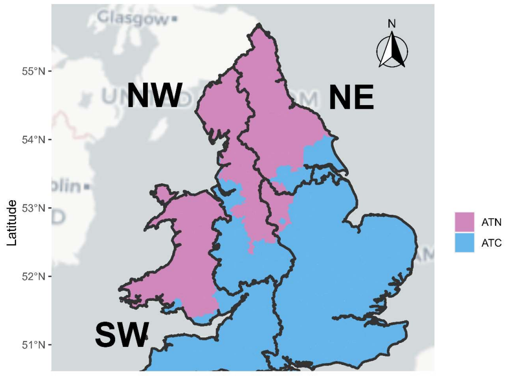

Figure 4.1: Environmental zones in the regions of England and Wales – classification based on NUTS2 regions.

We use Data Envelopment Analysis (DEA) to operationalise our framework (Banker et al., 1984; Charnes et al., 1978). DEA is a non-parametric approach that does not require the specification of a functional form for the estimation of the production frontier. In our empirical application, we extract farm-level input and output data from the Farm Business Survey (FBS). Our sample consist of farms in England and Wales from the year of 2015 until 2019, with an average of 329 observations per year (Table 4.1). We only selected farms in FBS that were present for at least 2 consecutive years, since the N balances from two consecutive years are necessary in our models.

To assess the implications of land reallocations on crop diversity, we calculate the exponential of the Shannon Index, also known as the Hill number (Hill, 1973).

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Table 4.1: Detailed sample size.

Year	NE	NW	SE	SW
2015	63	64	183	56
2016	86	87	197	105
2017	99	95	209	145
2018	115	112	259	180
2019	112	112	267	165

4.3 Results[1]

Our results show that it is possible to simultaneously improve crop production and reduce N balances by increasing efficiency and optimising land use allocation.

When **maintaining current land uses**, purely the elimination of inefficiencies can result in a 1.14% average increase in production across regions, rising from 905 GBP per hectare 915 GBP per hectare. Additionally, this process reduces the N surplus by -2.50%, decreasing from 41.93 kg of N per hectare to 40.88 kg of N per hectare.

With **land reallocation**, results show that further improvements in production and a reduction in N surplus can be achieved.

- Scenario focussing on maximizing production. Reallocation with the production objective results in gains of 9.25%, reaching 989 GBP per hectare, while concurrently reducing N surpluses by -7.29% to 38.87 kg of N per hectare.
- Scenario optimizing both production and nitrogen objectives. In the case of reallocation with the production-nitrogen objective, there are projected production gains of 7.94%, totalling 977 GBP per hectare, alongside a reduction in N surpluses by -19.20% to 33.88 kg of N per hectare.

The differences between these two scenarios suggests opportunity costs, or foregone output, on average of 2.37 GBP per kg of N.

With regard to **crop diversity**, findings show that in case of maintaining current land uses, the median farm has an effective number of species of 3.13 (Figure 4.2). After land reallocation, the median diversity increases by an additional 0.24 species for the production scenario and 0.23 species for the combined scenario (Figure 4.2). Figures at the regional level are summarized in Table 4.2.

[1] GBP reflects 2019 rates.

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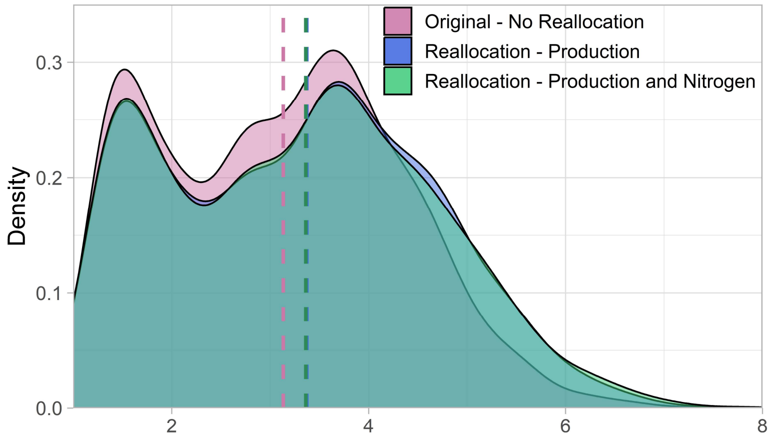

Figure 4.2: Weighted density distribution of farm level crop diversity, with maintaining current land uses (Pink: original – no reallocation) and with land reallocation (Blue: focussing on production; Green: addressing both production and nitrogen). The distributions of farm level crop diversity in the land reallocation scenarios are very similar.

Table 4.2: Yearly results of cropland diversity at the regional level.

Region	Scenario	2015	2016	2017	2018	2019	Average
NE	Original	4.50	5.17	5.39	5.55	5.36	5.20
	Reallocation - Production	4.50	5.35	5.40	5.71	5.38	5.27
	Reallocation - Production and Nitrogen	4.50	5.34	5.39	5.68	5.44	5.28
NW	Original	4.57	4.61	4.87	5.01	4.95	4.83
	Reallocation - Production	4.57	4.67	4.95	5.25	5.03	4.93
	Reallocation - Production and Nitrogen	4.57	4.71	5.01	5.23	5.04	4.94
SE	Original	5.89	5.88	6.50	6.50	6.25	6.22
	Reallocation - Production	5.93	6.02	6.53	6.67	6.33	6.31
	Reallocation - Production and Nitrogen	6.02	6.17	6.58	6.68	6.44	6.40
SW	Original	3.92	3.20	3.47	3.64	3.69	3.58
	Reallocation - Production	3.92	3.25	3.53	3.90	3.82	3.69
	Reallocation - Production and Nitrogen	3.90	3.24	3.53	3.90	3.85	3.69

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4.4 Conclusions

Our results indicate potential for English and Welsh farm to simultaneously increase production and reduce nitrogen losses, while also increasing crop diversity at farm and regional level. This improvement can occur through either efficiency enhancements ("maintaining current land uses") or reallocation ("land use reallocation"). However, we observe that reallocation leads to more substantial improvements.

Results highlight the importance for farmers and policymakers to be aware of the economic and environmental impact of land use choices. To achieve a significant reduction in nitrogen surpluses through optimal land use allocation, policymakers must provide instruments that can mitigate uncertainties associated with increasing crop diversity and improving fertiliser use efficiency. Our research encourages further exploration of the diversity allocation problem, considering other dimensions such as intra-species diversity, temporal variations, different scales, and the interaction between these diversity levels.

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5 Impact of cooperation between arable and dairy farmers on profitability and soil quality

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5.1 Introduction

Mixed systems can be organised at farm-level. However, they may also materialize through cooperation between specialised farms at the community or regional level, e.g. as part of increasing regional-level circularity or to achieve more extensive crop rotation patterns through the exchange of land (Kik et al., 2021a). While informal cooperation between farmers is common (as shown in WP1 Field workshops), the need to improve sustainability and resilience of agriculture (EC, 2020) incentivizes bottom-up farmers' interest to further explore the potential of such cooperations.

The aim of this chapter is to analyse the sustainability and resilience gains of cooperation between arable and dairy farmers. More specifically, the chapter analyses the economic benefits of exchanging land, manure, and feed, and the implications for soil quality. The resilience dimension herein lies in the premise of the cooperation itself, one of the core attributes of building resilience (Resilience Alliance, 2010).

We do this for the MIXED network in the Netherlands (https://projects.au.dk/mixed/networks-national-teams/the-netherlands). The farmers have already been collaborating for many years; their collaboration is based on mutual trust and principles of sharing[2].

Results in this chapter focus on the benefits of joint rotation schemes and were discussed with the NL-Network farmers on 18 March 2024. Based on their feedback, additional cooperation scenarios are currently being investigated. Outcomes will be explored together with the farmers during the final WP1 Field workshop (June 2024).

5.2 Methods

5.2.1 Bio-economic model

To model the impacts of the cooperation between arable and dairy farmers, an extended version of the farm-level bio-economic model called FarmAnalytics is used (Kik et al., 2021b; Kik et al., 2024). The FarmAnalytics model optimizes farm income while adhering to target values of various

[2] This type of cooperation roots in history and relates to the relatively poor soils in the region. In regions with highly fertile soils (such as Flevopolder), cooperations between farmers are based on commercial interests.

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chemical, physical and biological soil quality indicators (Kik et al., 2024). The concept of the *extended* version is shown in Figure 5.1.

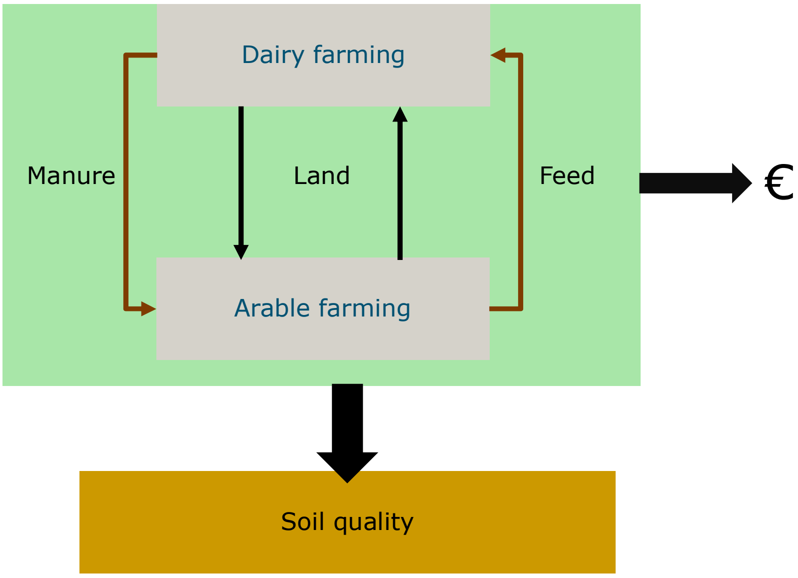

Figure 5.1: Conceptual framework of bio-economic model to analyse cooperation between arable and dairy farmers.

5.2.2 Bottom-up data

The bio-economic model uses detailed farm, plot and soil data. As part of MIXED, these data are retrieved through (i) access to farmers' management systems, (ii) individual WP2 handbook data collection rounds to elaborate on data from the management systems, (iii) WP1 field workshops to elicit past, current, and future farm and collaboration strategies, and (iv) the WP5 Dynamix serious game to elaborate on the exchange of specific field plots.

5.2.3 Cooperation scenarios

Three cooperation scenarios in which farmers work with joint (multi-farm) crop rotations are modelled (names of respective farmers are excluded for anonymity reasons):
1. Joint rotation grass/potatoes.
2. Mixed rotation grass/potatoes/maize/sugar beets.
3. Joint arable rotation potatoes/maize/sugar beets/barley

5.3 Results

Results of the three cooperation scenarios are presented in Table 5.1 for a number of selected soil quality and economic parameters. Results show that - if farmers would jointly optimize their

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rotations - most soil quality parameters are closer to target values, and economic performance improves in two scenarios, as indicated by the green cells.

Table 5.1: Impact of joint rotation scenarios for selected soil and economic parameters for current values and optimized outcomes[1]. Green and red cells indicate economic parameters which improve and worsen due to optimization respectively.

	Unit	Joint rotation		Mixed rotation		Joint arable rotation	
		Current	Optimal	Current	Optimal	Current	Optimal
Soil quality	Kg ha^{-1}						
P advised	Kg ha^{-1}	73	73	74	72	74	77
P realised	Kg ha^{-1}	90	80	71	80	68	80
K advised	Kg ha^{-1}	251	251	245	248	222	221
K realised	Kg ha^{-1}	324	251	255	248	260	221
Max soil compaction	Index	0.2	0.2	0.2	0.2	0.2	0.2
Realised soil compaction	Index	0.4	0.38	0.39	0.42	0.37	0.32
Min supply of organic matter	Kg EOS ha^{-1}	3000	3000	3000	3000	3000	3000
Realised supply of organic matter	Kg EOS ha^{-1}	5318	4643	4226	4637	3172	3000
Economic performance (gross margin)							
Crops	Euro ha^{-1}	2060	2060	2142	2110	1690	1634
Cover corps	Euro ha^{-1}	0	0	-45	0	-138	-57
Manure	Euro ha^{-1}	0	0	0	26	-40	21
Crop residues	Euro ha^{-1}	0	0	0	0	0	83
Chem. fertilizer	Euro ha^{-1}	-144	-207	-124	-145	-112	-59
Total	Euro ha^{-1}	1916	1853	1973	1991	1400	1622

[1]Scenarios are "joint rotation" (grass/potatoes), "mixed rotation" (grass/potatoes/maize/sugar beets), and "joint arable rotation" (potatoes/maize/sugar beets/barley).

5.4 Conclusions

Outcomes of the bio-economic model show that community-level cooperation between arable and dairy farmers has potential to improve soil quality and economic performance. Further analyses will address the influence of land exchange ratios (dairy farmers would receive relatively more land – but how much?), the sharing of benefits (who benefits most, and which criteria can be used to share these benefits?), and the multi-year impact of land exchange (e.g. long-term impact of multiple mowing rounds of grass per year on soil compaction?).

5.5 References

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6 Discussion: top-down and bottom-up analyses on MiFAS

The **top-down** analyses in Chapters 2-4 give us insights on the interaction between mixedness, economic benefits and environmental benefits at multiple scales in various contexts. Mixedness can be defined at multiple scales, going from the farm level to the regional level. Chapter 2 shows that, in the European context, mixed landscapes are often characterised by mixed crop-livestock farms. Although mixed regions may in principle constitute a combination of specialised crop farms and specialised livestock farms, this thus does not hold generally in practice. Chapters 3-4 show economic and environmental potential of mixed farms. Chapter 3 demonstrates that achieving mixed regions may not come at the cost of profitability at farm level in Danish agriculture. Interestingly, imposing mixedness at farm level can still result in profitable farms. Chapter 4 shows that simultaneously increasing production and reducing the nitrogen surplus may increase crop diversity in English and Welsh arable farms. Arguably, crop diversity may be seen as mixedness at farm level.

Achieving mixed regions can also be achieved by letting specialised livestock farms collaborate with specialised arable farms. The top-down analysis in Chapter 3 shows that imposing a combination of specialised livestock farms and specialised arable farms at regional level may be the least cost-effective option to achieve mixed regions. However, by the nature of the dataset employed, we cannot observe collaborations or the potential thereof. The **bottom-up** analysis in Chapter 5 allows us to observe the potential of exchanging resources between dairy farms and arable farms in the Dutch context. The results show substantial potential to increase farm-level soil quality and profitability in this potential exchange.

The bottom-up analysis per definition only holds for a particular context. The exchange of resources between specialised dairy farms and specialised arable farms may constitute a mixed landscape with economic and environmental benefits, as shown in Chapter 5. Although such an exchange of resources is unrecorded in the EUROSTAT and FADN databases, it is reassuring that, even with this data limitation, economic and environmental benefits can be identified for mixedness at various scales in the top-down analyses in Chapters 2-4. While a more detailed cross-validation between the top-down analysis and bottom-up analysis has proven difficult, this report does show the potential economic and environmental benefits of mixed agricultural systems.

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