Energy efficiency of various French farming systems: questions to sustainability

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1. INTRODUCTION

The method of energy analysis of farms **(8)** is hereby utilised. Already used during the seventies **(3, 5, 17)**, this method, as it is shown in figure 1, accounts all the non-renewable energy spent to obtain the farm inputs, from the extraction of raw materials to the final product available at the entrance of the farm. It also considers the gross energy of all agricultural products that are exported outside of the farm[1]. The energy analysis of farms, as monetary accounting, provides a global view on the efficiency of farming process through the production of various criteria, as it will be shown below.

The issues are environmental, particularly for the control of greenhouse gas emissions and also for the evaluation of the use of scarce non-renewable resources. They show also socio-economic aspects, as fossil energy may be replaced in some cases by human resources (labour). Energy analysis can therefore play a significant role in the evaluation of sustainability of agricultural process **(4)**.

Energy analysis provides a relevant view of the specificity of agriculture, as a user and a producer of energy simultaneously. This distinctive feature makes agriculture play a specific role in CO_2 cycles, thanks to the phenomenon of photosynthesis. With forestry and some other human activities utilising renewable energies, **agriculture is the only human occupation which may produce more energy than it had consumed**. It is interesting therefore to check if it is true in any farming process, and to explore the causes of variations in energy results.

[1] As in Life Cycle Assessment, renewable energies are not accounted, neither human labour. All the by-products which have no economical use are not considered **(2, 9).**

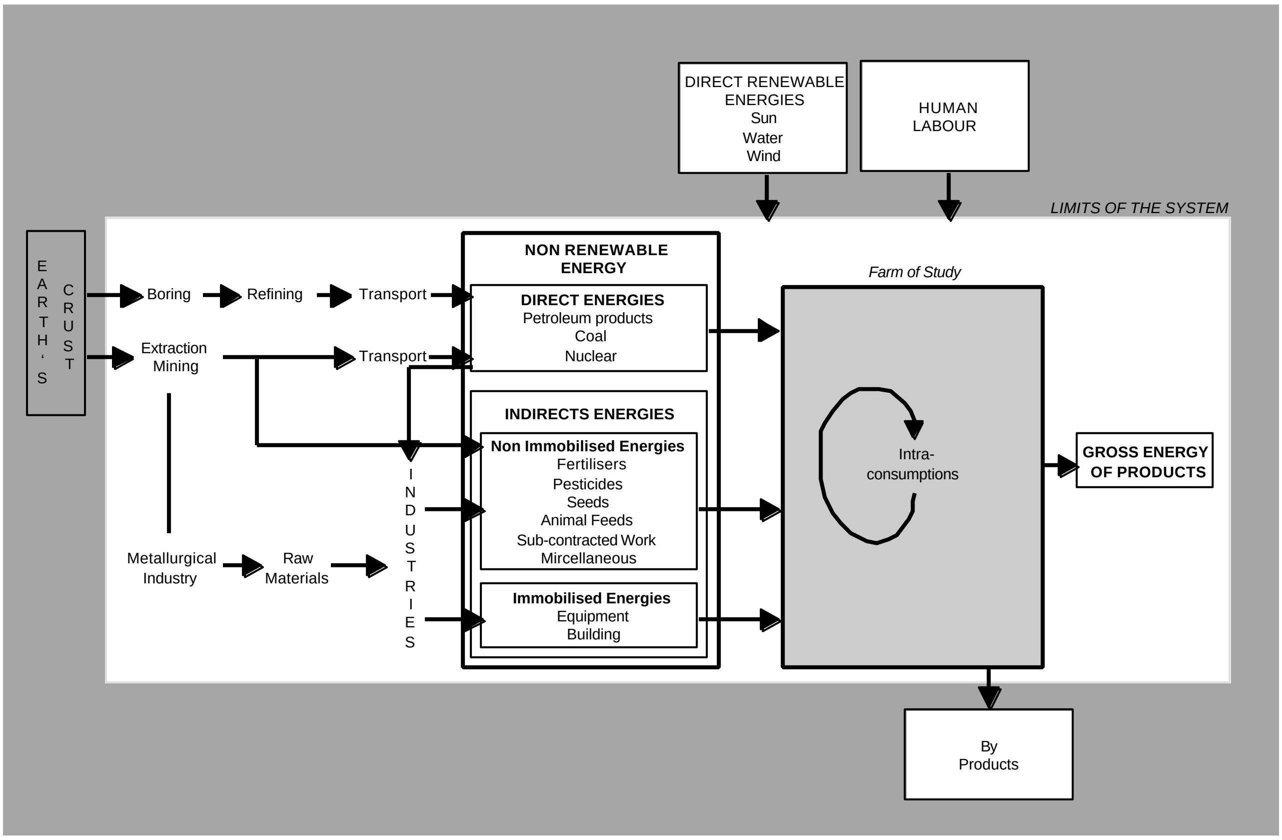

Figure 1*: Limits of the considered system for energy analysis of farms* ***(14)***

The scale of analysis may be also global or national: it is chosen here to work at the scale of the farms, in order to show the effects of farmers decisions and behaviour (i.e. mainly technical choices) on the results. The level of the farm is actually well adapted to interventions of development.

According to this method, **energy efficiency** of a farm is defined as the following ratio:

Gross energy of useful products / Non renewable energies used to produce them.

The **energy balance** is defined as the difference between these two terms.

If it is positive (i.e. energy efficiency is above 1), one may consider roughly that more CO_2 has been captured than spent in the farming process: in that case, agriculture is effectively a sink of carbon dioxide, even though it is a short term sink (like for biofuels).

2. CASE STUDY OF DIFFERENT TYPES OF FRENCH FARMS: ANIMAL VERSUS CROP PRODUCTIONS?

This study was carried out in the Burgundy region, in collaboration with Bernard CHOPINET (Professor of agro-equipment in ENESAD), with some of our students **(1)**.

The Planète group[1] has elaborated the system of references used to convert inputs into non-renewable energy. Some figures are provided as examples in table 1.

[1] The Planète group is constituted of Fédération des Herd-Books Luxembourgeois, (FHL) Institut de l'Élevage (Nancy), ENESAD, Centre d'Études Internationales Paysannes et d'Actions Locales (CEIPAL, an NGO from Lyon), CEDAPAS (Pas de Calais), Thiérache CETA and SOLAGRO.

INPUTS			
Type of inputs	**Units**	**Energy (MJ/unit)**	**Sources**
Gasoline	litre	40.7	Combes, FHL
Mineral fertiliser			
N	kg	47.1	Patyk, Audsley
P2O5	kg	15.8	Patyk, Audsley
K2O	kg	9.3	Patyk, Audsley
CaO	kg	2.1	Patyk, Audsley
Animal feeds			
Herbivore pellets	kg	4.3	CEIPAL, FHL, Agreste
Herbivore meal	kg	3.8	
Seeds			
Cereals	kg	8	CCPCS
Machinery (to be written off)			
Tractor	kg	23.4	Combes, Lambert
Transport			
By truck	tonne*km	0.85	OFEFP
By tractor	tonne*km	3.2	
By cargo boat	tonne*km	0.25	
PRODUCTS			
Type of products	**Units**	**Raw energy (MJ/unit)**	**Sources**
Wheat	kg DM	15.77	INRA
Maize grain	kg DM	16.16	INRA
Rape	kg DM	25.14	INRA
Cow milk	litre	3.06	FHL, CEIPAL
Beef meat	kg alive	15.2	FHL, CEIPAL

Table 1: *Examples of primary energy contents, from Planète system of references, 1999* ***(6,7,8,11,13, 14)***

Eleven farming systems showing the diversity of agricultural productions in Burgundy (except vineyards, which are very specific) have been analysed. Obviously, because of the low number of farms studied, it is not possible to get a statistical representativeness. The chosen farms illustrate only the disparity of agricultural systems in that region. Results are synthesised in table 2.

Farm n° (production)	**energy efficiency**	area (ha)	GOI[1] (kF)	Main products	Share of sale crops (% area)	Energy of inputs (GJ)	Share of spent energy			Energy spent per ha MJ/ha
							direct energy	fertiliser	feeds	
1 (crops)	**8.8**	150	430	crops	100%	1 300	47%	35%	0%	8.7
2 (crops)	**5.9**	180	610		100%	2 800	28%	57%	0%	15.6
3 (crops,milk)	**4.7**	120	na	Mixed : crop and animal products	50%	2 200	38%	17%	13%	18.3
4 (crops,beef)	**4.2**	180	360		50%	2 800	33%	33%	12%	15.6
5 (crop,pork)	**1.6**	200	890		50%	4 700	45%	27%	1%	23.5
6 (beef)	**0.8**	160	600	animal products	5%	1 300	32%	12%	23%	8.1
7 (milk)	**0.6**	100	540		0%	3 200	26%	22%	21%	32
8 (eggs)	**0.5**	0	na		Off-soil	5 300	7%	0%	86%	nr
9 (eggs)	**0.4**	0	na			500	3%	0%	88%	nr
10 (rabbit)	**0.3**	0	120			1 300	5%	0%	89%	nr
11 (goat milk)	**0.1**	3,5	na			500	36%	0%	61%	nr

Table 2: *Energy efficiency of various Burgundian farms* ***(19)***

[1] Gross Operating Income.

The energy efficiency shows a great range of variation, according to the specialisation of the farms:
- 2 arable farms, with efficiency above 5;
- 3 mixed farms (crop and animal production), with efficiency between 1 and 5;
- 6 farms specialised in animal production, with efficiency lower than 1.

This is due to the fact that animal production represents a further level in the food chain. It is necessary to provide animals with 4 to 8 joules of feed to get one more joule of meat. As animals are not able to photosynthesise, they are necessarily less energy efficient than crops. As a consequence, animal production may appear as a luxury source of food energy, which may question the level of meat consumption observed in developed countries. Nevertheless, from an agronomic viewpoint, animal production is useful to valorise mountain meadows or difficult zones, and also agricultural by-products. On the other hand, animals produce useful manure to fertilise the land, which allows savings of chemical fertilisers and improve the soil structure (humus). This is why the mixed farms, with energy efficiencies between 1 and 5, appear to be a good compromise.

In the share of spent energy, table 2, it appears that feeding in animal production is logically the first or second item consuming energy. In other productions, direct energy is the first, followed by fertilisers in farms specialised in crop production. Farm 2 is larger than number 1 (plus 30 ha, i.e. 20% more), this may partly explain a better GOI; it is nevertheless less energy efficient because it consumed 65% more chemical fertiliser than the first one. This point shows the range of possible improvement in farmer's practices in order to save energy, but it may be in contradiction to economic profitability. Actually, at first glance, there is no linkage between energy efficiency and economic one (see column GOI) **(10, 20)**. Nevertheless, the past years proved there could be a synergy between economic aspects and energy ones: the decrease of agricultural prices due to CAP reform of 1992 prompted farmers to reduce charges in supplying more accurately inputs according to the expected yield, this fact leading to an improved energetic efficiency. For the breeders, this decrease of crop prices led them more to self-produce animal feeds.

For crop production, an historical comparison of energy efficiencies is proposed in table 3. It appears that energy efficiencies in plant productions are today far better than 20 years ago.

Source (date) **(ref)**	Number of farms (plant production only)	Energy efficiency
Hornacek (1979) **(12)**	14	2.9 (average)
Bonny (1980) **(5)**	31	3.1 (average)
Ménégon (1996) **(15)**	9	5.5 –8.3
Risoud-Chopinet (1999) **(19)**	2	5.9 – 8.8

Table 3: *Energy efficiency in crop production*

This comes from the improvements obtained in industry in making inputs : for example, it was assumed that a unit of nitrogen required 81.7 MJ in 1979, meanwhile it is only 47.1 MJ today **(16)**. This is also due to better yield for the mid-eighties, and better management of inputs by farmers.

Could this positive point be extended to animal production? It may be assumed that two contradictory trends are operating. On one hand, there are also gains in animal productivity, i.e. transformation of feed into animal products is improved, but on the other hand, with the internationalisation of markets, the animal feeds may come from the opposite side of the Earth. As transportation requires a lot of energy, it is doubtful of obtaining improved energy efficiency in animal production when feeds are imported.

As a consequence, in a perspective of sustainable development, it is recommended to improve **crossed exchanges of feeds and organic manure, between specialised farmers (crop and animal) inside the same local region**, to limit transportation of feed and to lower the use of chemical fertilisers. This would lead to global energy efficiency of both farms similar to the ones of mixed farms.

This implies a more endogenous economic development, based on local resources, with a minimum transport of goods: nevertheless, this will be possible only when the prices of petroleum are high enough. Some other environmental issues will be improved at the same time (soil erosion, management of manure, greenhouse gas emissions, air pollution, noise,…).

A sustainable agriculture must therefore rely on integration of plant and animal productions on the same spot, with the most important as possible use of local resources. Energy efficiency on the level of small regions is a criterion to assess this orientation.

3. COMPARISON OF CROPPING MANAGEMENT SEQUENCES

On the scale of the farms, comparison of their energy efficiency in order to prove one technical system is better than the other, is relevant only if they are specialised into the same sole production. Except for this rare case, the inside proportion of crop and animal productions, or even of different more or less energy efficient crops, will act upon the energy efficiency more than the technical management itself. This is the reason why in order to compare different management sequences, data collection was done here at the scale of the plot of land (same size, same soil type) for a given crop.

Wheat cropping on an organic farm and on a conventional one under similar agro-climatic conditions is taken here as an example **(18)**. Results are presented in table 4. One should notice that the natural conditions are rather difficult in this area: in other places like Champagne, energy analysis of wheat production led to a balance of around 141000 MJ/ha (thanks to yields of 10 t/ha) and energy efficiencies between 8.7 and 11.5[1].

MJ/ha	NRE[2] of inputs (*incl. straw pressing)*	Raw Energy of grain product	Raw Energy of straw product	Balance with straw	Energy efficiency with straw	Balance without straw	Energy efficiency without straw
Organic	8 209 *(250.7)*	50 979	49 032	91 802	12.18	42 770	6.41
Conventional	14 825 *(220.6)*	95 586	45 967	126 728	9.55	80 761	6.55

Table 4: *energy analysis of two management sequences of a wheat crop, under same pedo-climatic conditions* ***(18)***

The energy efficiencies (excluding straw) of the two examples are surprisingly equivalent. Indeed, consumption of non-renewable energy (NRE) for inputs is quite different, as figure 2 shows it. But energy of wheat grain production[1] also varies in the same proportion (55%), leading to the results observed.

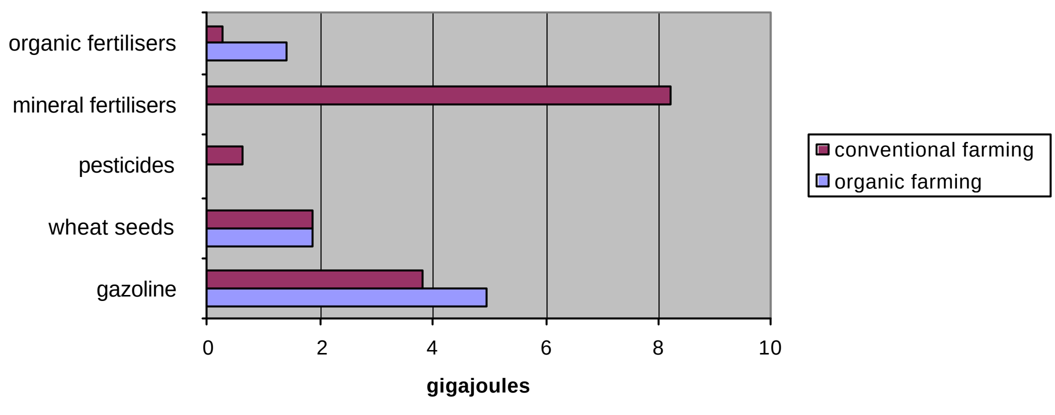

Figure 2: *comparison of inputs energy for wheat cropping (on 1 ha)*

Nevertheless, these equivalent energy efficiencies hide very different energy balances, the conventional one being almost double the organic one. : as a consequence, one may say that conventional wheat farming, with their greater yield, allows a formation of a more important carbon dioxide sink on the same area.

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[1] Results not yet published.
[2] NRE: non renewable energy.
[1] It is assumed that organic and conventional wheat grain are containing the same gross energy, even if their quality is different.

Therefore, from our limited examples, according to the environmental issues, both ways of production can be significant:

- regarding saving fossil fuel, organic wheat production is better;
- but regarding the increase of CO_2 sink, conventional wheat farming is better.

These points should be intensified in the future with more case studies, keeping in mind that results of energy analysis may be differently used, according to the considered problem.

If the straw product is also considered, because of the lowest production of straw in conventional farming due to the use of chemical straw shorteners, organic farming leads to better energy efficiency. In fact, by-products such as straw must be taken into account only if they have an economic use: again, it may occur when crop farming and animal husbandry are well integrated (it is the case in these two examples) or in a sustainable development framework. Regarding CO_2 sink, the using up of by products is important: if the straw is incorporated into the soil instead of being burnt, it will improve its carbon contents.

This incorporation will also allow a saving of phosphorus and potash fertilisers. But this will be noticeable only for the next crop: reasoning at the scale of the whole rotation would allow such consideration and would be more appropriate.

4. ENERGY ANALYSIS OF CROP ROTATION

To avoid the difficulties of allocation of inputs such as P and K fertilisers between the different crops of a rotation, a global approach of a rotation is shown here. The farm is rather particular, because it is organic and it received an experimentation on renewable fuel[1]. A tractor engine was modified to work with crude oil from rape as fuel, which required only 10,8 MJ per litre of non-renewable energy to be obtained (for rape growing and oil extraction). Transportation is negligible, these operations being made locally.

[1] Financed by the Burgundy Region and ADEME.

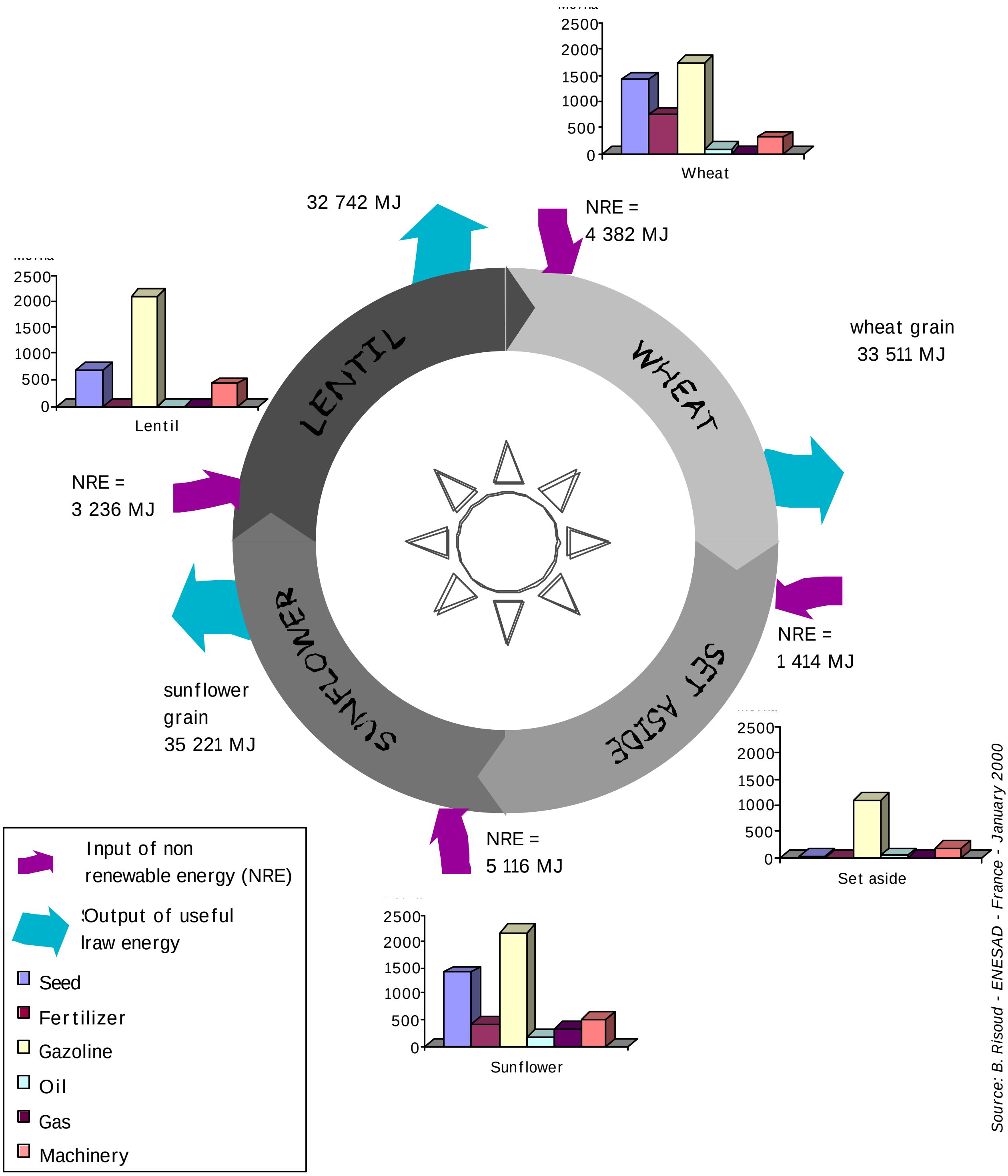

Figure 3: *energy analysis of a crop rotation in an organic farm, partly using renewable rape oil as gazoline (Côte d'Or, France)*

	Set-aside	Sunflower	Lentil	Wheat	Rotation as a whole
Energy Balance (MJ/ha)	- 1 414	30 105	29 506	29 129	87 326
Energy Efficiency	0	6.9	10.1	7.7	7.2

Table 5: *Energy results of the actual crop rotation*

In spite of the set-aside year in the rotation, global results are rather good (table 5) for this place with poor shallow soils. But the farmer does not use much his modified tractor because it is not very powerful (60 Ch). If all his tractors worked with renewable oil instead of gasoline, the results would be very noticeable, as shown in table 6.

	Set-aside	Sunflower	Lentil	Wheat	Rotation as a whole
Energy Balance (MJ/ha)	- 590	31 721	31 062	30 431	92 624
Energy Efficiency	0	10.1	19.5	10.9	11.5

Table 6: *Energy analysis of the same crop rotation if only renewable oil was used instead of gasoline*

Lentil is a particularly efficient crop, because as a legume, it does not require nitrogen fertiliser, organic or not.

This example is given to show the range of today possible improvements. It allows a rather optimistic point of view on future evolution in order to solve, a least partly, the problem of increased emission of carbon dioxide in the atmosphere. But again, this would happen only when oil prices will be high enough, so that renewable fuel will be economically profitable, without the help of subsidies.

CONCLUSION

Energy analysis is a relevant method to consider agriculture in a sustainable perspective. It shows the complementarity between crop and animal productions, and the importance of combining and balancing them at a local level, to improve the energy efficiency of animal production[1]. This would be profitable in terms of preservation of non-renewable energy, and would also be favourable to other environment issues.

Energy analysis of management sequences of crops allows comparison of their ability to save non-renewable energy and to fix carbon dioxide from the atmosphere. Energy balance is a relevant criteria for this latter, while energy efficiency is for the first.

As sustainable development **(18)** is far from being only a question of energy, but also of land, water, employment, economic return, etc., a combination of energy data with figures from other domains would be interesting to define and assess farming management in a sustainable point of view.

At the farm level, here are some examples of criteria to maximise (NRE : non renewable energy) :

Number of jobs / NRE used

Total product (Euro) excluding allowance / NRE used

Or to minimise:

NRE used / quantity of a given product

At the plot (area) level:

Energy efficiency and energy balance (to be maximised)

NRE used / ha (to be minimised)

Sustainable development implies a less specialised economy to emphasise complementarities and to use local resources more rationally, a less centralised organisation to decrease the cost of transport, and a better-balanced diet for a more equitable use of food on the scale of the Earth.

[1] In some places, like Brittany in France, to obtain this equilibrium would mean a global reduction of animal products, while it would be the opposite in Paris Basin.

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