How to reconcile agricultural production with environmental preservation through an efficiency analysis: Land sparing versus Land sharing?

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Abstract: Reconciling agricultural production with environmental preservation is one of the main challenging issues in the agricultural sector. We addressed this issue through the implementation of two strategies of land management: the land sharing and the land sparing strategies. We used efficiency analysis with DEA Method to measure the potential for implementing these two strategies taking into account farm categories. These categories were made following two criteria: the criterion of agricultural land productivity and the criterion of production structure. With an application on farm data of the Meuse Department over the period 2014-2016, results show that agricultural production can be reconciled with environmental preservation by sparing 25% of agricultural land for environmental preservation in the land sparing strategy, or by reducing agricultural intensity by 26% on all agricultural land in the land sharing strategy. Considering farms' categories, our findings suggested that the land sparing would be more appropriate for less productive farms and land sharing for more productive farms with the criterion of land productivity. And with the criterion of production structure, the land sparing would be more appropriate for farms less dominated by livestock, and the land sharing for farms more dominated by livestock. Our results underline the importance of taking into account farms' characteristics in implementing an agricultural land management strategy for environmental preservation.

Keywords: Agricultural production, environmental preservation, land sharing, land sparing, Data Envelopment analysis method, Meuse department.

JEL classification: Q1, Q5, R14.

1. Introduction

To these days, reconciling agricultural production with biodiversity and environment preservation is one of the major concerns in agriculture sector. Intensive and industrialized practices long implemented in agriculture to increase agricultural productivity and ensure food security have resulted in significant consequences on biodiversity and environment (Bianchi et al., 2007; Björklund et al., 1999; Dale and Polasky, 2007; Donald et al., 2001; Krebs et al., 1999; Kremen et al., 2002; MEA, 2005). Services provided by ecosystems have deteriorated over time in favor of agricultural yields maximization (MEA, 2005). Since the sustainability of agriculture depends on the provision of ecosystem services such as pollination, nutrient recycling, pest control, carbon sequestration, water flow regulation, etc (MEA, 2005), the interest in restoring and preserving these services is crucial. One of the ways suggested in the literature to reduce the impact of agriculture on environment and biodiversity is to manage agricultural intensity (see for instance Teillard, 2012; Teillard et al., 2017, among others). Agricultural intensity is considered at the same time as a key factor in increasing agricultural production, and a determinant of biodiversity erosion. To balance agricultural production with biodiversity conservation, Teillard (2012) and Teillard et al. (2017) analyzed not only the effectiveness of different scenarios of agricultural intensity (intensification, extensification, reallocation), but also their optimal allocation in agricultural area. Their results highlight the importance of a spatial planning of the agricultural intensity allocation to manage farmland biodiversity. Further to biodiversity preservation, Shi et al. (2021) studied the role of agricultural intensification to balance agricultural production with the provision of other ecosystem services such as carbon storage. These authors discussed the spatial configuration of different land uses to achieve an optimal solution of agricultural production and ecosystem services provision. Focusing on the sole environment aspect, our work analyze how agricultural production can be reconciled with environmental preservation through agricultural intensity reduction and its spatial allocation on farmland in different land management strategies.

Inspired by the literature in ecology about biodiversity conservation on agricultural landscapes, we analyzed two options to reduce the pressure of agriculture on environment: either adopt extensive agriculture less harmful to the environment on all farmlands, or intensify agricultural land on a reduced area so that some land can be spared for environmental preservation. In a study on biodiversity conservation, Green et al. (2005) qualified the first option as *land sharing* that consists of expanding the wildlife-friendly farming over a large area to improve biodiversity conservation, and the second option as *land sparing* that advocates a spatial separation of agricultural production from biodiversity conservation. In the land sparing option, agriculture is intensified on a small area that allows to spare land for conservation purpose. These two strategies were first applied to biodiversity conservation on farmlands (Dotta et al., 2016; Fischer et al., 2014; Hulme et al., 2013; Kamp et al., 2015; Kremen, 2015; Phalan et al., 2011; Teillard et al., 2017), before being extended to biodiversity preservation in urban areas (Caryl et al., 2016; Collas et al., 2017; Soga et al., 2014; Stott et al., 2015) as well as in forest (Edwards et al., 2014; Paul and Knoke, 2015). Few are the studies that have applied them to the provision of ecosystem services (Shi et al., 2021) and to the sole preservation of environment in agricultural sector (Legras et al., 2018). In line with Legras et al. (2018), we applied the land sharing and land sparing strategies to the environmental preservation from agricultural intensification impacts.

Developed in ecology, the implementation of the land sharing and land sparing strategies has been mainly approached from an ecological perspective. Economic and social aspects have been so far little addressed. Since these two strategies do not have the same implication in terms of land allocation, their implementation may require defining some choice criteria. In the ecological point of view, the choice between land sharing and land sparing is based on the relationship between agricultural production and biodiversity through the agricultural yield-species density curve (Fischer et al., 2014; Green et al., 2005; Phalan et al., 2011). In the case of a convex relationship, the land sparing strategy that suggests to allocate land either to agricultural production or to wildlife preservation would be more preferable. And in the case of concave relationship, the land sharing strategy that allows for both agricultural production and wildlife preservation to be allocated on the same land would be more preferable. Further to this choice criterion based on the dichotomous relationship between agricultural production and species density, other studies underlined the importance of economic, political and social criteria (Desquilbet et al., 2017; Legras et al., 2018; Salles et al., 2017). According to these studies, the choice and the implementation of the land sharing and land sparing strategies should take into account the social welfare and the rational behavior of farmers (Salles et al., 2017), the cost-effectiveness of each strategy and the influence of economic incentives policies (Legras et al., 2018), the type of inputs used in the production process, the soil quality heterogeneities and the influence of public policies (Martinet and Barraquand, 2012), and the effects of agricultural market through prices and demands of agricultural goods (Desquilbet et al., 2017). In our analysis, the choice and the implementation of the land sharing and land sparing strategies are based on efficiency analysis taking into account the impact of farms' categories.

Furthermore, we conducted an efficiency analysis using the Data Envelopment Analysis method (DEA method) developed by Charnes et al. (1978). This method has been widely used in the literature to measure the efficiency of decision-making units in non-parametric approaches. Since its development, DEA method has been applied to different issues in different domains including banking, transportation, health care, education and agriculture (Liu et al., 2013). In agricultural sector, farm efficiency measures with DEA first addressed technical and economic performance of farms in different contexts (Blancard et al., 2013; Chavas and Aliber, 1993; Coelli, 1995; Färe et al., 1985; Ray and Bhadra, 1993, among others), and then extended to other aspects of agricultural activity such as environmental issues (Berre et al., 2013; Juan-Javier et al., 2018; Kuhn et al., 2020; Kuo et al., 2014; Reinhard et al., 2000, among others). However, the issue of agricultural land management has not yet been well developed in DEA efficiency measures. Only a few studies mainly conducted in China addressed the analysis of land use efficiency in agriculture with DEA method (Fei et al., 2021; Kuang et al., 2020; Pascual, 2005). Fei et al. (2021) analyzed the land efficiency in the context of land shortage due to urbanization and industrialization process in China. They used a non-radial directional distance function to evaluate agricultural land efficiency (i.e. the production capacity per unit of land) as well as a propensity score matching method to assess the impact of land transfer on this land efficiency. In the same case of China, Kuang et al. (2020) analyzed the cultivated land use efficiency taking into account undesirable outputs (carbon emissions). They evaluated how cultivated land is used to maximize desirable outputs while minimizing carbon emissions as well as other inputs. On the other hand, Pascual (2005) focused on the land efficiency in a forest-fallow-based shifting cultivation system in Mexico. He analyzed how the efficiency of agricultural land can be improved through land use intensification in order to discourage farmers from expanding agriculture into forest frontier and reduce the ecological damage from burning plots. To the best of our knowledge, none of the previous studies have analyzed the optimal allocation of agricultural land with DEA efficiency measures in the context of the land sharing and the land sparing strategies. Since the development of the land sharing-land sparing strategies by Green et al. (2005), many studies focus on their conceptualization as well as on the scope of their application using theoretical analyses and models (Fischer et al., 2014; Kremen, 2015; Martinet and Barraquand, 2012; Paul and Knoke, 2015; Phalan et al., 2011; Salles et al., 2017; Soga et al., 2014). Applications of these strategies have been carried out using density-yield functions with parametric approaches (Desquilbet et al., 2017; Dotta et al., 2016; Edwards et al., 2014; Hulme et al., 2013; Kamp et al., 2015), and optimization methods (Legras et al., 2018; Shi et al., 2021; Teillard et al., 2017). Our first contribution is to show how DEA efficiency measures can be used to manage agricultural land through the land sharing and land sparing strategies.

Even though the DEA method is criticized for not taking into account the risk and exogenous factors that can influence efficiency measures, we chose it for at least three advantages: (1) it does not require the prior specification of the functional form of the relationship between variables, (2) it allows to measure efficiency in absence of input and output prices, and (3) its ability to compute multiple outputs realized by multiple inputs in a multiple-objective analysis. For more flexibility in our efficiency measures, we used directional distance functions developed by Chambers et al. (1998, 1996) which allow to define a specific direction while projecting each observed entity to the efficiency frontier. Both input and output oriented perspectives can be used. In the land sparing strategy, we chose an input oriented perspective to measure the ability of farmers to set aside some agricultural land at a given level of production. In the land sharing one, we chose an input and an output oriented perspective to measure at which extend farmers can reduce agricultural intensity on all agricultural land, first at a given level of production, second by considering the increase in production. These two efficiency measures allowed us to measurer the potential for implementing the land sharing and the land sparing strategies at the global scale.

Further to this global potential, we analyzed how different categories of farms can contribute to the implementation of the land sharing and land sparing strategies. For that, we categorized farms according to two criteria: the criterion of agricultural land productivity and the criterion of production structure. The aim is to know which strategy between land sharing and land sparing would be more appropriate for farms depending on whether they are less or more productive, and depending on whether their production is dominated by livestock or by crops. In the literature, Martinet and Barraquand (2012) considered soil quality heterogeneities in analyzing the choice between land sharing and land sparing for biodiversity conservation on agricultural landscapes. Through a theoretical model, their results suggested that it could be more efficient to increase production by intensifying the best quality land rather than expanding the area of land sharing on lower quality and less productive land. In line with this study, our work takes into account both criteria of agricultural land productivity and of production structure. To our knowledge, no study has considered these two criteria with the efficiency analysis in the assessment of land sharing and land sparing strategies for environmental preservation in agriculture. Thus our second contribution to the previous literature.

We applied our efficiency measures to farms located to the Meuse department in the northeast of France. We proceeded in two steps: first, efficiency measures were computed for each land management strategy and for all farms. This step allows us to measure the potential for implementing the land sharing and the land sparing at the Meuse department scale based on individual farm inefficiency scores. Second, we aggregated individual inefficiency scores at the group scales made from the two defined criteria. The aim is to measure the contribution of each farm group category to the implementation of the land sharing-land sparing strategies. This step allows us to know for which category of farm the land sharing and the land sparing would be more appropriate.

The reminder of this paper is structured as follows. The second section presents efficiency measures with the DEA method. The third section presents data that are used. Results are presented and discussed in the fourth section, and we conclude in the last section.

2. Methodology

As mentioned in the introduction, we used directional distance functions (DDF) to assess the potential for implementing the land sharing and land sparing strategies to reconcile agricultural production with environmental preservation. DDF are efficiency measures that project an input-output vector onto the efficiency frontier in a preassigned direction (Chambers et al., 1998, 1996). We assigned a specific direction to each efficiency measure of the land sharing and land sparing strategies.

Let K be the number of farms $k = (1,...,K)$, also called Decision-Making Units (DMUs), that transforms a vector of N inputs $x_k = (x_{1k}, \dots, x_{Nk}) \epsilon R_+^N$ into a vector of M outputs $y_k = (y_{1k}, \dots, y_{Mk}) \epsilon R_+^M$. The vector of inputs x_k is divided into variable inputs (indexed by v) and fixed inputs (indexed by f): $x_k = (x_{vk}, x_{fk})$. In fixed inputs, land (x_{fk^L}) is distinguished from capital and labor $(x_{fk^{K,W}})$. Each farm k faces the technology of production given by $T_k = \{(x_k, y_k) \epsilon\ R_+^{n+m}: x_k\ can\ produce\ y_k\}$. Based on assumptions presented in Fried et al. (2008), we assume that this technology satisfies these standards assumptions of the production possibility set:

1. Convexity
   If $(x_k, y_k) \in T_k$ and $(x'_k, y'_k) \in T_k$,
   then $(\alpha(x_k, y_k) + (1-\alpha)(x'_k, y'_k)) \in T_k$ for any $\alpha \in [0,1]$.
2. Free disposability of inputs and outputs
   If $(x_k, y_k) \in T_k$ and $x'_k \geq x_k$ then $(x'_k, y_k) \in T_k$
   If $(x_k, y_k) \in T_k$ and $y'_k \leq y_k$ then $(x_k, y'_k) \in T_k$
3. No output can be produced without some inputs
   If $y_k \geq 0$ and $y_k \neq 0$, then $(0, y_k) \notin T_k$.
4. $T_k\ (x_k)$ is bounded for $x_k \in R_+^n$
5. Inclusion of observations
   Each observed DMU $(x_o, y_o) \in T_k$

For each farm k, the general formulation of the directional distance function defined on this technology T_k is given by:

$$\vec{d}(x_k, y_k, -g_x, g_y) = Sup\,\{\beta: (x_k - \beta g_x, y_k + \beta g_y)\ \epsilon\ T_k\} \tag{1}$$

Where β is the measure of inefficiency and $g = (-g_x, g_y)$ the vector of direction in which the input-output vector (x_k, y_k) is projected onto the efficiency frontier T_k. The DDF $\vec{d}(x_k, y_k, -g_x, g_y)$ simultaneously measures the maximum expansion of outputs and contraction of inputs to reach the efficiency frontier. $\vec{d}(x_k, y_k, -g_x, g_y) = 0$ when the evaluated farm k is efficient and $\vec{d}(x_k, y_k, -g_x, g_y) > 0$ when it is inefficient.

The vector of direction $g = (-g_x, g_y)$ can be specified according to the objective pursued. In our analysis, we assigned to each measure of land sharing and land sparing strategies a specific direction. In the land sparing strategy that measures the potential for agricultural land reduction at a given level of outputs, we oriented our efficiency measure in the direction of the "input land". In the land sharing strategy aiming at reducing agricultural intensity on existing farmlands, we considered the direction of "variable inputs" in the first option (where outputs are considered at their current level) and the direction of "variable inputs and outputs" in the second option (where outputs can be expanded). This second option allows us to measure the extent to which both productive and environmental objectives can be improved on the same land. This refers to the notion of sustainable intensification that consists of increasing food production while minimizing pressure on environment (Garnett et al., 2013; Godfray and Garnett, 2014; Martin-Guay et al., 2018; Pretty, 2018). Leaner programming models corresponding to these strategies are presented below.

2.1. *Land sparing strategy*

In this strategy, DMUs are projected onto the efficiency frontier in the direction of fixed input land noted x_{f^L}. To allow for the aggregation of efficiency scores at the department level, we chosen the same direction for all DMUs. The directional vector is then given by g = $\left(-g_x, g_y\right) = \left(-\sum_{k=1}^{K} x_{fk^L}, 0\right)$. For each farm *k*, the linear programming is given by:

$$\vec{d}(x_k, y_k, -g_x, 0) = \max_{\beta, \lambda_k} \beta$$

Subject to:

$$\sum_{k=1}^{K} \lambda_k y_{rk} \geq y_{ro} \qquad r = (1, \dots, M) \tag{2}$$

$$\sum_{k=1}^{K} \lambda_k x_{fk^L} \leq x_{fo^L} - \beta * \sum_{k=1}^{K} x_{fk^L} \qquad f^L = (1, \dots, \mathrm{n})$$

$$\sum_{k=1}^{K} \lambda_k x_{fk^{K,W}} \leq x_{fo^{K,W}} \qquad f^{K,W} = (n+1, \dots, n')$$

$$\sum_{k=1}^{K} \lambda_k x_{vk} \leq x_{vo} \qquad v = (n'+1, \dots, N)$$

$$\sum_{k=1}^{K} \lambda_k = 1 \qquad k = (1, \dots, K)$$

$$\lambda_k \geq 0, \beta \geq 0$$

This program seeks for the maximum contraction of agricultural land that can be achieved for the DMUo while producing at least as much as before with no more than other fixed and variable inputs. β is the score of inefficiency which correspond to the amount of the total agricultural land each DMU can reduce to reach the efficiency frontier. λ_k is the value of intensity variable of the DMU k calculated from the best observed DMUs that make the efficiency frontier.

2.2. *Land sharing strategy*

This strategy consists of reducing agricultural intensity on existing agricultural land. In the literature, Teillard et al. (2017) measured agricultural intensity for each farm as the ratio between the sum of its different categories of input costs[1] and its utilized agricultural area (UAA). Following these authors, we measured agricultural intensity as a ratio between variable input costs and the utilized agricultural area.

Two options are considered for this strategy. In the first option aiming at reducing the use of variable inputs at a given level of output, DMUs are projected onto the efficiency frontier in the sole direction of variable inputs. The directional vector is given by g = $\left(-g_x, g_y\right) = (-\sum_{k=1}^{K} x_{vk}, 0)$. As in the previous strategy, the same direction is chosen for all DMUs.

[1] These input costs include pesticides, fertilizers, feedstuff, fuel, seeds, veterinary products and irrigation water.

For each farm k, the linear programming model is given by:

$$\vec{d}(x_k, y_k, -g_x, 0) = \max_{\beta,\lambda_k} \beta$$

Subject to:

$$\sum_{k=1}^{K} \lambda_k y_{rk} \geq y_{ro} \qquad r = (1, \dots, M) \tag{3}$$

$$\sum_{k=1}^{K} \lambda_k x_{fk} \leq x_{fo} \qquad f = (1, \dots, n')$$

$$\sum_{k=1}^{K} \lambda_k x_{vk} \leq x_{vo} - \beta * \sum_{k=1}^{K} x_{vk} \qquad v = (n' + 1, \dots, N)$$

$$\sum_{k=1}^{K} \lambda_k = 1 \qquad k = (1, \dots, K)$$

$$\lambda_k \geq 0, \beta \geq 0$$

For each DMUo, this program measures the maximum contraction of variable inputs that can be achieved at a given level of output while using at most the current level of other inputs. λ_k is the value of intensity variable of the DMU *k* calculated from the best observed DMUs.

In the second option of the land sharing strategy, we measured to which extend the objective of production and the environmental one of reducing agricultural intensity can be simultaneously improved on the same agricultural land. DMUs are projected onto the efficiency frontier in the direction of variable inputs and outputs. The directional vector become g = $\left(-g_x, g_y\right) = (-\sum_{k=1}^{K} x_{vk}, \sum_{k=1}^{K} y_{rk})$ for all DMUs. The linear programming for each DMU *k* is given by:

$$\vec{d}\left(x_k, y_k, -g_x, g_y\right) = \max_{\beta,\lambda_k} \beta$$

Subject to:

$$\sum_{k=1}^{K} \lambda_k y_{rk} \geq y_{ro} + \beta * \sum_{k=1}^{K} y_{rk} \qquad r = (1, \dots, M) \tag{4}$$

$$\sum_{k=1}^{K} \lambda_k x_{fk} \leq x_{fo} \qquad f = (1, \dots, n')$$

$$\sum_{k=1}^{K} \lambda_k x_{vk} \leq x_{vo} - \beta * \sum_{k=1}^{K} x_{vk} \qquad v = (n' + 1, \dots, N)$$

$$\sum_{k=1}^{K} \lambda_k = 1 \qquad k = (1, \dots, K)$$

$$\lambda_k \geq 0, \beta \geq 0$$

Here, the directional distance function measures simultaneously the maximum contraction of variable inputs and the maximum expansion of outputs that can be reached for each DMUo with no more than fixed inputs. We also considered here the same direction for all DMUs. The inefficiency score β measures by how much the DMUo can increase the overall outputs and reduce the overall variable inputs without restriction on fixed inputs. λ_k is again the value of intensity variable for the DMU k.

3. Data

To measure the possibility of reconciling agricultural production with environmental preservation through the land sharing and land sparing strategies, we applied our methodology to farm data of the Meuse department. These data were provided by the department of the French National Research Institute for Agriculture, Food and Environment (INRAE) and produced by the Meuse and Meurthe-et-Moselle center of accountancy and Management (CERFRANCE adheo 109). In Meuse, agricultural activity occupied 54.7% of the global area distributed in 68.6% of arable lands, 28.9% of grasslands, and 2.5% of other lands. Field crops, milk and beef are the main products of Meuse agriculture[2]. We considered both crop and livestock productions available in the CERFRANCE database composed of about 314 to 255 farms over the period 2014-2016. For the robustness of our analysis, we considered a balance sample of 220 farms or 660 observations observed in the years 2014, 2015 and 2016. To account for possible variabilities in the data that may be due to pedoclimatic or economic conditions from one year to another, each year was considered individually in the efficiency analysis. Results were presented in average over the three years to have an overview of the potential for each land management strategy. Farms are supposed to face the same prices of inputs and outputs.

Concerning variables of our model, we considered two groups of outputs measured in euros: (i) crop production composed of wheat, maize, barley, peas, rapeseed and sunflower production, and (ii) livestock production including grasslands. These outputs are realized by three fixed inputs (utilized agricultural areas (UAA) measured in hectare, capital measured in euros approximated by the depreciation of materials and buildings, and labor measured in annual work units (AWU) that includes family and hired labor), and variable inputs measured in euros that are composed of intermediate consumption for crops (fertilizers and seeds), for livestock (feeding stuffs, veterinary costs, animal husbandry costs), other intermediate consumption (fuel, water, gas, electricity), pesticides (herbicides, insecticides, fungicides, regulators and other chemical products) and other expenses (third-party works, insurance, maintenance, taxes, financial costs other than land). Descriptive statistics of these variables are presented in Table 1 at the Meuse department.

[2] https://meuse.chambre-agriculture.fr/

Table 1. Descriptive statistics for the 220 farms per year

Year	Mean	Standard deviation	Min	Max
2016				
Crops production (in euros)	171,443	113,119	26,242	630,115
Livestock production (in euros)	148,490	133,773	0	659,781
Land (in hectare)	221	112	55	748
Labor (in AWU)	1.92	0.96	0.2	6
Capital (in euros)	62,111	40,002	2,988	230,452
Operational costs (in euros)	209,995	117,307	49,631	719,046
2015				
Crops production (in euros)	215,768	148,058	22,266	873,873
Livestock production (in euros)	160,381	140,753	0	685,002
Land (in hectare)	220	114	63	801
Labor (in AWU)	1.98	0.97	0.2	6.50
Capital (in euros)	62,857	38,536	3,026	201,237
Operational costs (in euros)	214,885	120,186	52,674	755,194
2014				
Crops production (in euros)	214,299	148,745	25,613	893,707
Livestock production (in euros)	174,467	149,008	0	690,478
Land (in hectare)	218	112	48	747
Labor (in AWU)	2.04	0.98	0.2	6
Capital (in euros)	62,473	38,644	3,026	214,806
Operational costs (in euros)	220,765	212,136	45,739	743,638

As can be seen in this Table, crop and livestock productions in 2016 are lower than that observed in 2015 and 2014. This difference in production can be explained in part by the bad climate conditions recorded in 2016 in France (Ben-Ari et al., 2018). On average over 3 years, farms in our sample manage an agricultural area of 219 hectares. The average level of capital and labor is almost the same over the three years. Regarding operational costs, the year 2014 recorded slightly higher costs on average and high variability compared to the years 2015 and 2016. For some farms, the entire activity is devoted to crop production, which explains zero values in the column min for livestock. Livestock production represents about 45% of the global production for the years and farms considered in our analysis.

As mentioned in the introduction, we categorized farms according to their level of land productivity and their production structure. The aim was to know for which category of farms the land sharing and land sparing strategies may be more appropriate. Four groups of farms were made with the criterion of land productivity and three groups with the criterion of production structure. Results are presented in Tables 3 and 4. With the land productivity criterion, farm groups were made from the description of the average land productivity over three years for all DMUs, as seen in Table 2.

Table 2. Agricultural land productivity in average over the period 2014-2016 for all DMUs

	Min	1st Qu	Median	Mean	3rd Qu	Max
Land productivity in euro/hectare	798.2	1,259.0	1,543.1	1,724.0	2,120.7	4,331.6

On average over three years and for all farms available in our sample, the production in Meuse is of euros 1,724 per unity of land for both crop and livestock.

From this description, four levels of land productivity were obtained: low, medium, high and very high.

Table 3: Farm groups according to the criterion of agricultural land productivity

	Group 1 (55 farms)	Group 2 (55 farms)	Group 3 (55 farms)	Group 4 (55 farms)
Land productivity in euro/hectare	[798 – 1,259[	[1,259 – 1,543[	[1,543 – 2,120[	[2,120– 4,331]
Levels of land productivity	Low	Medium	High	Very High

Concerning the production structure, we made three groups of farms according to whether their production is dominated by livestock production or by crop production.

Table 4: Farm groups according to the criterion of production structure

	Group 1	Group 2	Group 3
Shares of livestock production in the overall production	Minority (< 50 %)	Equivalent (= 50 %)	Majority (> 50 %)
Number of farms	121	2	97

As can be seen in this Table, for the majority of farms (121 farms out of 220), the production is less dominated by livestock production. Most of them are dominated by crops.

4. Results

In this section, we first present results for each farmland management strategy based on individual efficiency scores. The distribution of inefficiency scores is presented for the 220 DMUs each year and on average over 3 years. Average inefficiency scores over 3 years were used to measure the potential for implementing the land sharing and the land sparing at the global scale (here the Meuse department). Second, we aggregated inefficiency scores for each strategy at farm groups constructed according to the criterion of land productivity and the criterion of production structure. This second step allowed us to measure the contribution of each farm group to the implementation of the land sharing and land sparing strategies. We considered that the more a farm group contributes to the implementation of a farmland management strategy, the more appropriate that strategy would be for that group.

4.1. Potential for the land sparing and the land sparing strategies at the global scale

We measured the potential for implementing the land sharing and land sparing strategies through results of inefficiency measures using DEA programs (2), (3) and (4). Inefficiency scores for the 220 farms in 2014, 2015 and 2016 are presented in the Table 5. Farms are considered efficient when their scores equal to 0 and inefficient in the case their scores are greater than 0. For each farm, the average inefficiency score ranges from 0.0011-0.0013 over three years for the land sharing and the first option of land sparing. These scores mean in the land sparing strategy that each farm can reduce agricultural land on average by 0.11 to 0.12% of the overall agricultural area of Meuse; and in the first option of the land sharing that each farm can reduce variable inputs on average by 0.11 to 0.13% of the overall variable inputs while maintaining at least the current level of production. In the second option of the land sharing aiming at simultaneously reducing variable inputs and increasing output on available agricultural land, inefficiency scores are very low. The potential for each farm to achieve this double objective is about 0.06% on average in 2014, 2015 and 2016. As can be noticed, the number of efficient farms per year is the same in each farmland management strategy. This means that efficient farms remain efficient regardless the farmland management strategy.

Table 5: Inefficiency scores for the 220 farms for each year

Year	Mean	Standard deviation	Min	Max	# of farms with score = 0
Land sparing					
2016	0.001228	0.001056	0.000000	0.004190	48
2015	0.001053	0.001018	0.000000	0.004200	51
2014	0.001182	0.001149	0.000000	0.005060	46
Land sharing option 1					
2016	0.001226	0.001237	0.000000	0.005110	48
2015	0.001091	0.001050	0.000000	0.004250	51
2014	0.001258	0.001198	0.000000	0.005740	46
Land sharing option 2					
2016	0.000620	0.000599	0.000000	0.002540	48
2015	0.000570	0.000551	0.000000	0.002190	51
2014	0.000626	0.000578	0.000000	0.002420	46

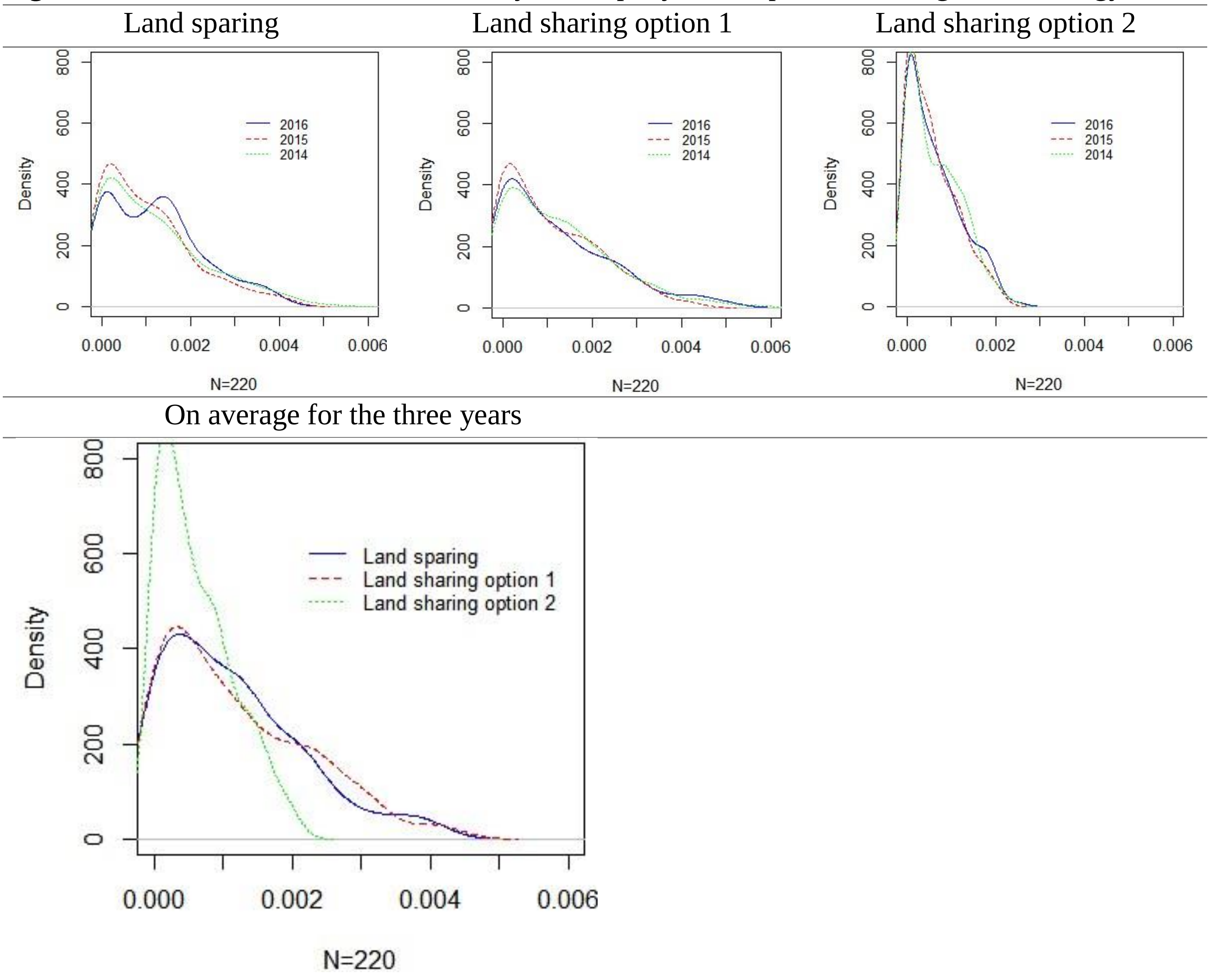
In addition to inefficiency scores per year, we calculated inefficiency scores on average over three years for each farmland management strategy. Results are presented in the Table 6. For each farm, the average potential of reducing agricultural land (reducing variable inputs) is of 0.12% in the land sparing strategy (in the first option of the land sparing) on average over three years without jeopardizing agricultural production. The number of efficient DMUs is now 31 in all farmland management strategies, i.e. the number of DMUs that remain efficient in each year and each farmland management strategy.

Table 6: Inefficiency scores on average over three years for the land sharing and land sparing strategies

	Mean	Standard deviation	Min	Max	# of farms with score = 0
Land sparing	0.001154	0.001001	0.000000	0.004166	31
Land sharing option 1	0.001191	0.001052	0.000000	0.004310	31
Land sharing option 2	0.000605	0.000530	0.000000	0.002107	31

We presented the distribution of these inefficiency scores in the Kernel density plots in the Figure 1 for each year and on average over three years for each farmland management strategy. In the land sparing strategy, the distribution of scores is almost similar with more farms having a score between 0 and 0.001, i.e. close to the efficiency frontier. An exception is observed in 2016 in the land sparing which exhibits a bimodal distribution. In this year, the majority of farms are distributed into two groups: the first group of farms with inefficiency scores closer to 0, and the second one with inefficiency scores ranges between 0.001 and 0.002. In the second option of the land sharing strategy, a large number of farms are closer to the efficiency frontier for the three years. On average over three years, the distribution is almost similar in the land sparing and the first option of the land sharing with inefficiency scores below 0.002 for the majority of farms.

Figure 1: Kernel distribution of inefficiency scores per year and per land management strategy



From this average distribution over the three years, the potential for implementing the land sharing and the land sparing strategies is measured at the Meuse department scale. In the land sparing strategy, result presented in Table 7 shown that agricultural land can be reduced at the Meuse department by 25.39% while maintaining the current level of production. This result means that farms can concentrate their production activities on 75% of land and spare 25% for other uses without jeopardizing their production capacity. For environmental preservation, the spared land can be fallowed or allocated to other uses beneficial for environment and biodiversity such as hedges planting, etc. In the land sharing strategy, result in the Table 8 show at the Meuse department that farms can reduce the use of variable inputs on all agricultural land by 26.2% at a given level of production. And if the economic performance is allowed to be improved with the environmental one, the potential for variable inputs contraction is of 13.3% while increasing outputs in the same proportion.

Table 7: Agricultural land contraction due to the elimination of the technical inefficiency at the Meuse department scale (in the **land sparing strategy**)

	Observed level in hectare	Optimal level after eliminating the technical inefficiency in hectare	Score of inefficiency	# of efficient DMUs	# of inefficient DMUs	Reduction of land in hectare
Land	48,373	36,092.64	0.253864	31	189	12,280.36 (25.39%)

Table 8: Potential contraction of variable inputs and expansion of outputs due to the elimination of the technical inefficiency at the Meuse department scale (in the **land sharing strategy**)

	Observed level in euros	Optimal level after eliminating technical inefficiency in euros	Score of inefficiency	# of efficient DMUs	# of inefficient DMUs	Reduction of variable inputs/expansion of outputs in euros
Option 1						
Variable inputs	47,347,221	34,934,045.59	0.262164	31	189	12,413175.41 (26.21%)
Option 2						
Variable inputs	47,347,221	41047149	0.133061	31	189	6300072.05 (13.31%)
Output 1 (crops)	44,110766.3	49,980192.2	0.133061	31	189	5,869425.91 (+13.31%)
Output 2 (livestock)	35,444826	40,161152.6	0.133061	31	189	4,716326.59 (+13.31%)

The above results show the potential for implementing the land sharing and land sparing at the Meuse scale considering all farms. Knowing that these individual farms may have different characteristics and contribute differently to the implementation of the two strategies, we address the impact of farm categories in the following section.

4.2. Contribution of farm categories to the implementation of the land sharing and land sparing strategies.

We categorized farms into groups according to the criterion of land productivity and the criterion of production structure. With the land productivity criterion, four groups of farms were formed, based on the low, medium, high and very high levels of productivity. The aim is to know how farms contribute to land sharing and land sparing according to whether they are less or more productive. And with the criterion of production structure, three groups were considered ranging from the one composed of farms less dominated by livestock to the group of farms for which livestock is the majority.

Considering the land productivity criterion, results in Table 9 show in the land sparing strategy that the group of farms with the lowest level of productivity contributes the most to the reduction of agricultural land (8.37 %), followed by the one with the medium level (7.6 %). The level of contribution decrease as the level of land productivity increases. Farmers with the highest land productivity level contribute the less (3.35%). This may indicate on one hand that more productive lands are managed efficiently than less productive ones; on the other hand, that more land is less productive, more it is easy to spare it for other uses other than agricultural production. In the land sharing strategy however, the contribution of farm groups to the overall potentials of variable input reduction and output expansion follows the same trend in the two options. Farm groups with a high level of productivity are the ones that contribute the most to the reduction of variable inputs in the first option (8.03% for the group 3 and 8.72% for the group 4) and simultaneously to the reduction in variable inputs as well as the expansion in outputs (4.36% for the group 3 and 3.57% for the group 4) in the second option.

Table 9: Contribution of farm groups to the land sparing and the land sparing according to the land productivity criterion

	Group 1	Group 2	Group 3	Group 4	Total
Levels of productivity	Low	Medium	High	Very High	
Land sparing					
Contribution of farm groups to the reduction of land in %	8.37	7.60	6.07	3.35	25.39
Land sharing					
Option 1 Contribution of farm groups to the reduction of variable inputs in %	4.03	5.43	8.03	8.72	26.21
Option 2 Contribution of farm groups to the reduction of variable inputs while increasing outputs in %	2.39	2.98	4.36	3.57	13.31

A link can be made between these findings and those of Martinet and Barraquand (2012) in their analysis about the implementation of land sharing and land sparing strategies for biodiversity conservation on farmland taking into account soil quality. One of their results shown that it would be more efficient to increase agricultural intensification on the best quality of land rather than expanding the land sharing area on lower quality and less productive land for biodiversity conservation. This means that high quality lands have to be used at the maximum for agricultural production and less quality ones can be spared for preservation purpose. In line with this result, our analysis shows that the more productive a farm is the less it contributes to the objective of sparing agricultural land for environmental preservation.

In addition to land productivity, the structure of production can also influence the allocation of land. One can imagine that more a farm's production is dominated by crops, more intensive and less diversified it is. Following characteristics of the land sparing strategy (intensification of production, mono-cropping, etc.) presented in Salles et al. (2017), one can expect that farms with the production less dominated by livestock are those that can contribute more to the land sparing strategy. Results in the Table 10 confirm this hypothesis. Farms less dominated by livestock production contribute more (15.78%) to the agricultural land saving than farms more dominated by livestock (9.36%). However, in the land sharing strategy, the trend of results is not the same following the groups in the two options. Farms with production dominated by livestock contribute the most to the contraction of variable inputs in the first option (15.13%) and to the reduction of variable inputs while increasing outputs in the second option (7.48%).

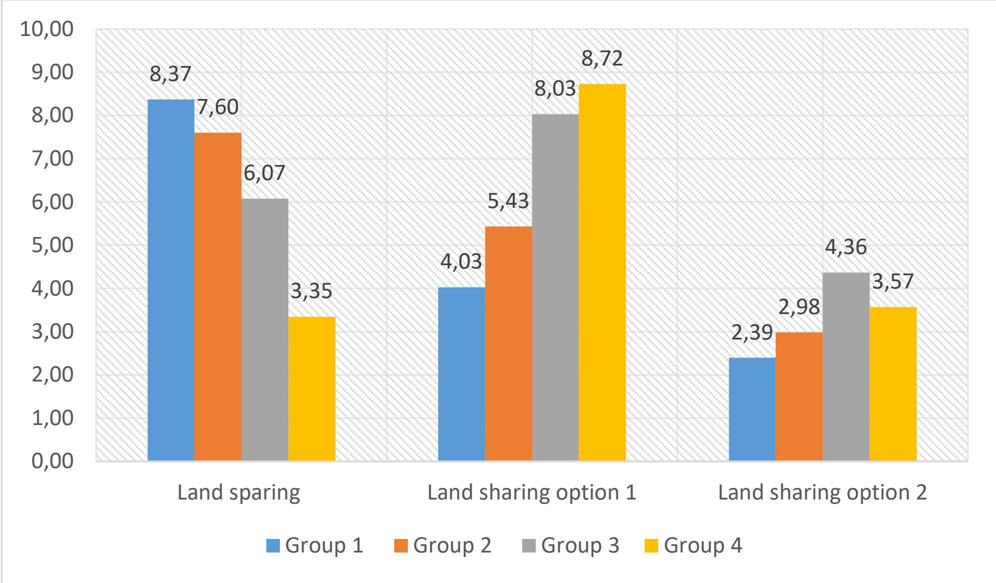
Table 10: Contribution of farm groups to the land sparing and land sharing according to the production structure criterion

	Group 1	Group 2	Group 3	Total
Share of livestock production in the total production	Minority (< 50 %)	Equivalent (= 50 %)	Majority (> 50 %)	
Land sparing				
Contribution of farm groups to the reduction of agricultural land in %	15.78	0.25	9.36	25.39
Land sharing				
Option 1				
Contribution of farm groups to the reduction of variable inputs in %	10.78	0.29	15.13	26.21
Option 2				
Contribution of farm groups to the reduction of variable inputs while increasing outputs in %	5.70	0.13	7.48	13.31

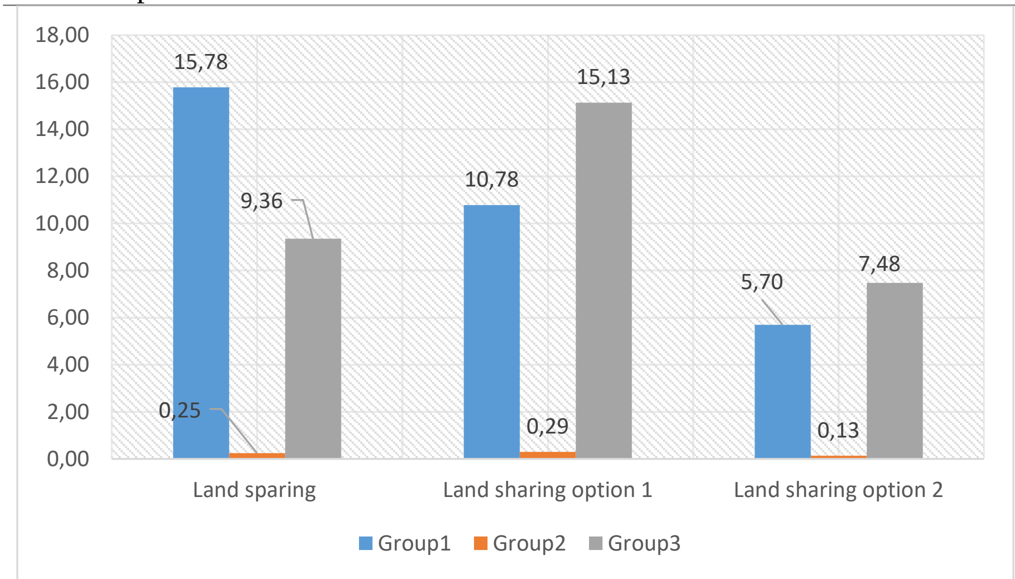
To highlight these different contributions of farm groups to the implementation of the land sharing and the land sparing, we summarized results of the Tables 9 and 10 in the Figure 2. Considering the criterion of land productivity, the groups 1 and 2 with low and medium land productivity levels contribute more to land sparing than the groups 3 and 4 with high land productivity. In contrast, the groups 3 and 4 are those that contribute more to land sharing in both options compare to the first two groups. These results suggest that the land sparing strategy would be more appropriate for less productive farms and the land sharing strategy for more productive ones. And by considering the criterion of production structure, the high contribution of the first group of farms in land sparing and the third group in land sharing suggest that the land sparing strategy would be more appropriate for farms less dominated by livestock and the land sharing strategy for farms more dominated by livestock. This can be explained by the characteristics of the two types of farms. More crop-dominated farms tend to concentrate their production on less land and use more chemical inputs, compared to more livestock-dominated farms that tend to be diversified and use fewer chemical inputs less harmful to environment and on-farm biodiversity.

Figure 2: Summary of the contribution of farm categories to the land sharing and the land sparing strategies.

With the land productivity criterion



With the production structure criterion



5. Conclusion

We analyzed how an objective of agricultural production can be reconciled with an objective of environmental preservation through the implementation of agricultural land management strategies. Based on the literature in ecology on rural land management, we analyzed two land management strategies: the first strategy that advocates the spatial separation of the production objective from the environmental preservation objective (land sparing) and the second strategy that promotes the spatial integration of the two objectives (land sharing). The potential for implementing each of these strategies was measured through an efficiency analysis using the DEA method in agricultural sector. With the directional distance functions, we measured the potential reduction in agricultural land at a given level of production in the land sparing strategy. And in the land sharing strategy, we measured the potential reduction in agricultural intensity on all agricultural land, first at a given level of production, second with the increase in production. We applied this analysis to farms in the Meuse department over the 2014-2016 period.

Results showed that it is possible to reduce the pressure of agriculture on the environment by leaving 25% of agricultural land out of production with the land sparing strategy or by decreasing the use of variable inputs by 26% on all agricultural lands with the land sharing strategy at a given level of outputs. If the aim is to simultaneously increase the economic performance and the environmental one, the potential increase in outputs is of 13% while decreasing variable inputs in the same proportion. These results show what can be giving up by choosing one strategy over another at the Meuse department.

In addition to this overall analysis, we conducted an analysis at the farm groups made according to the criterion of land productivity and the criterion of production structure. The aim was to know how farms can contribute to the land sharing-land sparing strategies depending on whether they are less or more productive with the criterion of land productivity and on whether their production is dominated by livestock or by crops with the criterion of production structure. This analysis allows us to assess for which category of farms each strategy may be more appropriate. Results showed that less productive farms contribute more to the saving in agricultural land than more productive ones, and that the latter contribute more to the reduction in the use of variables inputs on all agricultural land. These results suggest that land sparing would be more appropriate for less productive farms and land sharing for more productive farms. With the criterion of production structure, results showed on one hand that farms less dominated by livestock contribute more to the saving in agricultural land; on the other hand, that farms with the majority of livestock are those that contribute the most to the decrease in the use of variables inputs on all agricultural land. Hence the conclusion that land sparing would be more appropriate for farms less dominated by livestock, while land sharing would be more appropriate for those more dominated by livestock.

Differences in results of these two criteria underline the importance of taking into account farms' characteristics in implementing an agricultural land management strategy for environmental preservation. The land sparing and land sharing strategies can then be conjunctively implemented on the same area, as suggested by Fischer et al. (2014); Kremen, (2015); Legras et al. (2018), by selecting farms for which each strategy is more appropriate according to their characteristics.

With accounting data available in this work, we focused on identifying potential ways of environmental preservation in the agricultural sector through land sharing and land sparing strategies. Due to data limitations, we could not quantify environmental impacts such as biodiversity restoration, water quality preservation that may result in the agricultural intensity reduction in the land sharing strategy, or soil erosion reduction, carbon sequestration that may result in agricultural land saving in the land sparing strategy. Our work would be improved by taking into account such further environmental analyses.

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