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Efficient Use of Energy Resources on French Farms: An Analysis through Technical Efficiency

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Keywords: technical efficiency; energy resources; farms; Data Envelopment Analysis; France

JEL Codes: Q12, Q15, C61

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1. Introduction

Challenging a productivist agricultural model raises many thoughts and initiatives concerning different ways to design and implement sustainable agriculture capable of preserving natural resources while minimizing the use of external inputs to the ecosystem. In this perspective, Pretty [1], Balmford et al. [2], and Gliessman [3] stress the importance of integrating natural resources and ecological services in the production process. This integration, however, raises a number of limitations including economic assessment [2,4]. Indeed, it is difficult to measure the effectiveness of ecological services because of their difficult physical quantification and monetary valuation [5]. Despite attempts to integrate natural resources in the production function, initiated by Solow [6] and Stiglitz [7], only resources exhibiting economic characteristics of a production factor can be integrated into the production function. Thus, the measurement of natural resource efficiency remains difficult. However some functional approaches exist, at the farm level, which assess whether farmers make efficient use of natural resources to achieve their economic goals.

This is the concept linking economic and ecological efficiencies known as eco-efficiency [8]. This concept was also used by the Organization for Economic Cooperation and Development (OECD) [9], which defines it as "the efficiency with which ecological resources are used to meet human needs", and has been adopted and popularized by the World Business Council for Sustainable Development [10,11] as a way to encourage companies to achieve higher levels of competitiveness and environmental responsibility at the same time. In practical terms, eco-efficiency is the ability to obtain economic performance by making minimal use of natural resources and causing minimal degradation to the environment [12]. Eco-efficiency can be measured using ratios between the economic value of goods or services produced by any single entity (farm, company, sector...), and the environmental pressures generated by the production process [13]. This eco-efficiency improves when environmental impacts diminish and the economic value of production is maintained or increases [12]. On this basis, De Koeijer et al. [14] discussed the measurement of eco-efficiency by using environmental data collected from Dutch sugar beet farms. Picazo-Tadeo et al. [13] assessed the eco-efficiency of Spanish farms in Castilla y León. Basset-Mens et al. [15] analyzed the eco-efficiency of New Zealand dairy farms and the implications of intensification on their eco-efficiency. The eco-efficiency concept was also adapted for the analysis of policy strategies and their possible macroeconomic outcomes [16]. It is used to study efficiency of economic branches, or to connect individual companies to the macroeconomic level [17,18]. These authors consider eco-efficiency as the ratio between added value and environmental pressure, the latter comprising five variables: the specialization of farms, nitrogen and phosphorus levels, the pesticide risk and the energy ratio. Zentner et al. [19] studied the effect of input management and crop diversity on the use of non-renewable energy in Canadian prairie crop systems. Mousavi-Avval et al. [20] evaluated the technical efficiency of energy use on barberry farms in Iran by investigating the relationship between energy waste and farm size.

In the majority of studies dealing with eco-efficiency of farms, businesses, industries, regions or countries, the concept is studied through the relationship between the economic value of goods and services and the impacts of production processes on the environment. Thus, regardless of the method used-parametric, non-parametric, stochastic or econometric-eco-efficiency is measured by considering environmental degradation as an additional input or output. Based on the strict definition of eco-efficiency, which refers to the effective use of environmental resources, the originality of our article is to separate the natural resource input from other intermediate consumption inputs, and to study the technical efficiency of farms in terms of the use of these resources for the case study of France. In our article, we focus on inputs linked to energy resources, including all expenses relating to fertilizers, soil amendments (compost, manure, sulphur...) and fuel, which directly account for the majority of fossil fuel used on the farm. The aim is to demonstrate how, through further analysis of production factors, a more operational diagnostic of farm performance could be drawn. This can shed light on French farms' room for maneuver in terms of improving the efficiency of energy resource use, and can help design environmental policies targeted towards the efficient use of natural resources.

In the second section we describe the methodology with an overview of the efficiency concepts underlying the analysis, and a description of the method employed to compute excess energy factors (slacks). In the third section we present the data used. In the fourth section we discuss the main results in terms of levels of technical efficiency, slack of energy resources and their determinants. Finally, we conclude in Section 5.

2. Methodology

In an economy with limited resources, the concept of technical efficiency is useful. It gives an indication on the ability of decision-making units (e.g., firms) to use the existing technology in the most appropriate way. It consists of scale efficiency and pure technical efficiency. Scale efficiency relates to the optimal level of farm size while pure technical efficiency reflects the ability of a decision-making unit to achieve maximum production for a set of inputs regardless of the price of factors and goods. It provides information about managerial practices and the organization of the production unit.

The literature proposes two major approaches to construct a production frontier and measure technical efficiency: parametric [21–23] and non-parametric approaches [24,25]. The parametric approach, the stochastic frontier approach, requires a functional form to specify the production frontier and uses econometric tools to estimate it. Deviation from the production frontier can be separated between inefficiency of the decision-making unit and random noise. The non-parametric approach, the Data Envelopment Analysis (DEA) [24], has its origins in the work of Farrell [26] and Farrell and Fieldhouse [27], and offers a relative measure of the efficient production function constructed from observations of inputs and outputs of the sample farms. This approach is not related to a predetermined functional form and prevents the occurrence of misspecification. It has been widely used to study environmental and economic assessments in the agricultural sector (e.g., [28–30]) and has gained popularity in energy efficiency analysis [31].

DEA consists of comparing the performance of each farm with the best farms within the current sample, or with a hypothetical farm which uses the same inputs proportionally [32]. The concept of efficiency relates to the distance of the farm considered to the production frontier: a large distance indicates low efficiency. DEA allows calculate both pure technical efficiency and scale efficiency, both of them taken together providing total technical efficiency, and allows obtain input slacks. This, in addition to the fact that DEA avoids misspecification errors due to its nonparametric framework, is why we use DEA here.

Input slacks show which inputs are used in excess. This excess input corresponds to the potential additional reduction of an input in addition to the proportional reduction of all inputs as identified by the technical efficiency score. To illustrate this concept, Figure 1 shows a production frontier FF′ made up by the best performing decision-making units, let's say farms, C and D. The frontier shows the minimum use of both inputs considered (X_1 and X_2) to produce one unit of output (Q). Farms A and B are inefficient because they are not on the frontier. As defined by Farrell [26], technical efficiency of A, respectively of B, is given by the ratio OA′/OA, respectively OB′/OB. Hypothetical farms A′ and B′ are considered as peers for farms A and B respectively. Taking A as an example, this farm could reduce both inputs proportionally, that is to say along the ray OA, and produce as much as A′; this is the technical efficiency concept. However, A′ is not as efficient as C, since A′ could further reduce the use of factor X_2 by the quantity CA′ and continue to produce the same amount of output. Thus, to be efficient in the Koopmans' [33] meaning (Koopmans (1951) gives a more stringent definition of technical efficiency which suggests that the decision-making unit is technically efficient if it operates on the frontier and all the slacks associated with the inputs are zero [32]), farm A must reduce its two inputs proportionally (more precisely by a percentage equal to 1 minus the score of technical efficiency) and further reduce X_2 by CA′. This quantity CA′ is called a slack for input X_2.

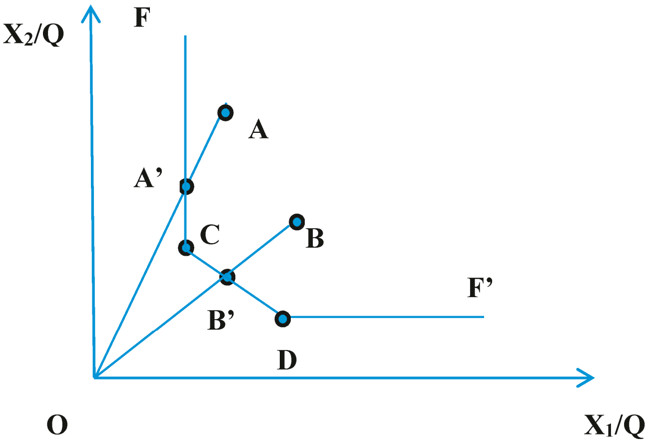

Figure 1. Representation of input slacks: case of two inputs, X_1 and X_2. Source: the authors, adapted from Coelli et al. [32].

Our objective is to measure slacks with respect to energy resource use, and to identify their determinants for French farms. For this, slacks calculated by DEA in a first stage are regressed on potential determinants in a second stage. Tobit models are used in this second stage due to the censored character at 0 of the dependent variables (some farms have no slacks for some inputs).

3. Model Specification and Data

3.1. Data Envelopment Analyses (DEA) Model Specification

Three types of farms are considered here, based on their production specialization, and a separate frontier is constructed for each sample. The computation of technical efficiency and of input slacks is carried out in two ways, depending on the specification of the technology.

Firstly, we use a reference technology (technology T1) which includes three outputs and four inputs, the latter being the inputs conventionally used for measuring technical efficiency of farms: land, labor, capital and intermediate consumption.

Secondly, we separate the energy resources from intermediate consumption, so that the new technology (technology T2) retains the three outputs as in technology T1, but includes five inputs: land, labor and capital as in technology T1; energy resources and the rest of intermediate consumption.

Table 1 summarizes the outputs and inputs selected for the two technologies. The three outputs considered are output from crop activity, output from livestock activity and output from other activities, all expressed in Euros. As for the inputs, land is measured by the utilized agricultural area (UAA) in hectares (ha); labor is measured in annual working units (AWU), that is to say in full-time equivalents; farm capital is measured in Euros; intermediate consumption includes fertilizers, pesticides, seeds, feed, soil amendments, fuel, water, electricity and maintenance costs, and is expressed in Euros; energy resources, which are a part of intermediate consumption, are also expressed in Euros and include direct consumption of energy in the form of fuel, as well as indirect consumption through fertilizers and soil amendments.

Table 1. Description of output and input variables used to calculate technical efficiency and slacks.

Name of the Variable	Description of the Variable	Included in Technology T1	Included in Technology T2
Inputs			
UAA	Utilized agricultural area (ha)	Yes	Yes
LAB	Labor (AWU)	Yes	Yes
CAP	Farm capital (Euros)	Yes	Yes
IC	Intermediate consumption (Euros)	Yes	-
ER	Energy resources including fertilizers, soil amendments and fuel (Euros)	-	Yes
R_IC	Remaining intermediate consumption, that is to say intermediate consumption without energy resources (Euros)	-	Yes
Outputs			
OUTPC	Crop output (Euros)	Yes	Yes
OUTPL	Livestock output (Euros)	Yes	Yes
OUTPO	Other farm outputs (Euros)	Yes	Yes

3.2. Specification of the Model for the Determinants of Input Slacks

In a second step we seek to identify the determinants of non-proportional excessive use of inputs (the slacks). For each slack we perform three Tobit regressions. In the first regression, we use as the dependent variable the intermediate consumption slacks calculated under technology T1. In the second regression, the dependent variable is the energy resource slacks identified under technology T2. In the third regression, the dependent variable is the slack of the remaining intermediate consumption calculated under technology T2. Variables used as determinants of input slacks are presented in Table 2. The selection of these variables was based on determinants identified in the farm technical efficiency literature (e.g., see the review by Latruffe [34]). In addition, only uncorrelated variables were selected.

Table 2. Variables used to explain input slacks.

Name of Variable	Description of Variable
UAA	Utilized agricultural area (ha)
CAP/UAA	Ratio of capital to UAA (Euros per ha)
Debt	Indebtedness ratio defined as debts to capital
Non-Paid/Lab	Ratio of non-paid labor to total labor
S_COP	Share of cereals, oilseed crops and proteinseed crops in the farm's UAA (in %)
S_LEG	Share of legumes in the farm's UAA (in %)
SUB/OUTP	Ratio of subsidies to total output
Age	Age of the farmer
ENVI	ENVI is a dummy variable. ENVI = 0 if the farm is not in Natura 2000 area; ENVI = 1 if the farm is in Natura 2000 area
S_TEXT	Percentage of the clay-sand soil texture in the area of the farm (in %)

Within the determinants, the farm structure is represented by:

- The size of the farm in terms of UAA, which has a mixed effect on technical efficiency in the literature:
- The technology intensity described by the ratio of capital to land, which is expected to increase farm performance;
- The indebtedness ratio, which also has been found to have a mixed effect in the literature;
- The extent of non-paid labor compared to hired labor in total labor, whose effect may also be positive or negative;
- The share of cereals, oilseed crops and protein seed crops, and the share of legumes in the farm's UAA. These shares can give indications on the farm room of maneuver to reduce the use of fertilizers. Indeed they give indications on the nature of agricultural practices used in the different types of farms considered here, such as crop rotation.

Among other variables, the dependence on subsidies is considered and proxied by the ratio of subsidies received by farms related to their total output produced. The subsidies considered here are those received by farms in the frame of the European Union's Common Agricultural Policy and include decoupled subsidies, direct payments made on the basis of hectares of specific crops or heads of specific livestock, payments provided for environmental friendly practices, and lump-sum payments for farms located in disadvantaged areas. Human capital is proxied by farmer's age. Two location variables are used. The first one captures the presence of environmental constraints: it is a dummy indicating whether the farm is located in an environmental zoning area Natura 2000 (Natura 2000 is a European Union's network of nature protection areas established under the 1992 Habitats Directive. It includes Special Areas of Conservation designated by European Union's Member States under the Habitats Directive, and Special Protection Areas delimited under the 1979 Birds Directive [35]). The second one informs on the soil conditions for production: it is the percentage of the clay-sand texture of the soil in the area of the farm considered. Soils with such texture have good water holding capacity but their heavy and compact structure makes it difficult to work them in the rainy season [36].

3.3. Data

The database used is the French Farm Accountancy Data Network (FADN) in 2010. This database consists of bookkeeping data for a sample of statistically representative French commercial farms. The analysis is performed for three types of farms based on their production specialization: cereals, oilseed crops and protein seed crop farms; dairy farms; and mixed farms producing crop and livestock outputs. These three types of farms account for 48% of French farms and 62% of the total agricultural area of the country [37]. The samples used here consist of 1,108 farms which specialize in cereals, oilseed crops and protein crops, 1097 dairy farms and 867 mixed farms.

Tables 3 and 4 present some descriptive statistics of the variables used to calculate technical efficiency and slacks, and of the potential determinants of slacks. Table 3 shows that cereals, oilseed crops and protein seed crops farms are on average larger in terms of land (UAA average of 148 ha) than dairy farms (96 ha) and mixed farms (137 ha). The levels of capital and labor are higher for farms with livestock activity. In terms of the use of energy resources, cereals, oilseed crops and protein seed crops farms use more per hectare on average (213 Euros) than mixed farms (195 Euros) and dairy farms (151 Euros). The share of energy resource expenses in total intermediate consumption is also greater for cereals, oilseed crops and protein seed crops farms (average share of 32.5%, compared to 19.3% for mixed farms and 13.5% for dairy farms). More precisely, the cost of fertilizers alone represents on average 23% of all intermediate consumption expenses for cereals, oilseed crops and protein seed crops farms, compared to 12% and 7.5% for mixed farms and dairy farms respectively. As for the percentage of fuel cost in all intermediate consumption, it is respectively 7.9%, 6.3%, 5.5% for cereals, oilseed crops and protein seed crops farms, mixed farms and dairy farms on average.

Table 4 indicates that livestock farms are more capital intensive than cereals, oilseed crops and protein seed crops farms, but that indebtedness level is similar. The subsidy to output ratio is on average 0.27 for all farms, indicating that on average farms in the whole sample receive 0.27 Euro of subsidies for every Euro of output produced.

Table 3. Descriptive statistics of the variables used to measure technical efficiency and slacks (averages).

Variables	All Farms	Cereals, Oilseed Crops and Proteinseed Crops Farms	Dairy Farms	Mixed Farms
Number of farms	3072	1108	1097	867
Inputs				
UAA (ha)	126	148	96	137
LAB (AWU)	1.9	1.5	1.9	2.3
CAP (Euros/ha)	1658	939	2587	1820
IC (Euros/ha)	892	660	1117	1010
ER (Euros/ha)	190	213	151	195
R_IC (Euros/ha)	701	446	966	815
Fuel (Euros/ha)	58	52	61	63
Fertilizers (Euros/ha)	126	156	83	121
Outputs				
OUTPC (Euros/ha)	778	1128	239	773
OUTPL (Euros/ha)	674	36	1516	802
OUTPO (Euros/ha)	81	60	67	123

Table 4. Descriptive statistics of the determinants of slacks (averages).

Variables	All Farms	Cereals, Oilseed Crops and Protein Seed Crops Farms	Dairy Farms	Mixed Farms
Number of farms	3072	1108	1097	867
CAP/UAA (Euros/ha)	1969	932	2655	2427
Debt	0.422	0.413	0.417	0.441
Non-Paid/Lab	0.90	0.90	0.93	0.85
S_COP (%)	52	84	22	51
S_LEG (%)	2	4	0.3	2
SUB/OUTP	0.27	0.30	0.24	0.28
Age (years)	48.3	50.1	46.8	47.7
ENVI (dummy)	0.04	0.03	0.05	0.04
S_Text (%)	52.7	50.7	55.2	51.9

4. Results

4.1. Technical Efficiency Scores

Table 5 reports average levels of total technical efficiency and pure technical efficiency obtained for the three types of farms considering technology T1, that is to say using the classic inputs (capital, land, labor and intermediate consumption). The results show that farms specializing in dairy are, on average, the most efficient in terms of total technical efficiency: their average efficiency level is 0.74 compared to 0.65 for cereals, oilseed crops and protein seed crops farms and 0.67 for mixed farms. These results indicate that the three samples considered could reduce, on average, all inputs proportionally by 26%, 35% and 33% respectively. This indicates that the average total technical efficiency of crop farms is significantly lower than that of livestock farms, a result which is consistent with the literature (see the meta-analysis of Bravo-Ureta et al. [38]): for example Latruffe et al. [29] found an average of 0.572 for cereals, oilseed crops and protein seed crops French farms between 2001 and 2007, and 0.737 for dairy farms. A lower average technical efficiency for crop farms relative to livestock farms reflects greater heterogeneity in the use of inputs among arable farms than among livestock farms. This can be explained by the fact that climatic and soil conditions that differ across farms influence more the process of production of crop farms than of livestock farms. Table 5 shows that, in terms of average levels of pure technical efficiency, dairy farms are the most efficient with an average of 0.84, significantly different than the average of 0.81 for cereals, oilseed crops and protein seed crops farms and mixed farms. This shows that in terms of production management practices, livestock farms are more efficient than crop farms.

Table 5. Total technical efficiency (TE) and pure technical efficiency (PTE) of the three types of farms calculated under technology T1.

Variables	**Cereals, Oilseed Crops and Protein Seed Crops Farms**		**Dairy Farms**		**Mixed Farms**	
Number of farms	1108		1097		867	
Total and pure technical efficiencies	TE	PTE	TE	PTE	TE	PTE
Average	0.65	0.81	0.74	0.84	0.67	0.81
Standard deviation	0.15	0.13	0.13	0.14	0.17	0.17
Minimum	0.13	0.37	0.26	0.41	0.17	0.39
Maximum	1	1	1	1	1	1
Percentage of efficient farms (%)	3.8	7.6	5.3	32.2	6.7	33.5

The efficiency scores estimated using technology T2, that is to say dissociating the energy resources from the rest of intermediate consumption, are presented in Table 6. They show the same trends as those calculated with technology T1 in Table 5. Regarding total technical efficiency, farms specializing in dairy are the most efficient on average, with an average efficiency of 0.75 compared to 0.67 for cereals, oilseed crops and protein seed crops farms and 0.70 for mixed farms respectively. Average levels of pure technical efficiency show that dairy farms are the most efficient with an average of 0.86.

Table 6. Total technical efficiency (TE) and pure technical efficiency (PTE) of the three types of farms calculated under technology T2.

Variables	**Cereals, Oilseed Crops and Protein Seed Crops Farms**		**Dairy Farms**		**Mixed Farms**	
Number of farms	1108		1097		867	
Total and pure technical efficiencies	TE	PTE	TE	PTE	TE	PTE
Average	0.67	0.82	0.75	0.86	0.70	0.83
Standard deviation	0.15	0.13	0.14	0.14	0.17	0.16
Minimum	0.15	0.37	0.26	0.41	0.25	0.39
Maximum	1	1	1	1	1	1
Number of efficient farms	56	108	73	368	77	310
Percentage of efficient farms (%)	5.1	9.7	6.7	33.5	8.9	35.8

4.2. Input Excess

Table 7 shows, for the three types of farms and under technology T1, the potential reduction of all inputs. Firstly, the proportional potential reduction of all inputs is shown, and it is calculated as 1 minus the total technical efficiency score. Secondly, the average additional non-proportional reduction of each input is given based on slack results and calculated as follows: slack of input i obtained from the DEA model divided by the level of the i-th input used. Finally, the levels of the total potential reduction of each input (calculated as the sum of non-proportional reduction and proportional reduction) is provided. Table 8 shows similar calculations but when considering technology T2.

Table 7. Percentage of potential reduction of inputs under technology T1 (averages).

Variables	Cereals, Oilseed Crops and Protein Seed Crops Farms	Dairy Farms	Mixed Farms
Proportional reduction of all inputs (1-TE) in % (1)	35.3	26.5	32.6
Additional input slack as a % of input level used (2)			
UAA	6.2	5.6	9.2
LAB	0.9	0.6	0.5
CAP	6.2	3.5	5.4
IC	0.8	1.0	1.0
Total reduction of inputs (1) + (2) in %			
UAA	41.6	32.0	41.8
LAB	36.2	27.1	33.1
CAP	41.5	30.0	38.1
IC	36.1	27.5	33.6

Table 8. Percentage of potential reduction of inputs under technology T2 (averages).

Variables	Cereals, Oilseed Crops and Protein Seed Crops Farms	Dairy Farms	Mixed Farms
Proportional reduction of all inputs (1-TE) in % (1)	33.1	24.5	29.8
Additional input slack as a % of input level used (2)			
UAA	5.6	6.1	9.7
LAB	1.5	0.8	0.6
CAP	5.9	3.7	6.6
ER	5.3	10.6	9.1
R_IC	1.2	1.1	1.7
Total reduction of inputs (1) + (2) in %			
UAA	38.7	30.6	39.4
LAB	34.6	25.3	30.3
CAP	39.1	28.3	36.4
ER	38.5	35.2	38.9
R_IC	34.3	25.7	31.5

Under technology T1 (Table 7) results show large slacks (i.e., non-proportional potential reductions) for land and capital inputs. Land slacks are on average highest for mixed farms, while capital slacks are highest on average for cereals, oilseed crops and protein seed crops farms. In terms of capital, results indicate 6.2% excess capital for cereals, oilseed crops and protein seed crops farms and 5.4% for mixed farms. In total, these farms could reduce their respective use of capital by 41.5% and 38.1%. This illustrates heavy capitalization on farms using arable land. Regarding the intermediate consumption, results show only low values of excess, not exceeding 1% of the inputs used in the three groups of farms.

The results of this model could lead us to conclude that the leeway for farms resides mainly in the improvement of their land and capital factors. In other words, we would say that farmers would benefit from adjusting their capital and land investment strategies without the concern of intermediate consumption expenses, which only show a small percentage of slack. However, intermediate consumption includes various components that may hide important differences. Efficiency computations under technology T2, where energy resources are separated from the rest of intermediate consumption, can help in this way. The results, presented in Table 8, also show that the three groups of farms are too land and too capital intensive. However, the results also indicate that slacks for energy resources are not low, and of a similar level as slacks for land and capital: 5.3% for cereals, oilseed crops and protein seed crops farms, 10.6% for dairy farms and 9.1% for mixed farms. This gives support to our idea that the slack of intermediate consumption, observed in the first model (Table 7), does not reflect truly the use of energy resources.

The difference in excess use in energy resources across the three types of farms shown by Table 8, reflects differences in the heterogeneity of agricultural practices within each type of farms. A low average of energy resource slack for cereals, oilseed crops and protein seed crops farms indicate that farms in this particular sample are clustered towards the sample's mean of slack, while the higher averages for dairy farms and mixed farms indicate a larger dispersion around the mean of slack in the respective samples. This suggests that in the livestock samples farms are more heterogeneous in terms of farming practices with respect to energy use. One explanation may be that some livestock farms use the organic fertilizers from livestock manure and thus reduce their external fertilizers' use, while other livestock farms do not.

4.3. Distribution of Slacks According to the Level of Pure Technical Efficiency

The results regarding input excess show some heterogeneity between the three types of farms, especially in the use of energy resources. To further the analysis, we classify each type of farms according to its level of pure technical efficiency, which represents the extent of how management practices could be changed to improve total technical efficiency. Three groups of farms were identified: a group with farms with low efficiency, where the farms' pure technical efficiency score is less than 0.60; a group with farms with medium efficiency, where farms' score is strictly greater than 0.60 but less than 0.85; and a group with farms with high efficiency, where farms' score is strictly greater than 0.85.

Table 9 shows some statistics regarding the slacks of energy resources (obtained under technology T2) for these three groups of farms. Results indicate that the highest slacks on average are observed in the group with highest efficiency scores, and the lowest slacks for lowest efficiency farms. For example, for cereals, oilseed crops and protein seed crops farms, the average slacks for low efficiency farms, medium efficiency farms and high efficiency farms are respectively 0.3%, 3.9% and 7.3%.

Table 9. Slacks of energy resource depending on farms' pure technical efficiency (PTE).

Farm Type	Variables	For Low Efficiency Farms (with PTE $\leqslant$ 0.60)	For Medium Efficiency Farms (with 0.60 < PTE $\leqslant$ 0.85)	For High Efficiency Farms (with 0.85 < PTE $\leqslant$ 1)
Cereals, oilseed crops and protein seed crops farms	Average slack in each group (%)	0.3	3.9	7.3
	Maximum slack in each group (%)	12	43	74
	% of farms in each group	7.3	43.1	49.6
Dairy farms	Average slack in each group (%)	6.2	8.5	12.7
	Maximum slack in each group (%)	23	53	69
	% of farms in each group	3.0	44.8	52.2
Mixed farms	Average slack in each group (%)	5.7	9.5	9.5
	Maximum slack in each group (%)	34	55	74
	% of farms in each group	9.9	39.5	50.6

4.4. Determinants of Slacks of Intermediate Consumption and Energy Resources

Table 10 (for cereals, oilseed crops and protein seed crops farms), Table 11 (for dairy farms) and Table 12 (for mixed farms) show the results from the Tobit models regressing input slacks on the set of determinants listed in Table 2. The input slacks considered here in three separate models are the slacks for intermediate consumption calculated under technology T1 (IC), the slacks of energy resources calculated under technology T2 (ER) and the slacks of the remaining intermediate consumption also calculated under technology T2 (R_IC).

The regression results for the slacks of intermediate consumption under technology T1 indicate that only two variables have a significant influence for cereals, oilseed crops and protein seed crops farms (Table 10): the share of cereals, oilseed crops and protein seed crops and the share of legumes in the total farm's UAA. More precisely, *ceteris paribus*, the increase of these shares reduces the slacks of intermediate consumption. This finding is confirmed for the slacks of intermediate consumption without energy resources in technology T2 (last column of Table 10). However, these two shares are not significant determinants of slacks of energy resources. These slacks are influenced in a negative way by the farm UAA, the ratio of capital to land, indebtedness, age and soil texture, and in a positive way by the share of non-paid labor. In other words, larger farms in terms of UAA, farms with a more capital intensive technology, farms with a higher indebtedness ratio, farms with an older manager, farms with a higher share of clay-sand soil texture, and farms with a lower resort to non-paid labor, use less excess of energy resource. In the case of dairy farms (Table 11), slacks of intermediate consumption in technology T1 are negatively influenced by UAA, capital to land ratio, non-paid labor to total labor, and positively influenced by the share of cereals, oilseed crops and protein seed crops in total UAA. Two results are confirmed when energy resources are considered separately (under technology T2): the capital to land ratio decreases the energy resource slacks, and the share of cereals, oilseed crops and protein seed crops in total UAA increases these slacks. In addition, results show that higher indebtedness decreases these slacks and subsidy dependence increases them.

Table 10. Determinants of input slacks for cereals, oilseed crops and protein seed crops farms.

Variables	**Technology T1**	**Technology T2**	
Dependent variable	Slack of IC	Slack of ER	Slack of R_IC
Determinants	Coefficient and significance	Coefficient and significance	Coefficient and significance
UAA	−0.022	−0.051 ***	−0.032 **
CAP/UAA	0.001	−0.005 ***	0.003 **
Debt	−0.016	−0.054 **	0.049 *
Non-Paid/Lab	4.054	22.144 ***	−7.622
S_COP	−22.323 ***	4.236	−25.004 ***
S_LEG	−50.165 **	−14.786	−62.718 ***
SUB/PROEX	−13.502	4.403	5.625
Age	−0.176	−0.227 ***	−0.151
ENVI	−1.409	1.325	3.509
S_Text	0.022	−0.167 ***	0.075
Log-Likelihood	−584.81	−2,045.83	−730.48

Note: *, **, ***: significant at 10%, 5%, 1%.

Table 11. Determinants of input slacks for dairy farms.

Variables	**Technology T1**	**Technology T2**	
Dependent variable	Slack of IC	Slack of ER	Slack of R_IC
Determinants	Coefficient and significance	Coefficient and significance	Coefficient and significance
UAA	−0.112 ***	−0.018	−0.167 ***
CAP/UAA	−0.003 ***	−0.002 ***	−0.003 ***
Debt	0.038	−0.188 ***	0.178 **
Non-Paid/Lab	−11.497 *	4.497	−0.353
S_COP	18.744 **	17.711 ***	−2.747
S_LEG	54.695	−15.837	99.549
SUB/PROEX	−9.076	38.676 ***	−10.692
Age	−0.187	−0.138	−0.204
ENVI	−0.806	−2.283	−3.907
S_Text	0.027	0.063	−0.157 **
R^2	0.93	0.99	0.93
Log-Likelihood	−650.78	−2866.46	−634.89

Note: *, **, ***: significant at 10%, 5%, 1%.

Regarding mixed farms (Table 12), slacks of intermediate consumption under technology T1 and slacks of energy resources under technology T2 are both negatively influenced by the UAA and the share of cereals, oilseed crops and protein seed crops in total UAA, and positively influenced by the dependence to subsidy and the soil texture area share. By contrast, indebtedness and age negatively influence the slacks of intermediate consumption under technology T1 but positively influence the slacks of energy resources under technology T2.

Table 12. Determinants of input slacks for mixed farms.

Variables	**Technology T1**	**Technology T2**	
Dependent variable	Slack of IC	Slack of ER	Slack of R_IC
Determinants	Coefficient and significance	Coefficient and significance	Coefficient and significance
UAA	−0.371 **	−0.197 **	−0.23
CAP/UAA	−0.038	−0.214 ***	0.027
Debt	−14.177 **	7.881 **	−11.993
Non-Paid/Lab	−3.966	−2.842	5.563
S_COP	−0.002 *	−0.002 ***	−0.003 **
S_LEG	−0.078	−0.015	−0.206 **
SUB/PROEX	23.793 ***	9.775 **	18.448 **
Age	−0.121 ***	0.053 ***	−0.187 ***
ENVI	−24.657	−2.571	−28.574
S_Text	16.255 **	17.637 ***	34.986 ***
Log-Likelihood	−454.44	−2,139.37	−593.95

Note: *, **, ***: significant at 10%, 5%, 1%.

Tables 10–12 overall show several findings as regard the determinants of the slacks of energy resources, recalling that the latter include fertilizers, soil amendments and fuel. The first finding is that the capital to land ratio significantly decreases these slacks for all three types of farms, and UAA decreases them for cereals, oilseed crops and protein seed crops farms and for mixed farms. This suggests that highly capitalized farms and large crop farms are able to generate less waste of energy resources. The relationship between farm size and technical efficiency is a debated issue in the literature and has been illustrated by various empirical results (see the review in Latruffe [34]). In our case farm size is a positive determinant of efficient use of energy resources. Our finding regarding the positive effect of capital intensity conforms to the literature on the determinants of technical efficiency. It suggests that high capitalization enables saving on transportation operations and thus on fuel.

The second finding is the mixed effect of indebtedness on energy resource slacks depending on the type of farm: the effect is significantly negative for cereals, oilseed crops and protein seed crops farms and for dairy farms, while it is significantly positive for mixed farms. The literature recognizes that farmers are credit constrained (e.g., [39,40]). In this context, indebtedness can help them make the necessary adjustments to improve their efficiency. Davidova and Latruffe [41] extensively investigated the relationship between indebtedness and technical efficiency for the case of Czech farms, and, as it is the case for our results regarding the relationship between indebtedness and energy resource slacks, they did not find clear-cut conclusions across different types of Czech farms.

The third finding is that the subsidy proxy has a positive effect on energy resource slacks in dairy and mixed farms. This indicates that highly subsidized farms have an inefficient behavior in the sense that they use energy resources more in excess than farms that are low subsidized. The literature on the effect of subsidies on farms' technical efficiency is relatively vast, e.g., see Zhu et al. [42] and a recent meta-analysis by Minviel and Latruffe [43]. Existing studies generally find that subsidies negatively impact farms' technical efficiency. No studies have been concerned with the impact of subsidies on input slacks. Our results are the first on this issue and they are in line with the existing literature on the subsidy-efficiency relationship. One explanation can be found in Serra et al.'s [44] model. The authors explain that subsidies modify farmers' attitudes towards risk, and as a consequence farmers may use more of a risk-increasing input. This is however not found for our sample of cereals, oilseed crops and protein seed crops farms.

The fourth finding regards the crop rotation. Surprisingly, the share of legumes in the farm's UAA does not impact significantly the energy resource slacks, although it could be expected that the use of legumes would imply lower resort to fertilizers. The share of cereals, oilseed crops and protein seed crops in total UAA impacts differently the farms: it increases the energy resource slack for dairy farms, it decreases it for mixed farms, and it has no significant impact for cereals, oilseed crops and protein seed crops farms. The latter result may come from the fact that cereals, oilseed crops and protein seed crops make most of the UAA of cereals, oilseed crops and protein seed crops farms, although Meul et al. [45] report that the share of cereals in arable farms' area in Belgium influences the energy efficiency. By contrast, in the case of dairy farms, this share captures the balance between pasture land and crops used for forage. Our results thus indicate that, for these farms, producing their own forage is a source of inefficient use of energy resources.

The fifth finding arising from Tables 10–12 is that the dummy variable indicating whether the farm is located in an environmental zoning area Natura 2000 (ENVI) has no significant effect on all considered slacks for the three types of farms. This indicates that location in Natura 2000 area does not help farms reduce their intermediate consumption slacks nor their energy slacks. This is, in a way, not problematic as Natura 2000 zoning does not aim at such reduction. It could, in opposite, be expected that farmers located in Natura 2000 area actually use more input excess than farmers located outside the zoning, as Natura 2000 zoning constrains farmers' choices and practices which may result in inefficient productive behavior. Our results show that this is not the case, since the dummy ENVI has no significant effect on the slacks.

5. Conclusions and Policy Implications

In this paper we have investigated the extent of energy resource excess use (slacks) and its determinants, with the help of a DEA model where energy resources are disentangled from the rest of intermediate consumption. The application was to three types of French farms in 2010.

A first conclusion is that our results show for all three types of farms that farms highly technically efficient have a higher slack of energy resources. This finding, contrary to the one in Mousavi-Avval et al. [20] for barberry farms in Iran, may suggest a trade-off for French farms: attaining high technical efficiency means sacrificing the energy efficiency. The management implication is that technical efficiency alone is not a sufficient measure of farms' performance. Accounting for input slacks in performance measures may give incentives to farmers to proceed to the necessary adjustments (such as enterprise reorganization, investments . . .) to improve further their performance. Another implication relates to policy recommendations. Energy policies based only on the level of pure technical efficiency would consist in assisting lowest efficiency farms, but they should instead be designed in a way to help the highest efficiency farms to reduce their energy use. This confirms Blancard and Martin's [46] result that energy policies need to target the most energy inefficient farms.

In terms of farm specialization, our results indicate that while cereals, oilseed crops and protein seed crops farms are the least technically efficiency on average, they used the lowest excess of energy resource, compared to dairy farms and mixed farms. Hence, despite soil and climate conditions which constrain more their technical efficiency than that of livestock farms, cereals, oilseed crops and protein seed crops farms perform well in terms of energy resource use. Although there exists some literature regarding technical efficiency differentials across various farm production types, the investigation of slacks across farm types is rare. Thus, our study would benefit from replications on various contexts to see if conclusions are robust.

A second important conclusion is that there are differences in the results when considering intermediate consumption as a whole (under technology T1) and when separating the energy resources from it (under technology T2). This is shown when computing the level of slacks (Tables 7 and 8): taken as a whole, intermediate consumption is not used on excess on average, while when energy resources are disentangled, the latter are used on excess as much as capital and land on average. Similar discrepancies can be highlighted from the analysis of the determinants of slacks. For example, in the case of mixed farms indebtedness significantly decreases the level of slacks of intermediate consumption under technology T1 (Table 12). However, when investigating the two components of intermediate consumption separately (under technology T2), we observe a significant effect on energy resources only, in the way that indebtedness significantly increases the level of slacks of energy resources. In the case of dairy farms the finding is even more problematic since under technology T2 the effect of indebtedness on the two components of intermediate consumption is opposite (Table 11):

indebtedness significantly decreases the slacks of energy resources but significantly positively impacts the slacks of the rest of intermediate consumption. Such findings show that when investigating technical efficiency, considering intermediate consumption as a single input may provide misleading recommendations to policy-makers depending on their objective. Considering again the case of mixed farms (Table 12), based on the classic case of studying intermediate consumption as a whole (i.e., under technology T1), it would be recommended that policy-makers design schemes that favor indebtedness so that slacks of intermediate consumption are reduced. However, this may have a positive impact on the excess use of energy resources, and policy-makers should be aware of this side-effect. Also, considering again the case of dairy farms (Table 11), it is evident that policy-makers would need to make a choice: designing debt-favoring policy schemes, which would help reduce slacks of energy resources but increase slacks of other intermediate consumption components; or designing debt-preventing policy schemes, which would have the inverse effects. Hence, if policy-makers are interested in energy consumption by farms, we recommend disentangling energy resources from intermediate consumption. However, this should not be made at the expense of the precision from DEA computation: indeed, increasing the number of inputs in a DEA model may increase efficiency scores due to the "curse of dimensionality".

The literature shows that the degree of dependence on subsidies is often a significant barrier to a farm's technical efficiency. We further show that it constrains French dairy and mixed farms' capacity to reduce the use of energy resources. This may however depends on the type of subsidies. The subsidy variable used in our paper encompasses several types of subsidies which may not have the same impact on farmers' use of resources. This may be particularly the case for payments for environmental friendly practices. Within the European Union's Common Agricultural Policy, these payments relate to agri-environmental schemes which farmers can voluntarily contract. Such schemes may help farmers reduce their fuel use. Thus, we recommend that further research concentrates on this.

Our paper does not aim at providing a novel theoretical nor methodological contribution within the DEA literature. It simply underlines that care should be taken when choosing the inputs for the DEA model, as conclusions may differ depending on the level of disaggregation of inputs. For the particular case of energy resources in French farms in 2010, our results show that policy recommendations may not be the same. The main limitation of our research is that robustness tests have not been conducted. Firstly, robust procedures developed for DEA could be used to confirm our findings. Secondly, other indicators of energy use performance could be computed.

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