Optimal allocation of pesticides use in France: spatial integration with Data Envelopment Analysis method (DEA).

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Abstract:

In agricultural sector, pesticides reduction is among the major challenging issues. Through efficiency measures with DEA method, we computed a two-stage radial efficiency to measure the potential reduction of pesticides on farms in the Meuse department: the technical efficiency realized at the firm level and the reallocation efficiency realized at the industry level, with spatial integration at four levels. These levels are made from the smallest to the largest according to the spatial location of farmers to account for scale effects. Results show that most of farms in Meuse are inefficient in pesticides use and that an efficient level can be reached without worsening farmers' income. With pesticides reallocation at the largest scale, a pesticides contraction of 46.6 % from the observed value can be reached with no change in outputs. This contraction would be of 26.7% if only technical efficiency was considered. Through pesticides reallocation, agriculture can spare land for environment or biodiversity preservation while reducing pesticides use intensity.

Keywords: Pesticides use, reallocation efficiency, Data Envelopment Analysis method, land sparing, Meuse department.

JEL classification numbers: C14 ; D24 ; Q52 ; R14.

1. Introduction

To these days, the reduction of pesticides use and its negative impacts on environment, human health and biodiversity remains among the most challenging issues in agricultural sector. Some solutions have been suggested to reduce pesticides use included the use of biological pest control (Boussemart et al. 2011), the conversion to organic farming (Zhengfei et al. 2005), the use of command and control policies in the form of restrictions as well as limits on the quantity used (Sexton et al. 2007) and economic incentives through taxes and subsidies (Skevas et al. 2012; Fernandez-Cornejo et al. 1998). Nevertheless, despite these solutions and the awareness about costs as well as negative impacts induced by pesticides, these inputs are still used and in a rising rate. In France for instance, despite the ECOPHYTO national action plan launched in 2008 with the aim to reduce the use of pesticides by 50% at the 2018 horizon at first, and then postponed at 2025 horizon, an increase of 12 % in the use of those chemical products has been recorded between 2014-2016. Relevant solutions are then still needed. Hence the main objective of this paper intended to provide an efficiency based analysis to measure the potential reduction of pesticides use in France.

In previous studies, pesticides efficiency has been addressed through marginal productivity analyses using mainly parametric methods. Results have shown that a total ban of pesticides will generate enormous costs to the community (Knutson et al. 1990; Sexton et al. 2007) and that a pesticides contraction to an efficient level can be reached without jeopardizing farmer's productivity as well as their profitability (Lechenet et al. 2017; Antle et al. 1998; Jacquet et al. 2010). However, enormous differences in design and results regarding the role of pesticides in the production function have been revealed in these studies with parametric approaches. To avoid this prior specification of the role of pesticides in the production system, a focus was made on non-parametric approaches in some analyses mostly carried out in Netherland (Lansink and Silva 2004; Skevas et al. 2014; 2012). In line with these authors, we implemented an efficiency analysis using a non-parametric method to measure the ability of farmers to reduce their pesticides use while reaching at least their current outputs with no more than other inputs. Lansink and Silva (2004) and Skevas et al. (2014; 2012) focused on technical efficiency of pesticides on farms level, without any involvement of the agricultural land management. Our first contribution is to move from a firm-wide pesticides efficiency analysis to an industry-wide analysis through two kinds of efficiency: (i) the technical efficiency realized at the firm level, and (ii) the reallocation efficiency realized at the industry level. Here, the firm refers to individual farms and the industry to the District[1] in the Meuse department in France. In the reallocation analysis, Districts were gradually integrated according to their geographical vicinity.

Specifically, we implemented a non-parametric method−Data Envelopment Analysis (DEA)− with an impact analysis on agricultural land management. We chose this method for three reasons: (i) it does not require prior specification of the statistical relationship between variables, (ii) it allows for simultaneous measurement of technical efficiency and reallocation of resources available in a given activity sector, and (iii) its flexibility and ability to compute many outputs realized by many inputs. Our model at the firm level is close to the third one developed in Lansink and Silva (2004) apart from that we applied it to French farms. At the industry level with pesticides reallocation, our analysis allows us to combine at the same area these two antagonistic results realized in the previous pesticides efficiency analyses with DEA methods: for Lansink and Silva (2004), pesticides are under-used, additional use would improve farmers' productivity; whereas for Skevas et al. (2014; 2012), pesticides are overused, an effective use less harmful to environment and biodiversity has to be found. Through reallocation, which we have also called "inputs pooling", farms who should over-use and those who should under-use pesticides are identified based on their efficient production capacity. The advantages of such a spatial mix of less and more intensive productions have been proved by Teillard et al. (2017) who showed how environmental impacts of agricultural intensity can be reduced through its spatial allocation, and Dakpo et al. (2018) who showed how four different production technologies (from the least to the most intensive) can improve the efficiency of pesticides through their spatial allocation.

Furthermore, reallocation does not only make some DMUs pesticide-intensive or pesticide-extensive, but also it allows a readjustment of their outputs and other inputs. As a result, two groups of DMUs are made after reallocation: the first group of DMUs that decrease their pesticide use as well as their outputs; the second group of DMUs that receive more pesticides and increase their outputs. This possibility of readjusting inputs and outputs leads us to test whether pesticides reallocation can save land for biodiversity or environment preservation, in

[1] The District corresponds to Canton, the French administrative entity serving as a framework for the election of departmental councils and made up of a group of Municipalities (https://www.insee.fr/fr/metadonnees/definition/c1566)

reference to the land sparing strategy[2] developed by Green et al. (2005), and where this saving can be realized. The spatial location of this land sparing strategy will allow us to identify areas where it is efficient to focus only on agricultural production and where agriculture can contribute to environment or biodiversity preservation. In the reallocation, Districts of the Meuse department are integrated according to their geographical vicinity to take into account the effects of spatial agglomeration at a large scale. To the best of our knowledge, we are the first to involve the concept of farmland management in a pesticides efficiency analysis in France at different scales of analysis spatially located. Hence our second contribution to the previous studies.

The remainder of this work is structured as follows: the second section describes the method, the third presents our findings and we conclude in the fourth section.

2. Method

2.1. Model

Reallocation efficiency analysis using DEA methods have been conducted in particular sectors focusing either on inputs (Berre et al. 2013) in the dairy sector; and/or on outputs in fisheries (Kerstens et al. 2006) and in public health economics (Dervaux et al. 2000). Two main scales are considered: the firm scale that determines the technical efficiency of each individual decision-making unit (DMU) and the industry scale that reallocates inputs and/or outputs at an aggregate level based on individual optimal quantities. As stated in the introduction, the firm represents "***the farms***" and the industry "***the Districts***" in this paper. With our spatial integration analysis in mind, we qualified the industry as "***Large District***" (LD), made by progressive integration of different Districts in the reallocation according to their geographic vicinity. The starting District was selected based on its high level of pesticide intensity in the baseline situation and its low capacity to reduce pesticides with the technical efficiency measured at the individual level.

To develop this two-stages model, we considered the production technology P that transforms a vector of N inputs $x = (x_1, \dots, x_N) \in R_+^N$ into a vector of M outputs $y = (y_1, \dots, y_M) \in R_+^M$. The set of all feasible input and output vectors: $P = \{(x, y) \in R_+^{N+M}$: x can produce y$\}$. We assume K the number of firms (DMUs) with $k = (1, \dots, K)$. With the aim focused on pesticides, our N-dimensional input vector x is subdivided into standard fixed inputs (indexed by f), standard variable inputs (indexed by v) and pesticides input (indexed by p): $x = (x_f, x_v, x_p)$. These variables are all indexed by $r = (1, \dots, M)$ for outputs, $v = (1, \dots, n')$ for standard inputs (fixed and variable) and $p = (n'+1, \dots, N)$ for pesticides input.

Efficiency at the firm level

Through an input-oriented model, this analysis at the individual scale measures the ability of DMUs to contract pesticides input given other inputs and outputs. As in Lansink and Silva (2004), we used a radial efficiency with the assumption of "free disposability" of inputs and outputs and the variable returns to scale (VRS) to measure this potential contraction. The firm technology is then computed for each observed (x_o, y_o) variable by solving the following linear programming problem:

[2] This strategy advocates a spatial separation of agricultural production uses from conservation uses.

$$
\begin{aligned}
& Min_{\theta^{firm},\lambda_k}\ \theta^{firm} \\
& \text{S.t. } \textstyle\sum_k y_{rk} *\ \lambda_k \geq y_{ro}\ , && r = (1, \dots, M), \\
& \textstyle\sum_k x_{vk} *\ \lambda_k \leq x_{vo}\ , && v = (1, \dots, n'), \\
& \textstyle\sum_k x_{pk} *\ \lambda_k \leq\ \theta^{firm}\ x_{po}\ , && p = (n'+1, \dots, N), \\
& \textstyle\sum_k \lambda_k = 1, && k = (1, \dots, K). \\
& \lambda_k\ \geq 0, \theta^{firm} \geq 0.
\end{aligned}
\tag{1}
$$

The computation of this program provide optimal quantities of inputs and outputs that are used in the industry technology. The aim of using optimal quantities is to measure whether efficient DMUs can again reduce their pesticides use when resources are aggregated at a larger scale.

Efficiency at the industry level

The transition from the firm-scale model to the industry-scale model first requires the aggregation of inputs and outputs that is given by:

$$U_r = \textstyle\sum_k y_{rk}\ ;\ X_v = \sum_k x_{vk}\ ;\ X_p = \sum_k x_{pk}\ . \tag{2}$$

With U_r, X_v, X_p respectively the aggregated outputs, standard inputs and pesticides input at the industry level.

Second, optimal quantities are computed for each DMU as follow:

$$\widehat{y_{rk}} = \textstyle\sum_k y_{rk} * \lambda_k^*\ ;\ \widehat{x_{vk}} = \sum_k x_{vk} * \lambda_k^*\ ;\ \widehat{x_{pk}} = \sum_k x_{pk} * \lambda_k^*\ . \tag{3}$$

The industry technology is then given by the following linear programming problem:

$$
\begin{aligned}
& Min_{\theta^{industry},,w_k}\ \theta^{industry} \\
& \text{S.t. } \textstyle\sum_k \widehat{y_{rk}} * w_k \geq U_r\ , && r = (1, \dots, \mathrm{M}), \\
& \textstyle\sum_k \widehat{x_{vk}} * w_k \leq X_v\ , && v = (1, \dots., n'), \\
& \textstyle\sum_k \widehat{x_{pk}} * w_k \leq \theta^{industry}\ X_p, && p = (n'+1, \dots, \mathrm{N}) \\
& 0 \leq\ w_k \leq 1, \theta^{industry} \geq 0 && k = (1, \dots, \mathrm{K}).
\end{aligned}
\tag{4}
$$

Here w_k is comprised between 0 and 1 to mean that the optimal level of pesticides of the industry cannot be exceed. This industry technology is computed for each level of integration.

These two stages of analysis allowed us first to distinguish efficient DMUs (on the efficiency frontier) from inefficient DMUs (outside the efficiency frontier) and bring these letter on the efficiency frontier through a radial contraction of their pesticides. Second, with all DMUs at the efficiency frontier, we measure whether it is still possible to improve the overall efficiency (by reducing its pesticides from the technical efficiency level) through interactions between DMUs according to the zones in which they are located on the frontier. The total effect of pesticides contraction is therefore a combination of the effect of technical efficiency and the effect of reallocation efficiency. With the VRS hypothesis in our analysis, three zones can be identified: (i) the zone of Increasing Return to Scale, IRS where an additional unit of input leads to a more than proportional increase in output, (ii) the zone of Constant Return to Scale, CRS where an additional unit of input leads to a proportional increase in output, (iii) and the zone of Decreasing Return to Scale, DRS where an additional unit of input results in a less than proportional increase in output. The reallocation system allows for some DMUs in the DRC and the CRS to decrease their pesticides for the sake of those located in the IRS that can produce much with additional pesticides. This input transfer between DMUs allows them to operate at their Most Productive Scale Size (MPSS) without excluding anyone from the production system. While recognizing that excessive use of pesticides is likely to harm the environment and biodiversity, reallocation will allow farmers to operate at their most efficient level with respect to economic and environmental performance.

2.2. Data

We used data of the Meuse provided by the department of the French Institute for Agriculture Research (INRA)[3] and produced by the Meuse center of accountancy and management[4]**.** Meuse has an advantage in agricultural production with its agricultural activity that occupied 54.7% of the global area distributed in 68.6% of arable lands, 28.9% of grasslands and 2.5% of other lands. In 2014, its production was dominated by cereals (30%), milk (24%) and beef (15%)[5]**.**

A sample of 220 farms was observed in 2016, with a look at their efficiency level in 2015 and 2014. Including these two years (2015 and 2014) in our analysis allows us to control for farm's inefficiency due to random events. We considered the former administrative entities of Meuse with 31 Districts (see the map in appendix, Figure B). Out of these 31 Districts, 28 are available in our database. Integration process in the reallocation was carried out by gradually including all Districts located in the direct vicinity of District 18 (see the complete process provided in appendix, Figure A.1). We chose this district as a starting point for two reasons: (i) it is the most pesticide-intensive and, (ii) it contributes less to pesticides reduction with technical efficiency at the individual level. An interaction with its neighboring Districts can then be an opportunity to boost its contribution to pesticide reduction.

As variables, we considered two outputs: cereals-oilseeds-protein products (wheat, maize, barley, peas, rapeseed, sunflower) and livestock-grasslands products. All outputs are expressed in euros.

These outputs were realized by three types of inputs: (i) standard fixed inputs that include land measured in hectare, labor measured in Annual Work Units (aggregation of family and hired labor) and capital measured in euros (approximated by the annual depreciation of equipments and buildings); (ii) standard variable inputs (operational costs) measured in euros that include intermediate consumption for crops (fertilizers and seeds), intermediate consumption for livestock (feeding stuffs, veterinary costs, animal husbandry costs), other intermediate consumption (fuel, water, gas, electricity) and other expenses (third-party works, insurance, rental expenses, maintenance, taxes, financial costs other than land); (iii) pesticides input measured in euros that includes herbicides, insecticides, fungicides, regulators and other chemical products. Descriptive statistics of these variables are provided in the Table 1 below:

[3] Sciences sociales, agriculture et alimentation, espace et environnement (SAE2)
[4] Association de Gestion et de Comptabilité de Meuse et Meurthe-et-Moselle (ADHEO 109)
[5] https://meuse.chambre-agriculture.fr/

Table 1: Descriptive statistics for the 220 farms in 2016

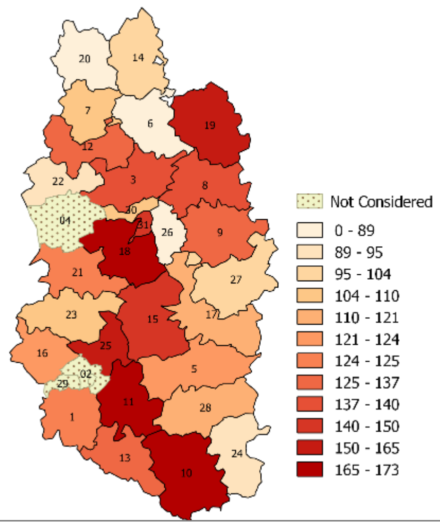
	Mean	Standard deviation	Min	Max
Outputs (in euros)				
Cereals-oilseeds-protein crops	108 172	84 910	400	466 581
Livestock-grasslands	148 490	133 772	0	659 781
Inputs				
Land (in hectare)	221	111	55	748
Labor (in AWU)	1.92	0.96	0.20	6.00
Capital (in euros)	62 111	40 002	2 988	230 452
Operational costs (in euros)	181 972	105 658	43 615	648 273
Pesticides costs (in euros)	28 125	20 758	0	126 857

On average, the 220 farms realize a product of 108 172 euros, 148 490 euros of cereals-oilseeds-protein crops and livestock-grasslands respectively on 221 hectares of land with 1.92 AWU, 62 111 euros of capital, 181 972 euros of operational costs and 28 125 euros of pesticides. Only one farm does not use pesticides in our sample.
Beyond these means and standard deviations, we computed an intensity analysis of pesticides use in the baseline situation. This analysis allows us to identify over and under uses of pesticides in the first pesticides allocation, as our analysis is dealing with their reallocation. Following Teillard et al. (2017), the pesticides intensity (PI) can be given by the ratio between pesticides costs and the land used:

$$PI = \frac{Pesticides\ costs}{Land\ (UAA)} \qquad (5)$$

This ratio, expressed in euros/hectare, was computed for all the 220 farms distributed in the 28 Districts available in our database. This PI is provided in Figure 1 for each District where pesticides underuses are recorded in the Districts 6 (€ 80.53 per hectare), 20 (€ 87.49 per hectare), 26 (€ 89.31 per hectare), and pesticides overuses in the Districts 18 (€ 172.93 per hectare), 10 (€ 168.88 per hectare), 11 (€ 167.38 per hectare) and 19 (€ 159.35 per hectare).

Figure 1: Pesticides intensity (PI) in euros/hectare in 2016 per District



With this diversity in pesticide use between Districts, the question that may arise is to know how this baseline situation may change with the technical efficiency analysis and with reallocation between farms of different Districts according to their spatial location.

3. Results

In this section, we firstly present efficiency scores at the individual scale without reallocation. This first stage allows us to measure the technical efficiency of DMUs in their use of pesticides and quantify its potential contraction, first at the department level and then distributed at the District level. Secondly, we present pesticides efficiency at the industry level with reallocation at different scales. This step allows us to measure whether it is still possible to reduce pesticides from the technical efficiency level, when the pooling of pesticides is allowed between DMUs. Finally, we measure the impact of pesticides reallocation on outputs and agricultural land evolution.

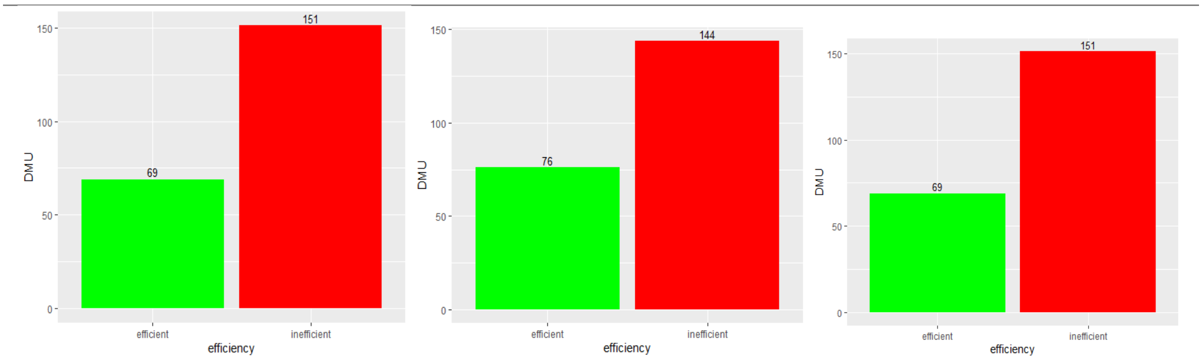
3.1. Pesticides use efficiency without reallocation at the firm level

We computed efficiency scores of 220 farms first in 2016, then in 2015 and 2014 to control for random events such as climate conditions or diseases that can lead farmers to use more pesticides in one particular year than before.

Figure 2 shows in green the number of efficient DMUs (those with an efficiency score of 1) and in red the number of inefficient DMUs (those of an efficiency score under 1) in pesticides use while realizing at least the current outputs and with no more than other inputs. For the three years, there are more inefficient DMUs than efficient ones. This means that farms are in general inefficient in pesticides use in the Meuse department. This is in line with Skevas et al. (2014; 2012) and many other authors, who showed that pesticides are used inefficiently and that an efficient use can be found.

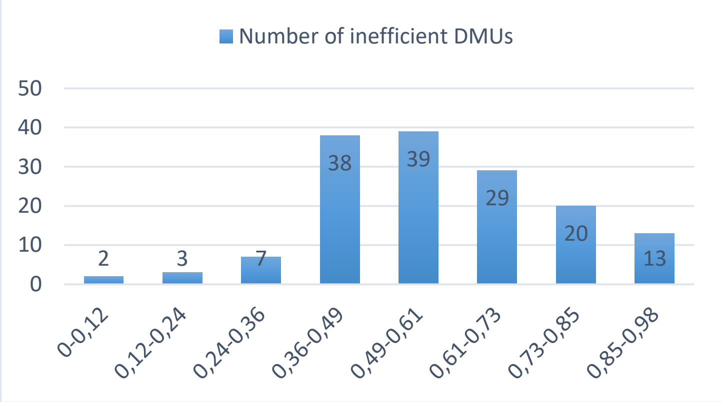
Figure 2: Pesticides efficiency at the farms level

Year 2016 | **Year 2015** | **Year 2014**



This analysis provides efficiency scores that project each inefficient DMU (in red) to the efficiency frontier by pesticides costs contraction. These inefficient DMUs are distributed in classes here below (Figure 3) according to their efficiency scores for the year 2016.

Figure 3: Frequency of inefficient DMUs by classes of efficiency scores in 2016



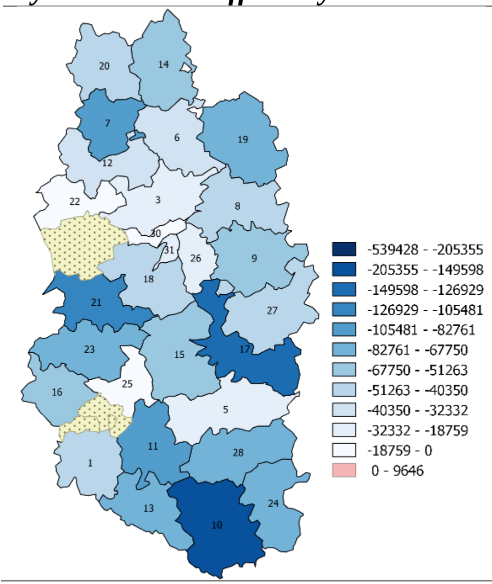
From this Figure, we can realize that farms are not very bad in pesticide use as many of them have scores close to 1 than close to 0. The largest number of farms have scores between 0.36 and 0.61. These different efficiency scores allow a global pesticides contraction of - € 1 656 556 or -26.7% from the baseline at the Meuse department (as seen in the following Table 2), while producing at least the same level of outputs.

Table 2 : Impact of technical efficiency on pesticide contraction at the Meuse Department in euros

	Baseline	Technical efficiency	Variation in euro	Variation in %
Pesticides	6 187 517	4 530 961	-1 656 556	-26,77

Districts contribute differently to this saving in pesticides use according to their levels of efficiency. In the following Figure 4, high contributions are recorded in the Districts 10 (- € 181 646) and 17 (- € 143 205), followed by the District 21 (- € 106 136).

Figure 4: Spatial distribution of pesticides contraction allows by the technical efficiency measure in euros per District



Comparing this Figure to Figure 1, one can see that pesticides intensive Districts are not necessary those that contribute much to their reduction through efficiency measure. As an example, Districts 18, 19 and 11 with a high pesticide intensity contribute less to pesticides contraction with technical efficiency (- € 50 278, - € 70 385 and - € 98 650 respectively) than the Districts 21 and 17 with a low pesticide intensity but with a high contribution (- € 106 136 and - € 143 205 respectively). For that reason, we considered the District 18, the most intensive in pesticides use, as the starting point of integration in the reallocation efficiency to measure whether the interaction with other Districts can improve its contribution to pesticides contraction.

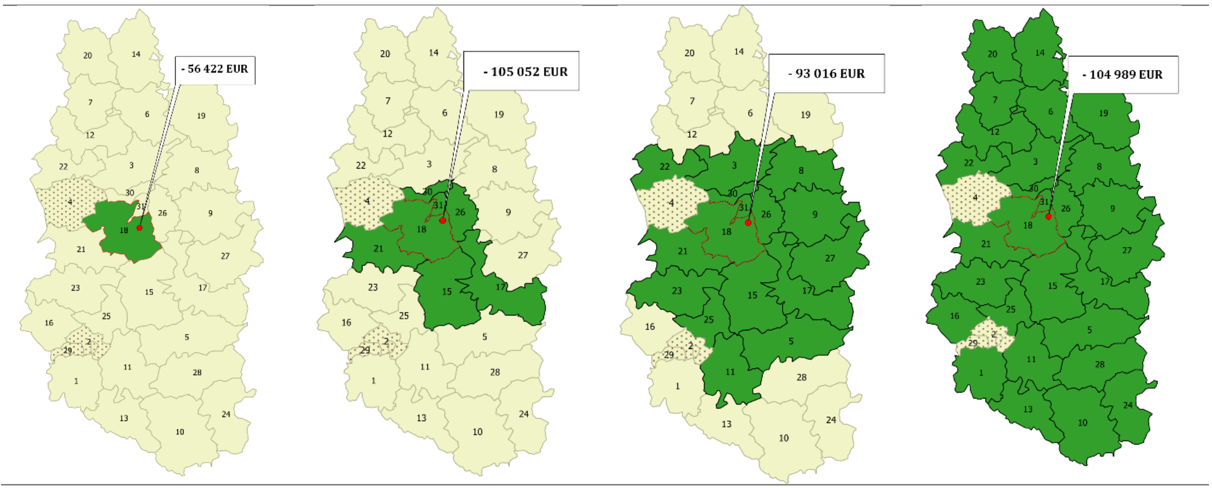
As seen in the Figure 2, there is no difference in number of efficient DMUs in 2016 and 2014, meaning that efficient DMUs in 2016 are also efficient in 2014. A small difference is observed in 2015 with an addition of 7 efficient DMUs, equivalent to 3.2% of the 220 farms. This difference being small, we concentrated on 2016 in the reallocation analysis.

3.2. Pesticides use efficiency with reallocation at the industry level

We computed the reallocation of pesticides first at the District 18, our starting point, to measure its impact on its pesticides contraction capacity. Second, we tested the impact of interacting with other Districts through their progressive integration in the pesticides pooling from the smallest to the largest scale. Results are presented in Figure 5 below:

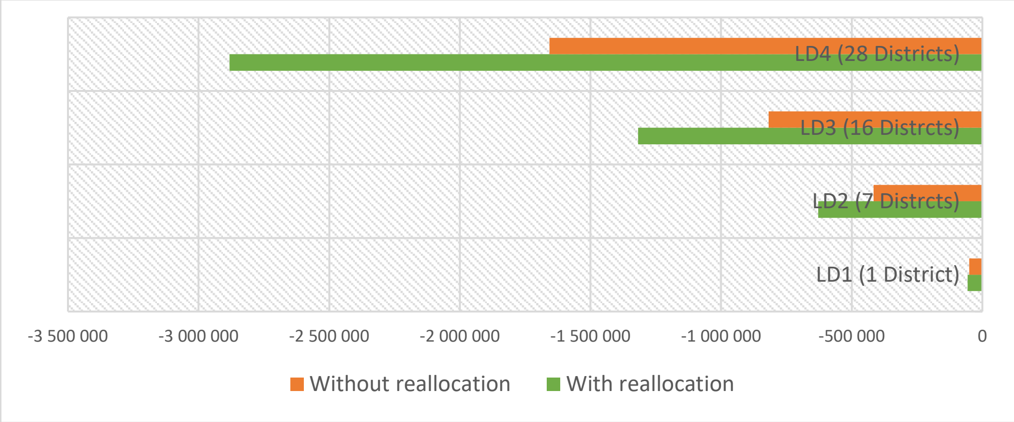
Figure 5: Impact of reallocation on pesticides contraction at the four scale levels: Example of District 18

First level	Second level	Third level	Fourth level



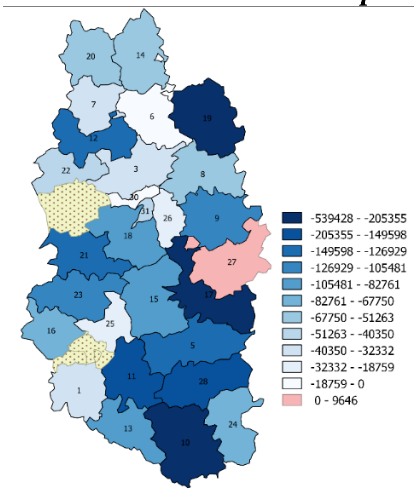
These Figures show that the District 18 saves much pesticides when it interacts with other Districts through pesticides pooling, e.g. - € 56 422 without interaction versus - € 105 052 with interaction with its direct neighboring Districts. A slight decrease in its pesticide contraction capacity is observed as the scale of integration increases. This is explained by the fact that when a large number of DMUs are involved in the reallocation, District 18 DMUs may receive additional pesticides from other DMUs that are not making optimal use of them. The main result is that, the gain in pesticides contraction is high at all levels of interaction with other Districts (from the second to the fourth level) than at the one without interaction. This result is confirmed in the following Figure 6, taking into account all Districts, and showing the high contribution of reallocation in pesticide contraction compared to technical efficiency.

Figure 6 : Pesticides contraction per Large District (LD) in euros



After the integration of all Districts in the reallocation (level LD4) pesticides costs can be reduced by - € 2 881 381 or - 46.6% (the contribution of each Districts in this global contraction is provided in appendix A.2) from the baseline. This is the total effect combining the gain from the technical efficiency amounted at - € 1 656 556 or -26.7 % from the baseline, and the gain from the reallocation efficiency amounted at - € 1 224 824 or - 27% from the optimal level achieved by the technical efficiency. Globally, the reallocation system improves the potential saving in pesticides use from the potential allowed by the technical efficiency. This is true for most of Districts (as seen in Figure 8) since their contribution to pesticides contraction increases after reallocation compared to their situation without reallocation. However, opposite results can be recorded in some Districts where the saving in pesticides decrease or even disappears, e.g. the District 27 in red, after reallocation.

Figure 8: Pesticides contraction or extension after reallocation at the Meuse Department in euros per District



More specifically, the potential saving in pesticides decrease after reallocation compared to their level achieved with technical efficiency for the District 7 (- € 89 261 with technical efficiency versus -€ 32 812 with reallocation efficiency), District 6 (- € 32 606 with technical efficiency versus - € 17 221 with reallocation efficiency), District 14 (- € 58 026 with technical efficiency versus - € 52 956 with reallocation efficiency) and District 24 (- € 75 912 with technical efficiency versus - € 73 703 with reallocation efficiency). For the District 27, two opposite situations are observed: a pesticides contraction with technical efficiency (- € 46 750) and a pesticides extension with reallocation (+ € 9 646). These results are explained by the fact that reallocation makes it possible to reduce the use of pesticides from some DMUs to the profit of others who can use them more efficiently. This transfer of pesticides from the least to the most efficient DMUs is accompanied by the change in outputs and in other inputs. This effect is captured in the following sub-section about the impact of reallocation on outputs and other inputs evolution. About other inputs, we will focus only on agricultural land as our aim is to test whether the reallocation can allow to save land for other uses or not.

3.3. Impact of reallocation on outputs and agricultural land

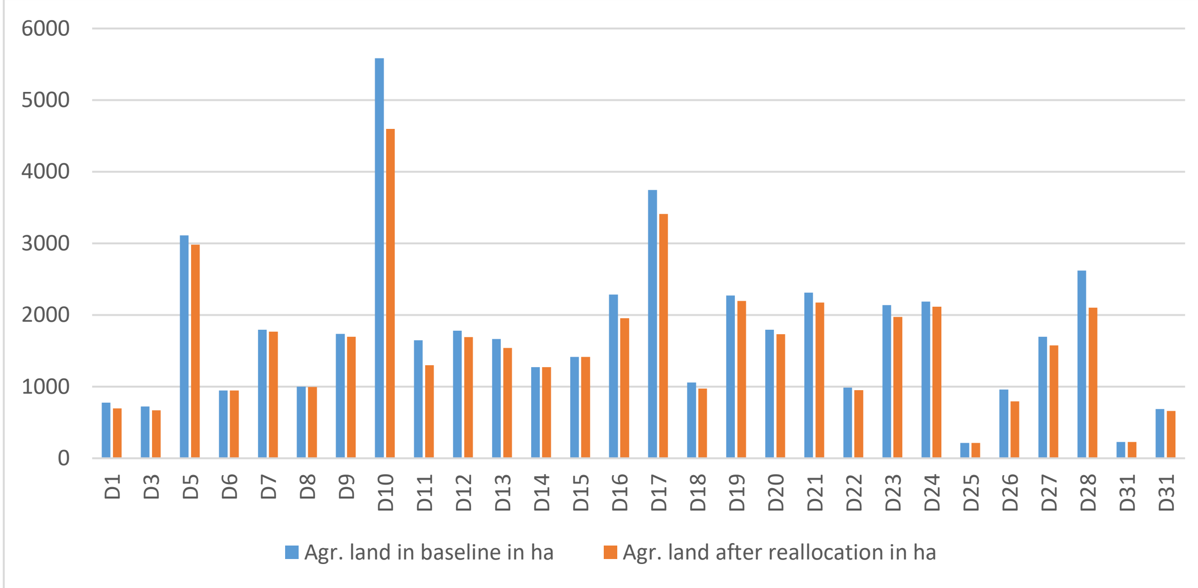
As mentioned before, the reallocation system allows the decrease in pesticides use from some DMUs in favor of those who can make the best use of it while increasing their outputs. This result is shown in Table 3 (detail results are presented in appendix A.3) that presents the variation in pesticides and outputs from the technical efficiency due to reallocation. Additional pesticides result in the increase in all outputs for some Districts (D1 and D7), whereas for others (D6, D14, D24 and D27), at least one output decrease, here livestock-grasslands in favor of cereals-oilseeds-protein. This choice can be explained by the fact that crops are the biggest users of pesticide than grasslands and livestock. In addition, the decrease in pesticides does not necessarily lead to a decrease in all outputs as seen for many Districts, at least one output increase. These output adjustments due reallocation of pesticides also lead to changes in the areas devoted to agriculture.

Table 3: Impact of pesticides reallocation on output evolution from the technical efficiency in euros

Districts	Pesticides variation	cereals-oilseeds-protein variation	Livestock-grasslands variation
D1	3 526	9 121	105 656
D3	-13 679	15 674	-183 110
D5	-124 388	14 009	-493 765
D6	15 385	209 102	-269 962
D7	56 448	366 261	262 913
D8	-9 495	75 139	-317 251
D9	-68 026	-48 035	-41 580
D10	-357 783	-794 838	761 437
D11	-77 692	-352 115	371 693
D12	-110 527	-213 936	-2 587
D13	-24 550	-6 470	226 610
D14	5 069	154 445	-136 231
D15	-19 815	132 276	-421 216
D16	-24 627	102 692	-54 756
D17	-100 972	7 266	-278 474
D18	-54 712	-29 585	87 605
D19	-159 146	-419 981	407 743
D20	-21 579	241 506	-666 595
D21	-23 265	45 425	-32 888
D22	-25 149	4 566	23 290
D23	-33 128	-26 638	-40 586
D24	2 208	209 272	-130 847
D25	-5 323	2 877	-88 375
D26	-740	75 344	-34 301
D27	56 395	377 567	-56 928
D28	-82 511	-129 822	124 902
D31	-6 691	-25 071	27 277
D31	-20 058	-35 253	-34 448

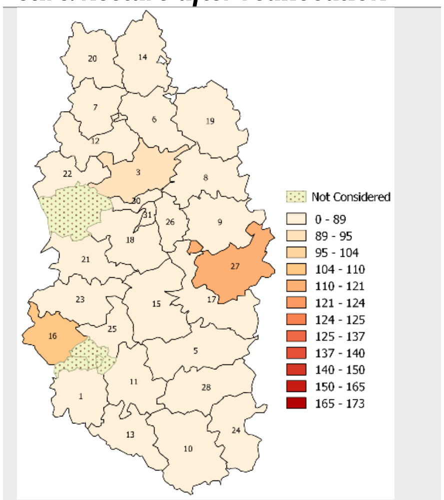
As seen in Figure 9 below, agricultural areas are slightly lower after reallocation compared to their level without reallocation for most of Districts. This means that reallocation allows to set aside a part of agricultural lands that can be devoted to other uses such us environment and biodiversity preservation. At the department level, this saving in land amounts to - 4006 hectares, with 5 Districts the major contributors: D10 (- 989 hectares), D27 (- 517 hectares), D11 (- 348 hectares), D16 (- 333 hectares) and D17 (- 331 hectares). It should be noted that not all Districts can contribute to this savings, some keep their initial level such as D6, D14, D15.

Figure 9: Agricultural lands before and after pesticides reallocation in hectare



While knowing that DMUs can reduce agricultural land in order to use more pesticides per hectare and that our goal is to reduce the use of this harmful input, we found better to computer the agricultural intensity index after reallocation. Figure 10 shows the decrease in pesticides use per hectare after reallocation for the majority of Districts, except for District 27, which become more intensive after reallocation (96.98 €/ha without reallocation versus 110.38 €/ha with reallocation).

Figure 10: Pesticides intensity in euro/hectare after reallocation



This result shows that through reallocation, agriculture can contribute to biodiversity or environment preservation in two simultaneous ways by setting aside a part of agricultural land for that purpose and by reducing the intensity of pesticides use.

4. Conclusion

We carried out an analysis of pesticides use efficiency in the Meuse department using the DEA method. The aim was to measure the potential contraction of this particular input that result in enormous negative impacts on environment, human health and biodiversity. We computed a two-pronged efficiency analysis: first a technical efficiency measured at the farms level; second a reallocation efficiency measured at the Districts level, taking into account the agglomeration effect at different scales of analysis. Four scale levels were considered from the smallest to the largest. Districts were progressively integrated in the reallocation process according to their geographic vicinity, with the hypothesis that it is easier for a farmer to interact with his close neighbors in a case related to the management of available resources. Furthermore, we carried out an analysis impact of reallocation on outputs and agricultural areas. Our choice of agricultural area among other inputs is explained by the fact that we would like to know whether the pesticides reallocation can allow to save land for biodiversity and environment preservation in reference to the land sparing strategy developed by Green et al. (2005).

Our results showed that farms in the department of Meuse are mostly inefficient in pesticides use. It is therefore possible to reach an efficient level for each farm resulting in pesticides contraction while realizing at least the current level of outputs. At the global scale, pesticide contraction is higher with the reallocation efficiency than with the technical efficiency. After integration of all Districts in the reallocation, a pesticides contraction of 46.6 % from the observed value can be reached without worsening farms' income. This contraction would be of 26.7% if only technical efficiency was considered. Districts contribute differently to this contraction according to their various characteristics. This result about pesticides contraction is in line with other findings already carried out in France: as an example, Jacquet et al. (2010) showed that a pesticides contraction of 30 % can be reached without worsening the productivity and the profitability of farmers. For Lechenet et al. 2017, this contraction can reach 42 % on 59% of farms. However, all these results have to be taken with caution as they highly depend on methodologies, variables and scales of analysis considered.

Moreover, pesticide transfers between DMUs are more important when a large number of Districts are involved in the reallocation. This means that reallocation is more beneficial at a large scale than at a small one as DMUs of different Districts are heterogeneous and are located in different zones of return to scale on the efficiency frontier. Reallocation leads to the decrease in pesticide costs from some DMUs in favor of those that can realize more outputs with additional pesticide costs. This is not a question of totally excluding certain farms from pesticides use, but of allowing them to operate at their most effective level. As a consequence, same farms become more intensive and other more extensive in pesticides use according to their efficiency level. This mixture of intensive and extensive farming results first in an increase in outputs (all or a part) for some DMUs and in their decrease for others, while keeping the same amount at the industry level. Second, it allows to set aside a part of agricultural land while reducing pesticides intensity at the department level. This result suggested that through pesticide reallocation, agriculture can contribute to biodiversity or environment preservation by sparing land for that purpose and by reducing pesticides intensity. The regulation of agricultural intensity has been suggested as one of agricultural policies that can encourage the implementation of the land sparing strategy or the wildlife-friendly farming (Fischer et al. 2008)

Our work could be extended in two ways. Firstly, our reallocation analysis could be developed differently: the industry level can be defined based on relevant criteria such as the type of biodiversity to be protected on the farmland or the degree of homogeneity of productions between farms. The integration process will therefore depend on different categories derived from these criteria as well as on the objective pursued. To do so require more data beyond pesticides costs available in this paper. Secondly, we focus on determining the potential of pesticides contraction through reallocation without delving further into how this strategy could be implemented in practice. Some economic policies such as usage quotas or other economic incentives at the department scale could be considered. This analysis could be more useful if the impacts of that pesticides contraction through reallocation on environmental and social benefits were quantified in order to support and justify the implementation of public policies. One can follow the analysis of Skevas and Oude Lansink (2013) focused on the composition of productivity growth of pesticides and their environmental impacts. With only data on pesticides costs in our database, we could not quantify such impacts that require a technical expertise from other domains and more information such as the quantity of pesticide used, their toxicity level, their infestation degree, etc.

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Appendix

A. Reallocation process and it is impact on pesticides contraction and on other variables

Figure A.1: Integration process in the pesticides reallocation

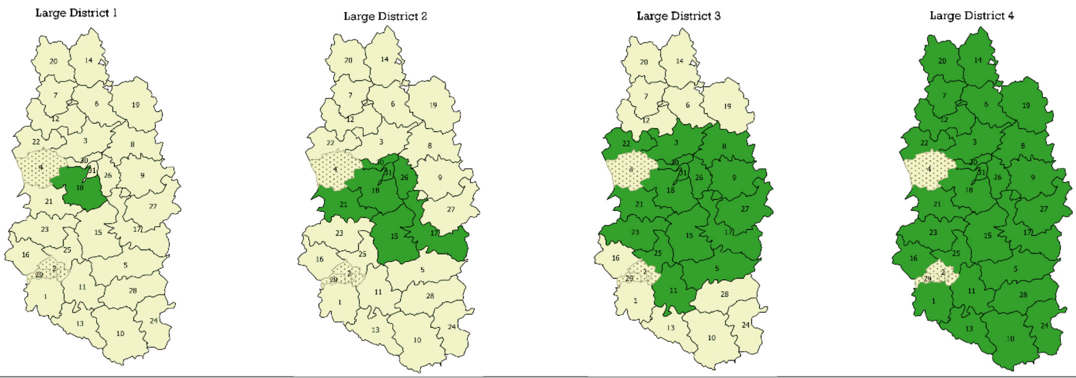

Figure A.2: Contribution of each District in the global pesticides contraction after reallocation

Districts	Pesticides in Baseline in euro	Pesticides After reallocation in euro	Pesticides contraction due to reallocation in euro	Share of each District in the global contraction in %
D1	96 923	59 021	-37 902	1,32
D3	99 635	60 232	-39 403	1,37
D5	380 725	237 337	-143 388	4,98
D6	76 265	59 044	-17 221	0,60
D7	188 928	156 116	-32 812	1,14
D8	139 114	80 929	-58 185	2,02
D9	235 961	113 359	-122 602	4,25
D10	943 004	403 576	-539 428	18,72
D11	276 003	99 660	-176 343	6,12
D12	244 736	96 029	-148 707	5,16
D13	208 573	107 330	-101 243	3,51
D14	126 340	73 384	-52 956	1,84
D15	201 700	117 504	-84 196	2,92
D16	282 573	203 638	-78 935	2,74
D17	452 552	208 375	-244 177	8,47
D18	183 129	78 140	-104 989	3,64
D19	361 721	132 189	-229 532	7,97
D20	157 138	91 620	-65 518	2,27
D21	287 055	157 653	-129 402	4,49
D22	91 801	48 156	-43 645	1,51
D23	234 460	126 763	-107 697	3,74
D24	196 436	122 733	-73 703	2,56
D25	33 076	12 472	-20 604	0,72
D26	85 742	58 213	-27 529	0,96
D27	164 480	174 126	9 646	-0,33
D28	315 904	157 391	-158 513	5,50
D31	23 935	13 548	-10 387	0,36
D31	99 608	57 600	-42 008	1,46
Total	**6 187 517**	**3 306 136**	**-2 881 381**	**100,00**

Figure A.3: Impact of technical and reallocation efficiencies on pesticides and outputs in euros

Districts	Pesticides			Cereals-oilseeds-protein product			Livestock-grasslands		
	Baseline	Technical Efficiency	Reallocation Efficiency	Baseline	Technical Efficiency	Reallocation Efficiency	Baseline	Technical Efficiency	Reallocation Efficiency
D1	96 923	55 495	59 021	428 791	428 791	437 912	187 429	287 326	392 983
D3	99 635	73 911	60 232	434 079	434 079	449 753	498 626	500 664	317 555
D5	380 725	361 725	237 337	1 628 179	1 628 179	1 642 188	1 916 844	1 916 844	1 423 079
D6	76 265	43 659	59 044	201 927	201 927	411 029	1 330 501	1 395 055	1 125 093
D7	188 928	99 667	156 116	653 148	653 148	1 019 409	1 179 662	1 203 239	1 466 152
D8	139 114	90 425	80 929	462 786	462 786	537 925	1 371 342	1 410 223	1 092 973
D9	235 961	181 385	113 359	977 237	977 237	929 202	1 227 775	1 227 775	1 186 195
D10	943 004	761 358	403 576	3 517 631	3 517 631	2 722 793	1 846 864	1 871 411	2 632 848
D11	276 003	177 353	99 660	995 064	995 064	642 949	335 773	344 403	716 096
D12	244 736	206 556	96 029	978 052	978 052	764 116	1 473 194	1 474 007	1 471 419
D13	208 573	131 879	107 330	784 728	785 247	778 777	835 143	858 450	1 085 061
D14	126 340	68 314	73 384	469 925	469 925	624 370	1 220 900	1 220 900	1 084 669
D15	201 700	137 319	117 504	674 065	674 065	806 341	1 534 644	1 593 956	1 172 740
D16	282 573	228 265	203 638	1 341 230	1 341 230	1 443 922	510 004	524 964	470 208
D17	452 552	309 347	208 375	1 610 691	1 610 691	1 617 957	2 564 653	2 667 664	2 389 190
D18	183 129	132 851	78 140	604 562	604 562	574 977	690 170	690 170	777 775
D19	361 721	291 336	132 189	1 493 394	1 493 394	1 073 413	1 105 713	1 130 894	1 538 637
D20	157 138	113 198	91 620	565 681	579 900	821 406	1 950 535	2 001 059	1 334 464
D21	287 055	180 919	157 653	1 017 437	1 021 444	1 066 869	1 930 858	1 951 872	1 918 984
D22	91 801	73 305	48 156	345 536	356 976	361 542	969 754	969 754	993 044
D23	234 460	159 891	126 763	920 846	920 846	894 208	1 649 999	1 724 690	1 684 104
D24	196 436	120 524	122 733	641 211	649 372	858 645	2 522 116	2 565 774	2 434 927
D25	33 076	17 795	12 472	93 274	93 274	96 151	228 441	228 441	140 066
D26	85 742	58 953	58 213	374 753	374 753	450 097	551 258	606 523	572 222
D27	164 480	117 730	174 126	709 915	710 771	1 088 338	1 259 792	1 342 636	1 285 708
D28	315 904	239 902	157 391	1 245 155	1 245 155	1 115 333	1 342 453	1 384 611	1 509 514
D31	23 935	20 239	13 548	129 682	129 682	104 611	98 827	98 827	126 104
D31	99 608	77 658	57 600	498 824	498 824	463 571	334 589	360 500	326 052
Total	**6 187 517**	**4 530 961**	**3 306 136**	**23 797 803**	**23 837 006**	**23 797 803**	**32 667 859**	**33 552 632**	**32 667 859**

Figure B: former Districts of the Meuse department located in Lorraine region