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# From fossil to sustainable diets:
## an assessment of farming energy footprint

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**Esame finale anno 2015**

This work is dedicated to the beloved memory of professor **George Washington Carver**, probably the first man in history who experienced the passage from slavery to world class agronomy, remembering us that all the professional research work must be devoted mainly to the progress of mankind.

# Index

# 1. Foreword

> «Suddenly we have discovered what we should have known long before: that the ecosphere sustains people and everything that they do; that anything that fails to fit into the ecosphere is a threat to its finely balanced cycles; that wastes are not only unpleasant, not only toxic, but, more meaningfully, evidence that the ecosphere is being driven towards collapse.»
> Commoner B, The closing circle. Nature, man and technology, 1971
>
> «Our world model was built specifically to investigate five major trends of global concern-accelerating industrialization, rapid population growth, widespread malnutrition, depletion of nonrenewable resources, and a deteriorating environment.
> These trends are all interconnected in many ways, and their development is measured in decades or centuries, rather than in months or years. With the model we are seeking to understand the causes of these trends, their interrelationships, and their implications as much as one hundred years in the future.»
> Meadows DH, Meadows D, Randers J, *The limits to growth*, 1972

The present research work has deep and long roots, that go back to when the doctoral candidate was a young man who suddenly became aware of the environmental problems of our age and of the necessity of a systemic approach to solve them. The above mentioned quotations from Barry Commoner and from the MIT group are an acknowledgement to those that I consider my intellectual and inspiration masters.

After several years of work in the field of research and teaching, I definitively came back to my environmental concerns by writing for ten years the professional environmental blogs *ecoalfabeta* and *ecoblog*.

Research work for the blog made me in contact with the Department of Agro-Food Sciences of the University of Bologna. I found the work of its academic dean prof. Andrea Segre'  on the sustainability of the food supply chain really inspiring and this led me to the apply for a PhD in International Cooperation and Sustainable Development.

I focused my work on the energy footprint of food production in its general and specific terms, as detailed in the following chapters, hoping to make a contribution to the path towards a more sustainable agricolture.

I would like to thank all the people that helped me through this task.

First of all thanks to my supervisor Matteo Vittuari for providing me endless helps on methodological issue, for insisting for rigorous and consistent analysis ,  for giving me an international perspective besides supervising all aspects of this work.

Thanks to my Missouri co-supervisor Thomas G. Johnson, who helped me in formulating the theoretical frameworks of my case studies, intellettualy challenged and sustained me during my stay in Missouri and supervised all the work.

Thanks to William Meyers of Missouri University for his kindnes and deep of thought who helped me in several occasions.

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Thanks to Ron Ledesma , Van Ayers, Emilio Caminati and  Alessandro Vanzini for having get me in contact with several dairy and rice farmers.

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Thank to all the 27 american and italian farmers whom I meet; for privacy reasons I cannot disclose their identities, but I remember them all as professional men and women committed to their activity, real people who work hard in order to provide food for the society. I have spent several pleasant and interesting hours in their company and they enriched me of many important aspects of rural life and practices that go beyond the purpose of the present work.

And last, but foremost, thanks to Anna Patrizia Caminati, my inspiring muse and companion, who followed and helped me in many aspects of this work, providing suggestions, incitement and enlightenment.

# 2. Objectives

> «It is clear that natural resources represent the limitative factor as concerns the life span of human species. Man's existence is now irrevocably tied to the use of exosomatic instruments and hence to the use of natural resources... The maximum of life quantity requires the minimum rate of natural resources depletion. By using these resources too quickly, man throw away that part of solar energy that will be reaching the hearth for a long time after he has departed.
> And everything man has done during the last two hundred years, or so, puts him in the position of a fantastic spendthrift. There can be no doubt about it: any use of the natural resources for the satisfaction of non vital needs, means a smaller quantity of life in the future»
> N. Georgescu-Roegen, *The Entropy Law and the economic process*, 1971, p 21

## 2.1 General background of research

Energy flows define all transformations occuring generally in the universe and more specifically within the earth ecosystem. The radiating energy from the sun that reaches our planet is about $3{,}8 \cdot 10^{24}$ J/year; one third of it becomes part of the hydrological cycle of evaporation and precipitation, while a much smaller amount is responsible for winds, waves and currents (Dorf 2001). All living species on the earth depend ultimately upon the photosynthetically fixed energy, about $2{,}8 \cdot 10^{21}$ J/year (Wright 1990).

Mankind is no exception and for great part of its history has relied on the energy coming from biomass, wind, water flow as well as the methabolic cycle that gives the muscular energy of men and animals.

Specific patterns in the use of energy have characterized the evolution of all human soci.eties: great energy availability has supported demographic and economic growth, but has also given rise to conflicts for resource control; more or less rapid changes in the accessibility to energy sources with respect to the existing population has been typically the cause of social crisis, economic shocks or eventually the entire collapse of civilizations (Diamond 2005, Ponting 2007).

The so called industrial revolution can be more properly defined as a “fossil revolution”, since it made available through thermal engines the bounty of the *subterranean forests* of coal, oil and gas that accumulated in million of years of the past geological areas (Patzek and Pimentel 2005, Sieferle 2001). The availability of a cheap and much more abundant alternative to solar energy is the main features that characterize the economic development of capitalism in the last two centuries (Goldstone 2002, Huber 2009, Wrigley 2010)

The most important, albeit often underrated use of energy in human society is for food production, which is basically essential for life. Preindustrial agriculture provided food within the limits of the natural ecosystem, in terms of availability of climate, water, nutrients and muscular energy for work.

The diffusion of industrial revolution in agriculture during the twentieth century from Western Europe and North America to almost all the rest of the world has dramatically increased the energy use in crop and livestock production sometimes beyond our recognition of the phenomenon.

The industrialization of farming practices has enormously increased the traditional output of natural ecosystems, generating such abundance of food to induce wastes along the supply chain and nutritional excesses.

This edible abundance as come at the double price of relying more and more on non renewable energy sources and contributing significantly to climate change with the emission of greenhouse gases.

Up to now the attention has been focused more on *low-carbon* practices in agriculture than on *low-energy* practices. While the former are important for climate change mitigation, the latter are at least equally important for being more resilient to energy shocks.

## 2.2 Research questions

The general objective of the present research is the assessment of the energy footprint in the agro-food chains of different agricultural systems in the world and their possible responses to the declining availability of conventional fossil fuels with related rising energy costs in the next decades, in a context of increasing population.

The direct and indirect dependence of the food production systems on oil and gas has reached a level of criticality which makes the system little resilient to small-medium changes in energy prices (Georgescu-Roegen, 1971; Pimentel and Pimentel 2008; Pagani and Vittuari 2013). This situation may expose many regions in the world to food insecurity in the next decades. (Lagi M. et al., 2011)

According to the well-established theory of the peaking of the extraction rate of non-renewable resources (Hubbert 1956; Pfeiffer 2006, Pagani and Caporali 2014), the social and economic problems linked to energy availability don't arise when resources are almost depleted, but long time before, when the end of the era of "cheap energy" progressively rises the energy cost beyond the capability of many actors to sustain them.

The effects of peak oil will not show within decades, but are already present and acting in multiple form, as can be seen from two facts. *First*, the oil price shock of 2007-2008 have been the result of the coupling of peaking of conventional oil production and increased market demand, mainly from Asia ( Hamilton 2009). *Second*, the current development of unconventional oil (tight oil and tar sands), with all its environmental burden of local and global pollution, is the response of the oil industry to the decline of conventional oil.

As a consequence, evaluating as precisely as possible the enormous reliance on non-renewable resources in food production is of the upmost importance in order to define programs to reduce energy use intensity and perform the transition towards more sustainable production and consumption practices. Policies oriented in this direction may improve food security in many regions of the world.

It is important to point out that energy availability is not the only constraint in the food production system, which is limited by other factors, like climate, access to land, green and blue water availability, mineral supply, machines, technology and, last but not least, labour.

However, energy supply must come first in this list, because all the previous factors are more or less dependent on it to work properly and any reduction in their availability usually needs more energy for compensation.

More specifically the research questions focus on the two following aspects:

1. What is the energy footprint of different agricultural systems?
2. What is the energy footprint of different livestock systems?

Following McConnell and Dillon, it is possible to define an agriculltural system as «an assemblage of components which are united by some form of interaction and interdependence and which operate within a prescribed boundary to achieve a specified agricultural objective on behalf of the beneficiaries of the system.» (McConnell and Dillon 1997). According to their classification, the research questions of the present work are dealing with farm-level systems of order level 4 (crop systems) and 6 (anymal systems).

The research questions are oriented to evaluate the relevance of the different components of the system in terms of energy consumption and most of all determine the effects of of different practices on energy spillage or saving.

## 2.3 Addressing the questions

A comprehensive and critical literature review (chapter 3) has been performed on a significant amount of papers published in the field of energy analysis in crop production, in order to obtain a general model for energy inputs in five categories: *(i)* direct energy usein terms of fuel and electricity; *(ii)* embodied energy in structures and machinery (Stout 1991 , Giampietro 2003, Mikkola and Ahokas 2010); *(iii)* fertilizers (Mortimer et al 2003 , Williams et al 2006, Jenssen and Kongshaug 2003), *(iv)* pesticides (Green 1987, West&Marland 2002, Helsel 2006, Audsley et al. 2009) and *(v)* water management (Pimentel 2008, Agha Alikhani et al 2013, Singh et al 2007, Tsatsarelis 1993, Singh and Mittal 1992).

Review includes also a comparative analysis of energy consumption in organic and industrial farming. The review has been enriched by an original work of data collection and modelling from FAOSTAT and other databases.

A similar analysis has been done in order to assess the energy input of livestock systems in the domains of feed preparation (Dalgaard et al 2008); pasture management (Refsgaard et al 1998) ; structures and machinery (Wells 2001, Koesling 2013) and stable operations. Again, the literature review has been completed with original work of data collection and modelling.

Possible future scenarios of energy availability in the medium-long term have been analized through proper literature review of peak oil, gas and carbon has been performed in order to assess the possible scenarios of energy availability.

In order to enrich the literature review with actual data from agricultural systems, an extensive archive research has been performed: the best source is the database of the Food and Agricultural Organization (FAOSTAT 2014), while specific information on the US and Italian agricultural pratices was found on the national archives ( USDA 2014, ISTAT 2014). Specific information on energy sources was found in the most accurate database on the subject (EIA 2014, BP 2014).

Chapter 4 is devoted to the methodology used in the present research, both in terms of general choices and of technical aspect. The reasons for the choice of the case study method are explained, together with the choice of the food products taken into consideration and of the particular agricultural systems analized.

All the computational methods used for the evaluation of the enegy footprints are explained in detail, with an appropriate collection of data and parameters typical of the invetigated areas.

Chapter 5 exposes the results of the comparative cases studies. The first case study is an assessment of the energy input of dairy farms in Emilia Romagna, Italy and Missoury, USA. The analysis was performed in both countries on three different typologies of farms: grain based, pasture based and organic. A total of 15 farms were visited and the farmers were interviewed with the aid of a standard survey form.

Direct and indirect energy inputs were taken into consideration and related to the functional unit of 1 kg of energy corrected milk.

The different agricultural systems (USA/Italy and grain/pasture/organic) were critically compared; a further comparison was performed with the existing literature, which is mainly related to other areas of the world. Energy inputs were analized also as a function of feed composition and milk productivity.

The second comparative case study is the assessment of the energy input of rice production in Piemonte, Italy and in Missouri, USA. The analysis was performed in both countries in two different typologies of farms: chemical-conventional and organic. A total of 12 farms were visited and the farmers were interviewed with the aid of a standard survey form.

Direct and indirect energy inputs were taken into consideration and related to the funcional unit of 1 kg of paddy rice at 12% moisture.

The different agricultural systems (USA/Italy and chemical/organic) were critically compared; a further comparison was performed with the existing literature. Energy inputs were analized also as a function of rice yield.

Chapter 6 is devoted to the scenarios of a more sustainable farming. The transition towards a farming system powered by renewable energy has been evaluated by exploring the possible integrations of renewable energy sources in common agricultural practices, integrating the information collected in the case studies with the analysis of current groundbreaking experiences.

Chapter 7 is dedicated to the conclusion s of the research work, summarizing the renewable energy potential of the farms under investigation and the possibile strategies to perform the energy transition in reasonable times.

Chapter 8 contains all literature references, divided in three parts: the first for chapter 2-3 (mainly general literature references), the second for chapters 4-5 (mainly more specific technical papers linked to the issues of the case studies) and the third for chapter 6-7 (mainly devoted to sustainability and renewable energies).

Chapter 9 is the appendix, that contains all the data sheets for crop and forage production, the information collected at the farms and the copies of the survey used for the case studies.

# 3. Literature review

> «Early humans who hunted and gathered their food in the wild depended primarly on their own energies. Even now many people in developing countries augment personal energy with animal and human power and firewood. In contrast, ample affordable fossil energy supplies have supported intensive agriculture, industry and transport in developed nations, However, along with increased population numbers, theper capita availability of ofssil energy has been declining worldwide.»
> Pimentel, D and Pimentel M, *Food energy and society* (2008)

## 3.1 Human metabolic energy and machine fossil energy

In order to better undestand the role of energy in the food chain, it is important to compare human metabolic energy to energy used by machines. The first may be defined as *somatic*, since it flows inside the organism, while the second as *exosomatic*, because machines can be considered as extensions of the human body (Georgescu-Roegen, 1983). Since machines are connaturated with the structure of industrial food chain, the fuel used to operate them can be seen as a sort of "indirect nutrition".

These two energies are hardly commensurable, since they are about two orders of magnitude different. Let us consider as an example the combustion of 1 kg of oil, which according to the standards of the International Energy Agency yields 42 MJ of energy. If this energy is used in an internal combustion engine of a tractor with a 30% efficiency, we can obtain about 12,6 MJ of mechanical work. Depending on the output power, the fuel consumption of a tractor is typically in the range 6-20 kg/h (Grisso et al. 2010), so 1 kg of oil is equivalent to ten minutes of operation at low power or three minutes at high power.

On the other hand, 12,6 MJ are equivalent to nearly 9 hard working hours of a labourer, expending 1,46 MJ/h or about 400 W: here we consider only the extra energy needed to perform work and not the basic energy used by metabolism to sustain life (PimentelD., Pimentel M.H., 2008, figure 10.3).

A full working day of somatic energy flow is thus burnt in a handful of minutes of exosomatic flow. It is clearly evident that a tractor, no matter how efficient, cannot perform in three minutes the manual work of nine hours and this fact lead us to the core of the problem: machines are powerful and sometimes awesome, but are also extremely energivorous. A ton of oil equivalent (toe, 42 GJ) compares to one thousand working days, that is nearly three man-years.

The advent of biofuels allows us to draw another comparison between somatic and exosomatic energy: a SUV tank filled up with bioethanol is equivalent to one year of food consumption (Brown 2006). This may seem amazing, but it is simply demonstrated. One hundred liters of biofuel in the tank of a large car come from 270 kg of maize (37% transformation yield) , which are equivalent to 4130 MJ (food energy 15,27 MJ/kg, USDA 2011), or more than one year's diet for a medium activity (10 MJ/day) and eight month of a heavy activity (17 MJ/day) . In this case we are considering the total somatic energy expenditure (basic plus work). This equivalence is more real than metaphorics for poor countries like Malawi where half of food energy and protein comes only from maize (FAOSTAT 2013).

## 3.2 Energy in traditional and modern agricultural systems

For thousands of years since its invention at the end of neolithic, agriculture was essentially based on human and animal muscular energy.

Depending on crop type and climatic conditions, from 1100 to 1400 hours of manual work are required to cultivate one hectare of cereals when agricultural activity is performed only by human labour; in energy terms, this equivalent to 2400-3000 MJ/ha, or 240-300 kJ/m². If operations are performed with the aid of animals, these contribute for 200-300 kJ/m² so the human input is reduced to 80-150 kJ/m² (PimentelD., Pimentel M.H. , 2008 tables 10.1-10.2-10.11).

Human energetic expenditure is computed by considering eight daily working hours (1460 kJ/h or 400 W), six hours spent on other activities (600 kJ/h or 170 W) and ten hours of rest (190 kJ/H or 50 W) for a daily total of 17200 kJ. This value may appear particularly high if compared to the typical 8000-10000 kJ/day expenditure of people performing little or no physical activity, but it is typical of anthropometric evaluations of young adults of average heigth and mass with a physical activity level[1] equal to two, that is expending twice the energy of the basic methabolic energy. (NAS 2005, chap. 5) .

Industrial agriculture and mechanization changed everything, reducing working time to about 10-20 hours per hectare with a negligible energy input. Nevertheless, the energy bill of tractors, harvester-treshers and trucks has been shifted to fossil fuels, that is coal, oil and gas; depending on crops, in the United States from 4000 to 14000 MJ/ha are needed for mechanical work, which correspond to 100-330 kg of oil equivalent per hectare.

Machinery and fuel are not the only voice in the energetic bill of modern agriculture. According to table 3.1, which illustates the energetic balance of maize and rice cultivation in traditional and industrial systems, the lion's share is taken by all treatments employed in crop farming: synthetic chemical fertilizers, pesticides and irrigation require about 21000 MJ/ha (2100 MJ/m²), that is more than a half ton of oil equi-

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[1] The *Physical Activity Level* is a dimensionless quantity defined as the ratio between the total energy expenditure and the basic energy expenditure.

valent. All these inputs will be discussed in detail in the rest of this chapter. More than 3700 kJ are required for each square meter of arable land, that is about 90 grams of oil equivalent (or 900 kg/ha).

Many other energetic inputs are necessary along the food supply chain after agricultural production, (but they are not the subject of the present work): food processing, packaging, transportation and retail (Foster et al 2006, Heller and Keoleian 2000, Pimentel and Pimentel 2008) and household consumtpion (Carlsson-Kanyama and Boström-Carlsson 2000). The intensity of energy use arrived to the paradox that for some products the energy embodied in the package is much greater than the energy provided by the food contained (Pagani et al. 2015).

Table 3.1

Comparison of energetic input/output in traditional and industrial cultivation of maize and rice.

Unit: kJ/m², except O/I yield which is a dimensionless quantity.

Sources: (a) Pimentel D., Pimentel M.H. (2008) chap 10 e chap 12

| Energetic Input/Output | Agriculture system | |
|---|---|---|
| | Traditional (Central America - Asia) | Industrial (USA) |
| Human/animal work | 350 | 2 |
| Mechanical work | - | 968 |
| Machinery | 12 | 368 |
| Seeds | 65 | 265 |
| Fertilizers | - | 1359 |
| Pesticides | - | 289 |
| Irrigation | - | 515 |
| Total Input | 427 | 3768 |
| Total Output | 2171 | 11594 |
| *Energetic Yield (out/in)* | *5,1* | *3,1* |

Crop yield has been considered by most agronomic studies as the only performance indicator of the agriculture process. It would be useful also to introduce an efficiency indicator of the food chain, defined as the ratio of the energy output and input of a particular process in the chain (last row of table 3.1). From this point of view, traditional systems are more efficient, since they yield 5,1 MJ for every MJ invested, while modern processes arrive only at 3,1. Of course, industrial agriculture has a signifcatly higher output (figure 3.1), but this is obtained at the cost of a higher energy input. In other words, industrial revolution in agriculture has increased production by a factor of 5,3, but the energy cost has inceased by a factor of 8,8.

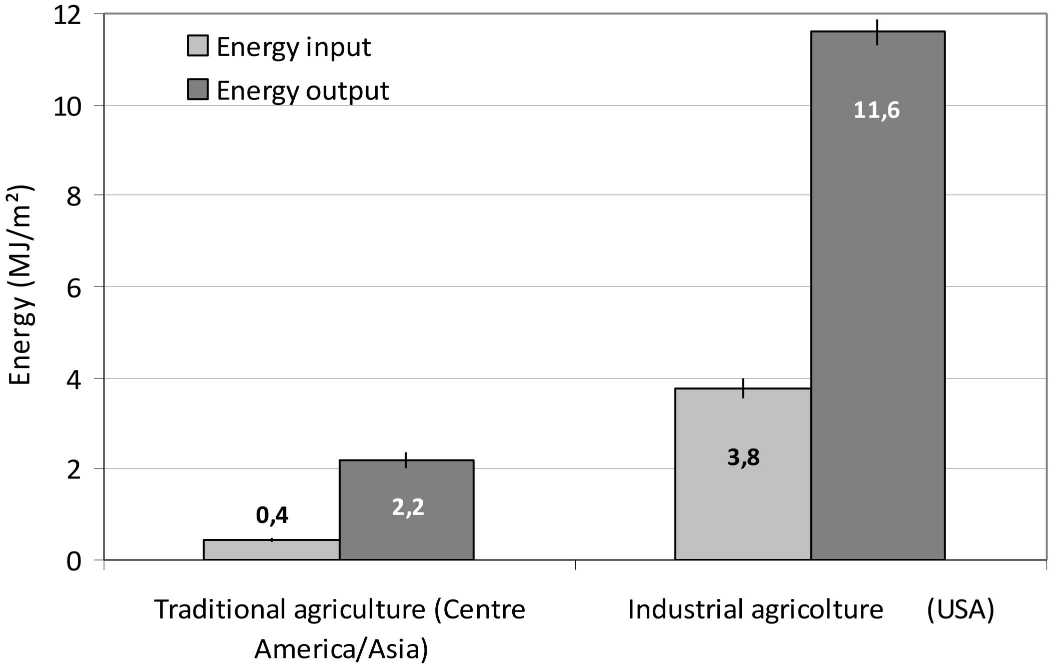


Figure 3.1 Energy input and output of maize and rice cultivation. Source Pimentel D, Pimentel MH, 2008

## 3.3 Farming machinery and fuel

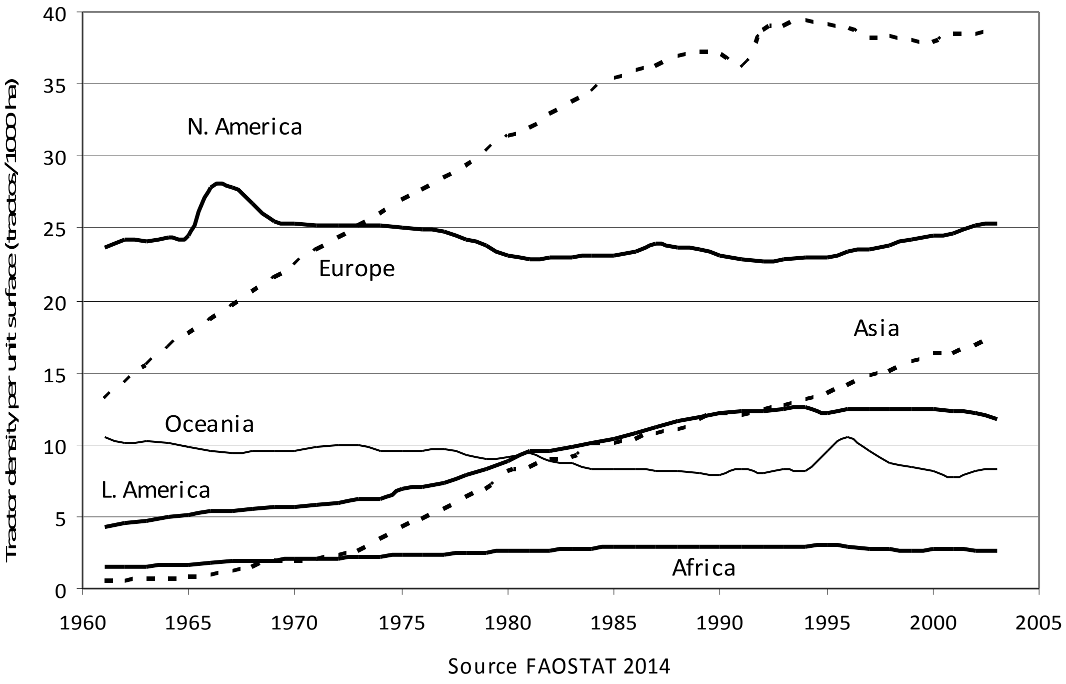
From the advent of the steam plough in the second half of the 19th century (Jevons 1865), industrial revolution rapidly spread the use of machinery in all farming practices. Steam tractors were quite common in USA and Great Britain before being substituted by diesel powered equipment; available power from tractors in the United States increased dramatically from 4 to 120 GW from the1920s to the 60s; conversely power available from horses and mules decreased from 16,5 to 2,2 GW (USDA 1966). By that period, the market was almost saturated and the the density of tractors didn't change any more in the following forty years (figure 3.2).

In Europe tractors spread later than in the US, and grow significantly from 15 to almost 40 per 1000 hectares during the second half of the century. The higher european density with respect to north America is due to the lower power in use: in the '90s the average power in the US was above 50 kW, while in european countries about two thirds of the tractors were below 40 kW (Pawlak 2003 and 2005; see also discussion below about the weight of machinery).

Similar increases are observed in Asia and Latin America, with the latter beginning with higher values in the '60s and saturating before the former in the years 2000s. Oceania has been stable around 10 tractors/1000 ha, while the tractor penetration in Africa is still very small.

The diffusion of tractors, harvester-threshers and relative equipment has significantly increased the energy input in agriculture, both in terms of embodied energy in the machinery and fuel consumption.

The energy equivalent for the production of machinery is estimated around 80 MJ for every kg of equipment (Stout 1991). This value has been substantially confirmed by more recent analysis on tractors and relative equipment (Mikkola and Ahokas 2010). Indeed, the lower energy input due to the reduction in steel and iron embodied energy has been compensated by the increase in aluminium and synthetic materials (tanks, cover plates, gear wheel hoses, moulboards...) that are more energy intensive than the replaced steel. Machinery needs also repair, service and maintenance; including all these activities rises the total input energy to about 140 MJ/kg (Giampietro 2003, Mikkola and Ahokas 2010).



Source FAOSTAT 2014

Figure 3.2 Number of tractors per 1000 ha of arable land per continent, 1961-2003. After 2003 FAOSTAT data are of poor quality and are not significant at continental level.

In order to allocate a proper yearly value of this energy, it is important to correctly define the energy lifespan of machinery. According to the ASABE standards, the lifetime of a tractor ranges from 12000 to 16000 operating hours (ASAE 2006). For an annual use of 500 hours, this is equivalent to a lifespan of 24-32 years, which is significantly higher than the economic lifespan, which is assumed to be 15 years for tractors and 10-12 years for other equipments. After this period, machinery has a salvage value which is about 25-30% of the initial purchase value (Edwards 2009). Extrapolating Edwards data, it is possible to see that the economic values of tractors tends to zero after about 30 years, in agreement with the ASABE lifetime evaluation.

Following Mikkola and Ahokas (2010) it is reasonable to assume a lifespan of 15 years for tractors and 12 years for other equipment, which respectively correspond to a yearly input energy of 9,33 and 11,67 MJ-kg year; after these periods the machines could still operate, but thet could not keep the same pace of new equipment so they cannot be employed anymore the same field tasks.

Machinery mass is variable in different regions of the world, according to terrain, economic and process conditions ; tractors are used to perform all crop prodution operations in North America and Australia, therefore the total mass of a tractor and associated equipment is estimated to be about 15 t. In developing countries of Asia and Africa, tractors are mainly used for tillage and transportation and the average size is estimated to be only 6 t. Europe and Latin America use slightly heavier equipment, around 8 t (Stout 1991).

Table 3.2 reports the world machinery distribution and the relative energy equivalent. In order to understand better these numbers, specific energy inputs per unit area of arable land and per capita have been computed and reported in figures 3.3 and 3.4

Table 3.2 Agricultural tractors and harvesters, year 2003 (FAOSTAT 2014), machinery unit mass, total mass and energy equivalent, fuel unit use and energy equivalent according to the conversion factors discussed in the text. 1 PJ = $10^{15}$ J = $10^{9}$ MJ

| Region | Tractors | Harvesters | Machinery |  |  | Fuel |  |
|---|---|---|---|---|---|---|---|
|  |  |  | Unit mass (t) | Total mass (Mt) | Energy (PJ/yr) | Annual unit use (t) | Energy (PJ/yr) |
| World | 27625095 | 3378465 | - | 271 | 2712 | - | 4733 |
| Asia | 8591512 | 1824550 | 6 | 62,50 | 625 | 3 | 1312 |
| Europe | 10833905 | 877392 | 8 | 93,69 | 937 | 4 | 1722 |
| Africa | 537928 | 42068 | 6 | 3,48 | 35 | 3 | 73 |
| North America | 5492730 | 494870 | 15 | 89,81 | 898 | 5 | 1257 |
| Latin America | 1768285 | 70612 | 8 | 14,71 | 147 | 4 | 270 |
| Oceania | 400735 | 68972 | 15 | 7,05 | 70 | 5 | 99 |

In terms of area, energy inputs are similar in North America and Europe, confirming that the higher tractors number in the old continent is compensated by a lower energy footprint of single equipments. These values of more than 9000 M/ha are nearly twice the world average and three times the energy densities in Latin America and Oceania, while African inputs are almost negligible.

In terms of per capita input, we see a shrinking of the values of Europe and Asia, owing to higher population densities.

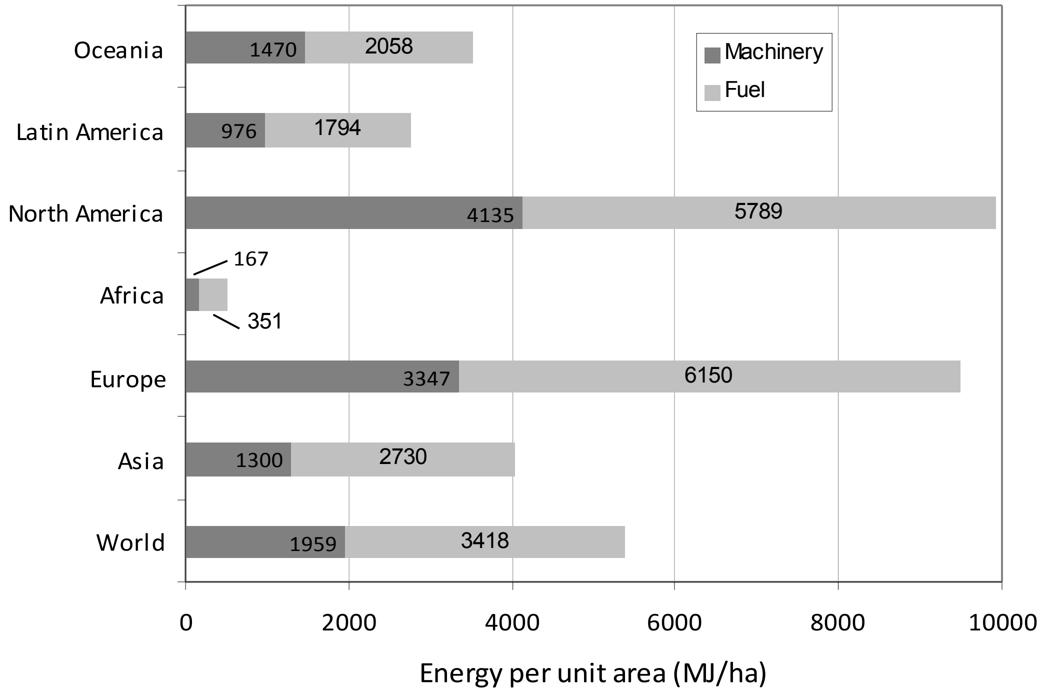


Figure 3.3 Energy input per unit area of arable land for agricultural machinery and fuel

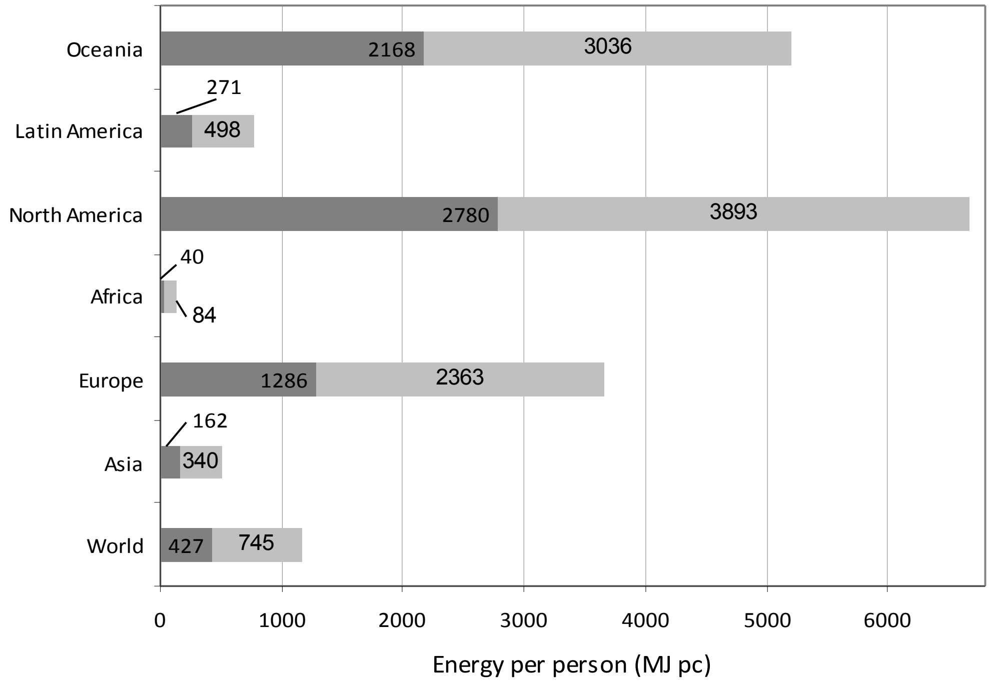


Figure 3.4
Energy input per capita of arable land for agricultural machinery and fuel

## 3.4 Fertilizers: consumption, availability and energy input

### 3*.4.1 Consumption and intensity of use*

Traditional agriculture systems have mantained soil fertility for centuries by using locally available organic amendments like animal manure, plants residues, ashes, green manure; nitrogen fixation with plants was also practiced by traditional societies, like intercropping beans with maize in Central America (Wilken 1987) or groundnuts with yam and maize in Western Africa (Lagemann 1977). Human manure was also used in already overpopulated pre-industrial China and Japan, where at the beginning of 20th century provided more than 4 tons of manure per hectare of cultivated land (Hinton 1969, King 1911)

More generally, promoting biodiversity in agroecosystems allows to exploit the complementarities and synergism that result from various combinations of crops, trees and animals such as polycultures, agroforestry systems and crop livestock mixtures (Altieri 1999): examples can be found in the forest gardens of Java island or in the integration of agriculture and aquaculture in the wetlands of south China (Reijtjes et al 1992).

Since all resources employed were renewables, the agriculture process was potentially sustainable, although limited by the quantity of available amendement, provided that the climate remained stable and good management avoided overexploitation of arable lands and pastures. Historical analysis of past civilizations shows that crises were the product of excessive deforestation (Easter Island, medieval Japan, contemporary Haiti), soil erosion by overuse (medieval Iceland and Central America) or climate change (medieval Central and Northern America, Greenland). Population growth added usually more pressure on the environment, which sometimes resulted in an acceleration of the crisis, even if it wasn't the main cause (Diamond J, 2005).

Modern agriculture has completely changed the rules of the game because soil fertilization has become strongly dependent on the mining industry for phosphorous (P) and potassium (K) and on chemical industry for nitrogen (N) . As can be seen from table 3.3, the integrated consumption of N, P and K fertilizers grew by a factor of 6 at world level, with the greatest increase in Asia (factor 29) and Latin America (factor 21). Europe and North America stated the transition to chemical fertilizing before the other regions, so present lower growth factors in the last fifty years.

Synthetic nitrogen showed the greatest increase in annual consumption: almost a factor of ten from 11,6 to 112 Mt: this amount is of the same order of magnitude of the nitrogen fixation of all natural ecosystems, whish is best extimated in the 100-290 Mt range (Cleveland et al. 1999). This fact, together with other biogeochemical circumstances, lead Paul Crutzen to name *Anthropocene* our present geological era (Crutzen 2002).

Besides absolute values of consumption, it is interesting to consider fertilizer use intesity data, which can be related to three different variables: arable land, population or vegetable product.

Table 3.3

Fertilizer consumption in different regions of the world, 1961 and 2011

(millions of tons per year)

| Region | 1961 | | | | 2011 | | | |
|---|---|---|---|---|---|---|---|---|
| | N | P | K | Total | N | P | K | Total |
| World | 11,6 | 10,9 | 8,7 | 31,2 | 112,3 | 41,1 | 30,4 | 183,8 |
| Asia | 2,1 | 1,0 | 0,7 | 3,8 | 71,4 | 23,2 | 14,9 | 109,5 |
| Europe | 5,5 | 5,8 | 5,4 | 16,7 | 13,6 | 3,5 | 4,1 | 21,2 |
| Africa | 0,4 | 0,3 | 0,1 | 0,7 | 3,3 | 2,2 | 0,4 | 5,9 |
| North America | 3,2 | 2,7 | 2,2 | 8,0 | 14,2 | 4,7 | 4,6 | 23,5 |
| Latin America | 0,4 | 0,4 | 0,2 | 1,0 | 8,5 | 6,1 | 6,1 | 20,8 |
| Oceania | 0,0 | 0,8 | 0,1 | 1,0 | 1,4 | 1,4 | 0,2 | 3,0 |

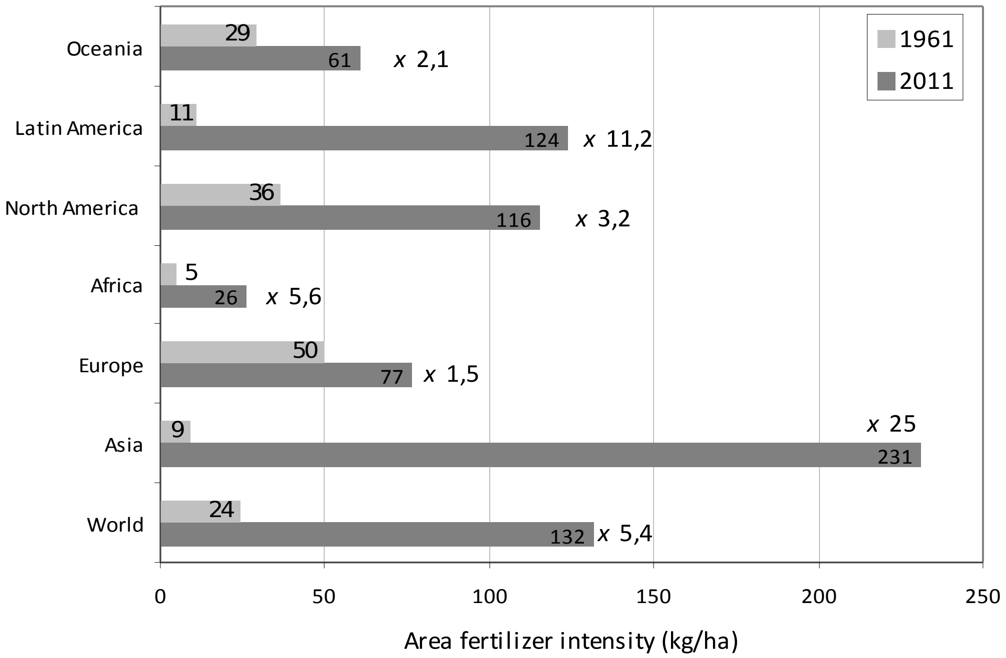


Figure 3.5 Per unit area fertilizer use intensity in different world regions, 1961 and 2011. Near each 2011 bar is reported the 1961-2011 growth factor

Grain crops receive the lion's share of soil amendment: according to the US department od Agriculture, four crops, Corn, Cotton, Soy and Wheat, absorb 65% of all fertilizer deployment (USDA 2012). The *fertilizer use per unit area of arable land* (kg/ha/yr) can be chosen as an indicator, neglecting to a first approimation the area of permanent crops. Values of this indicator are reported in figure 3.5 for the different regions of the world (FAOSTAT 2014, as for the other figures in this paragraph[2]).

Growth factors are similar to the consumption data of table 3.3, because crop area increased globally only by 10% much during the 1961-2011 period, with the exceptions of Africa and Latin America where the

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[2] The aggregated FAO values for the year 1961 set the former USSR in the european region; in this analysis former asian USSR republics have been accountend in Asia.

growth or area intensity was smaller than overall consumption because arable land increased at the expense of primary forests respectively by 46% and 89% .

Today Asia is the most fertilizer dependent region in the world, with 231 kg applied on each hectares of arable land; this is due to the higher population density of the continent, almost 9 people per hectare, with respect to a world average of 5. At the opposite end, Africa relies very ligltly on chemical fertilization: with half the population density of Asia its density of application is only 1/18 .

A second indicator is given by the *per capita use intensity*, which denotes the efficiency fertilizer are used to provide food to humanity and the diffusion of industrial agriculture (figure 3.6). Values are significantly higher than average for high developed and low populated area, like North America and Oceania. Since Oceania exports 60% of its cereals production, the per capita value is abnormally high, because it refers to a production which is not primarly consumed locally.

At world level it is remarkable to note that in 1961 10 kg of fertilizers were needed for each of the three billions of humans; to obtain the same results with the seven billions persons of 2011 an individual value od 26 kg is needed; this decreasing yield of fertilizer is the price to be paid by the enormous scale reached by industrial agriculture.

The last indicator is the intensity *per unit mass of cereal produced.* The choice has been limited to these products since cereals in 2011 cereals occupied 73% of all arable lands giving 55% of vegetal food energy and 66% of vegetal proteins. This input doubled at world level in the last fifty year from 36 to 72 kg per ton produced (figure 3.7). The cases of Europe and Oceania are significant, because they show that it is possible to reduce fertilizer input using resources more efficiently .

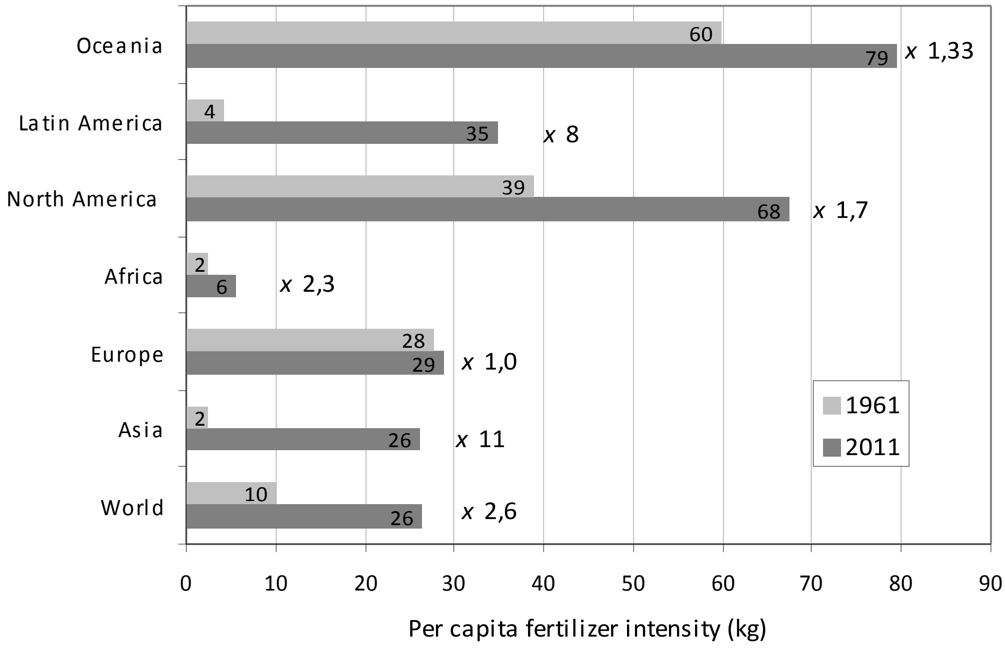

Figure 3.6 Per capita fertilizer use intensity in different world regions, 1961 and 2011. Near each 2011 bar is reported the 1961-2011 growth factor

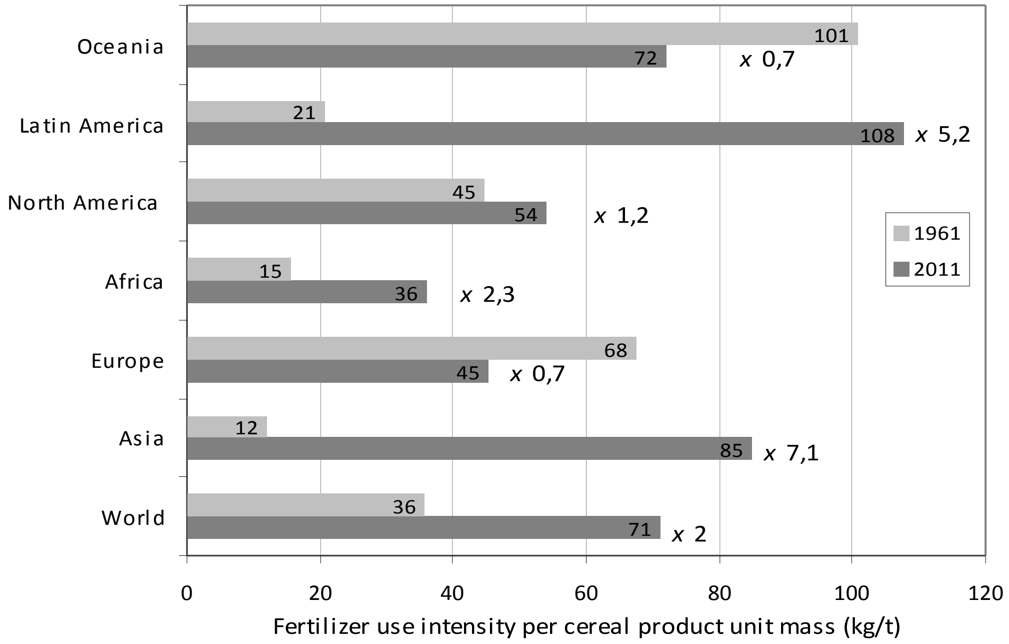

Figure 3.7 Per cereal product unit mass fertilizer use intensity in different world regions, 1961 and 2011. Near each 2011 bar is reported the 1961-2011 growth factor

### *3.4.2 Mining issues related to phosphorous and potassium*

Phosphate rock and potash are quite abundant on the Earth's crust, but the post WWII exponential growth of mined quantities (between 1945 and 1985 the doubling time for the extraction of both elements was about 10-11 years) is causing a significant depletion of reserves; up to now, according to the US Geological Service, we have already extracted about 40% or recoverable phosphate rock and 16% of potash that existed on the planet's crust before industrial revolution (figure 3.8, USGS 2013). Phosphorus reserves may be completely depleted in a range of 50-100 years, while Hubbert peak production may occur as soon as 2030 (Cordell D. et al. 2009).

Moreover, reserves for both fertilizers are unevenly distributed on the planet: five countries (Morocco, China, South Africa, Jordan and USA) count for 84% of the phosphate reserves[3] in 2009, while only three countries (Canada, Russia and Belarus) own 89% of potash reserves. The geopolitical implications of this concentration of resources as a potential source of conflicts and price shocks has not yet been properly addressed by the scientific community or by the United Nations (Neset and Cordell 2011).

The most important problem regarding phosphorus is however its global flow through the ecosystem from non renewable mines to the unavailable location of the ocean floor. Of 17,5 Mt mined in one year, about 9,5 Mt are lost to the sea (8 from soil erosion losses and 1,5 from human excretion), while other 7,5 Mt are lost in the environment, mainly in non arable soil or in the atmosphere (Cordell D. et al. 2009).

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[3] After 2010 Morocco reviewed its reserves reporting the questionable value of 50 Gt, ten times previous estimations. Also Algeria and Syria reported for the first time reserves for 2.2 and 1,8 Gt respectively.

Leaching of potassium is also common, especially from sandy soils (Kolahchi and Jalali, 2007) and despite of the increasing quantities used at world level, negative mass balances are widespread in irrigated rice cultivation (Dobermann et al. 1998).

The phosphate industry must face also with the serious environmental problem of disposal of *phosphogypsum*, an acidic by product of the fertilizer production process., which accumulates at the rate of 280 Mt per year . This by-product is mostly disposed of without any treatment, usually by dumping in large stockpiles or landfills; it is mainly composed of gypsum but also contains a high level of impurities, particularly heavy meatls and radionuclides. This greatly limits its employment as soil amendment, owing to the risks of grounwater contamination, and as building material for the hazard of Radon-222 ehalation. (Rutherford et al. 1994, Tayibi et al. 2009).

Nitrate fertilizers are not mined, but synthetized, starting with the Haber-Bosch process that produces ammonia by reaction of atmospheric nitrogen with methane at temperatures of 500 °C and pressures of 250 atmospheres. For field application, ammonia is then transformed to the most suitable form of urea or other nitrates. The mining issue related with nitrates is thus indirect, because it is related to the high natural gas consumption linked to its production, as pointed out in the next paragraph.

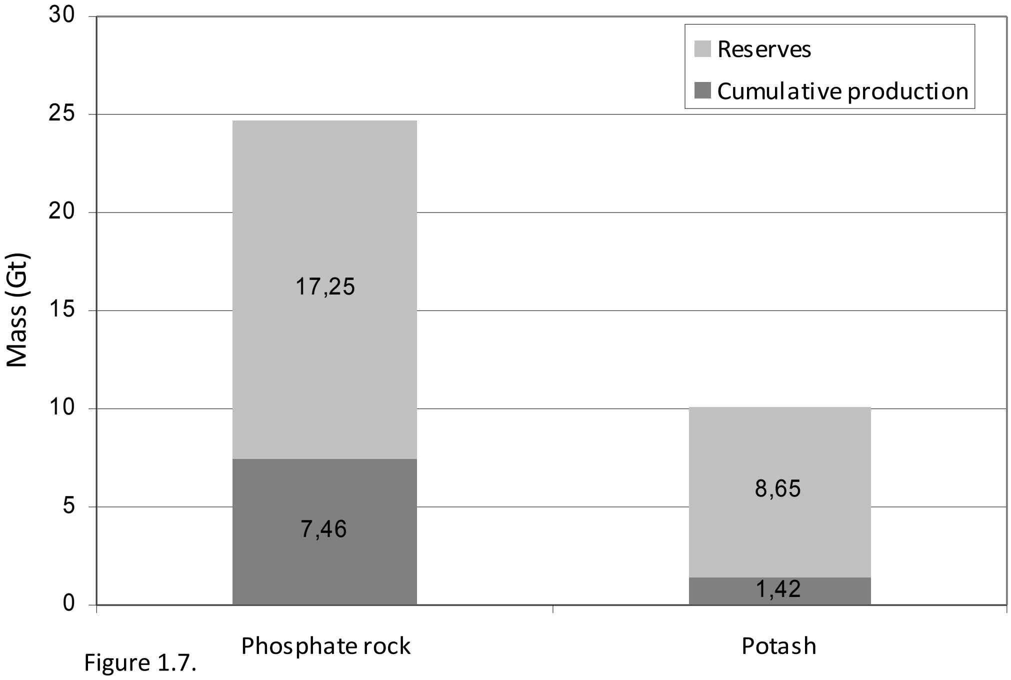

Figure 1.7.
World production and reserves of phosphate rock and potash. Source USGS

### *3.4.3 Energy input of fertilizers: per area, per capita and per kg of cereal products*

Fertilizer production requires great quantities of energy, mostly of fossil origin (table 3.4). Input is particularly high for nitrogen production, because methane is used both as reactant and fuel for reaching the temperature of reaction.

The great quantity of energy stored in fertilizers' chemical bonds can give rise to explosion if released all at once, as happenned in the serious industrial accidents of Texas city port (1947, 581 victims) and West Fertilizer near Waco, also in Texas (2013, 15 victims and 170 injured). One of the most common nitrogen fertilizer, ammonium nitrate, was used to prepare the terrorist attack in Oklahoma City (1995, 168 victims). Since according to table 1.3 world annual consumption of fertilizers is around 184 Mt (112 for N, 41 for $P_2O_5$ and 30 for $K_2O$, FAOSTAT 2014), using the data of the last three columns of table 3.4, it is possible to estimate an annual global energy bill of 205 ± 35 millions of tons of oil equivalent, which represents the 7% of natural gas consumption (3000 Mtoe) and nearly 2% of world energy consumption from all fossil fuels (11000 Mtoe).

Values reported in table 3.4 are the most recent determination of in put energy. For Nitrogen fertilizers this input decreased significantly in the last decades owing to the increased energy efficiency of the ammonia production process (Stout 1990), so the value of 78 MJ/kg reported by Helsel (1992) and used by Pimentel (2008) is nowadays unrealistic. On the contrary, the energy inputs for phosphate, potash and lime didn't changed over the year since it is most related to mining, and it could eventually increase in the future as lesser quality resources will be exploited.

Table 3.4

Energy intensity for fertilizer production. Sources: Mortimer et al (2003) , Williams et al (2006), Jenssen and Kongshaug (2003)

| Fertilizer type | Specific input energy | Unit |
|---|---|---|
| Ammonia | 38,6 | MJ/kg N |
| Ammonium Nitrate | 40,6 | MJ/kg N |
| Calcium Ammonium Nitrate | 43 | MJ/kg N |
| Ammonium Suplhate | 42 | MJ/kg N |
| Urea | 49 | MJ/kg N |
| Phosphate | 15,8 | MJ/kg $P_2O_5$ |
| Potash | 9,3 | MJ/kg $K_2O$ |
| Lime | 2,1 | MJ/kg CaO |

The energy input of fertilizes has been split by world regions in terms of intensity per unit area (figure 3.8) and per capita (figure 3.9). The record Asia value of more than 11000 MJ per hectares is an indicator of the extreme intensity of land use in this continent in order to satisfy the needs of nearly four billion people.

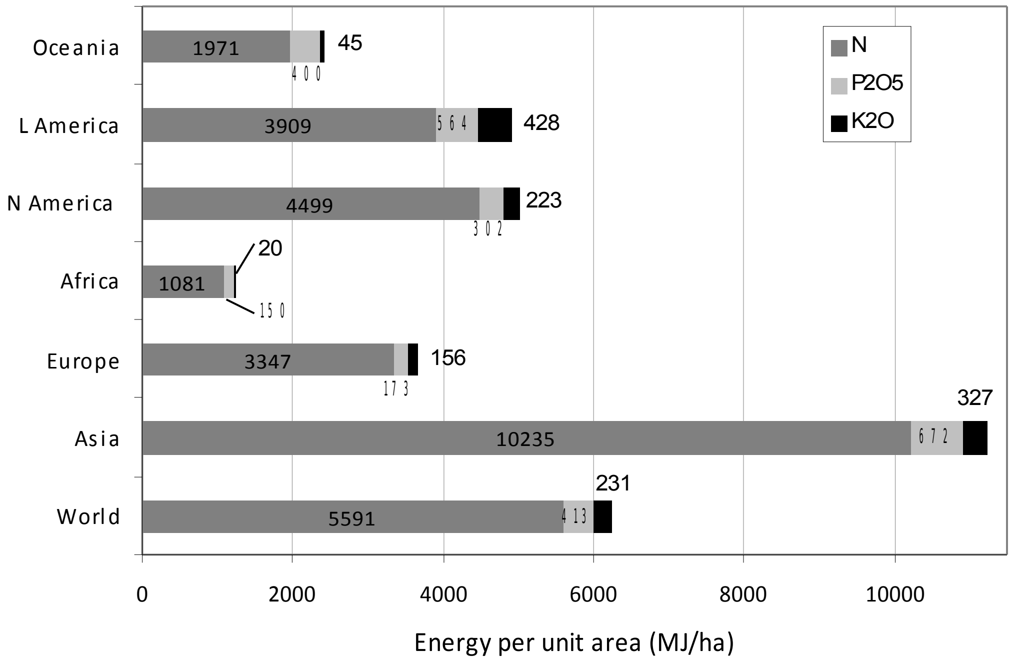

Figure 3.8 Energy input per unit area of arable land for synthetic and mineral fertilizers

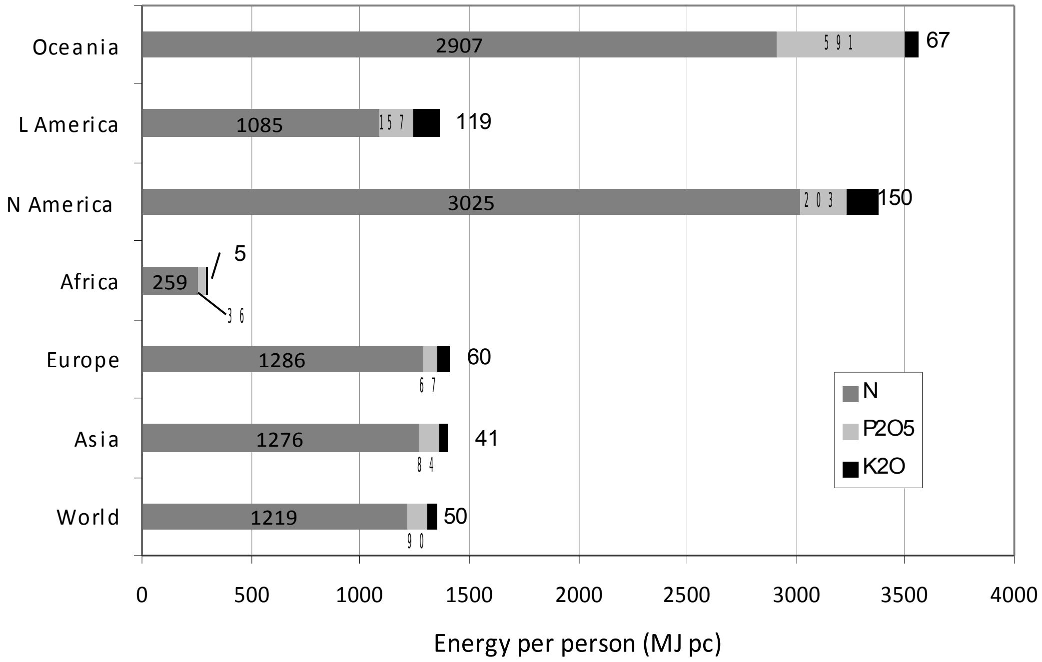

Figure 3.9 Energy input per capita for synthetic and mineral fertilizers

Other continents are below 5000 MJ/ha with the exception of Africa that is sligltly above 1000 MJ/ha. Africa is low also on a per capita basis, while North America and Oceania have the highest inputs owing to lower population densities.

Not surprisingly, the World Bank fertilizer price index[4] has been strogly coupled with the oil price during the 2007-2008 oil shock and more weakly coupled during 2010-2011 (figure 3.10). In the last years, the coupling seems to be vanished, but this is most probably due to fertilizer oversupply which is keeping prices low: from 2008 to 2011 production overtook consumption by 6-10%. In any case, at the end of 2013 the price index was twice the value of 2005.

Having underestimated the role of oil price in the dynamics of fertilizer pirces, in 2008 FAO forecasted a 9% increase in consumption for the year 2011 (FAO 2008), while the actual data showed only a 6% growth in the period.

Moreover, price volatily may have been exacerbated by financial operations of insurance companies and others investors that obtained returns as high as 60% over the period January 2004–December 2007 in the first phase of the oil price shock (Geman and Eleuterio, 2013).

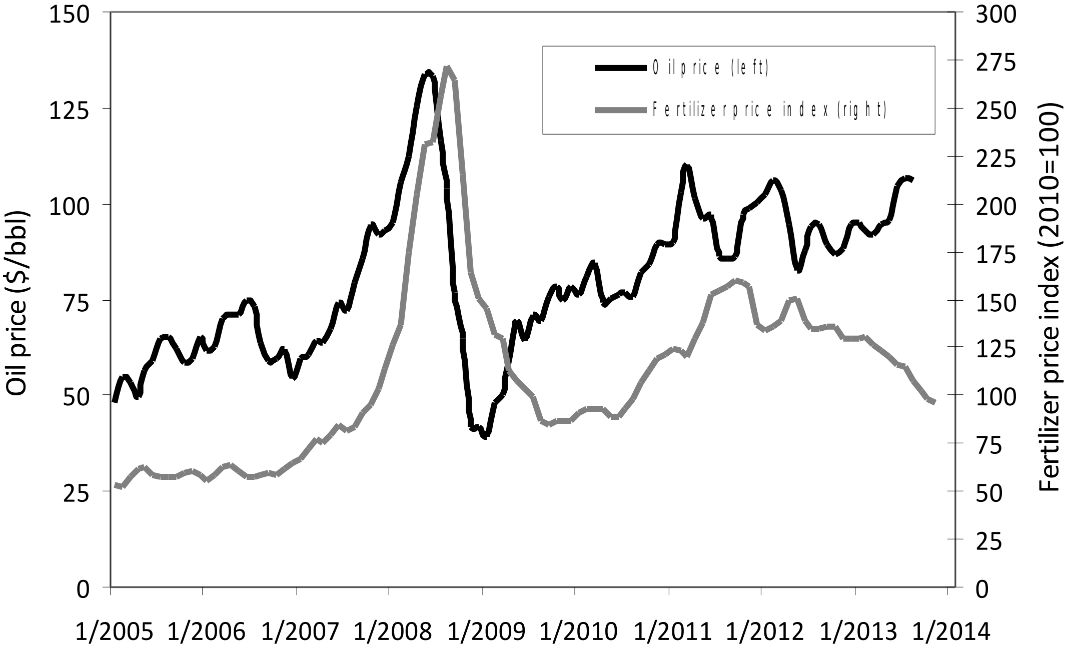

Figure 3.10 Fertilizer price index and crude oil price. Sources: World Bank, EIA

Concerns about the overall sustainability of the fertilizing process, both from material and energy point of view, is increased by the great waste occuring in the process.

During the period 1961-2011 global cereals yields incresead by a factor of 2,6, from 1,3 a 3,5 t/ha, but in the meantime P and K fertilizers use has increased 3,7 and 3,4 times respectively, while Nitrogen boosted

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[4] The index is a weighed average of the prices of nitrogen fertilizers (41%), phosphorous (39%) and potassium (20%)

almost by one order of magnitude from 11,8 to 112 Mt. This means that crops responses to fertilizers are gradually decreasing and a lot of nutrients are lost in the environment in a polluting and non exploitable form.

The illustrious *green revolution* in agriculture reveals more an act of force rather than a technological improvement.

## 3.5 Pesticides

As for the case of soil fertility analized in paragraph 4, traditional agriculture developed a great variety of methods to protect crops from the growth of competing plants or from the action of fungii, insects, spiders, rodents or birds. These practices in traditional agriculture are more a built-in process in the overall crop production system rather than a separate well-defined activity of "pest management"; indeed, the use ot the world "pest" for whatever living species is competing with *homo sapiens* for food resources denotes a poor ecological understanding of the complex links that make up an ecosystem.

Crop protection from competing species is perfomed in traditional agriculture by appropriate choice of sowing date, optimum plant density, varietal mixture intercropping and good crop husbandry, included the mechanical removal of undesired plants (Abate et al. 2000). It is also remarkable the knowledge of hundred of insecticidal plants in classic China (Rui 2007, Vanichpakorn et al 2010) or the use of natural predators like the weaver ant in Africa And Asia (Seguni et al. 2011)

All these traditional practices have been partially discarded by the advent of chemical pesticides during the second half of the 20th century. At global level, data are available only from the year 1990, when the use of the three main categories of pesticides (fungicides, herbicides and insecticides) was already above one million tons , as reported in table 3.5 (FAOSTAT 2014; numbers are underestimated, since data relative to several countries are missing). Three quarters of this consumption occurred in Europe and in the United States, which accounted roughly only for 40% of arable land and crop production.

Table 3.5. Pesticide consumption in different regions of the world, 1990 and 2006 (kt per year)

| Region | 1990 | | | | 2006 | | | |
|---|---|---|---|---|---|---|---|---|
| | Funcigides | Herbicides | Insecticides | Total | Funcigides | Herbicides | Insecticides | Total |
| World | 278 | 445 | 289 | 1011 | 363 | 545 | 313 | 1221 |
| Asia | 27 | 22 | 94 | 142 | 73 | 56 | 95 | 224 |
| Europe | 191 | 157 | 71 | 419 | 171 | 116 | 35 | 323 |
| Africa | 18 | 4 | 16 | 38 | 11 | 12 | 8 | 31 |
| N. America | 25 | 231 | 89 | 345 | 24 | 228 | 102 | 354 |
| L. America | 15 | 16 | 14 | 45 | 81 | 108 | 64 | 252 |
| Oceania | 2 | 14 | 5 | 21 | 3 | 25 | 8 | 36 |

In the following 16 years (2006 is the latest year with quite reliable FAO data), global consumption increased only by 20%; while Europe showed a significant reduction in use, the opposite happened in Latin America where pesticide spreading in the fields multiplied by more than a factor of five overcoming the consumption of all Asia. This great increase is mostly linked with the diffusion of genetically modified crops in Brasil, Argentina, Paraguay, Uruguay and Bolivia, that changed the agricultural model into one dependent on the massive use of agrochemicals (Lopez et al 2012)

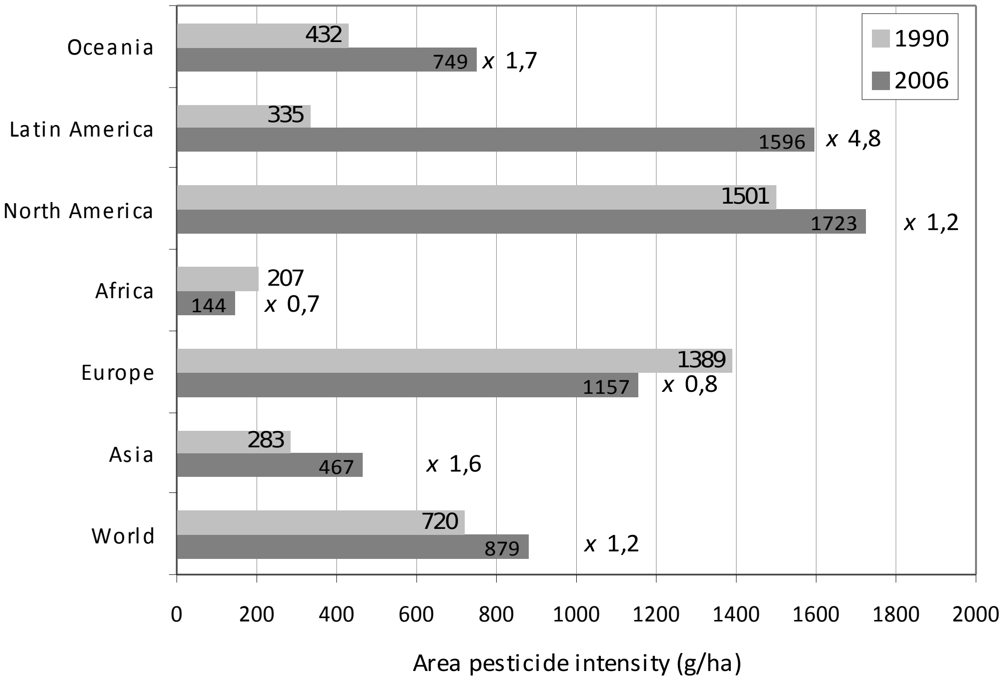

Figure 3.11 Per unit area pesticide use intensity in different world regions, 1990 and 2006. Near each 2006 bar is reported the 1990-2006 growth factor

In only fifteen years, Latin America almost reached the pesticides use intensity per unit area of arable land that USA and Canada built up in fifty years (figure 3.11). Europe riduced significantly its intensity of 20%, partly owing to the conversion of ten million hectares to organic farming (Willer et al 2013). The small and decreasing african intensity denotes a substantial failure to export the model of industrial agriculture to the continent.

On the average each year are consumed about 185 kg of pesticide for each person (figure 3.12). Numbers are double in Europe and Latin America and more than five times larger in North America and Oceania. In addition to their negative toxic side effects on environment documented by hundreds of peer reviewed studies, pesticides require high energy inputs for production, packaging and transportation.

The most detailed evaluation of energy use in pesticides production has been performed by Green (1987), who has computed feedstock and process energy for 40 different products, yielding values ranging from 80 to 580 MJ/kg; although this paper is rather old, most of the pesticides in use today are still included in Green's work. Green's values for herbicides, insecticides and fungicides are reported in table 1.6: 20 MJ/kg where added to all values to take into account pesticide mixing in solutions, packaging and transport (Helsel 1992).

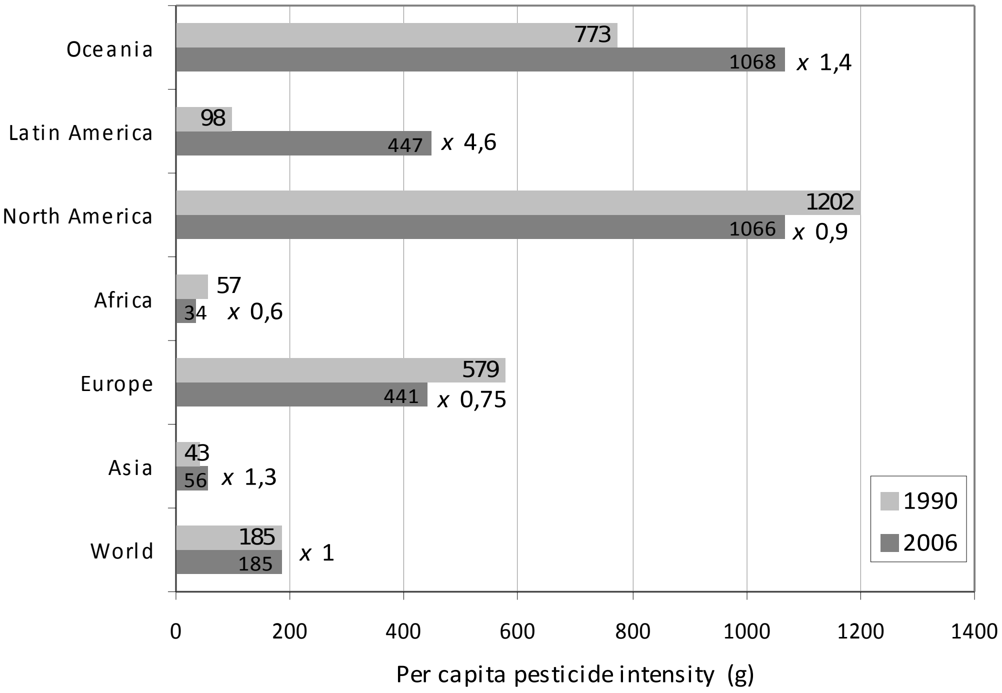

Figure 3.12 Per capita pesticide use intensity in different world regions, 1990 and 2006. Near each 2006 bar is reported the 1990-2006 growth factor

Since energy inputs vary so largely among the different pesticides products, it is unrealistic to assume a single value of 420 MJ/kg, has done by Pimentel (2008), while it is more meaningful to consider the actual mix of pesticides used on a particular region or crop as done by West&Marland (2002) and Helsel (2006) for the United States or by Audsley et al. (2009) for Great Britain (see table 3.6). The latter authors discovered also a "timeline correction": there is an increasing trend of input energies with respect to the year of first production, from 100 MJ/kg in the '40s to 500 MJ/kg in the '80s; this trend reflects the increasing complexity of the synthetized molecules.

According to the US Environment Protection Agency, in 2007 world consumption of pesticides was about 1600 kt (Grube et al. 2011) of which 950 kt of herbicides, 400 kt of insecticides and 250 kt of fungicides. This total seems to be more accurate than the FAO value of table 4, since the UN organizations didn't provide data for many countries. According to the input values reported in table 1.6, it is possible to stimate a global energy consumption ranging of 11 ± 3 Mtoe.

Table 3.6 Energy intensity for pesticides production.

| Source | Energetic input for kg of pesticide (MJ/kg active ingredient) | | |
|---|---|---|---|
| | Herbicides | Insecticides | Fungicides |
| | Average or range | Average or range | Average or range |
| Green (1987) corrected with Helsel (1992) | 100 - 540 | 80 - 600 | 80 - 420 |
| Pimentel (2008) | 420 | 420 | 420 |
| West & Marland (2002) | 266 | 290 | 290 |
| Helsel (2006) | 240 | 250 | 90 |
| Audsley et al. (2009) | 423 | 386 | 274 |

## 3.6 Irrigation

Energy consumption for irrigation comes from well pumps, long distance transportation and canals maintenance. Energy inputs can be quite well estimated for single crops in definite climatic zones of the world; as an example, we will consider the three major cereals: rice, wheat and maize, that account for about 80% of the total arable land devoted to cereals.

Being a water culture, the most energivorous crop is rice, which requires about 8000-9000 MJ/ha for water management (Stout 1991, West and Marland 2002, Pimentel 2008, AghaAlikhani et al 2013). Since rice world average yield is about 4400 kg/ha (FAOSTAT 2014), this translates in an average input of 1,8-2,0 MJ/kg of rice.

Energetic input for wheat cultivation typically ranges from 1500 to 4500 MJ/ha (that is 0,5-1,5 MJ/kg$_p$ with a yield of 3200 kg/ha), according to the amount of precipitation in the planet's different climatic zones (Singh et al 2007, Çiçek et al. 2009, Canakci et al 2005, Tsatsarelis 1993). Higher energetic costs in the range 4500-6000 MJ/ha are registered where wheat is cultivated in arid regions or during the arid season and water must be carried from long distance, like in India (Singh and Mittal 1992), Iran (Ghorbani et al. 2011, Koshnevisan et al.2013) or Australia (Jackson et al. 2010).

Maize requires usually less water and consequently energy: typical values are in the range 1000-2000 MJ/ha (Singh and Mittal 1992, Pimentel 2008), which is equivalent to or 0,2-0,4 MJ/kg$_p$ with a yield of 5150 kg/ha. In some extreme cases of arid environment inputs can reach 9000 MJ/ha (Sefeedpari et al 2012) or even 22000 MJ/ha (Jackson et al. 2010).

The task of evaluating precisely average energy input for irrigation at continental or world level is undermined by crop and regional variabilities, differences in the efficiency of the equipments and lack of reliable data from many nations.

In order to obtain an approximate estimation, it is useful to distinguish between grounwater and surface irrigation; for each of these items the input can be expressed as the product of two factors: *(i)* the specific energy required to irrigate one hectare of land and *(ii)* the extension of irrigated areas that use underground water.

### *3.6.1 Groundwater irrigation*

For the first factor many authors rely on the assessment performed by Stout who assigned specific values for equipment and operation energy inputs for the different regions of the world (Stout 1991 page 88, see table 3.7). Energy values for the equipment  were computed by Stout assuming 8,4 MJ per kg of machinery per year, with ten years of average lifetime, so that higher inputs simply reflect a greater weight of pumps and tubes. Energy used for operations depends on aquifer depth, equipment efficiency/ density and water requirements of the crops.

Since Stout estimation is quite old, it is important  to verify if these numbers are still meaningful for present day irrigation. From one side, input energy may have reduced owing to higher equipment efficiency: an old diesel driven unit may consume 4,5 times more fuel than a well run new unit while delivering the same effetive volume from the same depth (Smil 2008 p. 294). On the other hand, equipment density has increased significantly over time as in the highly populated province of Punjab in Pakistan (76 millions inhabitants), where the number of tubewells has grown from 300000 in the beginning of the 90s, the time of Stout analysis, to almost 900000 in the years 2000s (Siddiqi and Wescoat 2013). The combination of these two effects may have left the average input energy substantially unchanged.

This hypothesis is partially confirmed by three separate evidences: *first*, a more recent analysis assumes the same values of Stout (Vlek et al., 2004); *second*, a research that covers all over India (Shah 2009) yields an average input energy of about 8,4 GJ/ha; *third*, a similar analysis over China leads to about 7,3 GJ/ha (Zhang et al., 2013; areas actually irrigated with groundwater were used from Siebert et al., 2010, instead of areas equipped for irrigation reported in the paper). These to values are respectively 8% greater and 6% smaller  than Stout's value for Asia water use (7,8 GJ/ha).

The regions of South and East Asia surveyed by the works of Shah and Zhang et al. account for about 45% of the world population and more than 60% of the groundwater irrigated area, so we can assume that ther input values reported in table 3.7 are reasonable estimates of energy specific consumptions all over the world.

It is also worth noting that an energy consumption of about 8 GJ/ha corresponds to an aquifer depth of about 8 meters (Stout 1991 page 168), which is the current value in many districts of India, even if the increasing demand of water for agriculture is rapidly depleting the aquifer level (Sekhri 2012), as will be examined later in the paragraph.

Table 3.7 Specific energy input for irrigation (Stout 1991) area actually irrigated with underground water (Siebert et al 2010) and relative energy consumption. Specific input for Asia are averages of three different subregions (far east, near east and central Asia).

| Region | Specific energy input | | | Total irrigation area | Total energy use |
|---|---|---|---|---|---|
| | Equipment | Operations | Total | | |
| | GJ/ha | GJ/ha | GJ/ha | Mha | PJ |
| World | - | - | - | 98 | 844 |
| Asia | 1,0 | 7,8 | 8,8 | 73 | 638 |
| Europe | 1,2 | 6,7 | 7,9 | 5 | 38 |
| Africa | 0,8 | 8,4 | 9,2 | 2 | 20 |
| N America | 1,2 | 6,7 | 7,9 | 14 | 107 |
| S America | 1,2 | 7,6 | 8,7 | 4 | 36 |
| Oceania | 1,2 | 6,7 | 7,9 | 1 | 5 |

The second factor to take into account is the area of groundwater irrigation, which needs pumping to deliver water to the surface. A recent detailed analysis of FAO and two german universities gives a complete inventory of world areas that are actually irrigated using underground aquifers (Siebert et al. 2010); these areas are reported in table 3.7 and sum up to about 100 million hectares: They are about 40% of the areas simply equipped for irrigation but not effectively  in use, ranging from 20% in Africa to 60% in north America.

This inventory seems to be far more accurate than other estimates based on the assumption that only half of  the lands equipped for irrigation are fossil powered (Giampietro 2002) and so it is used in the present work.

### *3.6.2 Surface irrigation*

In this case specific input energy is lower, since work is needed only to overcome water viscosity and small gaps in pumping from rivers or reservoirs. Stout analysis provide a value of 0,75 GJ/ha for the equipment and a value of 4,2 ± 0,7 GJ/ha for water operations, depending on the efficiency of the pumps (Stout 1991, p 168).

The latter value is in good agreement with actual evaluation of surface irrigation in India, which indicates an average specific input of  4,3 GJ/ha (Shah 2009).  A similar average value of 4,2 GJ/ha is reported for rice cultivation in Bangladesh (Islam et al. 2011). We can then reasonably assume a value of 5 GJ/ha for equipment plus operation costs.

There area no comprehensive statistics at world level on areas of surface irrigation operated by pumps, but it is possible to find references in FAO Water Reports for Asia regions, Africa and Latin America, while USDA provides information for North America and the Asutralian Bureau of Statistics for Oceania;

Europe value comes from the Turkey department of idrology and can be assumed as characteristic of all the mediterranean region were most of european irrigation is performed.

Globally the energy impact of surface irrigation is about only 13% with respect to groundwater, with th eexception of East Asia where it reaches a value of 46%.

Table 3.8 Area actually irrigated with surface water (Siebert et al 2010), fraction performed by pumping systems , relative area (references are given for each region of the world) and total energy input.
A specific input energy of 5 GJ/ha has been assumed in all cases (Stout 1991) .

| Region | Area actually irrigated | Fraction performed by pumps | Area irrigated by pumps | Total energy use | References |
|---|---|---|---|---|---|
| | Mha | % | Mha | PJ | |
| World | 267 | 8,5% | 23 | 113 | - |
| Asia | 113 | 16,1% | 18 | 91 | - |
| *South Asia* | *33* | *11,8%* | *3,8* | *19* | FAO 1999 |
| *East Asia* | *60* | *23,2%* | *14* | *70* | FAO 1999 |
| *C. Asia -M. East* | *20* | *1,6%* | *0,3* | *2* | FAO 2012 |
| Europe | 8 | 16,0% | 1,4 | 7 | DSI 2005 |
| Africa | 9 | 9,7% | 0,9 | 5 | FAO 1994 |
| North America | 10 | 7,3% | 0,7 | 4 | Schaible and Aillery 2012 |
| Latin America | 12 | 11,1% | 1,4 | 7 | Aquastat 1997 |
| Oceania | 2 | 9,1% | 0,2 | 1 | ABS 2008 |

### *3.6.3 Energy input of irrigation: per area, per capita and per kg of cereal products*

Figure 3.13 shows the irrigation input energy per unit area of arable land,computed from the totla eergy values of tables 3.7 and 3.8. All land were included, not only irrigated ones in order to evaluate the average impact of irrigation on the different regions; in this way also climatic conditions are included in the analysis, since continents like Asia that have a higher proportion of irrigated lands have a consequent higher energy input.

The input per capita is shown in figure 3.14; in this case the situation is reversed, showing that highly populated asian countries manage quite efficiently the available water resources in term of individual use, while relatively low populated North America and Oceania have a larger input. Higher equipment efficiency cannot compensate the fact that per capita consumption of water for agricultural use is more than 300 $m^3$/year in North America, three time the asian value of 103 $m^3$/year (Sibert 2010).

The energy input per unit of cereal food produced is shown in figure 3.15. The choice has been limited to cereal products because they receive nearly 50% of the total water for irrigation (Mekonnen and Hoesrta 2010).

In this case, Asia regains the first position, with more than twice the values of other continents. The higher per unit product energy cost does not reflect also climatic conditions (evaporation is greater in south Asia, than in most North America), but also a scarcity of land with respect to people. Per capita arable land is indeed less than 1250 m², with respect to aworld average of 2200.

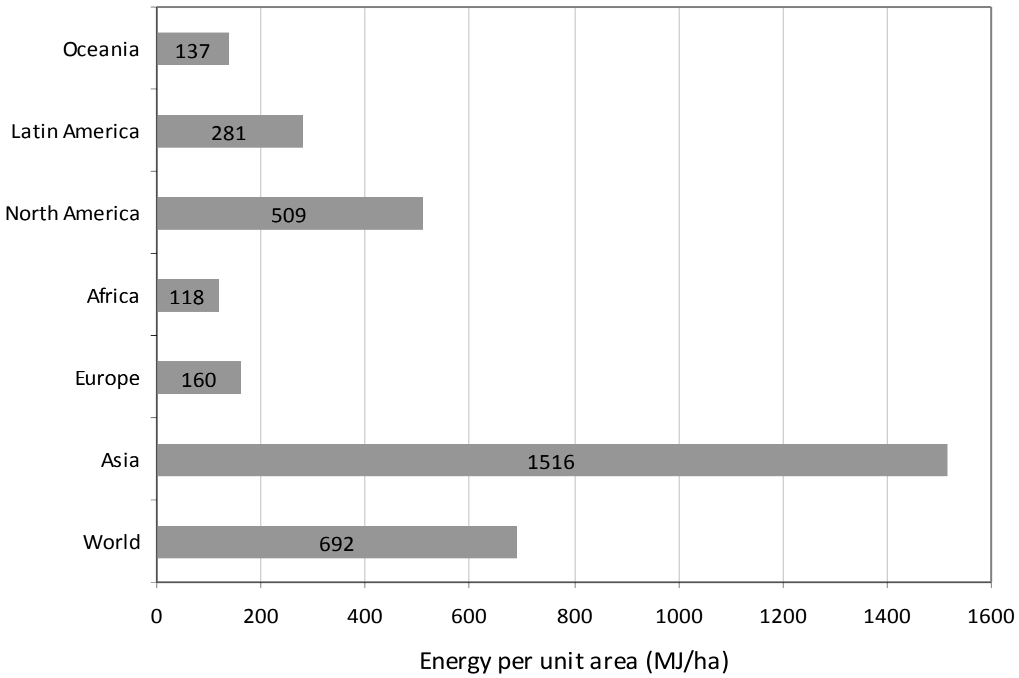

Figure 3.13
Energy input per unit area of arable land for groundwater and surface irrigation

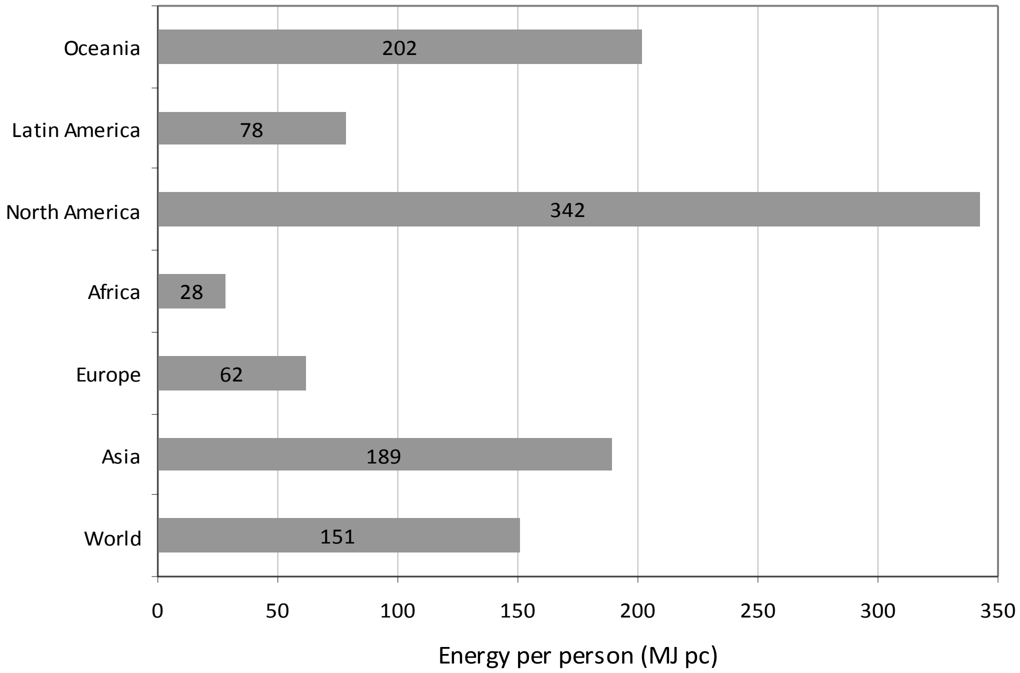

Figure 3.14
Energy input per person for groundwater and surface irrigation

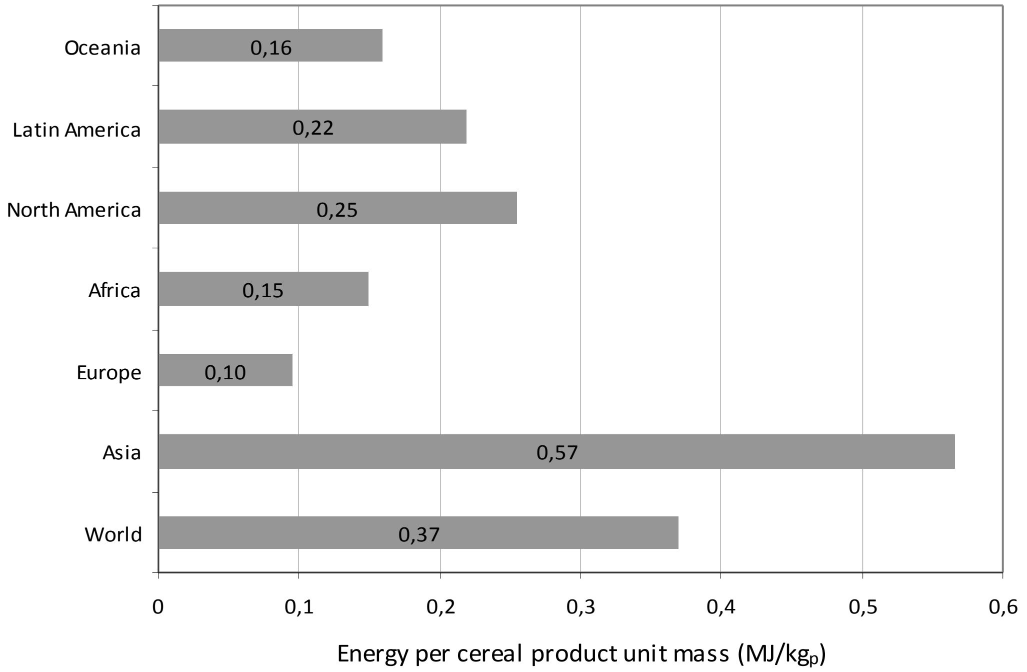

Figure 3.15
Energy input per cereal product unit mass for groundwater and surface irrigation

Since crops absorb only a fraction of the salts contained in the irrigation water, salts become more concentrated in soils and underground aquifers, giving rise to the phenomenon of salinization, which has significant negative consequences in terms of biodiversity loss and reduced agriculture production (Cañedo-Argüelles M. et al. 2013). Globally, about 1,5 millions hectares of agrifcultural land is lost anually due to salinization (Kahn 2006).

Excess aquifer use in many regions of the world are causing significant depletion of water tables. There is documented evidence in India (rodell et al, 2009), China (Changming et al 2010), Southern Usa (kaiser and Skillern 2001) and Mexico (Sangines 2007).

Underground aquifer are renewable resources, but if the are exploited beyond their natural rechargfe capacity, they behave as a non renewable resource.

## 3.7 Animal feed

For centuries animals in farms were fed by pastures and food waste, that is using vegetal products not suitable for direct human use. As for agriculture, this process has been sustainable as long as the pressure of livestocks on pastures didn't exceed a certain limit. When stocking rates exceed optimum values, the effect is generally overgrazing and land degradation (Salmon 2006, Odunze et al, 2003), especially in arid/semiarid zones or in the presence of steep land (Liu et al 2003, Berry 2003).

In the second half of the 19th century the increase in meat demand began a process of livestock farming industrialization in Europe and the United Staes (Rifkin 1992) that progressively spread to all continents during the 20th century .

The need of rapid animal growth resulted in a significant increase of grains in feed composition: between 1960 and 2010 cereals used at world level for animal feed grew by a factor of 2,5 from 288 to 746 Mt, while soyacake surged by a factor of 11 from 13 to 150 Mt. As can be seen from table 3.9, the main variations came from Asia and Europe since North America was already oriented to intensive farming already by mid century. In Italy cereals used for feed more than doubled from 6 to 14 million tons between 1960 and 2010 (FAOSTAT 2014).

In parallel, the land devoted to pasture for extensive farming grew by less than 10% in the second half of the 20th century from 31 to 33 millions of square km. The higher increases in Asia and Latin America are partially compensated by losses in Oceania, North America and Europe. In Italy, between 1920 and 2010, area for fodder production shrank from 6,7 to 4,4 million hectares. (ISTAT 1976, FAOSTAT 2014).

Table 3.9 Variations in the use of cereals for animal feed and in pasture area during the second half of the 20th century

| | Cereals for feed (Mt) | | | Pastures area (Mkm²) | | |
|---|---|---|---|---|---|---|
| | 1961 | 2009 | % variation | 1961 | 2011 | % variation |
| World | 288,4 | 746,2 | 158,7% | 30,9 | 33,6 | 8,7% |
| Asia | 32,0 | 238,0 | 642,2% | 8,8 | 10,8 | 22,5% |
| Europe | 115,6 | 229,6 | 98,5% | 1,9 | 1,8 | -6,4% |
| Africa | 4,8 | 30,8 | 539,2% | 8,9 | 9,1 | 2,6% |
| North America | 121,4 | 162,7 | 34,0% | 2,8 | 2,6 | -6,7% |
| Latin America | 13,0 | 73,5 | 463,1% | 4,5 | 5,5 | 20,7% |
| Oceania | 1,0 | 9,4 | 791,4% | 4,4 | 3,7 | -16,0% |

The transition from prevalent extensive to prevalent intensive livestock farming is seen better by considering the average per cattle head use of soybeans and cereals for feed (figure 3.16 and 3,.17). Data for livestock volumes and cereals feed come from the FAOSTAT database. The fraction of feed used for cattle was assumed to be 36% for Europe, 42% for USA and 30% for the world as average (Giampietro 2002)

At world level the +67% increase from 92 to 154 kg per cattle head per year is dwarfed by the dramatic variation occured in the European Union (+130%) and by the even higher italian increase of 244% from

230 to 800 kg.

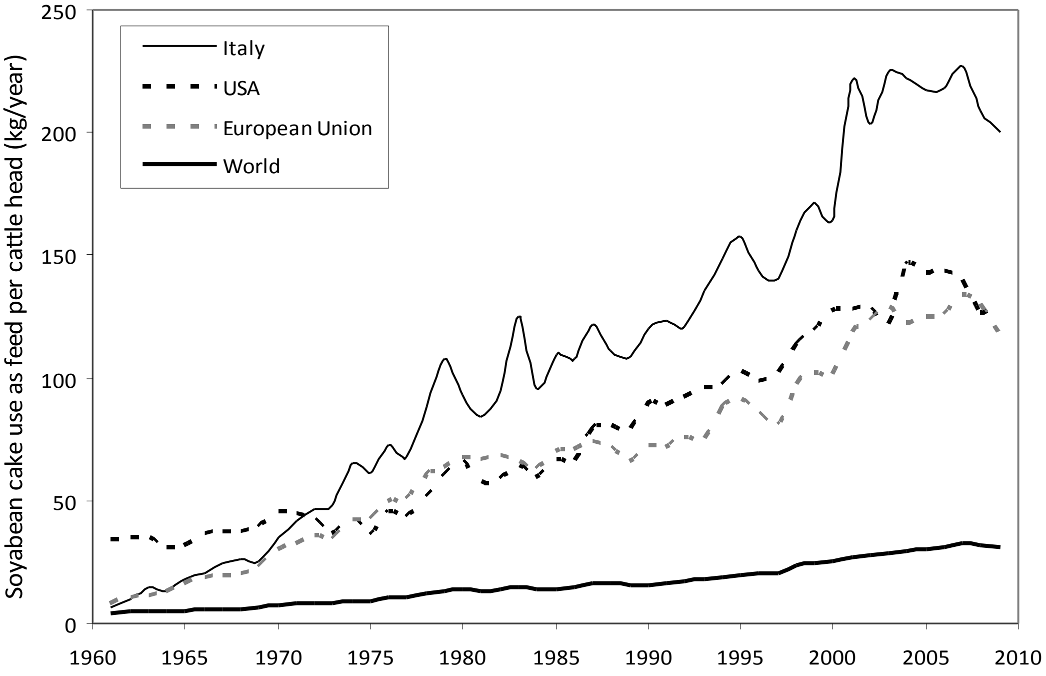

Figure 3.16 Soybean cake used for cattle feed, 1961-2010

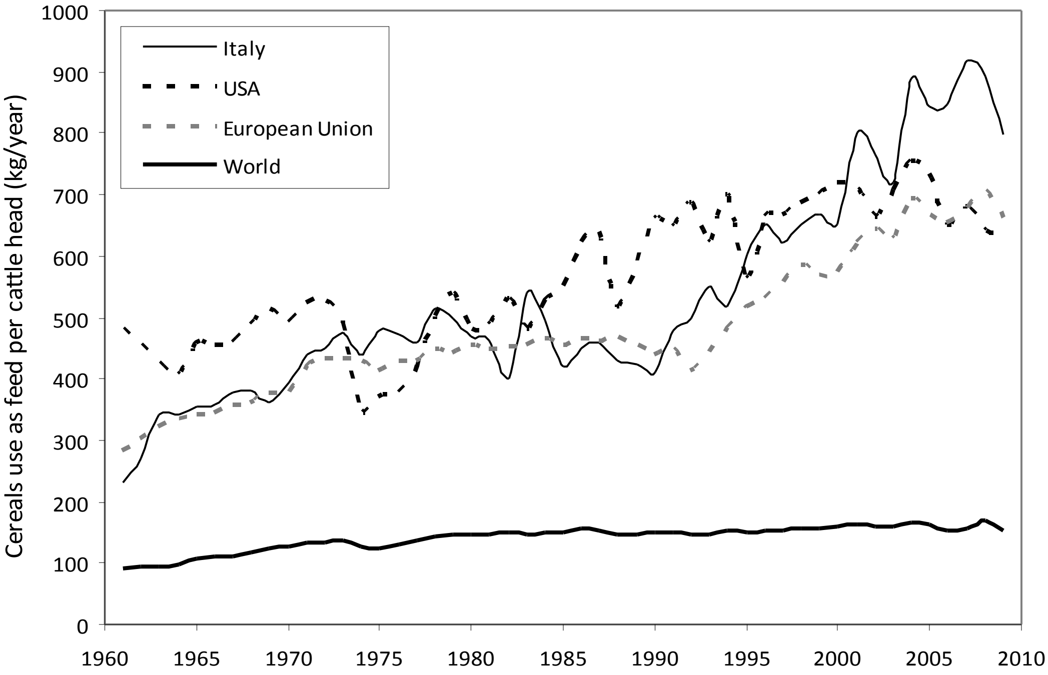

Figure 3.17 Soybean cake used for cattle feed, 1961-2010

At a global level the food chain of animal products is characterized by a quite low energy efficiency, as can be seen from table 6 where are listed energy and protein inputs and outputs evaluated on a per capita basis in each country.

One MJ of vegetal products apt for human consumptions yields on the average 0,45 MJ of animal products; in this case we are taking into account only the energy contained in the vegetal food and not the nergy spent to produce it, since this will be discussed later in the chapter. The output/inoput ratio is usually lower than one in all developed and devloping countries were intensive livestock farming is praticed and it reaches its minimum value for the United States (0,31).

The ratio is above one only in countries were extensive farming is prevailing, like in India, Pakistan or Ethiopia. In these cases there is a lower availibility of per capita animal products owing to the lower yields and to limitation in pasture areas. Argentina constitutes an exception because is characterized by a low demographic density.

There are large differences in the energetic yield of animal products, ranging from 6% for bovine meat to 12% for milk to 25% for pork meat to 32% for broilers. (Pimentel 2008, FAOSTAT 2012).

The energetic cost of the animal food chain has dramatically increased in the last fifty years owing to the great increase in consumption: from 70 to 280 Mt/year for meat and from 230 to 400 Mt/year for milk. The leading country for meat consumption is China with 80 Mt/year, that is more than double than the USA, with an annual growth rate of about 7% (FAOSTAT 2012).

Table 3.10 Per capita energy and protein inputs, outputs and output/input ratios in the animal products food chain for selected countries, year 2009 . Elaboration on FAOSTAT data.

| Country or region | Mass (g pc/day) | Energy (MJ pc/day) | | | Proteins (g pc/day) | | |
|---|---|---|---|---|---|---|---|
| | Output** | Input* | Output** | O/I | Input* | Output** | O/I |
| USA | 1380 | 21,8 | 6,9 | 0,31 | 208,7 | 86,1 | 0,41 |
| Italy | 920 | 8,2 | 3,5 | 0,43 | 68,3 | 49,6 | 0,73 |
| China | 315 | 5,8 | 2,8 | 0,48 | 54,4 | 29,5 | 0,54 |
| Brasil | 900 | 7,3 | 4,8 | 0,66 | 38,6 | 71,1 | 1,84 |
| India | 285 | 0,6 | 1,0 | 1,73 | 6 | 12 | 2,00 |
| Argentina | 1400 | 2,5 | 7,0 | 2,85 | 43,7 | 96,9 | 2,22 |
| Pakistan | 620 | 0,5 | 2,3 | 4,22 | 6,5 | 28,3 | 4,35 |
| Ethiopia | 90 | 0,1 | 0,4 | 7,34 | 0,36 | 6,27 | 17,42 |
| *Americas* | *960* | *14,3* | *4,8* | *0,33* | *138,9* | *64,2* | *0,46* |
| *EU* | *1660* | *12,2* | *6,9* | *0,57* | *97,6* | *91,2* | *0,93* |
| *Africa* | *175* | *1.8* | *0,8* | *0,42* | *10,9* | *11,8* | *1,08* |
| *Asia* | *300* | *3,2* | *1,7* | *0,54* | *25,5* | *20,4* | *0,80* |
| *World* | *520* | *5,8* | *2,6* | *0,45* | *47,2* | *32,4* | *0,69* |

***** Input formed by vegetable products apt to human use employed as animal feed
****** Output iformed by production/export of meat, offals, animal fats, milk and eggs.

## 3.8 Organic farming

### 3.8.1 Definitions, fundamental principles and diffusion of organic farming

The official definition of organic agriculture is quite recent and given by the *International Federation of Organic Agriculture Movements* (IFOAM 2008):

> «Organic Agriculture is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic Agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved.»

This sentence condenses the four main principles of organic farming (IFOAM 2005): *(i)* the concept that farming should sustain and enhance health as *common good* of soils, plants, animals and humans (*principle of health*); *(ii)* the idea of agriculture as a *particular organization of the ecosystem*, rather than an industrial process, which attains an ecological balance and doesn't use chemical inputs, mainly fertilizers and pesticides, that have negative effects on the environment (*principle of ecology*) ; *(iii)* the establishment of fair relationships at social level among farmers, workers, traders and consumers (*principle of fairness*); *(iv)* traditional knowledge/expertise is combined with modern scientific research, but innovations should be managed in a precautionary and responsible manner (*principle of care*).

The organic method strongly relies on the idea that farming must be sustainable, i.e. that it must last in time, without depletion of natural resources and build up of negative effects in the environment on the long run. So, "to last in time" means to last for the centuries to come, that is for all future generations that may inhabit the earth. Traditional societies, the ones that King called *farmers of forty centuries* (King 1911), have succeeded in managing agriculture more or less sustainably for very long periods; these good practices have become the basis for modern organic agriculture.

Starting from innovators and precursors during the 20th century like Howard, Steiner, Balfour and Fukuoka, organic farming began to spread during the 70s, when the IFOAM was funded. At the beginning of the 21st century 15 millions of hectares were cultivated under organic principles and the area more than doubled to 35 millions in 2011 (Figure 3.18, FiBL & IFOAM ,2013), a surface as large as Germany.

A similar extension of 34 millions hectares is occupied by the area of *wild collection*, like gathering of mushrooms, wild berries, nuts, medicinal and aromatic plants and beekeping in wild areas. Collection must be done sustainably and far away from urban and polluted areas.

The great part of organic land is made up by pastures (23,4 Mha, 63%) followed by arable land (6,3 Mha, 17%) and permanent crops (2,6 Mha, 7%); the split up of arable land cultivations is shown in figure 3.19.

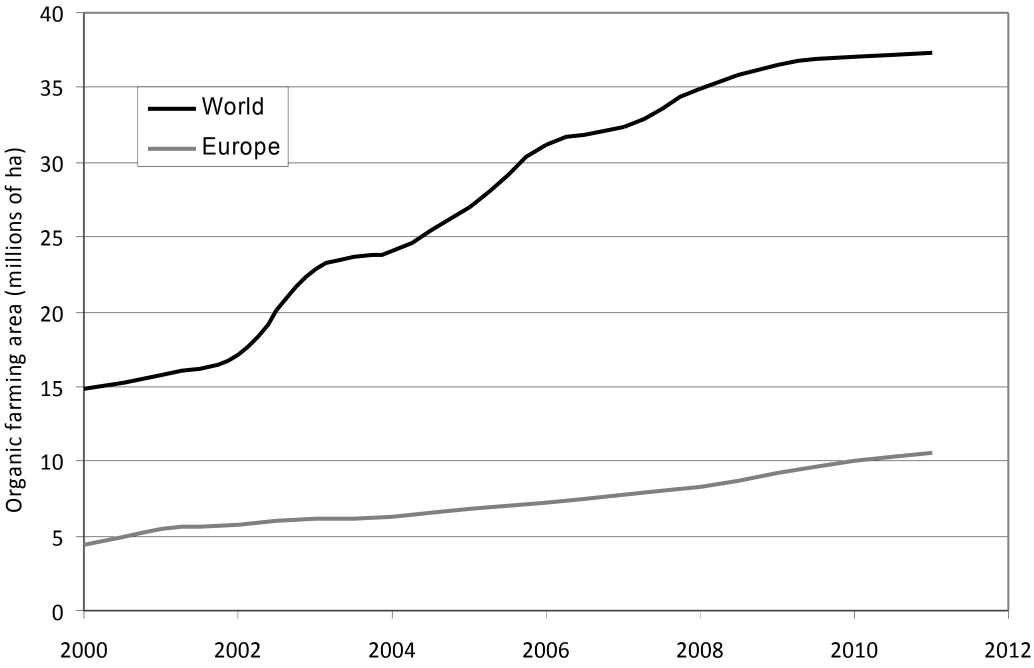

Figure 3.18
Area occupied by organic farming

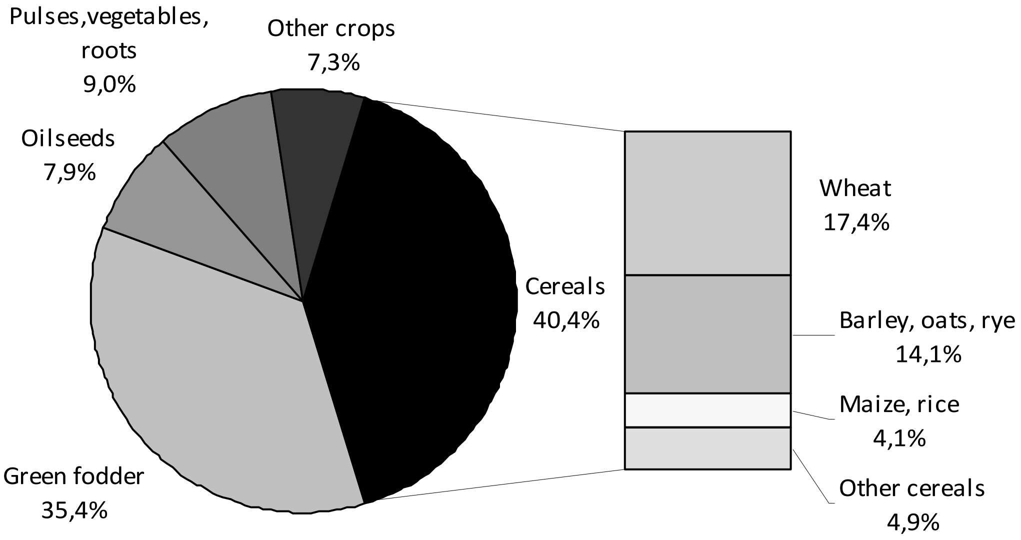

Figure 3.19
Distibution of organic arable land by cultivated species

### *3.8.2. Organic farming significantly reduces energy input*

Organic farming is generally appreciated for better quality products and for being more environmentally friendly, but this perception is seldom translated into quantitative terms. One underrated key point is the net input energy reduction performed by organic methods. This is mainly due to the exclusions of chemical fertilizers and pesticides, which contribute significantly to the total energy costs, as explained in paragraphs 3.4 and 3.5.

The are now many peer reviewed studies that address the problem of energy input at farm level, comparing the performance of organic and industrial agriculture. In this context we don't use the expression *conventional agriculture* because we think is inappropriate to define "conventional" a massive use of non renewable chemicals with heavy side effects on the environment and the climate. The term "industrial" is more pertinent, for the scale of operations, the productivistic viewpoint , and the wide use of any technology pushed to its limits.

We will consider them for each of the main food crops according to FAO taxonomy
Specific input energies for wheat cultivation from seven different studies are summarized in figure 3.20 The wheat has been cultivated in Germany, Switzerland and Great Britain, under different soil and climatic conditions, and different procedures, that explains the range of energy value from 1,5 to 4 MJ/kg$_p$. However, each comparative study has been performed in the same palce and under the same general conditions, so the comparison is absolutely meaningful.

On the average, organic farming requires 2,1 ± 0,5 MJ/kg$_p$, a reduction of one third with respect to the 3,2 ± 0,7 MJ/kg$_p$ of industrial agriculture. Energy savings range from 20 to 40%. The energy output/input ratio scores 6,8 for organic, about 50% more than the 4,6 of chemical.

The same happen for maize (figure 3.21): according to four different filed test performed in the United States, Canada, Greece and Slovakia, the input energy reduction is also one third from 3 ± 1,3 to 2 ± 0,75 MJ/kg$_p$.

Considering the global wheat and maize production of 1550 millions of tons (year 2012), a hypothetical planetary conversion to organic production would save about 40 Mtoe, equivalent to the primary energy consumption of countries like Austria or Algeria.

Energy inputs are reduced also for roots, tubers and bulbs (figure 3.22) and vegetables (figure 3.23), even if the reduction is less significant.

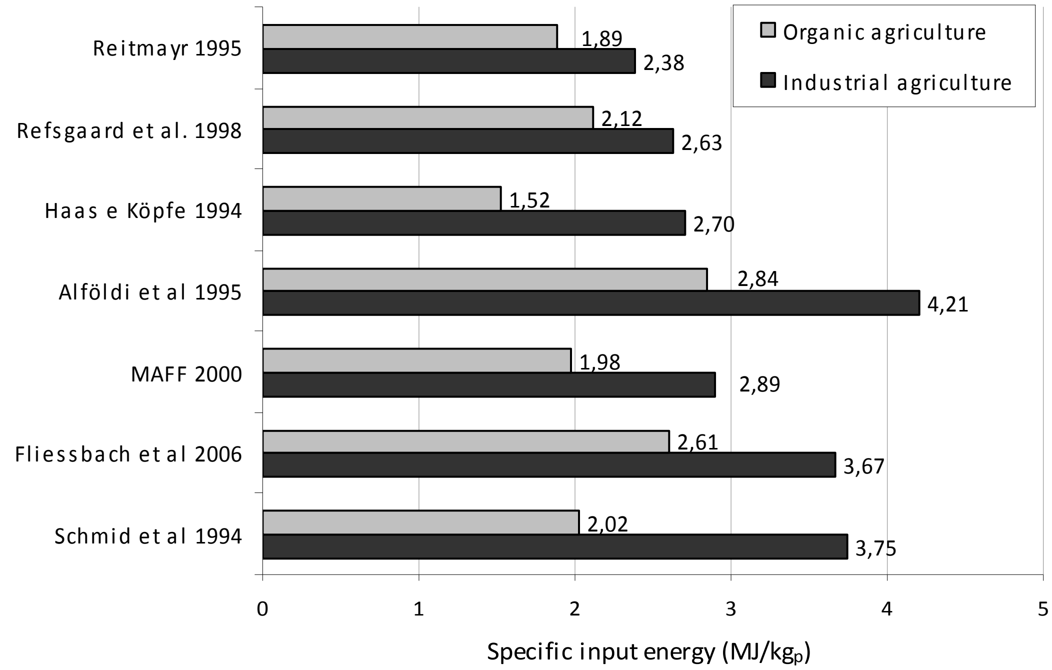

Figure 3.20 Energy for the cultivation of 1 kg of wheat using organic or industrial agriculture (MJ/kg$_p$)

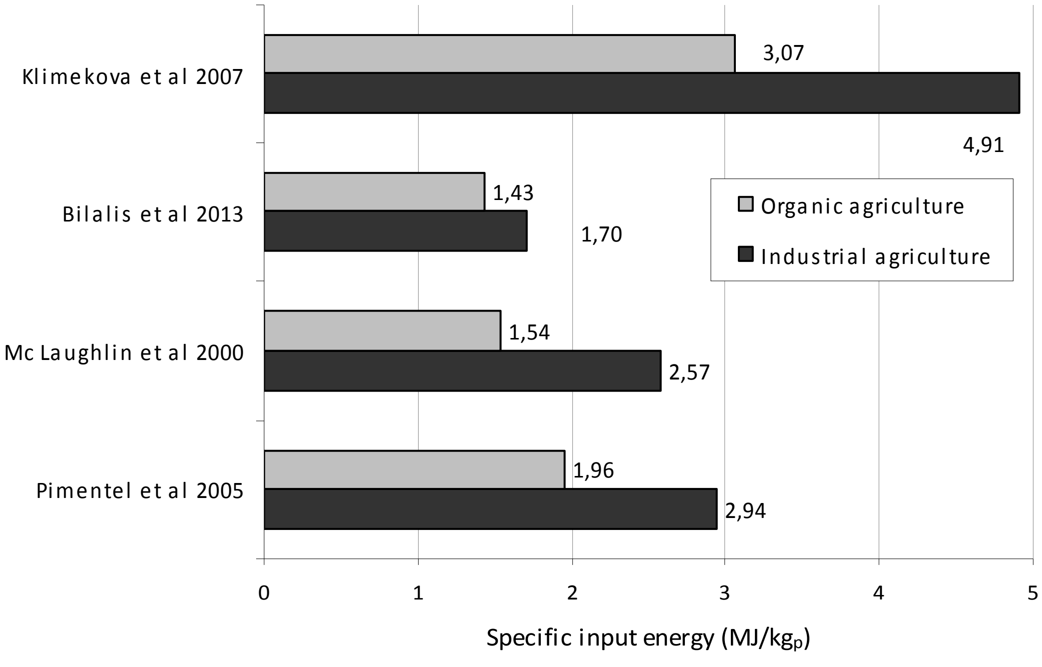

Figure 3.21 Energy for the cultivation of 1 kg of maize using organic or industrial agriculture (MJ/kg$_p$)

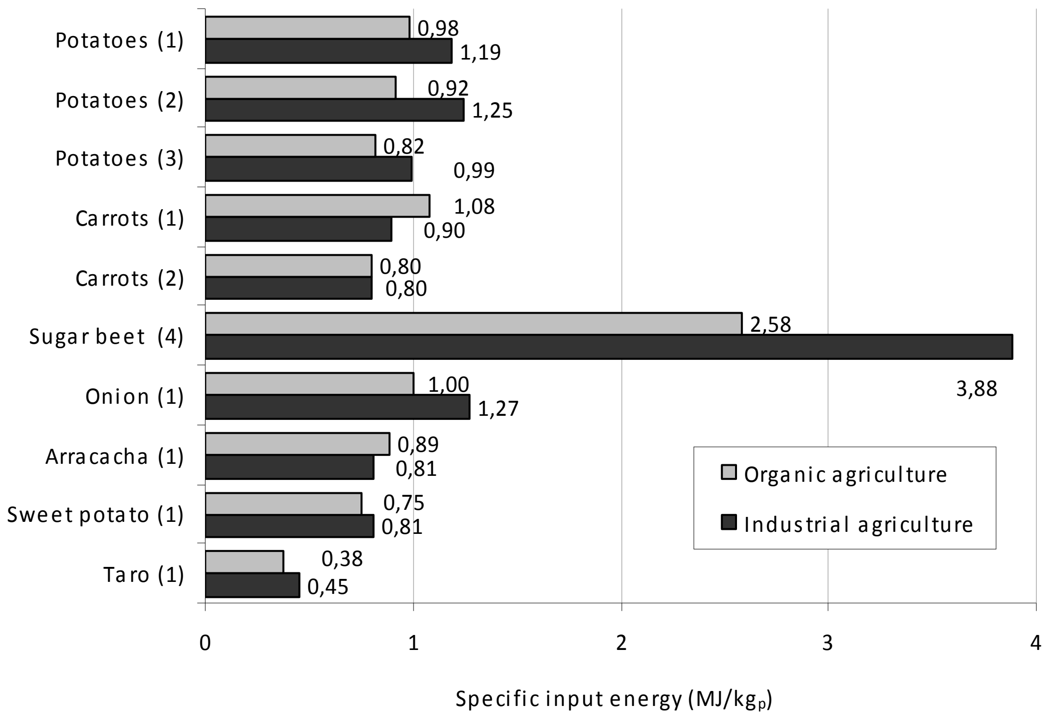

Figure 3.22 Energy for the cultivation of 1 kg of roots/tubers/bulbs with organic or industrial agriculture. Sources (1) De Souza et al. (2008), (2) MAFF (2000), (3) Fliessbach et al (2006),(4) Mrini et al. (2002)

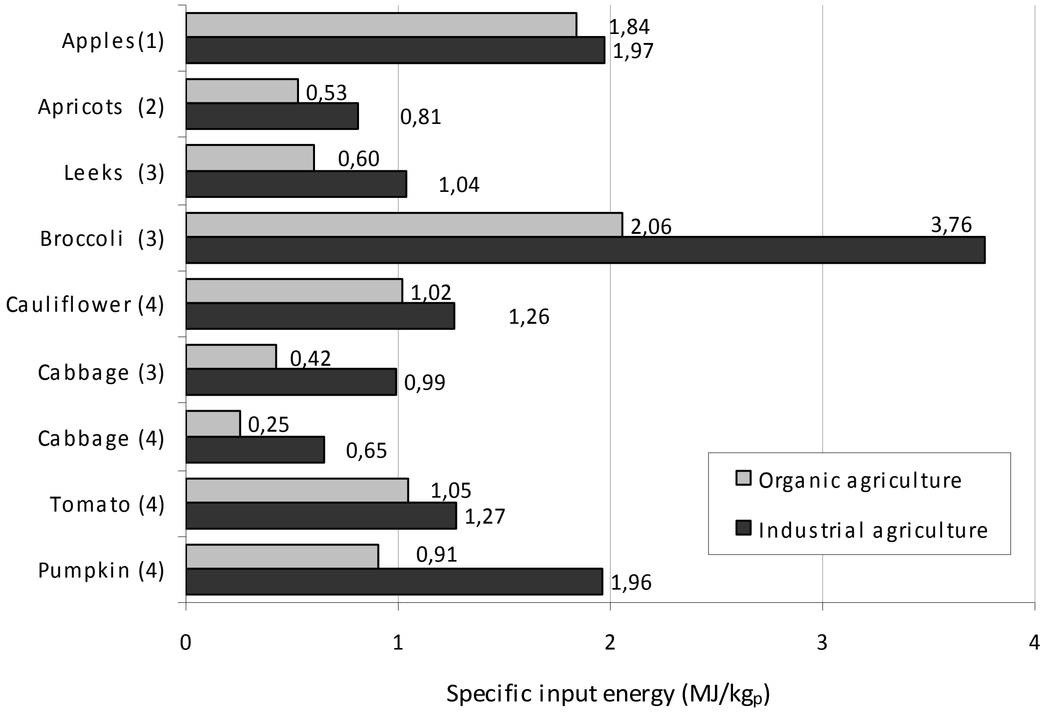

Figure 3.23 Energy for the cultivation of 1 kg of fruit/vegetables with organic or industrial agriculture. Sources (1) Reganold et al. (2001), (2) Gündoğmuş (2006), (3) MAFF (2000), (4) De Souza et al. (2008)

### *3.8.3 Yield comparison with industrial agriculture*

Industrial agriculture developed during the twentieth century with the obsession of increasing yields at any cost, leaving in second place any concern about social or environmental impacts of its operations. As can be seen from figure 3.24, during the last fifty years, cereal yield has always been a step forward population increase, but this happened at the cost of an enormous growth in the use of nitrogen chemical fertilizer, which are responsible of a significant quote of non renewable energy use and a more relevant impact on climate change, as discussed in paragragh 3.10.

To a certaint extaint, we can affirm that yields increase, together with better sanitary conditions, was one of the driving forces of population growth in the second half of the twentieth century; by increasing food production for humans at the expenses of other species, the effect has been, and continues to be, an increase in the overall population (Hopfenberg and Pimentel , 2001, Hopfenberg 2003 ).

Nevertheless, the yield issue remain of upmost importance on a planet populated by seven billions people, and it is important to evaluate which is the performance of organic farming in terms of land productivity. Table 3.11 summarizes the results of 37 recent peer reviewed studies which compare organic and industrial crops of 29 vegetal species in 20 countries belonging to different climate regions; the cultivation varieties in table 1 represent about 80% of the total world vegetal production.

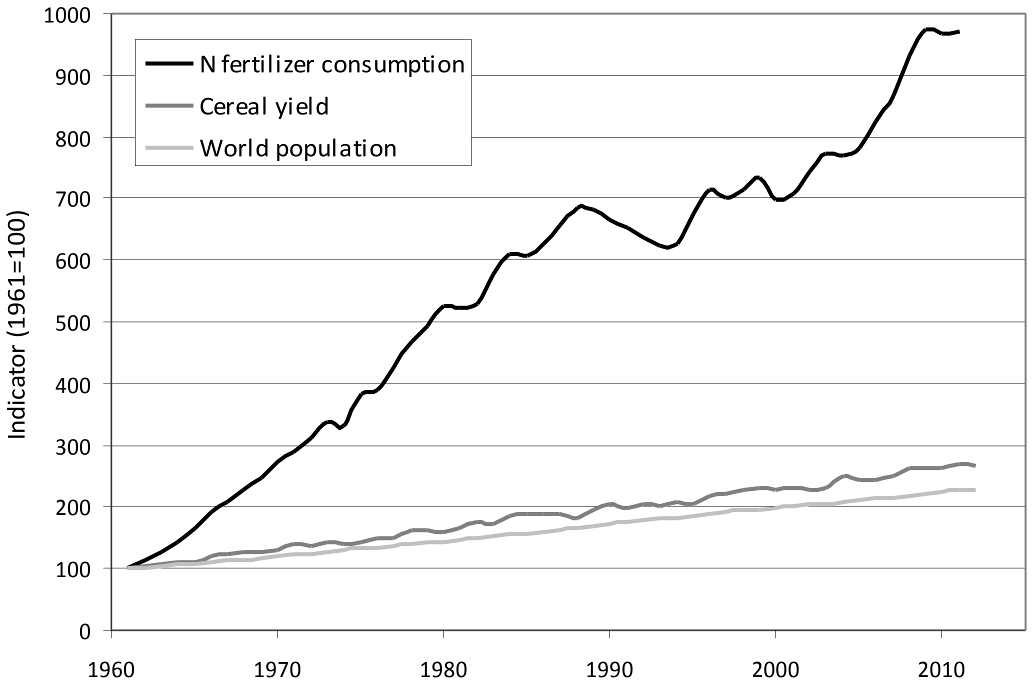

Figure 3.24
Indicators of world population, cereals yield and nitrogen fertilizer consumption, 1961-2011. All series are normalized to their 1961 values.

Table 3.11 Organic and industrial farming yields from specific comparison studies. When more than one is available, averages and standard deviations are reported. Standard deviations are also available within single studies.

| Cultivation | | N. of studies | Organic $Y_o$ | Industrial $Y_i$ | $Y_o/Y_i^{(*)}$ | References | Countries |
|---|---|---|---|---|---|---|---|
| *Cereals* | Wheat | 7 | 4,1 ± 0,7 | 5,4 ± 1,6 | 79 ± 16% | Singh 2002 and *see figure 3* | India, Germany, Switzerland,G. Britain |
| | Rice | 4 | 4,2 ± 0,5 | 4,5 ± 1 | 95 ± 21% | Nair 2013,<br>Rubinos 2007<br>Mendoza 2002,<br>Singh 2002 | Philippines, India |
| | Maize | 7 | 8,2 ± 1,9 | 8,5 ± 2,9 | 99 ± 8% | Lotter 2003,<br>Liang 2012 and *see figure 5* | Canada, USA, Greece, Slovakia |
| | Oats | 1 | 3,18 | 2,34 | 135,9% | Clark 1999,<br>FAOSTAT 2014 | USA |
| | Barley | 1 | 3,35 ± 0,7 | 4,47 ± 0,8 | 80 ± 4% | Leistrumaite 2008 | Lithuania |
| *Tubers* | Cassava | 1 | 10 | 11,8 | 84,7% | Agunbiade 2013 | Nigeria |
| | Potatoes | 3 | 27,3 ± 7,6 | 36,1 ± 9,6 | 76 ± 10% | De Souza 2008<br>MAFF 2000,<br>Fliessbach 2006 | G.Britain , Germany, Brazil |
| | Yam | 1 | 57,1 | 47,6 | 120% | Suja 2013 | India |
| *Sugarcrops* | Sugarbeet | 1 | 10 | 13,8 | 72,9% | Mrini 2002 | Morocco |
| | Sugarcane | 1 | 81,7 | 68,7 | 118,9% | Monteiro 2008 | Brazil |
| *Pulses* | Beans | 1 | 1,94 | 1,91 | 102% | Clark 1999 | USA |
| | Peas | 1 | 4,2 | 9,3 | 45% | Mourao 2012 | Portugal |
| | Soybeans | 3 | 2,2 ± 0,4 | 2,2 ± 0,4 | 97,9% | Pimentel 2005,<br>Lotter 2003<br>Forster 2013 | USA, India |
| *Oilcrops* | Groundnuts | 1 | 1,1 | 1,6 | 68,7% | Naturland 2000,<br>FAOSTAT 2014 | World average |
| | Sunflower | 1 | 2,5 ± 0,8 | 4 ± 1,75 | 62,5% | Mazzoncini 2006 | Italy |
| | Cottonseed | 1 | 2,0 | 2,3 | 85,7% | Forster 2013 | India |
| | Sesame sees | 1 | 5 | 5,59 | 89,6% | Olowe 2009 | Nigeria |
| | Olives | 1 | 2,4 | 3,7 | 64,8% | Apostolos 2007 | Greece |
| *Vegetables* | Tomato | 1 | 34,5 | 55 | 62,7% | De Souza 2008 | Brazil |
| | Onions | 1 | 25,77 | 35,4 | 72,8% | De Souza 2008 | Brazil |
| | Carrots | 2 | 22,9 ± 8 | 35,2 ± 14,3 | 65% | MAFF 2000, De Souza 2008,<br>Singh 2002 | G.Britain, Brazil, India |

Yields for the same crop may vary significantly from one study to another, reflecting different soil, climatic conditions and procedures, but the organic/industrial comparison within each study is meaningful, because it has been performed under the same general conditions. For instance, the wheat yields of the eight studies taken into consideration range from 2,7 to almost 7 tons per hectare, a 150% difference; in relative terms, the organic/industrial yiled ratio ranged instead more narrowly from 63% to 87%, a 40% variation, suggesting that the yield ratio may be a more robust indicator than the yield alone.

With the caveat that these studies are non representative of all the world possible climatic conditions, we can say that at global level organic methods score quite well with respect to industrial ones, provided that the great majority of crops show yields that are more 70% of the values obtained with chemical fertilizers and pesticides. Only one crop is below 50% (peas 45%) and six are between 60% and 70% (Banana 60%, Sunflower and Tomato 63%, Olive and Carrots 65% and groundnuts 69%). Cereals, the most imporant crops are all above 75%, with wheat at 76% and rice and maize over 90%.

In some cultivations organic methods provide an even greater yield with respect to industrial production, which reflects in a score over 100%: Oats (135%) Yam (188%), Sugarcane (119%), Pineapple (112%) and Cocoa (117%).

Lower organic yields are usually compensated by other better performances, like better organic prawn collection during the summer intercrop in India (Nair et al 2013), better maize yields during several drought seasons (Lotter et al, 2003), higher income for small farmers owing to less input costs (Forster et al. 2013), higher porosity and water holding capacity of soils (Suja 2013), higher iron and other micronutrients content and lower insect damage (Sing 2002), slightly greater oil and omega-3 content (Mazzonicini et al 2006) and higher resistance to fungal diseases (Leistrumaite 2008).

More generally speaking, organic agriculture helps farmers to be more socially and ecologically resilient to adverse weather events, price fluctuations and climate change (Milestad adn Hadatsch, 2003, Aurebach et al 2013).

Traditional crop protection techniques, like the ones described in chapter 1.5, are flanked in organic farming by ner methods of ecofunctional intesification, like usage of bush tea and legumes respectively to protect and fertilize organic cotton crops in Nigeria, system of rice intensification in Madagascar or the chicken-banana system in Zambia; chickens reduce weeds and insects in the plantation and provide directly for the fertilization (Aurebach et al 2013).

As a conclusive remark, we should note that a comparison between organic and industrial yields is made only for the practical purpose of trying to quantify the population that could be fed by organic method; the two yield are in effect not comparable because the former are based only on the ecosystem productivity, while the latter are doped with unsusutainable inputs.

## 3.9 Dependence on non renewable energy sources and peak oil

In traditional agriculture, energetic input comes from renewable sources (muscular energy, green or animal manure, rain or natural irrigation), while industrial agriculture is dominated by fossil fuels. Even the small contribution of human work can be considered a non renewable input, since workers nourishment is produced with non renewable energy.

A production process entirely based on non renewable fossil fuels is crearly unsustainable over the medium - long period (Georgescu-Roegen, 1971), but it may lead to instabilities and poor resilience also in the short period.

Human civilization is indeed facing the problem of *peak oil* (Hubbert 1956; Pfeiffer 2006, Pagani and Caporali 2013), that is the moment in history in which crude oil production reaches a maximum and then decreases. This is due to the fact that bigger and best quality oil fields are discovered and exploited first; gradually, as these resources are depleted, the extraction effort will shift towards smaller oil fields, more remotely located (deepwater, arctic) and of worse quality, which require more energetic, technological and infrastructural inputs, so they cannot grant the same fluxes of annual production.

Crude oil production grew by about 16% between 1985 and 1994 and by nearly 19% in the following decade; from 2005 to 2013 the increase was reduced to 3%, only due to the development of lower quality non conventional oil (tight oil in USA, tar sands in Canada, extra heavy oil in Venezuela). Indeed the production of conventional oil has decreased by 1,3% in the last nine years (figure 3.25).

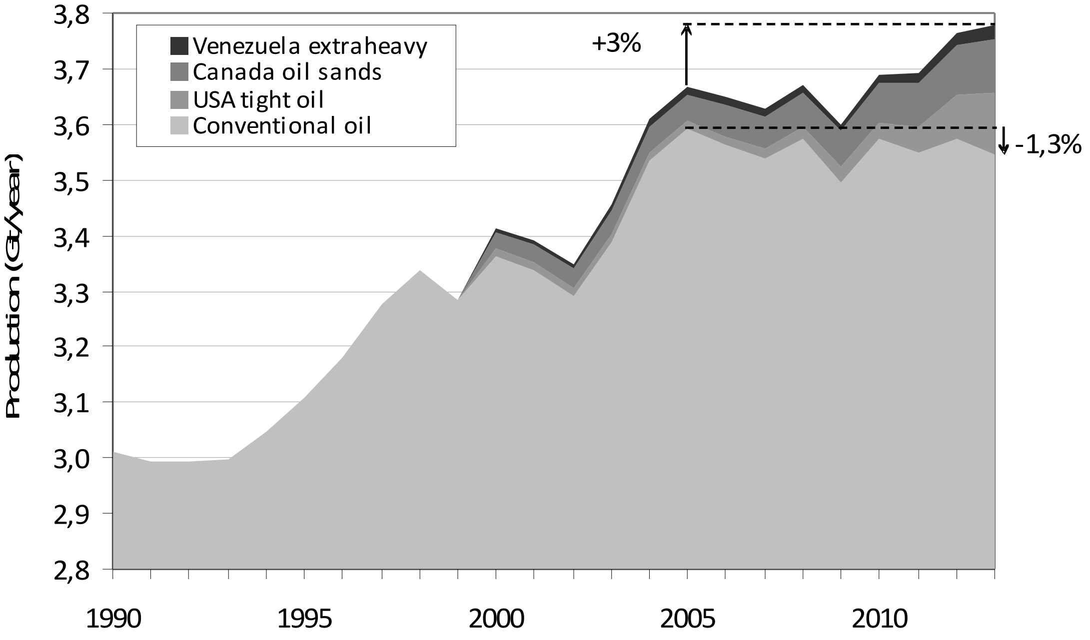

Figure 3.25 Global crude oil production. Sources: *Energy Information Administration*, *Canada Association of Petroleum Producers, Petróleo y Otros Datos Estadísticos*

Peak oil may already be happened in 2005 for conventional oil and is probably not far in the future for the total oil supply.

Production increased slowly, but energy demand didn't saturate, especially from China, that experienced an extremely fast industrial and economic growth in the last decade (+115% in cement production and +330% in iron ore extraction, USGS 2013) with a similar increase in energy consumption (+47% oil, +200% gas, + 60% coal). The combination of strong demand and stagnating production caused the oil shock of 2007-2008, when prices surged from 54 $/bbl in january 2007 to 134 $/bbl in june-july 2008 to collapse again to 42 $/bbl in january 2009. (Hamilton 2009). From 2009 to 2013, the oil prices increased again more gently and in the last three years has oscillated between 80 and 110 $/bbl. Cheap oil price probably will never return.

Peak oil and high oil prices had already a significant effect on the world prices of the basic food products which are condensed in the FAO food price index (FAO 2013).

Oil price (EIA 2014) is quite strongly correlated (R=0,85) with the food index, as can be seen from figure 3.26, where both values are plotted in a double scale graph. After the price shocks of 2008 and 2011, the food index has dumped his oscillations, but remained significantly high, between 200 and 220. The strong oil price decline of 2014-2015 was immediately followed by a decreased in the Fao index.

The value of 210 represents the threshold for food rebellions, which happened in 13 countries in 2008 and in 15 in 2011 (Lagi M. et al., 2011). Since it is highly improbable that the food price will decrease significantly below 200, food crises have a strong risk of becoming endemic in the near future.

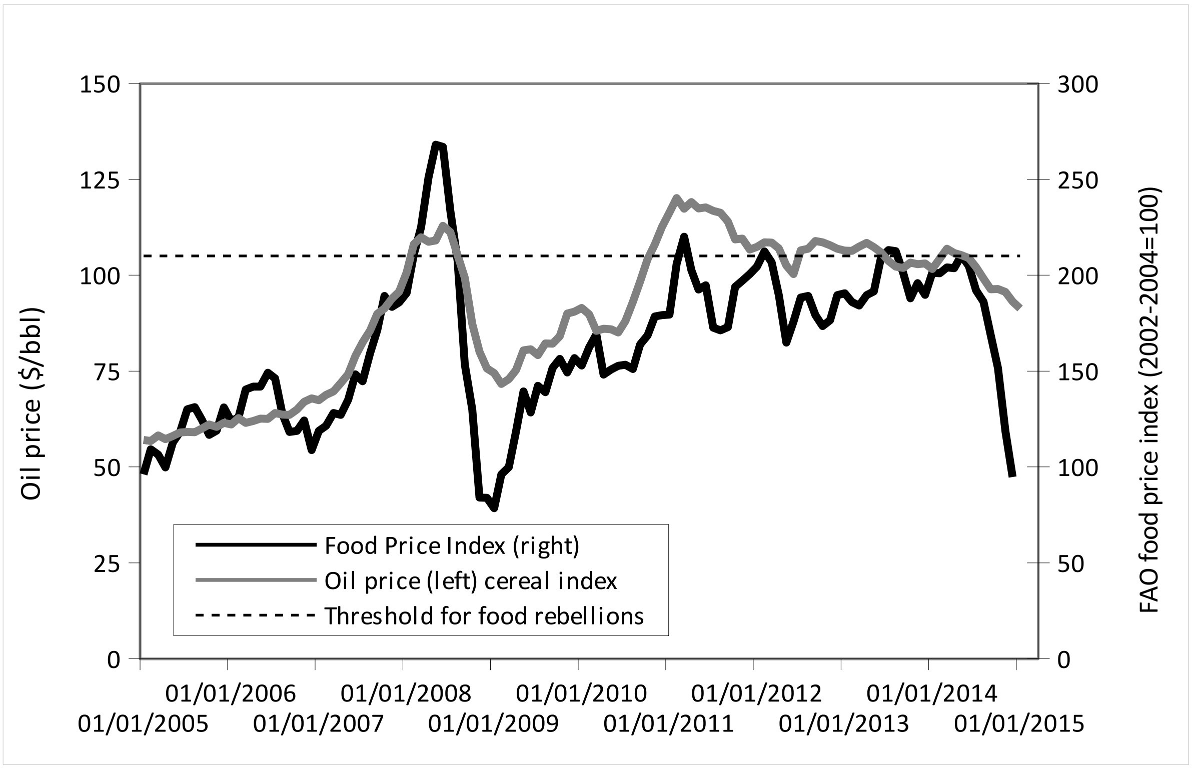

Figure 3.26 FAO food price index and crude oil price. Sources: FAO, EIA

# 4. Methodology

«The most important part of our worldview, the part that is least commonly shared, is our system perspective. Our training concentrated on dynamic systems - on sets of interconnected material and immaterial elements that change over time. Our training taught us to see the world as a set of unfolding behavior patterns, such as growth, decline, oscillation, overshoot. It has taugth us to focus non so much on single pieces of a system as on connections. We see stocks and flows and feedbacks and thresholds in the interconnections, all of which influence the way the system will behave in the future and influence the actions we might take to change its behavior.»

*D. Meadows, D. Meadows, J. Randers, The limits to growth: the 30 year update, 2004, p.4*

## 4.1 The reason for the case study method

The analysis of energy inputs in agricultural production can be performed in two complimentary ways: *(i)* a top-down approach that looks at the energy consumption at *nation* or *state* level for all materials and instruments used in the farming activity; *(ii)* a bottom-up method that looks analitically at energy inputs on a sample of farms.

The first approach is more general and comprehensive, but yields only average data that cannot tell us anything about the effects of different farming practices on energy consumption. It has been partially used in the literature review chapter, where energy inputs for direct and embodied energy were analized in different regions of the world.

The second approach has the advantage of obtaining much more precise information on energy use at single holding level, but it may lack generality, since the sample analized may be not representative.

In the present research work the bottom-up approach was used in two different case studies. Case studies are a common practice in social and economic research to investigate complex systems and can be use also in quantitative research (Yin 1994).

The purpose of the present work is to make a comparative evaluation of the energy footprint of different crop/livestock agricultural systems, where dissimilar choices were made in the use of land, input materials and instruments.

For this reason, the case study method applied to a relatively small sample of farms appear to be fully adequate, provided that those farms are using different agricultural practices in their activities. The possible lack of generality is not relevant to the purpose of this research, since it is not important wether the farms taken into consideration are representative of the area to which they belong, as far as they are representative of different agricultural and livestock methods.

## 4.2 The choice of food products and farm typologies

In agreement with the two research questions ofparagraph 2.2 , it was decided to study in detail one vegetal and one animal food product. In order to make the proper choice, the following criteria were taken into account: *(i)* the commodity should be produced and traded globally and (ii) it should provide a significant contribution to the human daily diet in different part of the world.

The two chosen commodities, milk and rice, meet both criteria.

### *4.2.1 Milk*

Since the diffusion of the lactase persistence genetic mutation among european peoples (Leonardi et al, 2012), cow milk and related products have become an important element of the daily diet both in the old world and in the so called “new Europes” (Crosby 2004). Present world production is 740 Mt (FAOSTAT 2014) or 90 kg per capita per year, corresponding to 10% of protein and 6% of energy daily supply. Consumption levels are much higher in North America (253 kg ) and in Europe (240 kg), where milk and its derivates grant 20% of protein and 10% of energy total intake.

Owing to the great relevance of the dairy food sector in the diets of a large part of the world , it is important to assess the dependence of this sector from non renewable fossil energy and the influence of different farming practices on the energy footprint.

The most diffuse livestock practices may be divided into three categories: *(i) grain based*, when cereals, soy and other by products constitutes more than 40-50% of the mass of the total daily ration; *(ii) pasture based*, when pastures or hay represent more than 70% of the diet (regardless if animals are kept on the fields or confined in barns) ; *(iii) organic*, when all feed and fertilizers follow the requirement of organic agriculture. In principle, organic may be grain or pasture based, but actually most organic holdings are giving more relevance to pasture and hay than to grains. At least two farms for each type were included in the present work.

Owing to the importance of milk consumption in Europe and North America, farms of the three different typologies were chosen in both areas.

### *4.2.2 Rice*

Rice (*Oryza sativa*) is one of the world's oldest and most important species used as food. Genetic molecular evidence shows that it was domesticated between 8000 and 13000 years ago in China (Ponting

2007, Molina et al 2011) and than spread all over the world, reaching Europe most probably during the renaissance (Crosby 2004) and North America a few centuries later, mainly through Africa (Carney , 2001). At world level, rice is the first vegetal product in terms of energy intake (19% of the diet) and the second after wheat for protein assumption (12,7%).

In North America and in Europe consumptions levels are significantly lower, a few percent of the intake, but rice production cover respectively one million and 650 000 hectares and North America exports about 60% of its production (FAOSTAT 2014). For this reason, input energy in rice production was studied in both areas

Many different varieties of rice are cultivated America and Europe, but the main relevant difference between farming practices is chemical vs organic. Organic rice production does not use any chemical fertilizer or herbicide. The case study included only one organic farm for each area, because this practice is still little diffused and not so common.

## 4.3 The choice of agricultural areas and farms

### *4.3.1 Dairy farms in Missouri and Emilia Romagna*

Several studies have been performed on the energy input of dairy farming, but they are mainly related to New Zealand (Wells 2001, Hartman and Sims 2006) and to northern Europe : Finland (Grönroos et al 2006, Mikkola and Akolas 2009), Estonia (Frorip et al 2012), Denmark (Refsgaard et al 1998), Sweden (Cederberg and Mattsson 2000), Norway (Eide 2002), Germany (Haas 2001, Kraatz 2012), Belgium (Meul et al 2007) and the Netherlands (Thomassen et al 2008).

Little attention was paid to Southern Europe and North America; even Pimentel (2008) addresses the milk issue ony marginally. Morevoer, european studies are mainly concentrated on grain based farming, wether conventional or organic, with substantially no consideration to pasture based farming.

The purpose of the present case study research is to fill this gap, by performing a comparative analysis of the energy input necessary for the production of cow milk in one region of southern Europe (Emilia-Romagna, Italy) and in one state of north America (Missouri, USA). Emilia-Romagna and Missouri have comparable populations (respectively 4,4 and 6 millions inhabitants) and GDP per capita as can be seen from figure 4.1.

Both areas have comparable values of cows and milk production, even if Emilia Romagna is characterized by larger herd sizes and milk productivity (see table 4.1).

Production is almost stable in the italian region, while the dairy sector in Missouri has declined in the last forty years from over 300 000 miking cows in 1975 to less than 100 000 in 2013 (MU 2000 and USDA

2014) mainly owing to competition from other states like California and Wisconsin, where more intensive farming is performed.

Pasture based farming is however putting new life in the missourian dairy sector and it may reverse the situation in a matter of a decade.

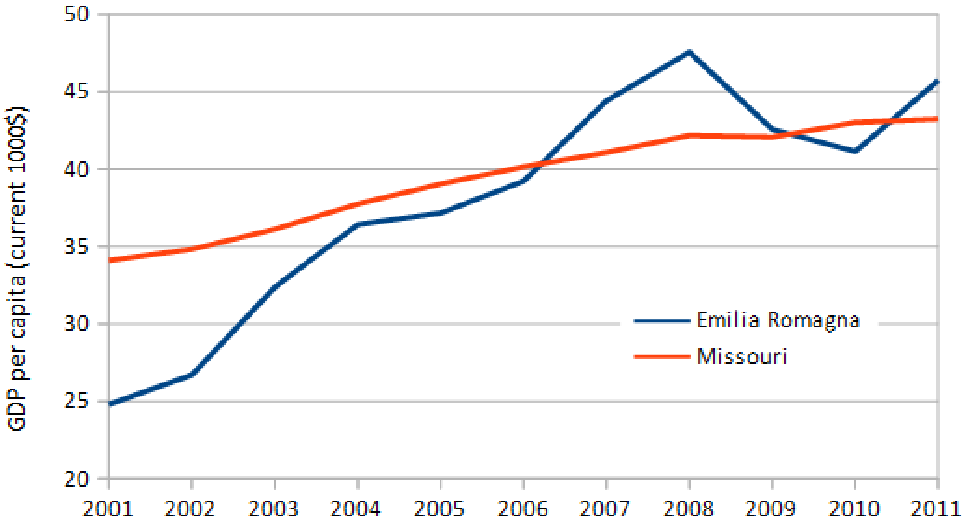

Figure 4.1 GDP per capita of Emilia Romagna and Missouri in current dollars.
Source: Eurostat 2014 and BEA 2014

Milk use in Emilia Romagna is mainly devoted to cheese making, especially the world class Parmigiano Reggiano, whose tradition dates back at least to the Middle Ages (Boccaccio, 1351); milk produced in Missouri is directly consumed and only a small fraction is used to produce cheese.

Table 4.1 Indicator for milk production in Missouri and Emilia Romagna

| Indicator | Missouri | Emilia Romagna |
|---|---|---|
| Farms | 1124 | 507 |
| Cows | 89729 | 303023 |
| Production 2013 (1000 t) | 608 | 2576 |
| Milk per cow (kg) | 6780 | 8502 |

The analysis was performed on 15 dairy farm of the three different typologies, 7 in Missouri and 8 in Emilia; following the rules of the Institutional Review Board, privacy of the data has been respected and the exact name and location of the single households is disclosed in the present work. All farms are indicated by a code: grain based (G1, G2,G3,G4 and G5), pasture based (P1, P2, P3 and P4) and organic (OP1, OP2, OP3, OP4 and OP5), that are also pasture based. No grain based organic farms were found.

Farm characteristics are reported in table 4.2, while their location is indicated in figures 4.2 and 4.3.

The functional unit for the research is one kg of raw *Energy corrected milk* (ECM) at farm gate, with no further processing; with this choice is possible to compare milk products with different content in protein and fat (see paragraph 4.5.9).

Table 4.2. Farms surveyed in the case study according to the use of chemicals and type of feed

| Farm | | Herd size (N) | Farm area (ha) | Lactations | Milk per cow (kg/year) | |
|---|---|---|---|---|---|---|
| | | | | | Raw | ECM |
| Missouri | G1 | 187 | - | 2,25 | 11408 | 12083 |
| | G2 | 30 | 8,2 | 3,5 | 6622 | 9303 |
| | P1 | 95 | 83 | | 5835 | 6691 |
| | P2 | 547 | 160 | 4 | 3976 | 4599 |
| | OP1 | 49 | 49 | 6 | 4139 | 4580 |
| | OP2 | 45 | 45 | 6 | 6804 | 7783 |
| | OP3 | 67 | 67 | 3 | 3049 | 3622 |
| Emilia Romagna | G3 | 850 | 820 | 2,25 | 10706 | 11334 |
| | G4 | 587 | 400 | 3,1 | 9478 | 10473 |
| | G5 | 1250 | 1225 | 2,3 | 10694 | 10950 |
| | P3 | 36 | 25 | 2,97 | 7188 | 7682,7 |
| | P4 | 45 | 19 | 2,37 | 6154 | 6944 |
| | OP4 | 42 | 26 | 4 | 6129 | 6456 |
| | OP5 | 48 | 36 | 4,5 | 7368 | 7588 |
| | OP6 | 180 | 140 | 3,5 | 9125 | 9359 |

Source: author's elaboration

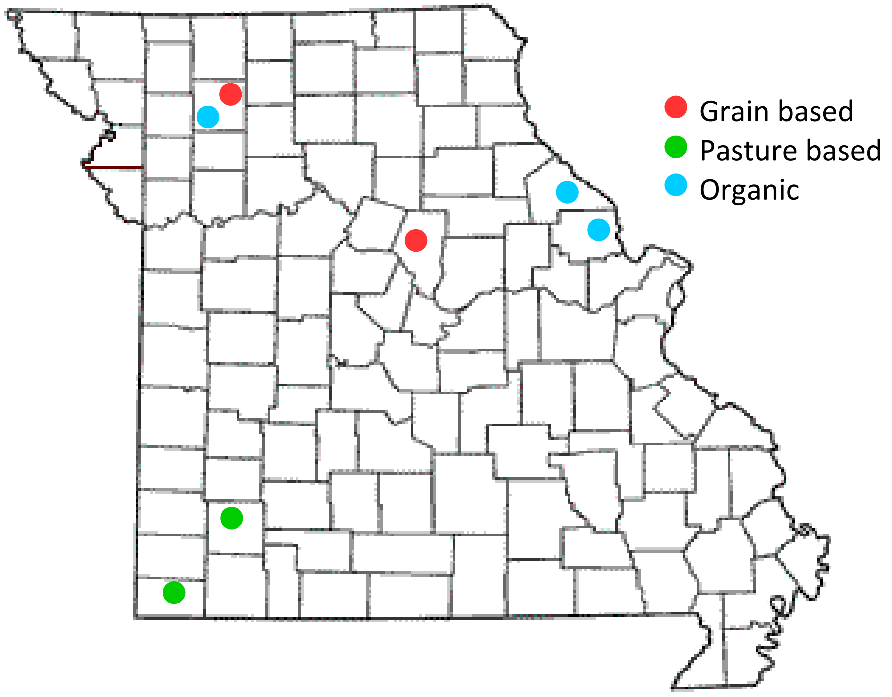

Figure 4.2. Location of surveyed farms within the State of Missouri

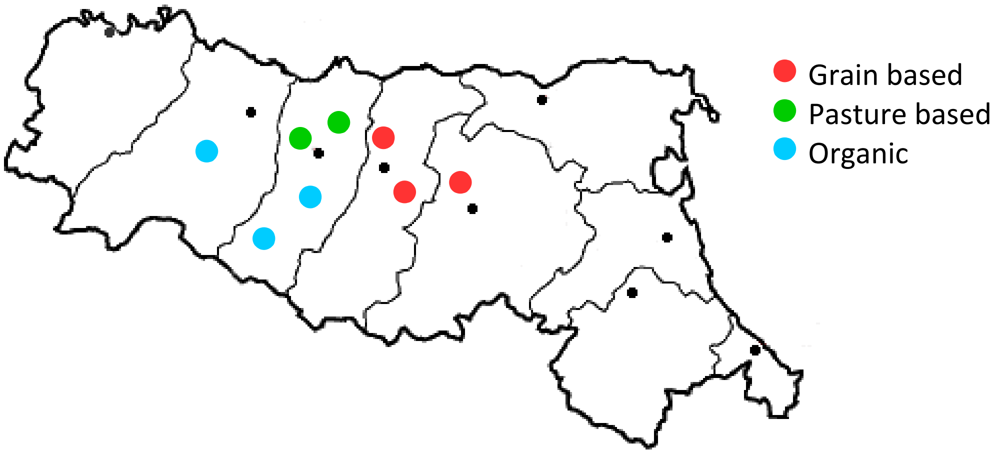

Figure 4.3 Location of surveyed farms within the Emilia Romagna region. This map is not drawn on the same scale of figure 4.2.

### *4.3.2 Rice farms in Missouri and Piemonte*

A number of studies were devoted to energy input in rice farming, but are mainly concentrate in Asia, were its consumption is higher: China (Lu et al 2010), Malaysia (Bockari Gevao et al, 2005), Japan (Saga et al 2010) Philippines (Mendoza 2002, Quilty et al 2014), Thailand (Caichana et al 2014), Iran (Eskandari 2015, Agha Alikani 2013, Pishgar-Komleh et al 2011) and Pakistan (Pracha and Wolf 2011).

As for milk, little attention was paid to Southern Europe and North America; the only studies devoted to the subject are an italian research (Blengini et al 2009) and a report not published on a peer reviewed journal (Pimentel 2006). The purpose of the case study research is to make an original contribution, by performing a comparative analysis of the energy inputs necessary for the production of rice in one region of southern Europe (Piemonte, Italy) and in one state of north America (Missouri, USA). Piemonte and Missouri have comparable populations (respectively 4,4 and 6 millions inhabitants), while the GDP per capita of Piemonte is comparable even if slightly lower (-7%). Emilia Romagna was not chosen for this study because its rice production is negligible (3,2% of the national production, Ente Risi 2013).

Piemonte is the first rice producing region in Italy, responsible for more than half of the national production and one quarter of the European; Missouri is the fifth rice producing State in the USA. Both areas have comparable values of area and rice production, even if Missouri is characterized by larger farms (see table 4.3) which are all located in the south east counties of the Mississipi delta region.

Italian rice is mainly of short and medium grain, while american rice is typically long grain, but the rice variety has non influence on the energy input, since the crop budget are identical for all varieties (MU 2014).

The main difference between the two rice cultivation system is linked to irrigation; most rice field in Piemonte can benefit from surface irrigation of the Cavour Canal which feeds a complex network of canals in the provinces of Novara and Vercelli. In Missouri there are non canal and water must be pumped from underground, adding an extra energy cost to the budget.

Table 4.3 Indicator for rice production in Missouri and Piemonte

| Indicator | Missouri | Piemonte |
|---|---|---|
| Farms | 435 | 2000 |
| Area (ha) | 72500 | 119000 |
| Production 2012 (1000 t) | 564 | 834 |

The analysis was performed on 12 rice farms of the two different typologies (chemical and organic), 5 in Missouri and 7 in Piemonte; as for the dairy case study, privacy of the data has been respected and all farms are indicated by a code: chemical (from C1 to C10) and organic (OR1 and OR2).

Farm characteristics are reported in table 4.4, while their location is indicated in figures 4.4 and 4.5.

The functional unit for the research is one kg of paddy rice after drying at 12% moisture. Milling was not considered since only two farms in the group where equipped with milling facilities.

Table 4.4. Farms surveyed in the case study according to the use of chemicals

| Farm | | Area (ha) | Yield (t/ha) |
|---|---|---|---|
| Missouri | C1 | 569 | 9,3 |
| | C2 | 142 | 8,0 |
| | C3 | 122 | 8,0 |
| | C4 | 1220 | 8,8 |
| | OR1 | 163 | 7,5 |
| Piemonte | C5 | 151 | 7,5 |
| | C6 | 90 | 6,14 |
| | C7 | 20 | 7,00 |
| | C8 | 58 | 5,18 |
| | C9 | 90 | 7,5 |
| | C10 | 71 | 7,24 |
| | OR2 | 110 | 6,13 |

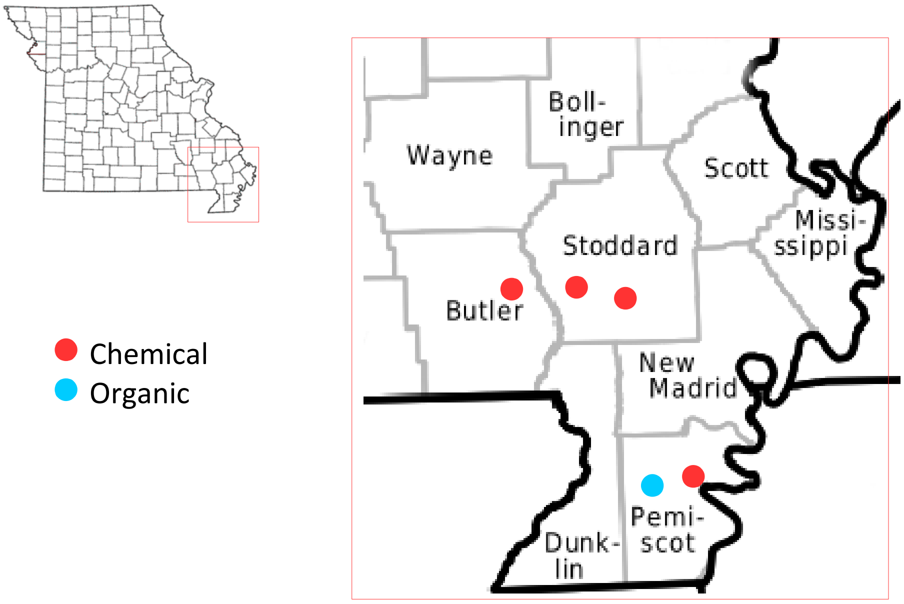

Figure 4.4 Location of surveyed farms within the  Mississipi Delta region of Missouri.

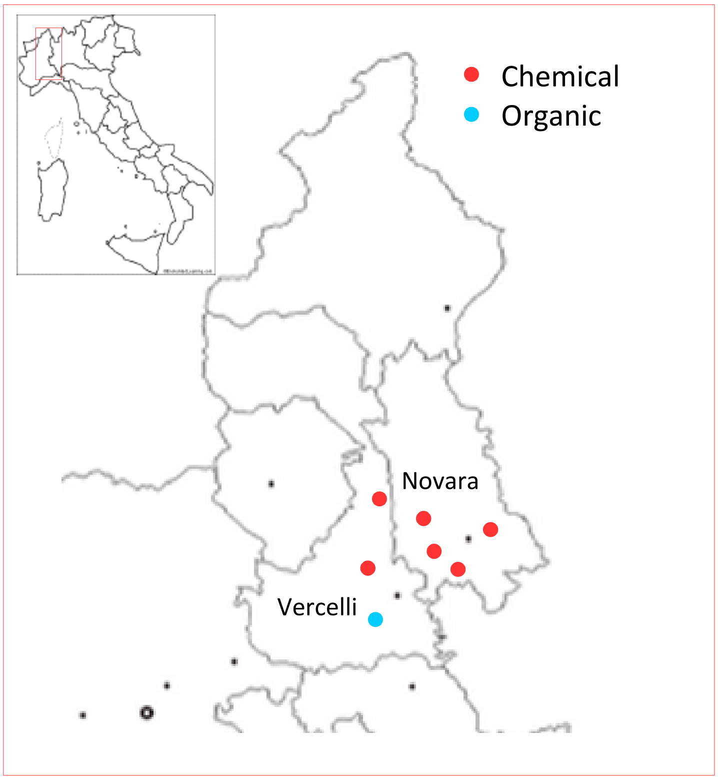

Figure 4.5 Location of surveyed farms within the Piemonte region. This map is not drawn on the same scale of figure 4.3.

### *4.3.3 Interviews with farmers*

From the first trial visit to a dairy farm in Missouri it was very clear that it was impossible to properly collect on line the data required for the case study. On the contrary, multiple advantages emerged from the field visits and the interviews with the farmers:

- understand the real life on the farm and the day-to-day farmers work and challenges;
- avoid possible suspicions and mistrusts through a face to face encounter;
- avoid technical misundestandings on single items of the interview;
- be sure to include all the direct and indirect energy inputs present in the farm;
- acquire new information about some previously unexpected issue related to the research.

Thanks to farmers advices, several aspects of the research were examined more in depth; for instance, a better understanding of organic fertilizer, heifers feed and pasture management was achieved in the case of dairy farms. For rice production, it was necessary to enhance the research on machinery, irrigation, rice drying and hulls management.

Visits on the fields required a significant time and effort, especially in Missouri, where the farms were scattered all around the state. Eight days were necessary to perform all the visits, with a total travel distance of 2800 km divided in four different trips (see table 4.5 and figure 4.6 (a)).

In Italy the visits required 5 days with a total travel distance of 700 km divided in two different trips (see table 4.5 and figure 4.6 (b))

Table 4.5 Travel distances for the field visits to the farms.
tineraries are shown in figures 4.6 (a) and (b)

| Itineray | | Period | Indicative destination | Visits | Distance (km) |
|---|---|---|---|---|---|
| Missouri | South east | December 2014 | Mississipi delta region | 5 rice farms | 1098 |
| | South west | December 2014 | Joplin | 2 dairy farms | 832 |
| | North east | November 2014 | Hannibal | 3 dairy farms | 396 |
| | North west | December 2014 | Jamesport | 2 dairy farms | 478 |
| | Total | | | | 2804 |
| Italy | Dairy | February 2014 | Modena, Reggio and Parma | 8 dairy farms | 598 |
| | Rice | February 2014 | Novara and Vercelli | 7 rice farms | 112 |
| | Total | | | | 710 |

Figure 4.6(a) Itineraries for the field visits in Missouri. All journeys started from Columbia

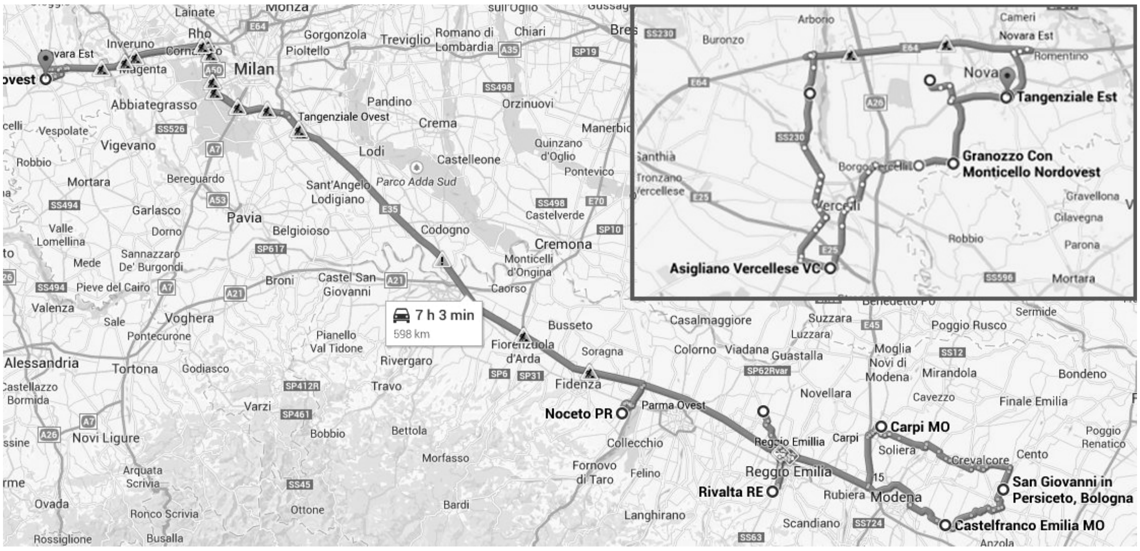

Figure 4.6(b) Itineraries for the field visits in Italy, dairy farms in larger map, rice farms in The frame in upper right corner. All journeys started from Novara

## 4.4 System boundaries

The assessment of energy inputs in milk production requires the analysis of several different items; as illustrated schematically in figure 4.7(a), these can be grouped in three sectors at the dairy level and three at the crops level.

At the dairy level it is necessary to consider structures (barns and warehouses), equipment (milk parlors and refrigerators) and materials (essentially animal feed). All three sectors have direct and indirect (embodied) energy costs.

The feed sector is dependend on the crop level (which may or may not be physically part of the farm), which as before is subdivided into structures (silos and hangars), machinery (tractors, harvesters, planters, carts) and materials (seeds, fertilizers and pesticides). Structures and machinery have direct and indirect costs, while for materials only indirect cost are considered, since direct costs are already included in the machinery sector.

The assessment of energy inputs in rice production is shown in figure 4.7(b). The system is similar, but simpler and include only the crop level: structures, machinery and matierials.

While direct energy inputs can be easily measured from data collected directly from the farms, the indirect inputs need a more complex and delicate analysys; typically they could be underestimated, since it is extremely difficult to include all possible contributions.

In the present work, the system boundaries have been set around the farm, considering:

- all direct inputs occurring in the farms level, both for dairy and rice;
- all indirect inputs immediately related to structures building, machinery manufaturing and materials production.

The present analysis does not include two factors: *(i)* energy consumption for equipment and material transportation, since it is impossible to reconstruct the whole network of movements of machinery fertilizers, forages and other items to the single farms: (ii) *second order* indirect inputs, like the energy used for building the factories that produced machinery or fertilizers, or the banks that granted the loans, or the law offices that wrote the contract.

It is possible to estimate that these two factor weighs about 10% of the total energy input for milk and 7% for cereal grains, so the present analysis is covering about 90-93%. According to the method of *Economic Input Output Life Cycle Assessment* (Hendrickson et al 2006), trasport energy represents 5,1% of the total energy for milk production, while all other costs that aren't included in the present analysis count for 5,5%. For cereal grains (there is no specific voice for rice) transport weighs for 4,2% andother voices less than 3% The analysis was run on the www.eiolca.net site and is related to the US 2002 Benchmark related to producer prices.

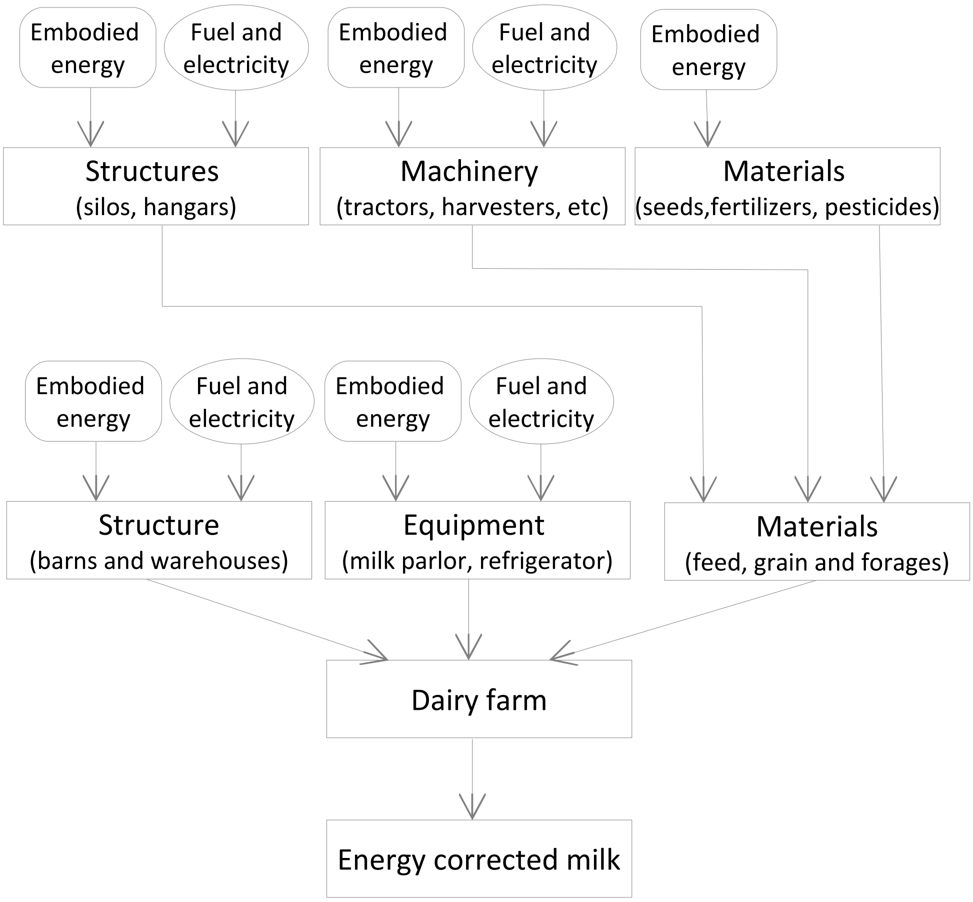

Figure 4.7 (a) Scheme for the assessment of direct and indirect energy costs for milk production

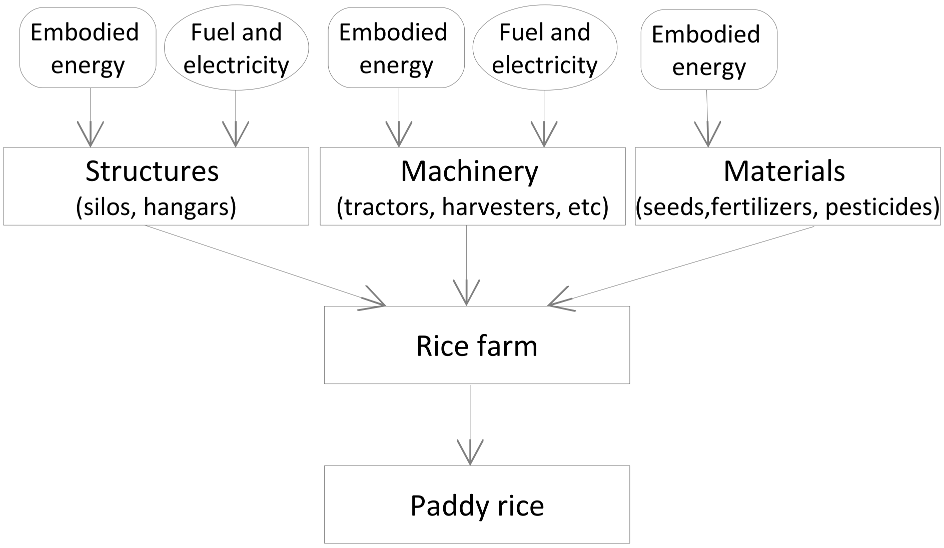

Figure 4.7 (b) Scheme for the assessment of direct and indirect energy costs for rice production

## 4.5 Specific techincal issues in dairy farming

### *4.5.1 Farm structures: silos and flat warehouses, milking palors and barns*

Silos are commonly used to store maize, maize silage and hay silage; the embodied energy cannot be neglected since a significant amount of steel is used for the building. Table 4.6 reports radius, heights, storage volume and steel mass of silos of different size (columns 1,2,3 and 4).

Embodied energy in steel is 35,3 MJ/kg for new material and 9,5 MJ/kg for recycled (Hammond & Jones 2008). Since in the US about 65% of steel has been recylced in the period 2008-2012 (Papp 2012), the average embodied energy is 18,5 MJ/kg of steel.

Table 4.6 Volume, mass and energy data realtive to steel silos

| Radius | Height | Storage volume V | Steel mass | Embodied energy | | |
|---|---|---|---|---|---|---|
| | | | | total | per year | per year and unit volume, *e* |
| m | m | $m^3$ | t | GJ | GJ/yr | $MJ/m^3$ year |
| 1,05 | 4 | 14,1 | 2,643 | 48,97 | 1,63 | 0,116 |
| 1,05 | 6 | 21 | 3,268 | 60,56 | 2,02 | 0,096 |
| 1,05 | 8 | 28 | 3,893 | 72,14 | 2,40 | 0,086 |
| 1,05 | 10 | 34,9 | 4,518 | 83,72 | 2,79 | 0,080 |
| 1,25 | 4 | 20,1 | 3,17 | 58,74 | 1,96 | 0,097 |
| 1,25 | 6 | 30 | 3,914 | 72,53 | 2,42 | 0,081 |
| 1,25 | 8 | 39,8 | 4,658 | 86,31 | 2,88 | 0,072 |
| 1,25 | 10 | 49,6 | 5,403 | 100,12 | 3,34 | 0,067 |
| 1,5 | 8 | 57,5 | 6,172 | 114,37 | 3,81 | 0,066 |
| 1,5 | 10 | 71,7 | 7,065 | 130,91 | 4,36 | 0,061 |
| 1,5 | 12 | 85,8 | 7,958 | 147,46 | 4,92 | 0,057 |
| 2,0 | 10 | 128,4 | 11,20 | 207,54 | 6,92 | 0,054 |
| 2,0 | 12 | 153,5 | 12,589 | 233,27 | 7,78 | 0,051 |
| 2,0 | 14 | 178,6 | 13,978 | 259,01 | 8,63 | 0,048 |
| 2,0 | 16 | 203,7 | 15,367 | 284,75 | 9,49 | 0,047 |
| 2,25 | 12 | 194,9 | 14,531 | 269,26 | 8,98 | 0,046 |
| 2,25 | 14 | 226,7 | 16,093 | 298,20 | 9,94 | 0,044 |
| 2,25 | 16 | 258,4 | 17,656 | 327,17 | 10,91 | 0,042 |
| 3,0 | 15 | 434,5 | 28,047 | 519,71 | 17,32 | 0,040 |
| 3,0 | 18 | 519,2 | 31,619 | 585,90 | 19,53 | 0,038 |
| 3,0 | 21 | 604 | 35,191 | 652,09 | 21,74 | 0,036 |

Source for geometrical and mass data: General Engineering corporation, for other data see text

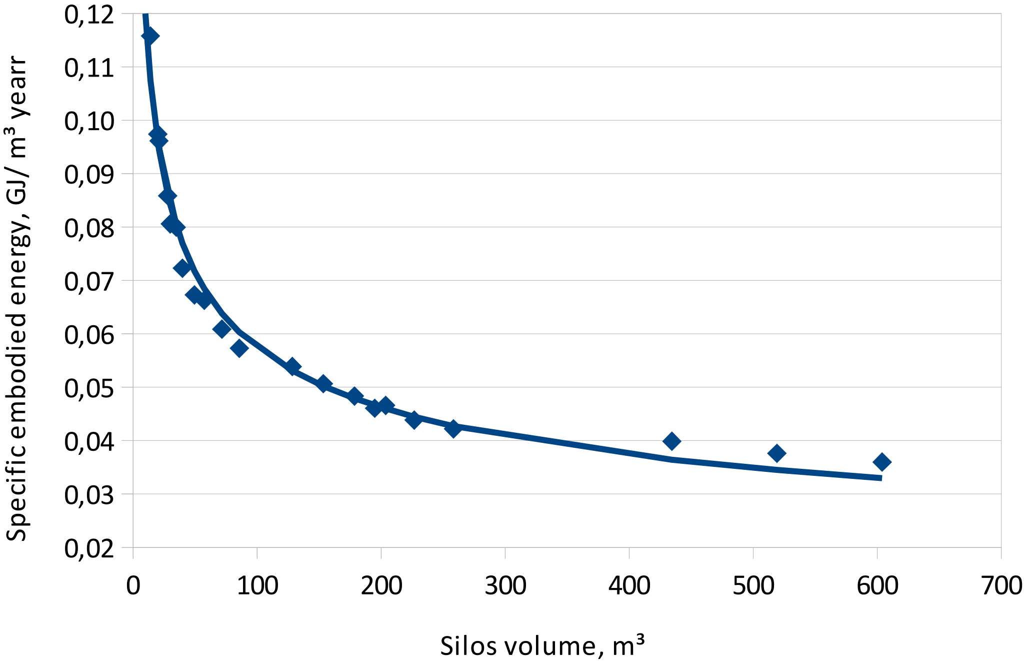

Figure 4.8 Embodied energy per year and unit volume in steel silos as a function of storage Volume. Continuos line is the graph of eq (1) in the text

Multiplying this value by the steel mass yields the total embodied energy (column 5 of table 4.6), which should be divided by the structure lifespan, which is estimated in 30 years (DLGF 2001), in order to allocate the proper value on a year basis (column 6). The last column reports the specific embodied energy per year and unit of storage volume.

Figure 4.8 shows the trend of specific embodied energy per unit time and volume as a function of storage volume; the superimposed continuos line is the curve of equation

$$e = 0{,}003 + \frac{0{,}25}{V^{1/3}} \quad , \tag{4.1}$$

obtained as best fit (r= 0,99) of data in table 4.5. The dependence on $V^{-1/3}$ is related to the fact that embodied energy is proportional to the silo surface, that is proportional to $V^{2/3.}$, while the asymptotic value of *e* is almost zero (it would be zero if all silos would have the same radius/height ratio).

In other words, as silos grow in size, the surface/volume ratio decreases and so does the the steel energy contribution to each cubic meter of storage space.

For storage volumes smaller than 50 m$^3$, the embodied energy decreases sharply as the volume increases, but over this value the size effect become less significant. For volume greater than 50 m$^3$ the average embodied energy is 0,05 ± 0,01 GJ/m$^3$ year. In order to compute the energy per unit mass of crop, it is necessary to divide this value by the crop density (dry matter density for silage), as it is reported in table

4.7. These energies are small, but not negligible with respect to other input sectors, as will be illustrated in chapters 5 and 6.

Table 4.7 Average impact of silos indirect energy on 1 kg of maize, maize silage and hay silage

| Forage | Density (t/m$^3$) | Input energy (GJ/t yror MJ/kg yr) |
|---|---|---|
| Maize | 0,72 (a) | 0,07 ± 0,01 |
| Maize silage | 0,23 (b) | 0,21 ± 0,04 |
| Alfalfa/Hay silage | 0,24 (b) | 0,20 ± 0,04 |

Source : (a) White (2012); (b) Bolsen et al. (1992); values are referred to dry matter

Silos are not suitable for stocking soybeans or soymeal, because they would be too much pressed and are more properly store in a flat warehouse.

As an example, the parameters of a typical grain warehouse with a single pitched roof are listed in table 4.8. It is assumed that the effective soy storage volume is one half of the geometrical volume of the building. The structure has precast concrete walls , a steel lattice and a PVC fabric.

Concrete has the highest embodied energy input, 25200 GJ, corresponding to a specific yearly value per kg of stored soybean of 0,04 MJ/kg yr. Steel structure contributes to another 0,007 MJ/kg yr, while PVC embodied energy is almost negligible (0,0003 MJ/hg yr, for this reason the detail of the computation were not reported in table 4.8).

Table 4.8 Parameters for computing embedded energy in a flat grain warehouse

| Warehouse parameters | | | Materials parameters | | |
|---|---|---|---|---|---|
| Length | 100 | m | *Steel* | | |
| Width | 50 | m | Density for unit of floor area (c) | 50 | kg/m² |
| Walls height | 5 | m | Total mass | 250 | t |
| Roof height | 16 | m | Embodied energy (d) | 4632 | GJ |
| Floor area | 5000 | m² | Spec. energy per year & kg soy | 0,007 | MJ/kg yr |
| Geometric Volume | 52500 | m³ | *Precast concrete* | | |
| Storage volume | 26250 | m³ | Density for unit of floor area (e) | 2665 | kg/m² |
| Lifespan (a) | 30 | yr | Total mass | 13300 | t |
| Soybean density (b) | 0,75 | t/m³ | Embodied energy | 25200 | GJ |
| Soybean mass | 20700 | t | Spec. energy per year & kg soy | 0,04 | MJ/kg yr |

Sources: (a) DLGF 2001; (b) Schroeder 2012; (c) Steelconstruction 2011; (d) Specific energy 18,5; MJ/kg steel, see section 1.1; (e) Value elaborated from precast concrete supplier data <http://hansonsilo.com/bunkers-media.php>

This analysis was repeated for different warehouse storage volumes from 10000 to 180000 m³ with similar ratios among geometrical dimensions obtaining an average input value of 0,037 ± 0,008 MJ/kg yr for concrete and 0,008 ± 0,0006 MJ/hg yr for steel with a total input of 0,045 ± 0,009 MJ/kg yr.

The embodied energy in milk parlors increases linearly with the number *x* of cow stalls according to the relation *E*(GJ) = 24,2 *x* + 293 (Wells 2001, least square fit over 13 parlors, $R^2$=0,96). There is no significant difference between herringbone and rotary parlors.

Assuming a lifetime of 30 years (DLGF 2001), the energy input is

(4.2) $E_{milk} = 0{,}81\,x + 9{,}77$ GJ/stall year

Depending on the efficiency of operations, one stall can generally accomodate from 12 to 32 cows milked twice a day (Smith et al., 2003), so the input per cow should reduced by the same factor. Taking into account that the average 2012-2013 Missouri productivity is 6718 kg of milk per cow (USDA 2014) , it is possible to compute the specific embodied energy of milking parlors per kg of milk and year (figure 4.9).

Owing to the high fixed cost in eq (4.2), the embodied energy decreases for increasing herd size, but even for small farms the amount of energy is almost negligible.

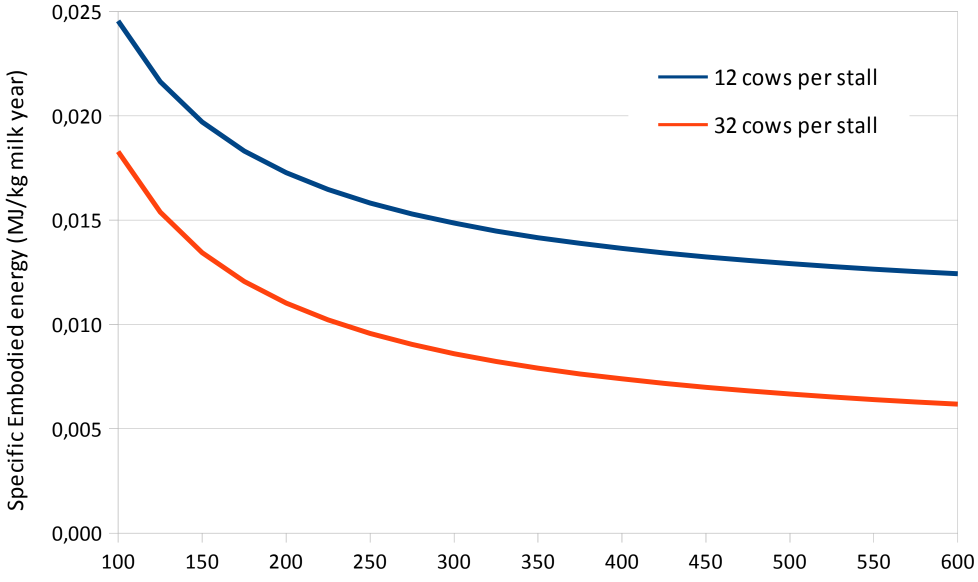

Figure 4.9 Specific embodied energy of milk parlors per kg of milk and year vs herd size

The embodied energy in dairy stables is slightly higher: 1,5 ± 0,8 GJ per cow per year (Koesling 2013), which is equivalent to 0,22 ± 0,12 MJ/kg of milk with the current Missouri productivity. The embodied energy for milk tank is negligible: the steel mass of a small tank of 1000 liters is around 265 kg, that is 2516 MJ, that is 168 MJ/year with a lifetime of 15 years which is equivale to $2 \cdot 10^{-4}$MJ/kg of milk.

### *4.5.2 Machinery for field operations*

Farm machines typically used for forage or crop field operations in Missouri are listed in table 4.9, together with masses, yearly use time and lifespan (fist three columns). Yearly value for embodied energy has been computed by multiplying the embodied energy factor of 140 MJ/kg (see paragraph 3.3) by the machinery mass and dividing by the lifespan.

Table 4.9 Mass, use time, lifespan and embodied energy of farm machinery

| Type of machinery | Total mass [(a)] | Use time [(b)] | Lifespan [(c)] | Embodied energy |
|---|---|---|---|---|
| | kg | hours/year | years | MJ/year |
| Tractor 45 kW | 2298 | 400 | 15 | 21445 |
| Tractor 55 kW | 2612 | 400 | 15 | 24374 |
| Tractor 80 kW | 4293 | 450 | 15 | 40063 |
| Tractor 100 kW | 5780 | 450 | 15 | 53944 |
| Tractor 120 kW | 6472 | 500 | 15 | 60402 |
| Tractor 150 kW | 8198 | 500 | 15 | 76513 |
| Tractor 200 kW | 10609 | 300 | 15 | 99015 |
| Tractor 230 kW | 13642 | 400 | 15 | 127323 |
| Field cultivator – 6 m | 3800 | 100 | 12 | 44333 |
| Field cultivator – 12 m | 4300 | 100 | 12 | 50167 |
| Row crop planter – 6 row | 8237 | 80 | 12 | 96908 |
| V-Ripper – 3m | 5316 | 100 | 12 | 62020 |
| Tandem disk – 10m | 5223 | 100 | 12 | 60929 |
| Split row no-till planter – 16/31 row | 1104 | 130 | 12 | 12880 |
| Boom sprayer – 10 m | 385 | 100 | 12 | 4488 |
| Anhydrous applicator – 7 m | 454 | 250 | 12 | 5297 |
| Disk mower-conditioner – 3m | 1697 | 80 | 12 | 19798 |
| Swather mower-conditioner – 3 m | 1253 | 80 | 12 | 14618 |
| Wheel rake, V hitch –8 wheel | 460 | 80 | 12 | 5367 |
| Hay tedder – 3 m | 180 | 250 | 12 | 2100 |
| Small square baler | 1905 | 250 | 12 | 22225 |
| Round baler, silage kit – 750 kg | 2313 | 250 | 12 | 26985 |
| Round bale wrapper haylage | 1870 | 250 | 12 | 21817 |
| Combine, flexible grain head – 30 ft | 2886 | 120 | 12 | 33670 |
| Combine, corn head - 8 row. | 2650 | 200 | 12 | 30917 |
| Grain cart - 500 bushel | 2672 | 120 | 12 | 31170 |
| Grain auger 5000 bu/hr – 25 m | 1633 | 200 | 12 | 19051 |
| Silage Chopper, 2 row – 2m | 1100 | 400 | 12 | 12833 |

Sources : (a) Catalogues of different machinery manufacturers
(b) FAPRI (2014): (c ) Edwards (2009);

In USA, lifespan was assumed to be 15 years for tractors and 12 years for other equipment (Edwards 2009). Embodied energy values in column 5 are related to the machine total annual use time; the embodied energy related to a particular crop can be computed by knowing the actual working time per hectare of all machinery involved in the cultivation and the crop yield. Both informations are available from FAPRI data (2014) and are used later in section 4.5.6.

One of the farms surveyes pulled its equipment with horses instead of tractors. In this case, the related energy consumption was assumed to be related to two items: energy to prepare the feed and energy embodied in stables. It was assumed that a 700 kg heavy working horse needs 8 kg/day of grains and 9 kg/day of hay (ISU 1997). According to the specific energy input of feed (see paragraph 4.5.6) it is possible to estimate an average daily input of 27 MJ).

Machinery masses used in italian farms were estimated from their power according to an average mass/power ratio of 60 kg/kW (Lazzari 2010). Lifetime for italian tractors and combines is estimated to be around 40 years by considering the machinery stock and the rate of renewal (Federunacoma 2002). At first impression, this value apperas to be quite high compared with the american lifetime, but it has been confirmed by all the field visits: all farms keep their tractors even when they are very very old until they are no more woring , eventually just to perform simple tasks.

### 4.5.3 Chemical and organic fertilizer use

The different nitrogen products employed in the US agriculture are reported in table 4.10. Their mixture is equivalent to a weighed average input energy of 43,14 MJ/kg N. The energy input for ammonia aqueous solution has been determined by its nitrogen content. The input for UAN 32 Nitrogen solution has been computed as a weighed average of ammonium nitrate (45%) and urea (35%) in the solution. The average input energy for Italy is higher (46,57 MJ/kg) owing to the grater use of urea, which is the most energy intensive fertilizer.

For other fertilizers the input energy values reported in table 3.4 of the literature review was used and specifically 15,8 MJ/kg $P_2O_5$ for phophate, 9,3 MJ/kg $K_2O$ for potash and 2,1 MJ/kg CaO for lime.

Average Missouri use of fertilizer on the most important crops used for animal pastures are listed in table 4.11.

These values have been used whenever more detailed information on fertilizer application were not available. Typical Nitrogen use in Emilia Romagna is 120 kg/ha for barley and hay, 130 kg/ha for wheat and sorghum and 19 kg/ha for alfalfa (Bortolazzo et al, 2007); these values were used as default when no other specific information was available

Table 4.10 Determination of the average value of nitogen fertilizer input energy according to the actual use of different products in the USA and in Italy

| | N fertilizer | N mass fraction | 2001-2011 Average use (a) | N content | Input Energy (b) | Total energy |
|---|---|---|---|---|---|---|
| | | % | Mt | Mt | MJ/kgN | PJ |
| USA | Anhydrous Ammonia | 82,24% | 3,65 | 3,00 | 38,6 | 115,87 |
| | Ammonia solution | 20,00% | 0,32 | 0,06 | 9,39 | 0,60 |
| | Ammonium Nitrate | 35,00% | 1,05 | 0,37 | 40,6 | 14,92 |
| | Ammonium Sulphate | 21,20% | 1,12 | 0,24 | 42 | 9,97 |
| | UAN | 32,00% | 9,58 | 3,07 | 44,28 | 135,73 |
| | Urea | 46,62% | 4,94 | 2,30 | 49 | 112,85 |
| | Total | | 20,66 | 9,04 | | 389,94 |
| | *Average* | | | | *43,14* | |
| Italy | Ammonium Nitrate | 35,00% | 0,107 | 0,037 | 40,6 | 1,52 |
| | Ammonium Sulphate | 21,2% | 0,042 | 0,009 | 42 | 0,38 |
| | Urea | 46,62% | 0,345 | 0,161 | 49 | 7,89 |
| | Others | 32,00% | 0,085 | 0,027 | 42 | 1,14 |
| | Total | | 0,580 | 0,234 | | 10,94 |
| | *Average* | | | | *46,57* | |

Sources: (a) USDA 2013 ISTAT 2014; (b) table 3.4 of literature review of the present work

Table 4.11 Fertilizer used in Missouri crops and forages in kg/ha

| Cultivation | Nitrogen | Phosphate | Potash | Lime |
|---|---|---|---|---|
| Maize | 157 | 67 | 50 | 1 |
| Soybeans | 0 | 45 | 78 | 1 |
| Maize silage | 112 | 67 | 50 | 1 |
| Fescue clover hay | 45 | 52 | 67 | 1 |
| Alfalfa | 0 | 78 | 224 | 0 |

Source: FAPRI 2014

Organic farms do not use chemical synthetic Nitrogen fertilizers, so the required N is applied to fields in form of manure, green manure, compost or biological fixation by legumes. With the exception of the latter, these organic inputs sometimes provide also the required amount of phosphate and potash.

The specific energy input of 1 kg of manure can be assessed by knowing its N-P-K content (Stout 1990). Average nutrient contents of the most used types of manure are listed in table 4.12 (cow manure wasn't considered because it is recycled directly in the farm fields and its input energy is already accounted in all other voices). The N-P-K content of poultry manure can vary about 15-30%, according to different type of livestock (broiler, breeder, grower etc) and processing.

The variation for pig slurry is generally much higher, more than one order of magnitude; in the case of the present analysis, however there is no uncertainty, because the precise content of the only farm using pig manure (O3) is known (column 2 of table 4.12).

Table 4.12. Typical nutrient composition of manures (range in parenthesis)

| Nutrient | Pig slurry [(a)] | Pig slurry [(b)] | Turkey manure [(c)] | Chicken manure [(c)] | Pelleted Chicken manure [(d)] | Horn and hoofs[(e)] |
|---|---|---|---|---|---|---|
| | kg/m³ | kg/m³ | kg/t | kg/t | kg/t | kg/t |
| Total N | 3,27 (0,6-12) | 3,37 | 2,18 (1,75-2,7) | 2,79 (1,7-3,6) | 4,5 | 100 |
| Phosphate | 0,94 (0,04-3,9) | 0,70 | 2,51 (2,15-3,2) | 3,13 (2,65-3,45) | 3,5 | 0 |
| Potash | 1,16 (0,09-5,3) | 2,84 | 1,43 (0,9-1,95) | 2,01 (1,65-2,3) | 2,5 | 200 |

Sources: (a) Sanchez and Gonzalez (2005); (b) Data from farm OP3;(c) Chastain et al. (2014); ,

(d) commercial pellet information (e) Data from farm OR2

N, P and K contained in the manure have their origin in chemical fertilizers , so the energy content of the manure can be evaluated by multiplying each nutrient content by its specific energy input (see previous paragraph); for instance, in the case of the pig slurry of farm O3, the specific input energy is given by

$$E = 43{,}1\ \mathrm{MJ/kg} \cdot 3{,}37\ \mathrm{kg/m^3} + 15{,}8\ \mathrm{MJ/kg} \cdot 0{,}70\ \mathrm{kg/m^3} + 9{,}3\ \mathrm{MJ/kg} \cdot 2{,}84\ \mathrm{kg/m^3} = 182{,}9\ \mathrm{MJ/m^3}.$$

The computed energy inputs for the manures in table4.12 are reported in table 4.13.

Table 4.13 Energy inputs for different manures

| Nutrient | Pig slurry [(a)] | Pig slurry [(b)] | Turkey manure [(c)] | Chicken manure [(c)] | Pelleted Chicken manure [(d)] |
|---|---|---|---|---|---|
| | MJ/m³ | MJ/m³ | GJ/t | GJ/t | GJ/t |
| Total Nitrogen | 141 | 145,4 | 0,94 | 1,20 | 1,94 |
| Phosphate | 14,9 | 11 | 0,40 | 0,49 | 0,55 |
| Potash | 10,8 | 26,4 | 0,13 | 0,19 | 0,23 |
| Total energy | 166,8 | 182,9 | 1,47 | 1,88 | 2,73 |

Sources: (a) Sanchez and Gonzalez (2005); (b) Data from farm O2;(c) Chastain et al. (2014); ,

(d) commercial pellet information

The energy input for organic compost from municipal waste is about 0,4 MJ/kg (Martinez-Blanco et al, 2009). Energy comes from electricity and fuel used to process and transport the compost. Energy embodied in the organic biomass wasn't considered, because this waste would have gone to a landfill if not properly composted, so it can be considered a zero cost resources.

### *4.5.4 Pesticides*

Energy use for herbicide production is listed in the firt column of table 4.14 (Green 1987 and Audsley et al. 2009). Herbicide use intensity in Missouri maize and soybeans cultivation is available from the National Agricultural Statistcs Service (NASS 2006) and is listed in the second and third columns of the same table. Use of insecticides and fungicides on these crops is negligible.

Total chemical agent use has been computed multiplying specific use by the 1997-2012 average crop areas, that are 1,2 Mha for maize and 2,0 Mha for soybeans (USDA 2012).

Table 4.14 Average energy input for herbicides for maize and soybean cultivation in Missouri. Total use computed using 1997-2012 average crop areas: maize 1,2 Mha,soybeans 2,0 MHa (USDA 2012)

| Herbicide type | | Specific use [(b)] | | Total use | | Total energy expenditure | |
|---|---|---|---|---|---|---|---|
| | Energy input [(a)] | Maize | Soy | Maize | Soy | Maize | Soy |
| | MJ/kg | kg/ha | kg/ha | kt | kt | TJ | TJ |
| Acetochlor | 278 | 2,44 | | 2,91 | | 810 | |
| Imazaquin | 518* | 2,28 | | 2,71 | | 1406 | |
| Cyanazine | 221 | 2,28 | | 2,71 | | 600 | |
| Metolachlor | 276 | 1,92 | 2,28 | 2,29 | 4,55 | 631 | 1257 |
| Atrazine | 208 | 1,57 | | 1,87 | | 389 | |
| Dimethenamid | 519* | 1,15 | | 1,38 | | 715 | |
| Simazine | 226* | 0,99 | | 1,18 | | 266 | |
| Glyphosate | 474 | 0,78 | 1,02 | 0,94 | 2,04 | 444 | 967 |
| 2,4D | 107 | 0,49 | 0,58 | 0,59 | 1,17 | 63 | 125 |
| Bromoxynil | 302* | 0,28 | | 0,33 | | 101 | |
| Clopyralid | 432* | 0,11 | | 0,13 | | 58 | |
| Mesotrione | 691* | 0,09 | | 0,11 | | 74 | |
| Trifluralin | 171 | | 1,01 | | 2,02 | | 345 |
| Pendimethalin | 421* | | 0,99 | | 1,97 | | 831 |
| Paraquat | 460 | | 0,76 | | 1,53 | | 702 |
| Pyraclostrobin | 702* | | 0,12 | | 0,25 | | 173 |
| Total | | 14,38 | 6,76 | 17,16 | 13,52 | 5557 | 4400 |
| | | | | | | | |
| Average input energy in Missouri (MJ/kg active ingredient) | | | | | | 323,90 | 325,32 |

Sources: (a) Green (1987) and Audsley et al. (2009, values with *); (b) NASS (2006)

By performing a weighed average of all herbicides with the aid of the last columns, the average input energy is equal to 323,9 MJ/kg for maize and 325,32 MJ/kg for soy. Despite the fact that chemicals use is quite different between the two crops, the final result is almost identical. On a per hectare basis, however energy input is significantly higher for maize (4658 MJ/ha) than for soy (2200 MJ/ha).

It has to be noted that these value reflect the particular use of pesticides in the State of Missouri and may be different from other States  or from the Nation average.

### 4.5.5 Seeds

The production of hybrid and genetically engineered seeds is very energy intensive and requires about 104 MJ per kg of seeds for maize (Patzek 2004) and 33,4 MJ/kg of seeds for  soybeans. (Pimentel and Patzek 2005).  Taking into account the typical Missouri seed density and crop yield  (FAPRI 2014) the specific energy input  is 0,30 and 0,76 MJ per kg of crop respectively.

Table 4.15 reports the details of the calculation, together with the energy input for the most common forages.

Table 4.15. Computation of energy required for seed production

| Crop or forage | Energy for seed production | Seed density [(d)] | Area energy input | Crop yield [(d)] | Specific enerfy input |
|---|---|---|---|---|---|
| | MJ/kg seeds | kg/ha | MJ/ha | kg/ha | MJ/kg of crop |
| Maize | 104 [(a)] | 24,6 | 2560 | 8470 | 0,30 |
| Soybeans | 33,4 [(b)] | 69,4 | 2317 | 3030 | 0,77 |
| Maize silage | 104 [(a)] | 18,8 | 1960 | 17900 | 0,11 |
| Alfalfa | 259[(c)] | 6,8 | 1760 | 11700 | 0,15 |
| Hay | 88[(c)] | 6,3 | 560 | 6750 | 0,08 |

Sources: (a)Patzek (2004); (b) Pimentel and Patzek (2005); (c) Pimentel (2008)
(d) FAPRI 2014,    (e) White and Johnson (2003);

### 4.5.6 Energy input for maize, soy and forages and byproducts

Energy input for the most important animal feeds have been computed using the methods outlined in the previous paragraphs, assuming standard fertilizer and pesticide inputs (FAPRI 2014 and NASS 2006). The results are reported in table 4.15 and exploded for each  sector in Figure 4.10, while the detailed calculations for each crop are reported in  the annexes (chapter 10).

The  energy inputs reported by Pimentel (2008) for corn, soy and forages are about twice the values reported in table 4.16, owing to an overestimation of nitrogen process energy (see chapter 3) and unrealistic assumption for fuel consumption  and machinery  allocation, respectively three and ten times greater than the values assessed by FAPRI (2014).

Table 4.16 Energy input intensity for the production of crops and forages used for animal feed

| Crop | Input energy (MJ/kg) |
|---|---|
| Maize | 2,21 |
| Soybeans | 2,75 |
| Maize silage | 1,10 |
| Alfalfa | 1,28 |
| Hay | 1,06 |

Source: Author elaboration

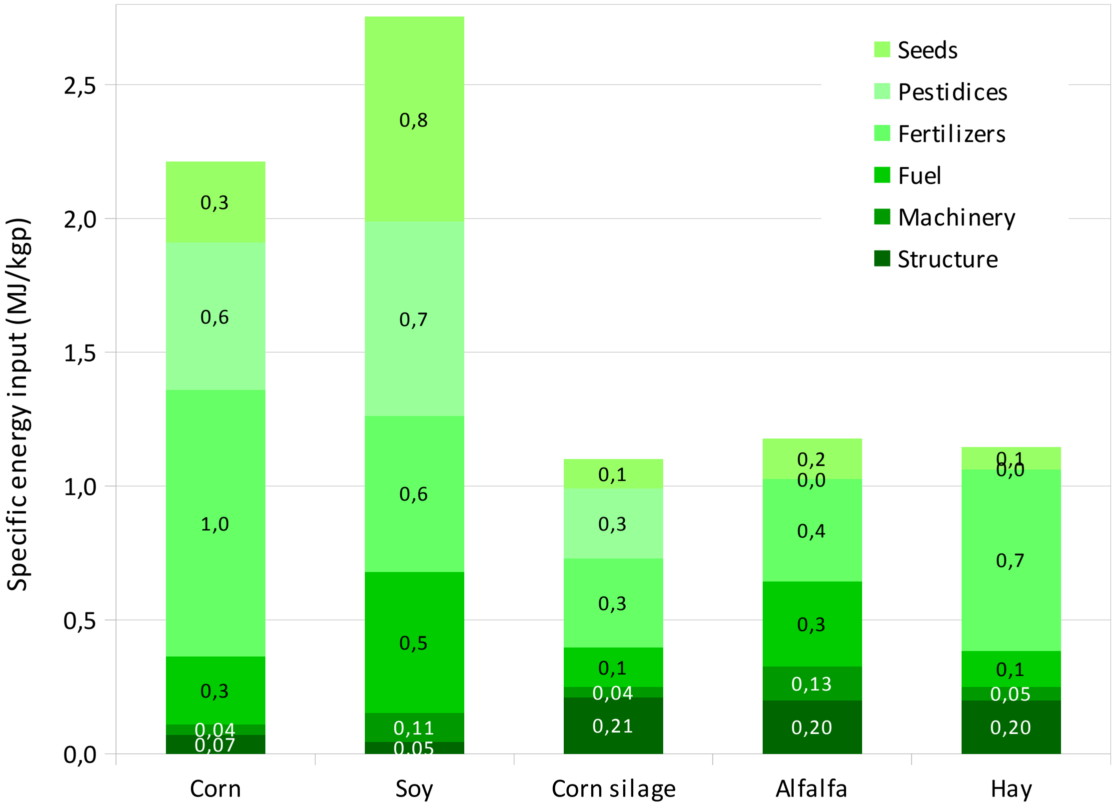

Figure 4.10 Energy input intensity for the production of crops and forages used for animal feed split for the different sectors

Soybeans require is the most energy intensive crops owing to the lower yields; maize comes second and the most important item in its energy cost comes from nitrogen fertilizers. Forages requires lower input; the higher incidence of structures, due to the low density of dry matter, is more than compensated by absence of pesticides (alfalfa and hay) or by the high yields (maize silage).

Only a small fraction of soybean production is used directly as feed, since the most is given to animals in the form of *soybean cake* and *soybean hulls*, after extraction of oil for human consumption. This process yields 79,2% of cake, 18,7% of oil and 2,1% of hulls (average of US processing from 2000 to 2011, FAOSTAT 2014a) and requires an input of 3,89 MJ per kg of soybeans (Kim and Dale 2002) that sums up to 6,63 MJ/kg by taking into account the energy for cultivation (table 4.16). It is assumed that this energy is embodied equally in each mass unit of the three byproducts (cake, oil and hulls)

*Gluten maize feed* and *gluten maize meal* are by products of the wet milling process for bioethanol production and are used as protein supplement in animal feed. Maize processing requires 8,76 MJ per kg of maize and yields 50,8% of ethanol, 34,5% of gluten feed, 8,1% of gluten meal and 6,6% of oil. (Kim and Dale 2002).

As before, it is assumed that the agriculture and process energy of 10,96 MJ/kg (8,76 + 2,21 of table 4.15) is embodied equally in ethanol and gluten fedd/meal.

*Dried distillery grain and solubles* (DDGS) are a by product of the dry milling process fr bioethanol production. In this case maize processing requires 8,46 MJ/kg and yields 52,1% of ethanol and 47,9% of DDGS. (Kim and Dale 2002).

Again, it is assumed that the agriculture and process energy of 10,67 MJ/kg (8,46 + 2,21 of table 4.12) is equally embodied in all byproducts.

The third important commodity used in animal feed is the byproduct of the beer industry, commonly known as brewers' spent grains. Barley is the most important cereal used for beer production and requires about 2,8 MJ/kg for its cultivation (Khan et al. 2010), while the brewing process counts for other 2,13 MJ per kg of barley (Kløverpris et al., 2009), for a grand total of 4,93 MJ/kg.

For every kg of barley used in the process 0,71 kg of spent grains, sharps and sprouts are produced and only 0,29 kg end up in beer (Kløverpris et al., 2009). As before, it is assumed that this energy is equally embodied in spent grain and beer

This assumption may seem unrealistic, since the market price of beer is roughly sixty times the values of spent grains; however, the present economic value of beer is a direct consequence of the current over abundance of cereals. In case of shortage or famine, one would prefer to eat 100 g of barley (1,48 MJ of nutritional value), instead of drinking the equivalent values of 380 g of beer (only 0,65 MJ).

The true value of spent grains can be fully appreciated when they are used as a source of energy for the brewing process itself, allowing to supply 100% of electricity and 60% of the steam used in the process reducing fossil fuel consumption by 87% (FAO 2009). Moreover there is increasing interest in in using spent grains for human nutrition (Mussatto et al 2006).

### *4.5.7 Energy for feeding heifers*

Cows are typically kept for a number of lactations ranging from 2 to 3 in larger industrial farms and from 4 to 6 in smaller traditional ones. After that period they are usually sold for meat, owing to low productivity, difficulty to become pregnant or for illnesses, and must be replaced by a new generation.

The breeding of heifers requires energy inputs than can be subdivided in three periods: *(a)* milking (60 days) and *(b)* weaning and growth until calving.

*(a)* During milking, calves are feed with milk or milk replacer with an average daily ration of 3,5 kg/day (ranging from 2,5 kg/day at birth to 4,5 kg/day at the beginning of weaning, Wattiaux 2014). When farms are using dirctly their own milk for calves, this is subtracted from the production data and no energy cost are allocated. If on the contrary farms are buying milk or replacer, it is necessary to allocate an average energy cost of milk production and processing; it is assumed that the energy cost is the same in both cases, since the replacer is generally made of milk by products, which, as assumed before for maize and soy byproducts, share the same embodied energy of the main products (cheese, butter, cream). No data are available for US milk, so it was chosen to use an "international" value of 3,4 MJ/kg, obtained by averaging 22 different studies on the subject (see paragraph 5.3.3). Assuming a milking period of 60 days, the total energy input is $E_M$ = 0,7 GJ. This input value is small considered to the energyused in the following phase.

(b) During weaning and growth, the average specific input of a typical feed can be estimated in 4 MJ per kg of dry matter (see table 4.17 for details).

Table 4.17 Typical diet for heifers from weaning to calving and embodied energy in the different feed products. All data are referred to dry matter

| Feed products | Diet composition at [(a)] | | Specific input energy | Input energy in mixture | |
|---|---|---|---|---|---|
| | 4 months | 23 months | | 4 months | 23 months |
| | % | % | MJ/kg DM | MJ | MJ |
| Hay | 8,0% | 15,0% | 1,19 | 0,10 | 0,18 |
| Corn silage | 12,0% | 25,0% | 3,14 | 0,38 | 0,79 |
| Corn | 40,5% | 31,25% | 2,47 | 1,00 | 0,77 |
| Soybean meal | 9,0% | 0,0% | 7,46 | 0,67 | 0,00 |
| DDGS | 7,0% | 15,0% | 11,99 | 0,84 | 1,80 |
| Wheat Middlings | 10,0% | 10,0% | 0,36[(b)] | 0,04 | 0,04 |
| Molasses | 10,0% | 0,0% | 6,84 [(b)] | 0,68 | 0,00 |
| Urea | 0,5% | 0,75% | 49 | 0,25 | 0,37 |
| Lime | 3,0% | 3,0% | 2,1 | 0,06 | 0,06 |
| Total | 100,0% | 100,0% | - | 4,01 | 3,99 |

Sources: (a) Zanton and Heinrichs (2008); (b) Davulis and Frick (1977) and paragraph 4.5.6, Input energies are referred to 1 kg of dry matter

The daily dry matter mass intake of heifers can be modeled according to the data of Zanton and Heinrichs (2008) as

(4.3) $m(t)=0{,}0122\,t+1{,}340 \quad (kg_{DM}/day)$ ,

and the related embodied energy is

(4.4) $e(t)=0{,}0496\,t+5{,}362 \quad (MJ/day)$

where *t* is the heifer age (days) assuming that weaning starts after 60 days. The total feed embodied energy from weaning to calving is then the integral of (4.3) evaluated between weaning time and calving time $T_C$:

(4.5) $E(T_c)=0{,}0248\,T_c^{\,2}+5{,}362\,T_c-402{,}6 \quad (MJ)$ .

For $T_C$=24 months, the total embodied energy is of the order of 16 GJ for a total feed mass of 4 tons. This energy input was used for every cow (milking and dry) in the herd; in order to allocate this value to one year, it must be multiplied by the *herd turnover rate r*, that is the number of cows that must be replaced each year owing to sales, illnesses or deaths:

(4.6) $E_{cow}(T_c, r)=r\cdot[E(T_C)+E_M]$

In order to understand the meaning of eq (4.6), let's suppose that $r$ = 25%; in this case it is necessary to allocated each year a 25% of the total input for feed, since the cow's life before its replacement is 4 years.

### *4.5.8 Direct energy consumption*

Direct energy consumption refers to fuel consumption for equipment and machinery and electrical energy. In order to compute energy consumption related to fuel, higher heating values (HHV) have been considered, since HHV represents the maximum energy available from the combustion of 1 kg of fuel.

Actual machines may not exploit all this energy if they aren't equipped with water vapor condensation, but the HHV is in any case a measure of the energy recoverable from a particular fuel. HHV and densities for the most common fuels used in agricultural operations are listed in table 4.18.

The net electrical energy consumption is accounted with the well known equivalence 1 kWh = 3,6 MJ. In 2013 the US power network used 41,3 EJ of energy from coal, natural gas, uranium and other fuels in order to produce 13,7 EJ for the end user (EIA 2013), so1 MJ for the end user is equivalent to 3 MJ of primary energy.

The situation is significantly different in Italy, where nearly 40% of electricity production is provided by renewable sources (hydroelectric, photovoltaic, eolic and geothermal): in this case in 2013 the italian power network used 1278 PJ of fossil energy in order to produce 998 PJ of electrical energy (MSE 2013), so 1 MJ for the end user is equivalent to 1,28 MJ of primary energy.

Energy produced from renewable sources (photovoltaics or biogas) was not accounted, since it doesn't imply consumption of fossil resources.

Table 4.18 Fuel heating values

| Fuel type | Density | Higher heating value | | Lower heating value | |
|---|---|---|---|---|---|
| | kg/l | MJ/kg | MJ/l | MJ/kg | MJ/l |
| Diesel fuel | 0,832 | 44,8 | 37,27 | 43,4 | 36,11 |
| Gasoline | 0,755 | 47,3 | 35,71 | 41,2 | 31,1 |
| LPG | 0,51 | 50,35 | 25,68 | 46,35 | 23,6 |

### 4.5.9 Energy corrected milk

In order to compare milk from several farms that are characterized by different values of fat and rotein concentration it is necessary to normalize the data. It is possible to do so by using the so-called energy corrected milk (ECM).

ECM expresses the amount of energy in milk according to the following formula (DRMS 2014):

$$ECM = 12{,}95\,f + 7{,}65\,p + 0{,}327 \quad , \tag{4.7}$$

which gives the multiplying factor for normal milk, where *f* is the fat concentration (%) and *p* the true protein concentration (%) (94,06% of total protein content). As can be seen from table 4.19, fat and true protein and standardized respectively to 3.5% and 3%.

Table 4.19 ECM factor for different concentration of fat and protein in milk

| | | True protein concentration | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 3,0% | 3,1% | 3,2% | 3,3% | 3,4% | 3,5% | 3,6% | 3,7% | 3,8% | 3,9% | 4,0% |
| Fat concentration | 3,0% | 0,95 | 0,95 | 0,96 | 0,97 | 0,98 | 0,98 | 0,99 | 1,00 | 1,01 | 1,01 | 1,02 |
| | 3,2% | 0,97 | 0,98 | 0,99 | 0,99 | 1,00 | 1,01 | 1,02 | 1,02 | 1,03 | 1,04 | 1,05 |
| | 3,4% | 1,00 | 1,00 | 1,01 | 1,02 | 1,03 | 1,04 | 1,04 | 1,05 | 1,06 | 1,07 | 1,07 |
| | 3,6% | 1,02 | 1,03 | 1,04 | 1,05 | 1,05 | 1,06 | 1,07 | 1,08 | 1,08 | 1,09 | 1,10 |
| | 3,8% | 1,05 | 1,06 | 1,06 | 1,07 | 1,08 | 1,09 | 1,09 | 1,10 | 1,11 | 1,12 | 1,13 |
| | 4,0% | 1,07 | 1,08 | 1,09 | 1,10 | 1,11 | 1,11 | 1,12 | 1,13 | 1,14 | 1,14 | 1,15 |
| | 4,2% | 1,10 | 1,11 | 1,12 | 1,12 | 1,13 | 1,14 | 1,15 | 1,15 | 1,16 | 1,17 | 1,18 |
| | 4,4% | 1,13 | 1,13 | 1,14 | 1,15 | 1,16 | 1,16 | 1,17 | 1,18 | 1,19 | 1,20 | 1,20 |
| | 4,6% | 1,15 | 1,16 | 1,17 | 1,18 | 1,18 | 1,19 | 1,20 | 1,21 | 1,21 | 1,22 | 1,23 |
| | 4,8% | 1,18 | 1,19 | 1,19 | 1,20 | 1,21 | 1,22 | 1,22 | 1,23 | 1,24 | 1,25 | 1,25 |
| | 5,0% | 1,20 | 1,21 | 1,22 | 1,23 | 1,23 | 1,24 | 1,25 | 1,26 | 1,27 | 1,27 | 1,28 |

## 4.6 Specific technical issues in rice farming

Most of the issues were already covered in section 4.5, so here they will be shortly summarized, together with items specific for rice farming.

The silos energy analysis of paragraph 4.5.1 leads to an average embodied energy is 0,05 ± 0,01 GJ/$m^3$ year for volume greater than 50 $m^3$ . The energy input for kg of rice is sligthly higher than for maize or wheat, 0,08 ± 0,02 MJ/kg, owing to the lower mass density of rice (5800 kg/$m^3$).

Energy input for machinery is the same as described in paragraph 4.5.2, both for Missouri and Piemonte. Input for chemical and organic fertilizer are the same as described in paragraph 4.5.3, while there are many herbicides that are specifically used in rice growth. Their embodied energy is listed in table 4.20.

Table 4.20 Herbicides use for rice production

| Herbicide type | Energy input |
|---|---|
| | MJ/kg |
| Glyphosate | 474 |
| Clomazone | 530* |
| Quinclorac | 562* |
| Propanil | 220 |
| 3,4-dichloropropionanilide | 476* |
| Thiocarbamate | 314* |
| Halosulfuron | 171 |
| Pendimethalin | 540* |
| Penoxsulam | 724* |
| Oxadiazon | 335* |
| Viper | 821* |
| Clincher | 703* |
| MCPA | 98* |

Sources: Green (1987) and Audsley et al. (2009, values with *)

In rice farming seeds doesn't requires higher specific input energies as for maize and soy (paragraph 4.5.5), since they are not genetically engineered. According to some of the farmers who were interviewed there is no significant difference in energy input between rice used for seed and for direct human consumption. The area use of rice seeds *s* ranged from 100 to 200 kg/ha, depending on the farms. The related energy cost is taken into account by increasing the total input energy by a factor of $s/Y$, where $Y$ is the rice yield of the single farms. Depending on farms, seeds input range from 1,5% to 3% of the total energy costs.

Direct energy consumption is treated in the same way as paragraph 4.5.8.

The functional unit is one kg of paddy rice at 12% of moisture. Different level of moisture were normalized to 12% according to the formula

$$R_c = R \frac{1-m}{1-0{,}12} \tag{4.8}$$

where $R$ is the actual rice production of the farm at final moisture $m$, while $R_C$ is the corrected rice mass related to 12% moisture.

# 5. Results and discussion

«The only people  who are really making money from dairy farming are those writing books on it.»

«We should have the humility to learn from poorer countries where the rice is managed  in a more sustainable way»
*Told by two farmers during the interviews*

## 5.1 Case study A: energy input in dairy farming

### *5.1.1 Results for Missouri*

Energy input for milk production in Missouri is reported in table 5.1 in terms of MJ per kg of ECM and in terms of GJ per cow. Energy input per kg of ECM is also reported in figure 5.1. Analytical data for all farms are listed in chapter 10.2.

Energy input in *grain based farms* ranges from 5 to 6 MJ/kg; for farm G1, more than half of the 6,51 MJ/kg cost is related to feed, since G1 is using a heavy feeding and is buying all the feed on the market with no self production and therefore has no fuel and fertilizer costs linked to crop/forage growth. In farm G2 machinery has a higher  importance due to its small scale (30 animals), but the significant lower impact of feed keeps the total footprint 1 MJ lower than G1.

*Pasture based* farms P1 ad P2 show very similar results, despite the different size (95 and 547 heads); the energy footpint per cow is dramatically lower than in grain based holdings, about 75% less: the reason is  the large use of pasture, that reflects in savings in feed (silage is given only to dry cows in winter), fuel and structure/machinery inputs (less tractors and no barns, since animals are always in the fields).

This reduction is compensated by the lower animal productivity (about 45% less milk per cow); still, with 3,4 MJ/kg, the input for P1 and P2 is about 40-50% lower than in G1 and G2.

The result for *organic* farms is much more varied, since inputs range from 2,4 to more than 8 MJ/kg. The reason for this difference is due to the fact that, although the milk produced by OP1, OP2 and OP3 is equally certified organic, the three farms use significantly different practices.

Farm OP2 has the lowest input of all; the recipe for this result is a combination of cow pasturing, no use of electricity, no tractors, high number of lactations per cow which keeps low the cull index. The seven horses used in the farm to pull the tiller are roughly equivalent in term of input energy to one tractor, and all other farms own more than one tractor.

Table 5.1 Specific energy input per kg of ECM and per milking cow in Missouri

| | Farm code | G1 | G2 | P1 | P2 | OP1 | OP2 | OP3 |
|---|---|---|---|---|---|---|---|---|
| Energy input per ECM (MJ/kg) | Feed | 3,49 | 1,12 | 0,79 | 1,01 | 0,25 | 0,47 | 1,12 |
| | Fuel electricity | 2,36 | 2,55 | 1,52 | 1,16 | 2,89 | 0,27 | 3,13 |
| | Fertilizers | - | 0,29 | 0,33 | 0,31 | 1,12 | 0,27 | 2,15 |
| | Machinery | 0,13 | 0,92 | 0,08 | 0,06 | 1,05 | 0,51 | 1,04 |
| | Heifers feed | 0,53 | 0,44 | 0,68 | 0,86 | 0,57 | 0,34 | 0,90 |
| | **Total** | **6,51** | **5,32** | **3,39** | **3,40** | **5,89** | **1,85** | **8,33** |
| Energy input per animal (GJ/cow) | Feed | 42,16 | 10,42 | 5,26 | 5,11 | 1,14 | 3,66 | 4,05 |
| | Fuel electricity | 28,49 | 23,69 | 10,17 | 5,87 | 13,23 | 2,07 | 11,32 |
| | Fertilizers | 0,00 | 2,68 | 2,20 | 1,54 | 5,15 | 2,09 | 7,78 |
| | Machinery | 1,62 | 8,58 | 0,54 | 0,29 | 4,82 | 3,98 | 3,76 |
| | Heifers feed | 6,45 | 4,10 | 4,53 | 4,36 | 2,62 | 2,62 | 3,27 |
| | **Total** | **78,72** | **49,48** | **22,70** | **17,16** | **26,95** | **14,41** | **30,18** |

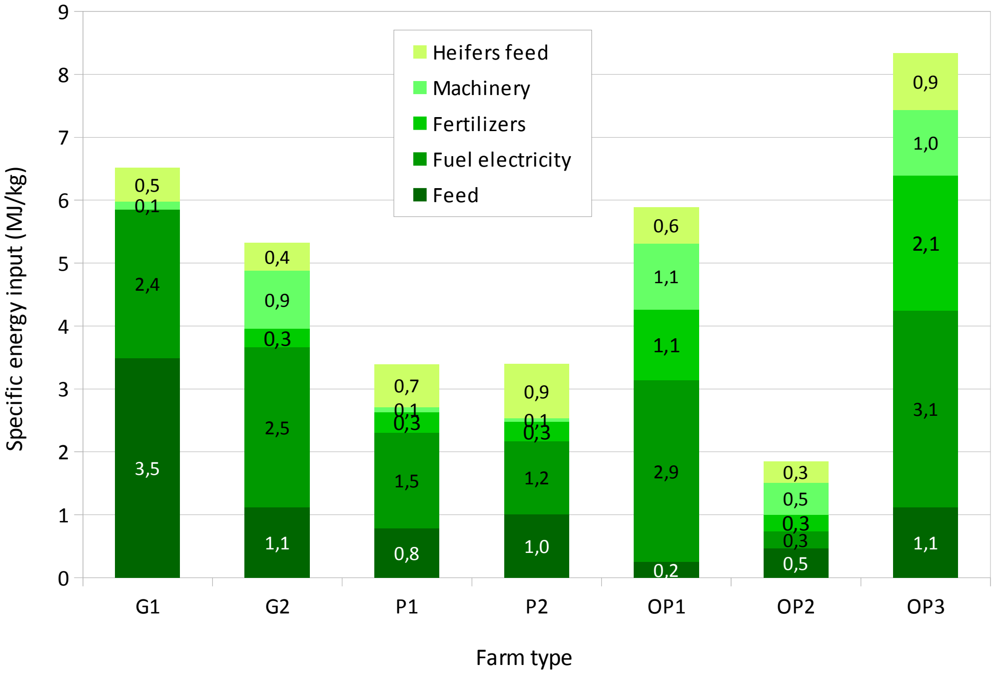

Figure 5.1 Energy inpt per kg of ECM for the surveyed farms in Missouri

Farm OP1 has a higher cost for fuel and electricity, mainly because it uses compost as fertilizer, which requires a significantly longer time for field work.

The reason for the very high energy cost of farm O3 (twice the average of the other organic farms) is mainly due to its low milk production, only 3600 kg/cow/year, that is 25-50% less that the other organic holdings.; indeed, on a per hectare basis, the energy consumption is just 1,5 times greater.

The energy cost of fertilizer of OP3 is significantly high, since the farm uses the manure of 2000 hogs that are part of the same company. After analizing all data, it is possible to suppose that the core business of farm OP3 is to sell pork meat, while the pasture based dairy is just a secondary activity, that is not particularly well managed and is used as a way  to dispose the pigs' waste.

### *5.1.2 Results for Emilia-Romagna*

Energy input for milk production in Emilia-Romagna is reported in table 5.2 in terms of MJ per kg of ECM and in terms of GJ per cow. Energy input per kg of ECM is also reported in figure 5.2. Analytical data for all farms are listed in chapter 10.2.

Energy input in *grain based farms* oscillates from 3 to 3,6 MJ/kg; G3, G4 ad G5 have similar performances, with slight differences. The lower direct energy cost of farm G4 is due to the production of renewable energy from PV panels and a biogas plant, that cover all electricity requirements. Farm G3 has a very low value for heifer feed since it succeeded in obtaining the first calf at 14 month of age, while the average emilian value is around 24 months.

Table 5.2 Specific energy input per kg of ECM and per milking cow in Emilia-Romagna

| Farm code | G3 | G4 | G5 | P3 | P4 | OP4 | OP5 | OP6 |
|---|---|---|---|---|---|---|---|---|
| | Energy input per ECM (MJ/kg) | | | | | | | |
| Feed | 1,27 | 1,52 | 1,70 | 0,47 | 0,41 | 0,34 | 0,35 | 0,74 |
| Fuel electricity | 0,95 | 0,53 | 0,84 | 1,22 | 1,03 | 0,23 | 0,77 | 0,96 |
| Fertilizers | 0,14 | 0,28 | 0,32 | 0,34 | 0,05 | 0,00 | 0,00 | 0,00 |
| Machinery | 0,18 | 0,21 | 0,18 | 0,58 | 0,56 | 0,58 | 0,48 | 0,30 |
| Heifers feed | 0,22 | 0,51 | 0,58 | 0,71 | 0,82 | 0,20 | 0,49 | 0,43 |
| **Total** | **2,76** | **3,05** | **3,61** | **3,32** | **2,87** | **1,35** | **2,09** | **2,42** |
| | Energy input per animal (GJ/cow) | | | | | | | |
| Feed | 14,42 | 15,89 | 18,57 | 3,59 | 2,88 | 3,20 | 2,62 | 4,76 |
| Fuel electricity | 10,71 | 5,50 | 9,20 | 9,38 | 7,13 | 2,11 | 5,88 | 6,17 |
| Fertilizers | 1,63 | 2,98 | 3,51 | 2,62 | 0,37 | 0,00 | 0,00 | 0,00 |
| Machinery | 2,03 | 2,19 | 1,96 | 4,45 | 3,86 | 5,43 | 3,68 | 1,91 |
| Heifers feed | 2,48 | 5,34 | 6,32 | 5,48 | 5,66 | 1,29 | 3,70 | 4,00 |
| **Total** | **31,27** | **31,89** | **39,57** | **25,52** | **19,90** | **12,03** | **15,88** | **16,84** |

Energy footprint is nearly one half with respect to similar farms in Missouri, owing to smaller daily rations and lower embodied energy in less powerful machinery and lower fuel consumption. This comparison will be analized in more depth in paragraph 5.3.2.

*Pasture based* farms P3 and P4 have energy footprints slightly lower than grain based farms, but, as will be detailed in paragraph 5.2.4, the difference is not significant. This is mainly due to the fact that they differ from grain based farms G3, G4 and G5 only for a lower amount of rain in the daily rations, but the general organization of the farm is similar: lower input for feed are compensated by higher value for fuel, machinery and heifers feed due to the small size ot these farms.

The result for *organic* farms are almost similar, since they are in the small range 1,35 - 2,5 MJ/kg. With respext to grain based holdings, they benefit of zero cost for fertilizer (they use substantially only cows manure) and lower costs for feed, since pastures require less inputs.

The outstanding performance of farm OP4 (only 1,35 MJ per kg of milk) is due to the following factor: few mechanical operation, with only one tractor (low machinery and fuel costs), extensive field farming with manure fertilization, higher number of lactations, with very small culling index. Farms OP5 and OP6 have a slightly higher consumption because they have more contribution from machinery and fuel use, but their performance is still on the lower end of the energy range, both for missourian and non organic emilian farms.

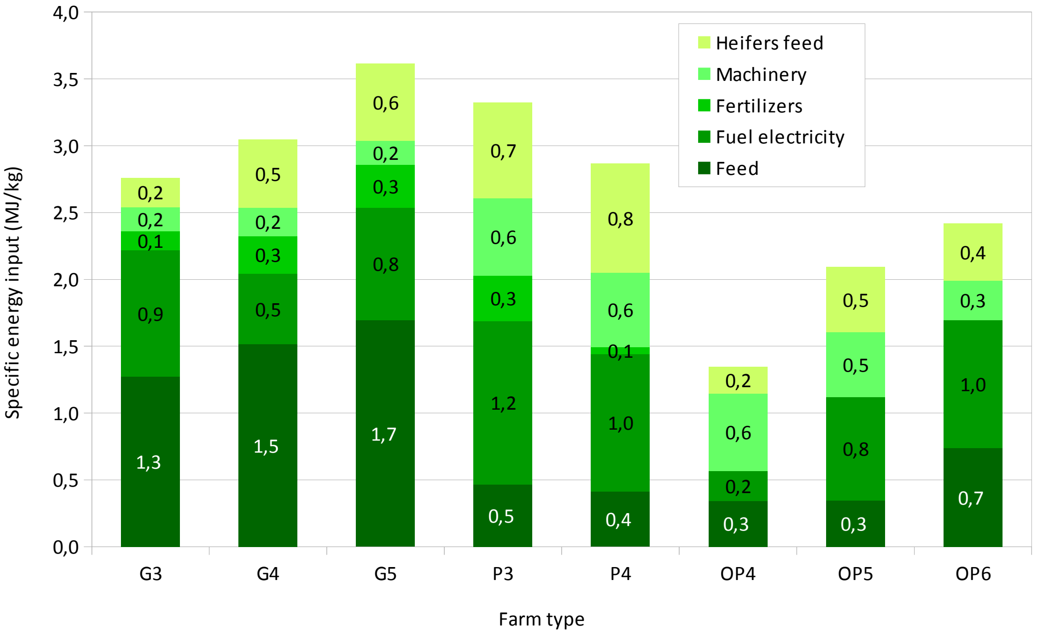

Figure 5.2 Energy inpt per kg of ECM for the surveyed farms in Emilia Romagna

## 5.2 Case study A: discussion and comparison with literature

### 5.2.1 Relationship between feed practices and energy input

Feed composition has a strong influence on the energetic cost of milk, as can be seen from figure 5.3, where the specific energy input for feed and fertilizers is plotted versus the fraction of grain in the daily rations of the cows. The analysis is limited to emilian farm, where the exact ammount of grains and pasture is known, because the latter is fed in the form of hay, while in all missourian pasture based farm grass is consumed *in situ*, so it cannot be measured, but only estimated.

The correlation is quite significant ($R^2$=0,86), indicating that energy consumption grows in proportion with the maize, barley, sorghum or soy in the diet; every increase of grain composition by 1% leads to an increase in energy input of 0,035 MJ per kg of milk. This is due to the fact that grains require more input energy than grass forages (see paragraph 4.5.6).

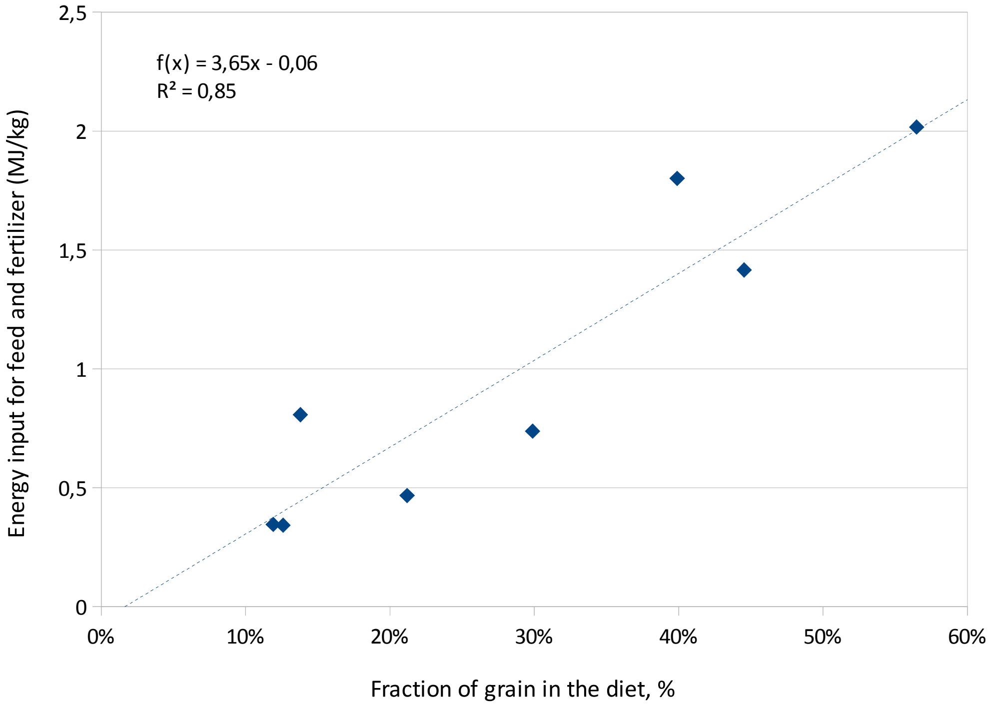

Figure 5.3 Correlation between fraction of grain in the diet and energy input for feed and fertilizers

### *5.2.2 Relationship between energy input and productivity: Italy-USA comparison*

As already mentioned before, italian farms are more energy efficient than american farms, since they can achieve almost the same milk productivity at about half the energy cost; the average emilian milk productivity (8800 ± 1980 kg/cow/year) is higher than missourian (7016 ± 2700 kg/cow/year), but the difference is not statistically significative at the 5% significance (*p* = 0,10 t-test).

The difference in energy input between the two groups of farms (Emilia 3,0 ± 0,53; Missouri 5,0 ± 2,21) is on the contrary statistically significant at the 5% significance (*p* = 0,03 t-test); more detailed difference between farms of the same typologies are given in the nextparagraph.

Cows productivity increases almost linearly with the total energy input, as can be seed from figure 5.4, where the productivity (liters of ECM/cow/year) is plotted versus the total energy input on cow basis. Blue dots are the emilian farm and orange dots the missourian.

On the average, every increase in energy input of 1 GJ per cow results in a rise in milk productivity of 164 kg/cow/year for Italy compared to 129 kg/cow/year for USA. Conversely, it is possible to save 1 GJ/cow (equivalent to about 24 kg of oil) at the cost or reducing the milk productiviy of the same amount (producvitiy loss would be higher in Italy, but italian farms are already more energy efficient, so the option is addressed to american farms).

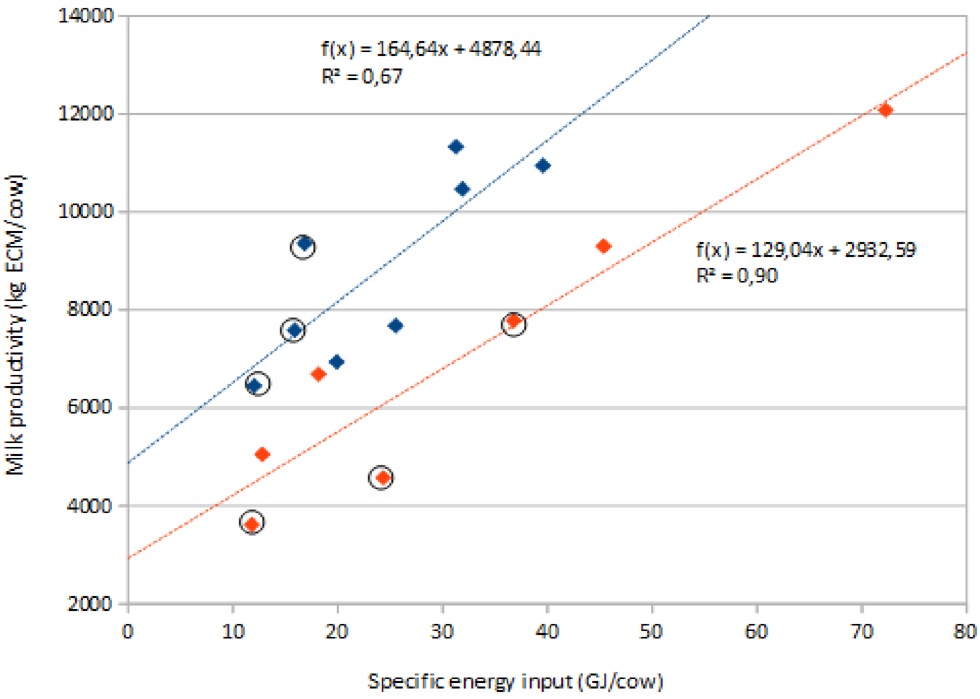

Figure 5.4 Correlation between total energy input per cow and cow productivityfor farms in Missouri (orange) and Emilia (blue). Data point enclosed in a circle are organic farms

Speaking of produtivity reduction may sounds strange, since for decades the imperative has been to increase it. It is however worth mentioning that in the USA every year it is wasted about 18,6% of all the milk produced, from the farm to household consumption (FAO 2011). If it would be possible to eliminate this waste and reduce cow productivity of the same amount, it would be achieved an energy saving of the order of 10 GJ per cow (240 kg of oil equivalent). Considering that the average milk productivity of the surveyed missorian farms is 7016 kg/year a reduction of 18,6% would correspond to minus 1300 kg of milk, with an energy input reduction of 10 GJ (1300 kg/ 129 kg/GJ, see figure 5.4).

### *5.2.3 No "economies of scale" for enegy*

As can be seen from figures 5.5 and 5.6, respectively related to missourian an emilian farms, there is no correlation between specific energy input on a cow basis and herd size. Data points for the different farm types are coloured according to the legend used in paragraph 4.3.1. No economies of scale are present for energy; on the contreary, it is possible to see a slight increasing trend in energy cost with herd size for grain based farms, but it is not significant owing to the small sample size in both countries.

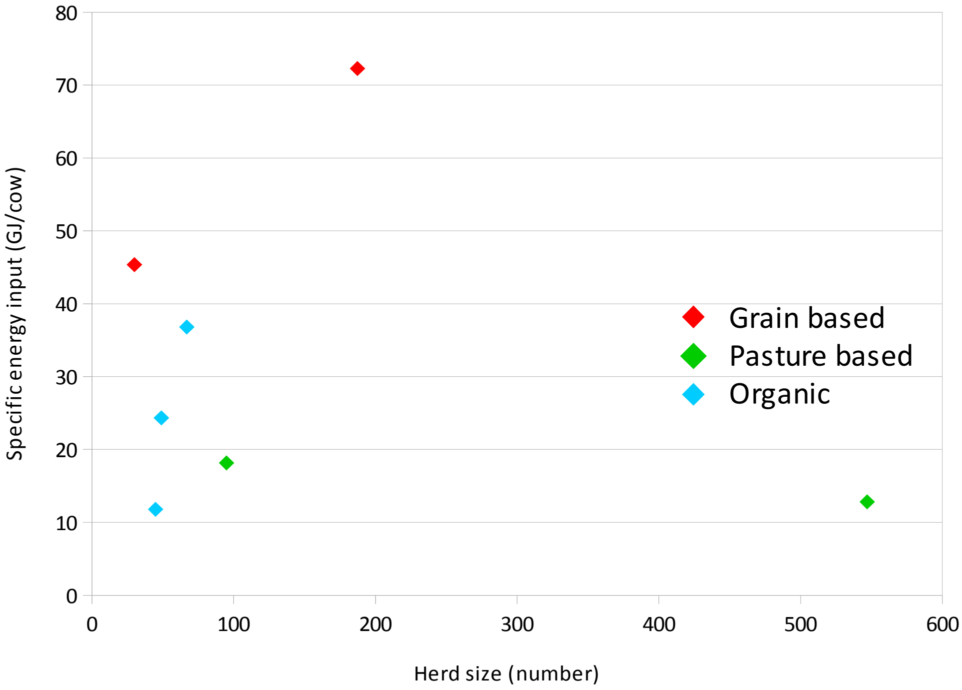

Figure 5.5 Correlation between specific energy input per cow and herd size for MIssouri

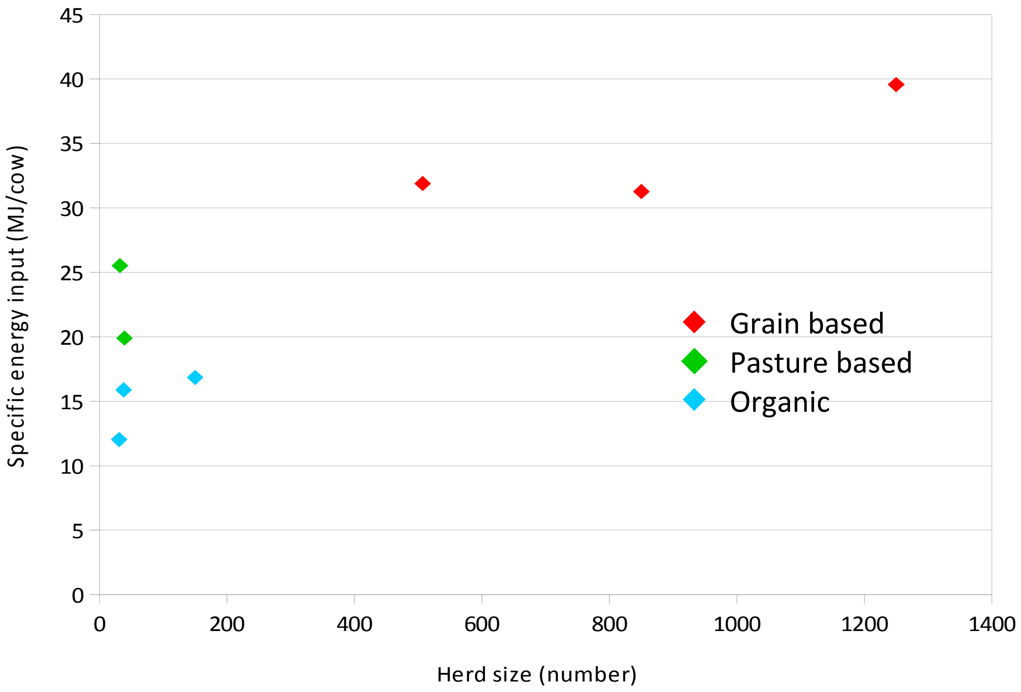

Figure 5.6 Correlation between specific energy input per cow and herd size for Emilia Romagna

### *5.2.4 Grain, pasture or organic: which is better?*

One-tailed t-tests were performed on the collected data from american and italian farms. The results are shown in table 5.3 (a) and (b) respectively with respect to specific energy for 1 kg of ECM and for one cow.

Results are quite different between the two countries. In Missouri, pasture based farming is more energy efficient with respect to grain farming, consuming 43% less energy per kg of ECM ($p$ = 0,073). Organic farming input is 34% lower with respect to grain fed, but the difference is not significant. The same can be said for the comparison between organic and non organic pasture based farms: the average consumption of the firsts is 14% higher but $p$= 0,42.

In Emilia-Romagna, on the contrary, organic farming is more energy efficient, with an energy reduction of about 37% , respect both to grain fed and grass fed farms and the difference is significant in both cases ($p$ = 0,02 and $p$ = 0,03, respectively). Non organic grain and grass fed farms don't differ significantly ($p$ = 0,45).

This difference in performance can be explained by the fact that the surveyed organic missourian farms have dissimilar pratices in feed, fuel and fertilizers use (see paragrph 5.1.1), so the sample presents a higher variance. Pasture based farms are on the contrary much more homogeneous, so their lower input is statistically significant. In Emilia-Romagna organic farms have comparable practices and lower energy inputs, so the difference is significant both with respect to non organic grain and pasture based farms.

Grain and organic emilian dairy farms have significant lower inputs than their equivalent missourian holdings, with *p*=0,05 and *p*=0,1 respectively. No significant difference was found on pasture based farms.

Energy inputs difference on a cow basis are similar, but the significance level is slightly better, because data show a smaller standard variation.

Table 5.3 Average input energies for different farm types and significance level.
Percent difference are related to grain based farms (3rd, 5th and 6th rows) or to Missouri (last column)

(a) Average energy per kg of ECM

| Farm type | | Missouri (M) | Emilia-Romagna (ER) | (ER-M)/M |
|---|---|---|---|---|
| | | Energy input MJ/kg | Energy input, MJ/kg | |
| G | Grain based | 5,92 ± 0,84 | 3,14 ± 0,43 | -46,9% (*p*=0,05) |
| P | Pasture based | 3,40 ± 0,01 | 3,09 ± 0,31 | -8,8% (not significant) |
| (P-G)/G | | -42,6% (*p*=0,07) | -1,5% (not significant) | - |
| OP | Organic | 3,87 ± 2,85 | 1,95 ± 0,55 | -63% (*p*=0,1) |
| (OP-G)/G | | -34,6% (not significant) | -37,8% (*p*=0,02) | - |
| (OP-P)/P | | +13,9% (not significant) | -36,8% (*p*=0,03) | - |

(b) Energy per animal (GJ/cow)

| Farm type | | Missouri (M) | Emilia-Romagna (ER) | (ER-M)/M |
|---|---|---|---|---|
| | | Energy input GJ/cow | Energy input, GJ/cow | |
| G | Grain based | 64,1 ± 20,6 | 34,24 ± 4,62 | -46% (not significant) |
| P | Pasture based | 19,9 ± 3,9 | 22,71 ± 3,97 | -12% (not significant) |
| (P-G)/G | | -68,9% (*p*=0,1) | -33,7% (*p*=0,03) | - |
| OP | Organic | 23,8 ± 8,3 | 14,9 ± 2,54 | -37% (*p*=0,1) |
| (OP-G)/G | | -62,8% (*p*=0,1)) | -34,3% (*p*=0,04) | - |
| (OP-P)/P | | +13,9% (not significant) | -56,4% (*p*=0,08) | - |

### 5.2.5 Comparison with the literature

The results of 16 different analysis on energy input in milk production are listed in table 5.5. Literature data cover the range of values found in the present analysis. For conventional farms, the average and standard deviation values of 4,0 ± 1,37 MJ/kg is not significantly different from the values of the present work, 3,87 ± 1,23 (MJ/kg (*p* = 0,41 t-test).

Table 5.5 Literature values for conventional and organic milk input energy (MJ/kg)

| Source | Country | Conventional | Organic |
|---|---|---|---|
| Eide (2002) | Norway | 4,47 | |
| Refsgaard et al (1998) | Denmark | 3,34 | 2,16 |
| Cederberg&Mattsson (2000) | Sweden | 3,55 | 2,51 |
| Gronroos et al. (2006) | Finland | 6,4 | 4,4 |
| Mikkola&Akolas (2009) | Finland | 3,2 | |
| Frorip et al. (2012) | Estonia | 5,4 | |
| Thomassen et al (2008) | Netherlands | 5 | 3,1 |
| Iepema&Pijnenburg (2001) | Netherlands | 3,7 | 2,4 |
| Meul et al (2007) | Belgium | 4,26 | |
| Kratz (2012) | Germany | 3,5 | |
| Haas et al (2001) | Germany | 2,7 | 1,2 |
| Hospido et al (2003) | Spain | 6,03 | |
| Koknaroglu (2010) | Turkey | 5,03 | |
| Wells (2001) | New Zealand | 2,02 | |
| Hartman& Sims (2006) | New Zealand | 3,9 | |
| Smil (2008) | USA | 6 | |
| Average and standard deviation | | 4,0 ± 1,37 | 2,63 ± 1,06 |

The same can be said for organic milk: the population of literature values (2,63 ± 1,06) doesn't different significantly (*p* = 0,33 t-test) from the data of the present work (3,12 ± 1,86).

In contrast, a significant difference (*p* = 0,015) can be found between the reported data populations of conventional and organic milk, since on the average the input energy for the organic product is 34% lower. Energy inputs above 5 MJ for kg of milk production reported in table 5.4 are related to farms that use a high level of grains in the diet, ranging from 63% (Gronroos et al. 2006) to 75% (Hospido et al. 2003) to 87% (Thomassen et al. 2008); this results is consistent with the results of emilian farms (figure 5.3).

On the other hand, studies that reported low energy consumption were related to pasture based farms (Hass et al. 20010; Wells 2001) or to farms with limited amount of grans in the cow rations (Refsgaard et al. 1998, 22%C; Mikkola&Akolas 2009, 40%), which is consistent with the findings of the present study on missourian farms.

## 5.3 Case study B: energy input in rice farming

### *5.3.1 Results for Missouri*

Energy input for rice production in Missouri is reported in table 5.6 in terms of MJ per kg of rice and in terms of GJ per hectare. Energy input per kg of rice is also reported in figure 5.7. Analytical data for all farms are listed in chapter 10.3.

Energy footprint for conventional farms that uses chemicals ranges from 3,5 to 5,2 MJ/kg, with little significant differences among the holdings. C1 used heavier fertilizer and herbicide inputs in order to achieve higher yields; C4 had a slightly lower yield (-6%) but significant energy savings (-25%), due to lower herbicide use, economy of scale for machinery and lower costs for irrigation (as farm OR1), because it is located in lowlands nearer to the Mississippi river, so the water table is higher.

Farms C2 and C3 are comparable in terms of yield and total energy input with slight difference in input allocation: C2 is spending more in fertilizer, herbicides and fuel, while C3 has more energy embodied in machinery.

Table 5.6 Specific energy input per kg of paddy rice and per hectare in Missouri

| Farm code | C1 | C2 | C3 | C4 | OR1 |
|---|---|---|---|---|---|
| Yield (kg/ha) | 9333 | 7983 | 7983 | 8781 | 7527 |
| Rice area (ha) | 570 | 142 | 122 | 1220 | 163 |
| Energy input for paddy rice (MJ/kg) | | | | | |
| Machinery | 0,27 | 0,23 | 0,72 | 0,18 | 0,27 |
| Seeds&Fertilizers | 2,68 | 1,52 | 1,16 | 2,31 | 0,26 |
| Herbicides | 0,56 | 0,14 | 0,08 | 0,07 | 0,15 |
| Fuel | 0,94 | 0,43 | 0,27 | 0,64 | 0,34 |
| Irrigation | 0,79 | 1,28 | 1,35 | 0,39 | 0,18 |
| Drying | 0,25 | 0,78 | 0,52 | 0,5 | 0,5 |
| Total | 5,50 | 4,38 | 4,09 | 4,09 | 1,70 |
| Energy input per unit of land (GJ/ha) | | | | | |
| Machinery | 2,53 | 1,81 | 5,75 | 1,55 | 2,03 |
| Fertilizers | 25,04 | 12,14 | 9,23 | 20332 | 1,98 |
| Pesticides | 5,23 | 1,08 | 0,63 | 0,64 | 1,09 |
| Fuel | 8,78 | 3,47 | 2,17 | 5,59 | 2,56 |
| Irrigation | 7,37 | 10,25 | 10,77 | 3,42 | 1,35 |
| Drying | 2,33 | 6,23 | 4,15 | 4,39 | 3,76 |
| Total | 51,29 | 34,97 | 32,70 | 35,91 | 12,77 |

The energy footprint of the organic farm is significantly lower, about 70% less than the average of the other holdings and the difference is statistically significant (*p* = 0,0018 t-test). This outstanding results was achieved with low input for fertilizers (hog manure) and weed control obtained by low cost flam weeding and low energy input soybean dipeptide and soybean plasma. Morevover, farm OR1 uses a 40 kW photovoltaic panel that provide energy for irrigation and drying (see paragraph 6.2.1).

The energy consumption for rice drying is comparable to the values reported in literature, that range from 0,38 to 0,84 MJ/kg of dried rice at 12% of moisture (Billiris&Siebenmorgen 2014).

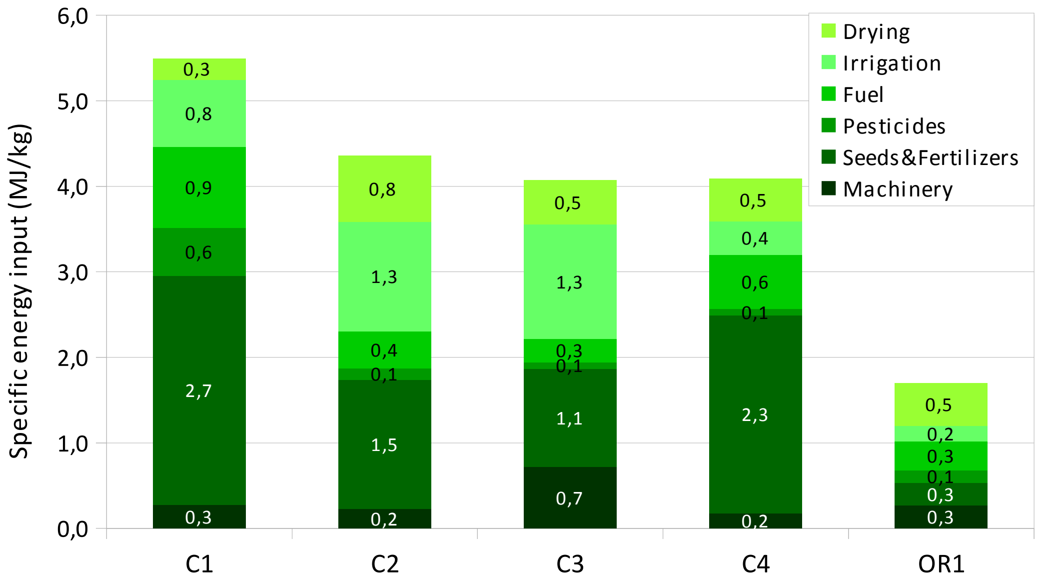

Figure 5.7 Energy inpt per kg of paddy rice for the surveyed farms in Missouri

### *5.3.2 Results for Piemonte*

Energy input for rice production in Piemonte is reported in table 5.7 in terms of MJ per kg of rice and in terms of GJ per hectare. Energy input per kg of rice is also reported in figure 5.8. Analytical data for all farms are listed in chapter 10.3.

Energy footprint for conventional farms using synthetic fertilizers and pesticides ranges from 4 to almost 7 MJ/kg: four farms (C6,C8, C9 and C10) are in the range 4-5 MJ/kg, while the remaining two are above . Farm C7 has the highest footprint of 6,78 MJ/kg, since it used the heaviest fertilizers input in order to increase the production as much as possible on it small extension of land (only 20 ha).

The specific fuel consumption of C5 is significantly higher than the others; the farm, beside rice cropping, has multiple activities (forestry, corn cropping, pasture and dairy farming that is not object of the present work) whose fuel consumption were deducted from the total fuel . Nevertheless, it is possible that is value is still overestimated because it may include somre othrer activities not related to rice cropping.

Farm C4 has the lowest footprint among conventional farms because it uses a PV system that almost fully covers its electricity consumption.

Organic farm OR2 has an even lower energy input, -40% with respect to the average of conventional holdings and the difference is statistically significant at 5% (p = 0,075 t-test). This results is the consequences of three main practices: use of low input organic fertilizers, manual weeding by hand and use of rice hulls to produce electricity.

Hand weeding of rice is a labour intensive practice that is still common in many south and east asian countries, like China, Indonesia, Thailand, Malaysia, Philippines and Vietnam (Gupta&O'Toole 1986, Hasanuzzaman et al 2009). In italy, hand weeding of rice was typically performed by women who were temperary hired during the spring. This practice was active up to the 60s (Secci 2012). Occasionallt, some farms returned to manual weed control in order to reduce the cost of pesticides. The work is usually done by immigrants, but in the surveyed farms was done by the family of the owner plus two employees; the task required 4 workers a day who controlled about 2,3 hectares.

Table 5.7 Specific energy input per kg of paddy rice and per hectare in Piemonte

| | C5 | C6 | C7 | C8 | C9 | C10 | OR2 |
|---|---|---|---|---|---|---|---|
| Yield (kg/ha) | 7500 | 6139 | 7000 | 5240 | 7500 | 7245 | 6136 |
| Area (ha) | 151 | 90 | 20 | 58 | 90,2 | 71,1 | 110 |
| Energy input for paddy rice (MJ/kg) | | | | | | | |
| Machinery | 0,09 | 0,33 | 0,50 | 0,24 | 0,19 | 0,28 | 0,65 |
| Seeds&Fertilizers | 0,95 | 1,56 | 3,38 | 1,38 | 1,66 | 1,54 | 0,45 |
| Pesticides | 0,33 | 0,44 | 0,23 | 0,56 | 0,51 | 0,51 | 0,00 |
| Fuel | 3,10 | 1,23 | 1,85 | 1,13 | 1,97 | 1,97 | 1,18 |
| Drying | 1,10 | 0,42 | 0,82 | 1,18 | 0,59 | 0,59 | 0,71 |
| Total | 5,57 | 3,99 | 6,78 | 4,49 | 4,92 | 4,15 | 3,01 |
| Energy input per unit of land (GJ/ha) | | | | | | | |
| Machinery | 0,70 | 2,02 | 3,49 | 1,27 | 1,39 | 2,07 | 3,97 |
| Seeds&Fertilizers | 7,12 | 9,61 | 23,68 | 7,22 | 12,43 | 11,14 | 2,87 |
| Pesticides | 2,50 | 2,70 | 1,61 | 2,96 | 3,82 | 3,28 | 0,00 |
| Fuel | 23,22 | 7,58 | 12,96 | 5,93 | 14,79 | 5,44 | 7,25 |
| Drying | 8,24 | 2,60 | 5,73 | 6,16 | 4,46 | 8,18 | 4,39 |
| Total | 41,78 | 24,50 | 47,46 | 23,54 | 36,88 | 30,10 | 18,49 |

The productivity of a single worker can thus be estimated in about 700 m²/hour. This value is confirmed by data from farm C10, where the use of pesticides is associated to because the farm produces high quality seeds. The work is accomplished by immigrants, who spent 1000 work hours on surface of 71 ha.

Weeding productiviy could be doubled with the use of hand operated weeder (Wassan 2006).

Rice yields are lower in Piemonte than in Missouri owing to climatic reasons : see discussion in paragraph 5.4.1.

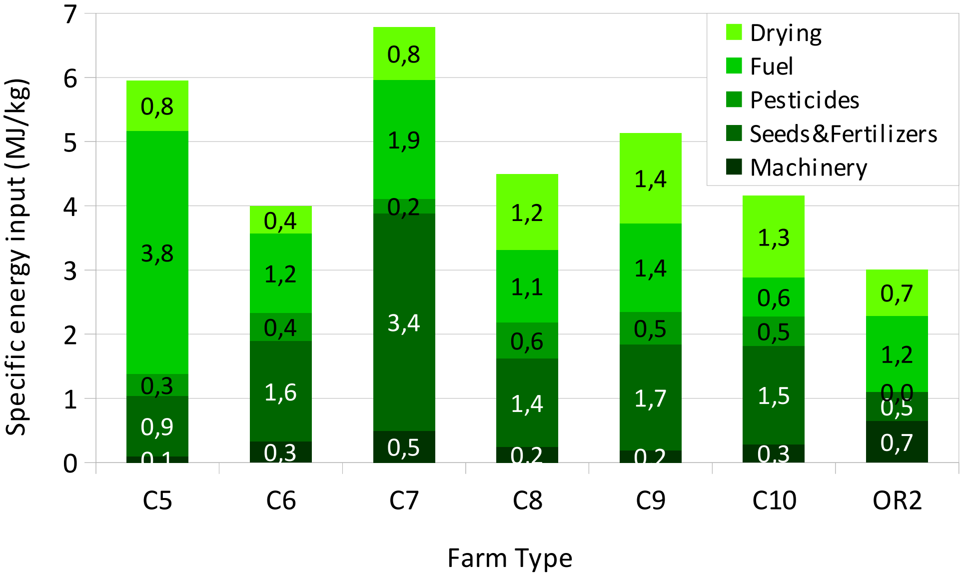

Figure 5.8 Energy inpt per kg of paddy rice for the surveyed farms in Piemonte

## 5.4 Case study B: discussion and comparison with literature

### *5.4.1 Comparison between Missouri and Piemonte results*

In terms of energy per unit of land, conventional farms in Piemonte used 33,9 ± 9,7 GJ/ha , about 5 GJ less than farms in Missouri (38,7 ± 8,4 GJ/ha); this difference roughly representes the extra energy used in the US state for underground irrigation. However it should be noted that the difference between the two means is not statistically significant (*p*= 0,22).

As can be seen in figure 5.9, heavier fertilizer employ in Missouri is compensated by higher fuel consumption in Piemonte, both for traction and for rice drying.

The situation is reversed looking at energy input per unit of mass(figure 5.10), since average input in Piemonte (4,96 ± 1 MJ/kg) is slightly higher than in Missouri (4,51 ± 0,67 MJ/kg) : this difference is due to the higher yields obtained in Missouri: more energy is used by unit land, but more rice is produced per hectare, so the energy input is slightly lower . The difference is not statistically significant (*p*=0,23)

The yield difference is on the contrary statistical significant: 8,53 ± 0,65 t/ha in Missouri vs 6,77 ± 0,90 t/ha in Piemonte gives a *p* value of 0,005.

Italian yields are about 25% less than missourian values: this results is determined by the difference in solar radiation between the two zones (FAO 1998) than are separated by 9 degrees of latitude (45 °N and 36 °N). The average insolation in Piemonte is 1525 kWh/m²/year, that is 25% less than in Missouri , where is 1916 kWh/m²/year (see paragraph 6.2.1 for details on solar radiation).

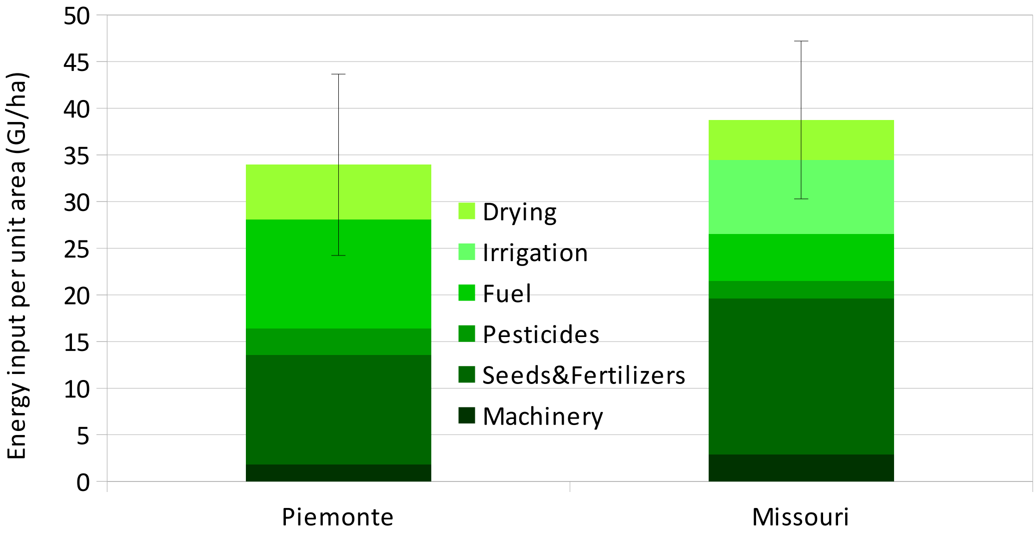

Figure 5.9 Comparison beween average energy inputs per unit land for conventional farms in Missouri and Piemonte

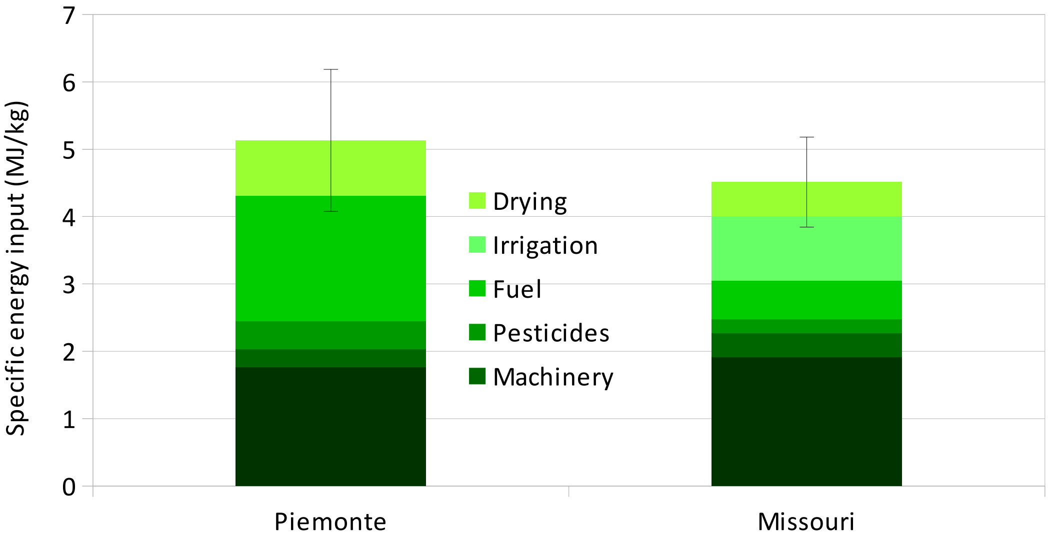

Figure 5.10 Comparison beween average energy inputs per kg of rice for conventional farms in Missouri and Piemonte

Organic farms were not included in this comparison, since their input are significantly lower than conventional farms, as detailed in the previous paragraph.

### *5.4.2 Relationship between energy input and rice yield*

Rice yield roughly increases linearly wit total energy input (figure 5.11). The increase is approximatively 50 – 60 kg/ha per every GJ/ha of energy expenditure.

It should be noted however that in Missouri it is necessary to increase the total energy input by a factor of three, from 13 to 51 GJ/ha, in order to obtain a yield increase of 24%, from 7500 to 9300 kg/ha. In Piemonte the difference is less striking, but still significant: energy inputs must increse by a factor 1,5 (from 18 to 47 GJ/ha) to obtain a 22% incresae (from 6100 to 7500 kg/ha).

Figure 5.11 could read the other way, that is it is possible to reduce energy input by reducing rice yield. This proposal may sound strange, but as it has been remarked for milk, lower yields could be associated with intervention to reduce the food losses.

In the USA every year about 11% of the rice from the fields to the distribution level is wasted (FAO 2011). If it would be possible to eliminate this waste and reduce rice yield of the same amount, it would be achieved an energy saving of the order of 20 GJ per hectare (475 kg of oil equivalent).

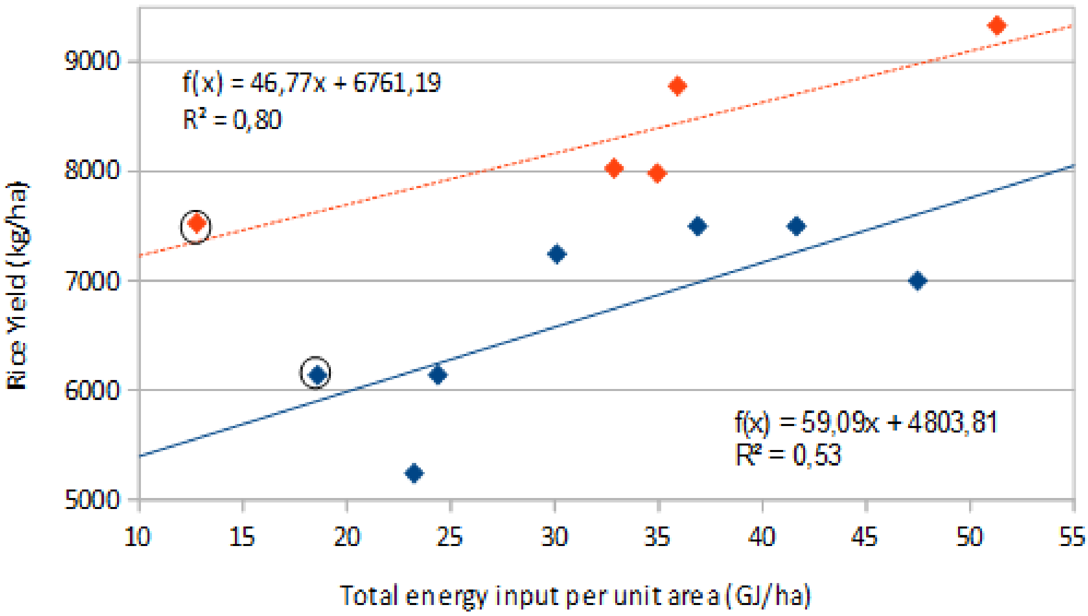

Figure 5.11 Rice yield vs energy input per ha for Missouri (orange) and Piemonte (blue) farms. Data point enclosed in a circle belong to organic farms

### *5.4.2 Relationship between energy input and farm area*

No correlation can be found between the energy input per unit area and the extension of the farm (figure 5.12). As it has already been observed for dairy farms (paragraph 5.2.3), also in rice production no significant economy of scale was observed. Usually, smaller farms have a higher specific cost for machinery, but this term is non important in the global energy budget (figures 5.7 and 5.8).

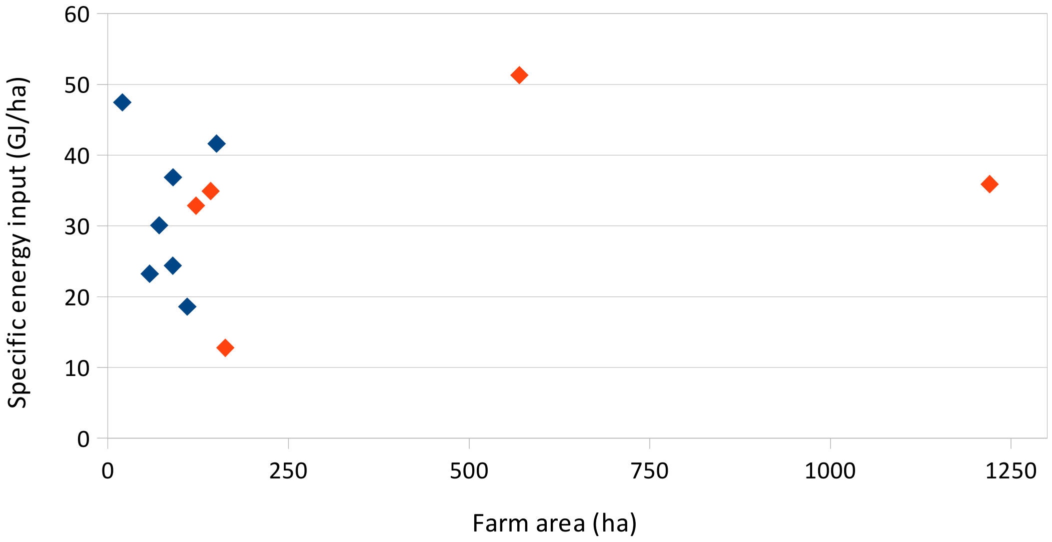

Figure 5.12 Specific energy input per ha for Missouri (orange) and Piemonte (blue) farms vs farm cultivated area

### *5.4.3 Comparison with the literature*

The results of 10 different analysis on energy input in rice production are listed in table 5.8 Other studies related to Iran were not taken into consideration, since the arid environment requires significantly higher inputs for irrigation.

Literature data cover approximatively the range of values found in the present analysis. Indeed, the average and standard deviation values of 4,31 ± 2,26 MJ/kg is not significantly different from the values of the present work, 4,38 ± 1,3 MJ/kg ($p$ = 0,46).

It should however be noted that the input values obtained in this study are respectively 26% and 36% lower than what reported in two analysys performed in USA by Pimentel (2008) and in Italy by Blengini and Busto (2009). This difference is due to a great variation in some direct or indirect energy costs , as will be detailed below.

Table 5.8 Literature values for rice cultivation in put energy

| Source | Country | Energy input (MJ/kg) |
|---|---|---|
| Lu (2010) | Cina | 6,83 |
| Saga et al (2010) | Japan | 2,50 |
| Bockari Gevao (2005) | Malaysia | 1,89 |
| Chaichana et al (2014) | Thailand | 6,77 |
| Quilty et al (2014) | Philippines | 3,54 |
| Mendoza (2002) (*) | Philippines | 1,91 |
| Mendoza (2002) | Philippines | 4,00 |
| Pracha and Volk (2011) | Pakistan | 2,05 |
| Pimentel (2008) | USA | 6,12 |
| Blengini and Busto (2009) | Italy | 7,46 |
| Average | - | 4,31 |
| Std Dev | - | 2,26 |

As can be seen from figure 5.13, direct energy consumption of diesel fuel, gasoline and electricity is unexplicably high in Pimentel study, that reported 280 liters per hectare, more than double than the actual average use in Missouri, which is 134 liter/ha for non organic farms; other inputs are substantially comparable.

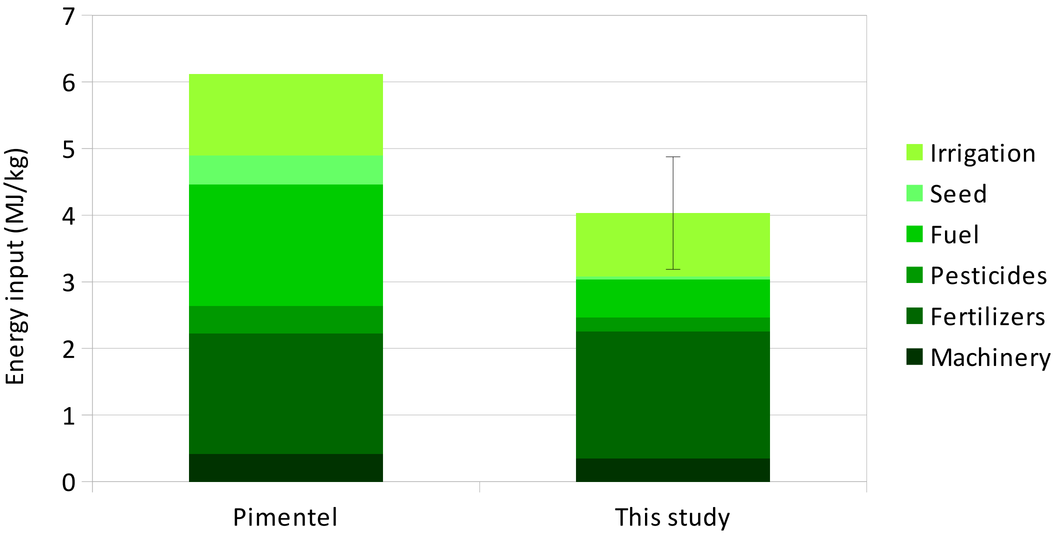

Figure 5.13 Comparison between the average energy inputs of non organic missourian Farms and the data reported by Pimentel (2008) on rice cultivation in the USA

For Italy, the main difference between this study and the one reported in table 5.8 is linked to fertilizer consumption: the farms surveyed in the present study applied on the average a total of 320 kg/ha of N, P and K, while Blengini and Busto reported a total use of 590 kg/ha and used higher specific energy values for the fertilizers, probably relying on the older evaluation for Ammonia produciton (see paragraph 3.4.3). Other inputs are comparable (see figure 5.14)

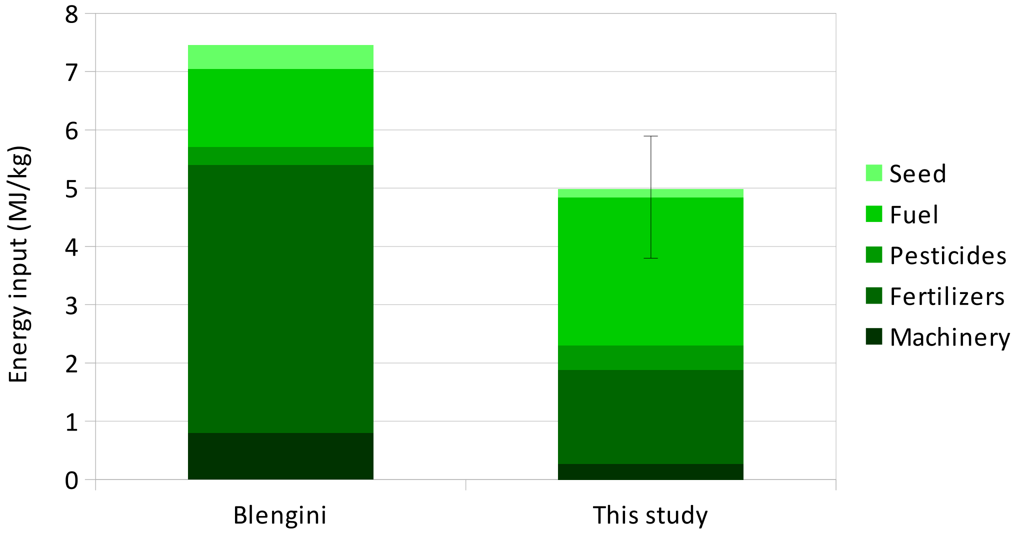

Figure 5.14 Comparison between the average energy inputs of non organic italian farms and the data reported by Blengini and Busto (2009) on rice cultivation in Italy

# 6. Sustainable rice and dairy farming scenarios

> «Modern agriculture is heavily based on the energy supply obtained from fossil fuels and it can be defined as a technology that transforms fossil fuels into food. However, the available amount of fossils is not infinite and climate change is creating a critical necessity of reducing their use. Therefore, it is not too early to start considering how agriculture could be adapted … in order to utilize the electric power provided by renewable energy technologies such as wind and photovoltaics. In this sense, the problem can be stated as the need of developing technologies able to turn electricity into food.»
> Bardi et al,*Turning electricity into food: the role of renewable energy in the future of agriculture* 2013

## 6.1 The path towards sustainability

### *6.1.1 What is “sustainable”?*

The adjective *sustainable* and the derived noun *sustainability* have become very popular in the last decades, with respectively about 220 and 120 millions of results in search engines. The idea of a *sustainable society* dates back at least to 1982 (Brown, 1982), but the term acquired international celebrity with the so called *Bruntland Report*, when it was first associated to the idea of development (WCED 1987):

> «Humanity has the ability to make development sustainable to *ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs*. The concept of sustainable development does imply limits - not absolute limits but limitations imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activities. But technology and social organization can be both managed and improved to make way for a new era of economic growth.»

This text, and particularly the sentence in italics, has been quoted millions of times from them on, despite its embarassing vagueness and scientific lack of foundation.

The attention posed on the needs of future generations is an important issue that reflects the idea of the so called *imperative of responsibility* (Jonas 1984), but the above mentioned definition is strongly questionable and controversial for the following reasons:

- It deliver an abstract idea of what *may be* a sustainable devlopment, without even questioning if the actual historical fossil fuel based industrial society is sustainable;
- it states that the limits posed by the biosphere are not absolute, that is an *absolute nonsense*, pro-

vided that mankind lives on a planet of finite dimensions;

- It therefore foster the idea that technological improvements can push on the limits of the biosphere in order to pursue an endless growth, even if somehow controlled and balanced.

Sustainability of human societies is strongly linked to the existence of well defined limits in the biospehre: availability of land, water, food, reliable energy sources, and last but not least the natural ability of the ecosystems to absorb and recylce all anthropogenic waste.

These ideas were stated long before the Bruntland Report, in one of the most important and innovative scientific and cultural achievements of the 20th century, the report *The limits to growth*, written by a group of MIT specialist on the behalf of the Club or Rome (Meadows and al, 1972).

The authors of the report, Donella and Dennis Meadows, Jørgen Raenders and William Behrens, express very clearly what does it mean *sustainable*, on the basis of the physics and mathematics founded discipline of system dynamics (Forrester 1968 and 1971):

> «1. If the present growth trends in world population, industrialization, pollution, food production, and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next one hundred years. The most probable result will be a rather sudden and uncontrollable decline in both population and industrial capacity.
> 2. It is possible to alter these growth trends and to establish a condition of ecological and economic stability that is sustainable far into the future. The state of global equilibrium could be designed so that the basic material needs of each person on earth are satisfied and each person has an equal opportunity to realize his individual human potential.
> 3. If the world's people decide to strive for this second outcome rather than the first, the sooner they begin working to attain it, the greater will be their chances of success.» (Meadows et al, 1972, pp 23-24)

According to these authors, the issue of sustainability is not just a speculative subject, but is the fundamental problem of our time: the actual industrial development is not sustainable and limits will be reached in a matter of decades, so it is mandatory to change and somehow divert the growth trends in order to achieve an ecological stable society.

It is important to point out that the present condition of unsustainablity of human society emerges from two different kind of limits:

- Limits on the side of the *resources.* The economic growth is presently based mainly on exhaustible fossil resources that are rapidly extracted and exploited. The main concern is not *how long* they will last in the future, but when the *peaking of the extraction rate* will occur; indeed the dynamics of resource extraction always follows the Hubbert curve (see paragraph 3.9), so that production start to decline long before exhaustion, when the best and cheapest resoruces are fully exploited, as has already happenened for conventional oil.

- Limits on the side of the *sinks*. Waste generated by human activities must be absoberd and rcycled by the ecosystems in order to achieve a stable society in the long run. Unnatural  waste, that is materials that are not usually found in the biosphere (like heavy metals, artificial chemical compounds or radioactive substances) represent toxic waste that cannot be absorbed (Glodsmith and Precott-Allen 1972). Natural waste cannot be recycled and sustained if its flux exceed the ecosystem abiity to recicle it. This is the case of the anthropogenic emissions of carbon dioxide that go strongly beyond the capability of photosynthesis and ocean absorption (IPCC 2013)

Sometimes the constraints comes from the side of resources, as happened for conventional oil that peaked in 2005-2006 giving rise to the oil crisis of 2008 (see paragraph 3.9), sometimes it may come from the side of sinks: this is for instance the case ot the great smog of London of 1952. Resources were abundant, but the accumulation of air pollution caused  more than 7000 deaths in a few days (Bell et al 2004). If it is possible to control and avoid pollution locally it is not possible to do it on a global level if the current trend of greenhoues gases emissions will continue unperturbed.

From an analysis of the current world situation of fossil fuels, it is clear that constraints on the side of resources will determine the availability of oil and gas: global peak oil will occur soon in the future (Bardi 2009), while for gas is a matter a few decades (Bentley 2002). For coal, the constraint on the contrary is coming from the side of sinks: resources are abundant, but if fully exploited they will increase the atmospheric concentration of CO2 beyond any limit bearable for mankind.

According to climatological studies, if all fossil fuels are burned, including unconventional oil and gas, the CO2 concentration in the atmosphere could reach a level as high as 16 times the 1950 atmospheric amount. In that event, the global temperature increase would strongly exceed the 2°C recommended by IPCC, resulting in a planet uninhabitable by humans (Hansen et al 2007).

In order to keep global warming within  2°C, only a fraction ranging from one fifth to one third of the current fossil reserves could be burned (Mc Glade and Ekins 2015). This simple fact has given rise to the expression *unburnable carbon* to indicate the amount of fossil fuel that cannot be burned for constraints on the sink side (Leaton et al 2013).

The conclusion is that *fossil fuel consumption must peak in the next decades*, wether for constraints from the source side or from the sink side: speaking of sustainable development may make sense only for undeveloped countries who are not yet exploiting theis share of burnable carbon, but is a complete nonsense for all over developed countries of the western world. To quote the economist Georgescu-Roegen: «There cannot be much doubt, sustainable development is one of the most toxic recipes" (Georgescu-Roegen 2011).

### *6.1.2 Strategies for a sustainable agriculture*

The issue of *sustainable agriculture* is of the greatest importance because it is related to the basic human need of nutrition; while manufacturing, transport or services sectors could eventually be downsized according to resource availability, it is not possible to reduce human food income below somatic basic energetic expenditure without serious health consequences.

Perhaps the most sharp and convincing definition of sustainability in agriculture has been given by Patzek (2004):

> «A cyclic process is sustainable if and only if
> 1. It is capable of being sustained , i.e., maintained without interruption, weakening or loss of quality "forever," and
> 2. The environment on which this process feeds and to which it expels its waste is also sustained "forever."»

From this approach it is clear the substantial analogy between ecosystems and thermodynamic cycles. A process is sustainable if and only if it is cyclical, that is if it returns after a certain period to the initial conditions. During each cycle energy is exchanged between the system and its environment, so that the total energy is conserved.

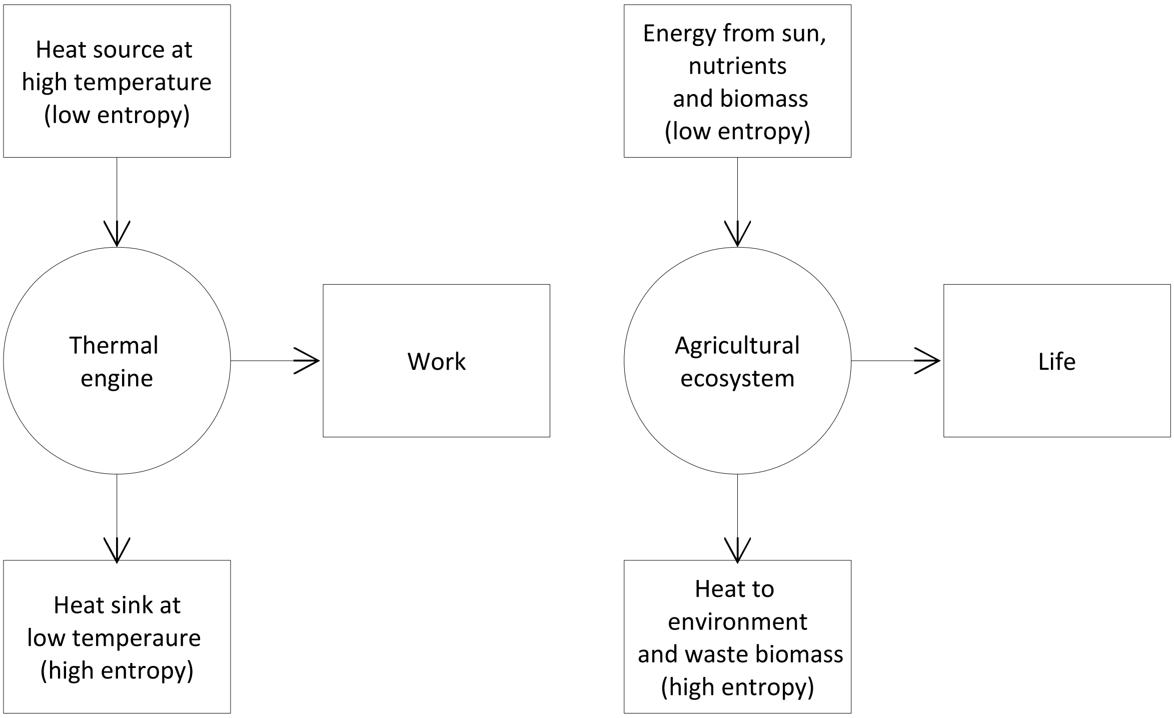

Figure 6.1 Analogy between thermodinamic cycle and agricultural ecosystem.
Adapted from Patzek (2004)

However, since every physical process is irreversible, entropy builds up during the cycle; the only way to keep it going without any time limitation is to continuosly provide low entropy energy and matter from external sources (sunlight, nutrients and biomass) and to give up high entropy energy and matter to the environment (heat and "waste products"), as detailed in figure 6.1.

Patzek's definition and analogy with thermal engines has four natural and fundamental consequences related to the characteristics of energy and mass flows:

1. the energy source for a sustainable process must be renewable, otherwise the process cannot be mantained indefinitely;
2. a sustainable cyclic process must not reject heat into the environment at a rate that is too high for the earth to export this heat to the universe; otherwise, the environment properties will change.
3. the source for nutrients and biomass should come from other sustainable processes;
4. the process must not reject extraneous chemicals into the environment, i.e., its net mass production must be "close" to zero "forever."

For practical purposes, "forever" is intended to mean "for long times on historic scale". Traditional pre-industrial agriculture approached sustainability since it was mainly based on renewable energy and natural materials.

However, sometimes sustainability lacked on the medium-long term because processes were not really cyclical: this is the case of soil salinization in the early civilizations of Mesopotamia (Ponting 2007), or soil erosion and deforestation (see paragraph 3.4.1).

Perhaps the best example of sustainable agriculture comes from China, where some regions sustained a high food productivity for more than nine centuries (Ellis and Wang 1997). During this very long period agriculture technology remains basically unchamged, as did the yields of rice, wheat and other crops. Nevertheless, grain production increased over time as a result of increased multiple cropping and intensified use or organic fertilizers; without degrading soil resources, continuous intensive farm management supported nutritional and other needs of the population, which grow to the remarkable figure of ten people per hectare of cultivated land, which is roughly more than double of the highest density registered in Europe before the advent of industrial agriculture.

What are then the opportunities for increasing sustainability in agricultural production and more specifically in the milk and rice food chain which are the subject of this work? It is possible to group them in the following five areas:

1. Increase the production/use of renewable energy from sources external to the farm (sun, wind, water, geothermal) in order to cover as much inputs as possible;
2. shift as many mechanical operations as possible to electric power;
3. produce renewable energy from sources internal to the farm (mainly biogas from manure and heat from rice hulls;
4. reduce the use of synthetic fertilizers.

## 6.2 Production/use of renewable energies from sources external to the farm

### 6.2.1 Photovoltaics

Solar cells uses the photovoltaic effect (Becquerel 1839) that converts radiating energy from solar visible and UV photons to electrical current when striking a suitable semiconductor device. The efficiency of the energy conversion process increased from 12% of the early '70s to 20,4% for polycristalline silicon and to 25% for single crystal in 2014, while the best available technology (multijunction cells) can reach an efficiency of 46% (NREL 2015).

Lifetime of solar cells is generally assumed to be 25 years, but after 20-25 years the relative efficiency of the cells is still around 90%, (Chianese et al. 2004, Kyocera 2009). At the end of the useful life, more than 80% of the solar panel materials can be recycled (Krueger 199).

An important indicator for the sustainability and the robustness of a particular energy technology is the so called EROI, *Energy Return On Investment* (Murphy et al 2011), defined as

$$\varepsilon = \frac{E_{gross\ out}}{E_{inv}} \tag{6.1}$$

where $E_{gross\ out}$ is the gross energy ouput of the technology and $E_{inv}$ the energy invested to produce $E_{gross\ out}$. EROI values may change if the energy investment include only extraction costs or also refining and transportation to the point of use.

For PV panels the EROI is estimated to be around 10 (average of 79 different values from 45 publications, Hall et al 2014), that is that 1J invested in the manufacturing, installation and maintencance of a solar panel yields 10 J of energy ouput during all the panel life. This means that it would be possible to sustain the PV supply chain only relying on energy produced by solar panels. This is the basic idea of the *Sahara Solar Breeder* (Komoto et al 2007), a joint Japanase-Algerian project that plans to use the strong solar irradiation and the sand availability of the Sahara desert to manufacture solar panels using solar energy. This could potentially lead to a rapid exponential increase of the PV industry.

Photovoltaic energy is available everywhere on the planet, and may cover electrical energy needs even at high latitudes. Energy production varies during the different hours of the day and months of the year, but with appropriate equipment design it is possible to satisfy all household or farm needs by exchanging energy with the network or storing it in batteries for isolated locations.

The actual use of PV panels in six dairy or rice farms surveyed in the present study is reported in Table 6.1 , together with the coverage of electrical and total energy needs (embodied energy in structures and machinery wasn't considered in this total, since this type of energy wasn't consumed in the farm). Solar energy covers up from 16 to 50% of the total energy footprint; and for three farms the production cover from 2 to 3 times the current electrical needs.

Table 6.1

Surveyed farms equipped with PV panels: installed power, energy produced and coverage of electrical and total energy consumption.

| Farm code | | OR1 | C5 | C6 | G4 | OP4 | OP5 |
|---|---|---|---|---|---|---|---|
| Type | | Rice | Rice | Rice | Dairy | Dairy | Dairy |
| Location | | Missouri | Piemonte | Piemonte | Emilia | Emilia | Emilia |
| Power (kW) | | 40 | 106 | 120 | 680 | 19 | 80 |
| Production (GJ) | | 238 | 880 | 1022 | 2877 | 50 | 620 |
| Energy use (GJ) | Total | 1223 | 5353 | 2012 | 16170 | 300 | 2977 |
| | Electrical | 91 | 312 | 294 | | 82 | |
| Coverage | Total | 19% | 16% | 51% | 19% | 17% | 21% |
| | Electrical | 260% | 283% | 347% | | 61% | |

Table 6.2 Potential production of electrical energy from PV panels according to the area available on the dairy farm roofs oriented S, SW or SE. Radiation: Missouri 6,9 GJ/m² y (Roberts 2009); Emilia 5,13 GJ/m² y (Suri et al . 2008). PV efficiency :20%(NREL 2015)

| Effective Area | | Total Electrical energy | | Specific electrical energy | | Coverage of demand |
|---|---|---|---|---|---|---|
| | | Potential production | Actual use | Potential production | Actual Use | |
| m² | | GJ/y | GJ/y | MJ/kg milk | MJ/kg milk | % |
| G1 | 1882 | 1948 | 1185 | 0,86 | 0,52 | 164% |
| G2 | 384 | 398 | 99 | 1,42 | 0,35 | 403% |
| G3 | 6118 | 4708 | 3442 | 0,49 | 0,36 | 137% |
| G4 | 2803 | 2158 | | 0,41 | | |
| G5 | 6086 | 4684 | 5759 | 0,34 | 0,42 | 81% |
| P1 | 620 | 642 | 192 | 1,01 | 0,30 | 334% |
| P2 | 417 | 432 | 909 | 0,16 | 0,33 | 47% |
| P3 | 632 | 487 | 60 | 1,98 | 0,24 | 811% |
| P4 | 616 | 474 | 38 | 1,75 | 0,14 | 1248% |
| OP1 | 392,4 | 406 | 96 | 1,81 | 0,43 | 423% |
| OP2 | 527,4 | 546 | - | 1,56 | - | - |
| OP3 | 749,7 | 776 | 152 | 3,2 | 0,63 | 22,5% |
| OP4 | 79,2 | 61 | 6 | 0,32 | 0,03 | 1015% |
| OP5 | 754,2 | 580 | 107 | 2,01 | 0,37 | 542% |
| OP6 | 2417,4 | 1860 | | 1,33 | | |

Farms have generally enough roof space to produce more solar energy than their actual consumption. Table 6.2 and 6.3 show the potential renewable energy production of the surveyed dairy and rice farms, respectively, if they were all equipped with PV panels.

For each farms were considered only the areas of the roof portions that were oriented south, south-east and south-west. In order to take into account possible reduced efficiencies due to orientation or tilt angle, only 90% of each area was considered.

If properly equipped, 17 over 27 farms would therefore be self sufficient for operation like lighting, venting and milk cooling (dairy) or irrigation and drying (rice) and would produce extra electrical energy that could be sold to the network, used for other electrical applications, as detailed in the paragraph 6.3, or employed for fertilizer production (paragraph 6.4).

Table 6.3 Potential production of electrical energy from PV panels according to the area available on the rice farm roofs oriented S, SW or SE. Radiation: Missouri 6,9 GJ/m² y (Roberts 2009); Piemonte 5,5 GJ/m² y (Suri et al . 2008). PV efficiency :20%(NREL 2015)

| Effective Area | | Total Electrical energy | | Specific electrical energy | | Coverage of demand |
|---|---|---|---|---|---|---|
| | | Potential production | Actual use | Potential production | Actual Use | |
| m² | | GJ/y | GJ/y | MJ/kg rice | MJ/kg rice | % |
| C1 | 3045 | 3151 | 4197 | 0,59 | 0,79 | 75% |
| C2 | 1287 | 1332 | 1459 | 1,17 | 1,28 | 91% |
| C3 | 369 | 382 | 1315 | 0,39 | 1,34 | 29% |
| C4 | 1337 | 1384 | 4171 | 0,13 | 0,39 | 33% |
| C5 | 1127 | 929 | 312 | 0,82 | 0,28 | 298% |
| C6 | 837 | 690 | 163 | 1,25 | 0,30 | 423% |
| C7 | 372 | 307 | 24 | 2,19 | 0,17 | 1278% |
| C8 | 297 | 245 | 68 | 0,80 | 0,22 | 359% |
| C9 | 579 | 477 | 314 | 1,57 | 1,03 | 152% |
| C10 | 663 | 546 | 58 | 1,80 | 0,19 | 941% |
| OR1 | 190 | 238 | 91 | 0,12 | 0,078 | 260% |
| OR2 | 378 | 312 | 208 | 0,46 | 0,31 | 150% |

### *6.2.2 Micro and pico hydro power*

Hydroelectric power is the most relevant source of renewable energy on the planet, delivering more than 3700 Twh of electricity, that is 13,6 EJ (BP 2014), with a 43% increase in the last decade and 50% more production with respect to thermonuclear, the second non fossil (but non renewable) energy technology.

Very large hydroelectric power plants (more than 1 GW electric) obtained with the costruction of large dams cannot be properly defined as sustainable, since they contibrute to global warming through methan and nitrous oxide emissions from the decomposition of organic matter on the bottom of reservoirs. Greenhouse gas emissions lay in the range 160-250 g $CO_{2\ eq}$/kWh for temperate dams, that is about one half the emission of a gas-fired power plant, but can reach 1300-3000 g $CO_{2\,eq}$/kWh for reservoirs in the tropical regions, that is more than a coal-fired power plant (Steinhurst et al 2012) . Building of the dams caused flooding of vaste agricultural areas, with the consequent forced displacement of 40 to 80 million people during the twentieth century (WCD 2000) and disruption of river ecosystems.

About half of the large hydroelectric projects are producing less energy than forecasted (WCD 2000); in the worst cases, it would have been possible to produce the same amount of energy by deploying PV panels on a small fraction of the flooded land.

On the contrary micro and pico hydropower (respectively less than 100 kW and less than 5-10 kW) has minimum environmental impact and GHG emissions and could provide renewable energy production on a small scale suitable to farm needs.

Surface irrigated rice farms in Italy are the best candidates to exploit the hydroelectric potential, since they are located in a complex network of large, medium and small canals with a significant constant water flow that lasts almost all year for the larger canals and about five month a year for the smaller ones. No hydroelectric power is predictable for Missouri since there is no surface irrigation.

The contribution from smaller canals is marginal: near the surveyed farms there are canals 2,5 - 4 meters wide that could host only very small hydroelectric turbines of 1-2 kW that could cover only part of the farms household consumption.

The situation is radically different for the larger canals. Water management in the rice producing zones of Piemonte and Lombardia is performed by two different authorities, the West and East Sesia Consortiums.

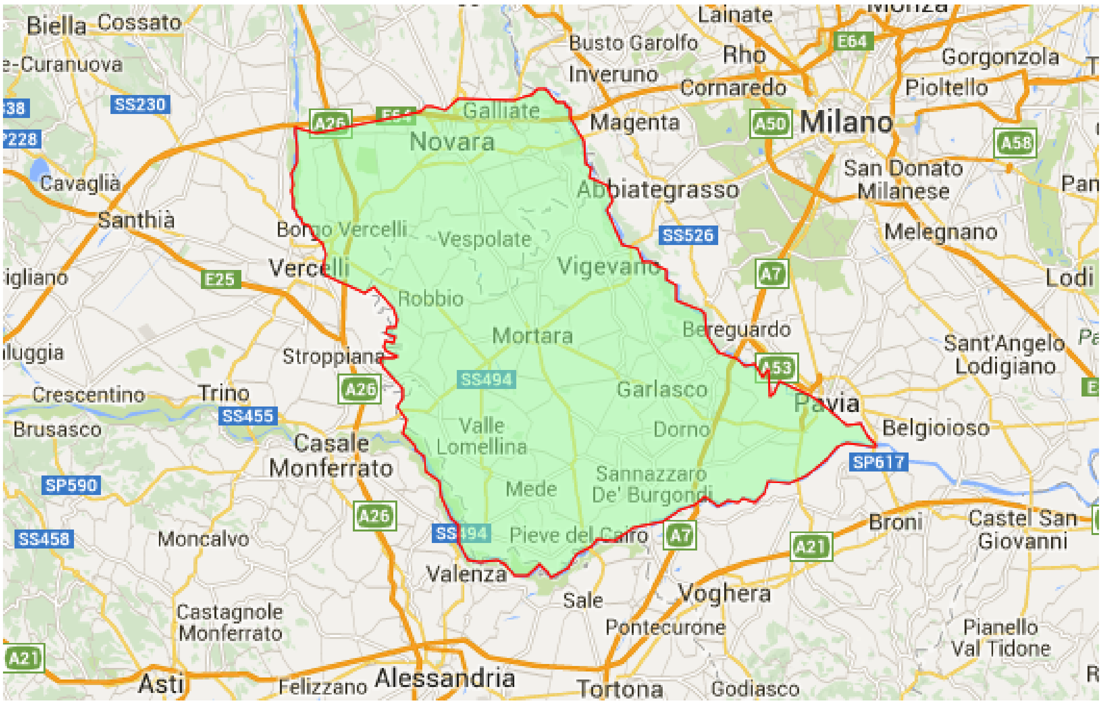

Figure 6.2 The irrigation basin of the East Sesia Consortium

The East Sesia consortium covers an area of 210 000 hectares (see figure 6.2) included by the rivers Po, Sesia and Ticino; on the north is limited by the Canale Cavour and other canals . On its network of canals, there are currently operating 41 micro and mini hydroelectic plants for a total installed power of 27 MW. Other plants are under construction or in projects for an additiopnal power of about 29 MW. In the basin area there should be other addirional 115 sites suitable for hydropower, with several meters of head and flows in the range 10-25 $m^3/s$ (Est Sesia 2015).

If the potential would be fully exploited, it is possible to assume an expecgted production of 3410 TJ/y, that is about 16 GJ pr hectare of land in the basin (see talbe. 6.4). This could also be translated in 2,75 MJ for kg of paddy rice, according to the average yield of 6500 kg per hectare..

Since this energy is generated in the rice producing zone, it may be accounted as energy produced by the farms (see paragraph 6.5); this energy could actually be owned by farmers if they would cooperate to install and use for their own needs the power station on the available sites. In order to follow a conservative approach it is reasonable to assume that only half of the unexploited sites are suitable for production (last row of table 6.4), giving an energy density of 11,6 GJ/ha

Table 6.4 Hydroelectric potential of the east Sesia river basin. Energy production estimated according to a flow regime of ten months a year.

| Plant status | Sites | Power | Energy | Energy density |
|---|---|---|---|---|
| | Number | MW | TJ/y | GJ/ha |
| Operating | 41 | 27 | 700 | 3,3 |
| In costruction or in project | 44 | 29 | 750 | 3,6 |
| Other possible sites | 115 | 76 | 1960 | 9,4 |
| Total (with all other sites) | 200 | 132 | 3410 | 16,3 |
| Total (with half other sites) | 142 | 94 | 2430 | 11,6 |

## *6.2.3 Wind power*

Energy can be harnessed from the wind using properly designed turbines coupled with an electric generator. The total incident wind power $P_i(v)$ is proportional to the area $A$ swept by the rotor and the cubic power of the velocity, $v$.

Owing to the conservation of mass and energy, an ideal turbine could extract only about 59% of this power, the so called Betz limit. Real turbine can reach output power $P_o$ that are about 40-50% of $P_i$ . If the time - velocity distribution over one year $t(v)$ is known, it is possible to forecast the energy production of the turbine by integrating P(v) t(v) over time. The ratio between the energy produced in one year and the nominal power is called energy producibility; it has the dimensions of a time and indicates the equivalent hours at full power in one year.

The EROI of eolic energy is about 18 (Hall et al. 2014) , nearly double than solar energy, but the drawback is that only sites with a minimum wind speed are suitable.

Wind speed increases linearly with the quote, so that it usually more profitable to install large turbines 100 m high with powers ranging typically from 1,5 to 3 MW for onshore generation, while even greater powers are used offshore.

There is no potential for wind energy in the plain regions of rice and dairy farms in Piemonte and Emilia Romagna: the average wind speed is lower than 3,5 m/sec (RSE 2013). On the contrary, Missouri presents some potential, as can be seen from figure 6.3. The county boundaries were superimposed on the original map, in order to locate the dairy and rice farms.

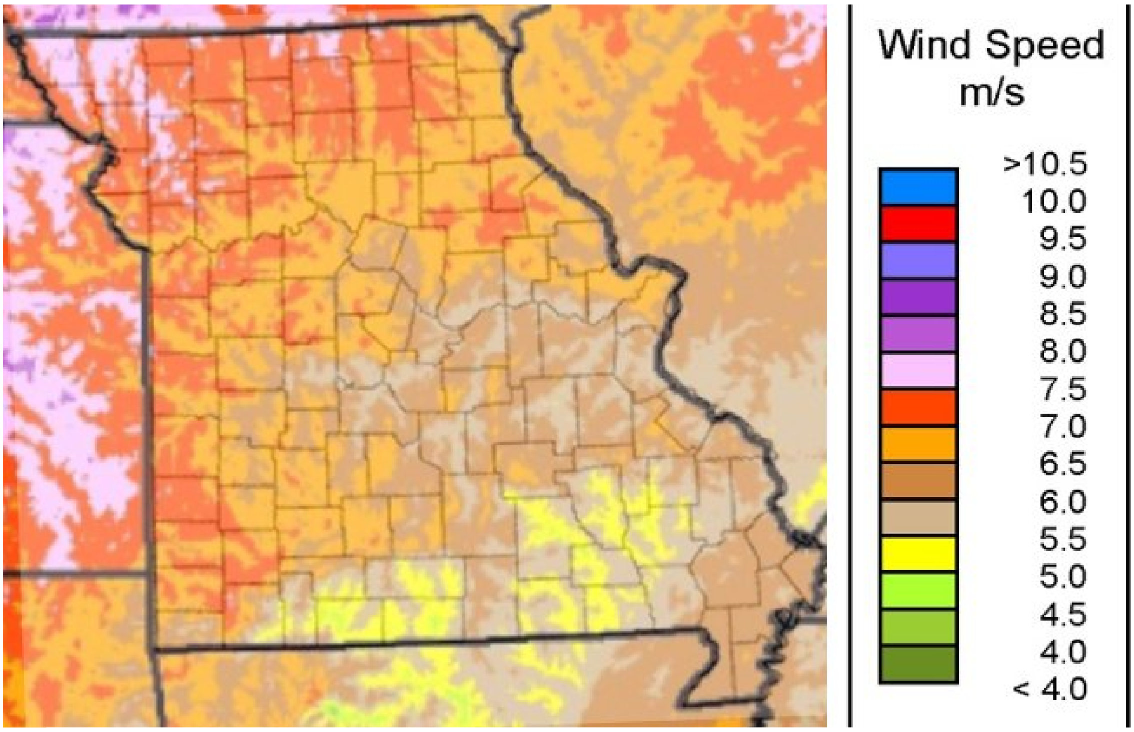

Figure 6.3 Average wind speed in Missouri at 100 m from the ground. Source NREL (2013)

Missouri has currently five main wind farms, all located in the north-west corner of the State, where the wind average speed is highest, around 7,75 m/sec. According to the data reported in table 6.5, turbines are deployed with a density of one every 100 hectares, with an average energy production of about 17 TJ. The surface energy density is 165 GJ per hectare of agricultural land.

The wind energy potential of the surveyed farms is reported in table 6.6. The local average wind speed of each farm has been estimated from figure 6.3; energy production has been estimated as a function of the speed, according to the relation:

(6.2) $$E(v)=0{,}75\ Eo\left(\frac{v^3}{v_o^3}\right) \quad ,$$

where $v_o$=7,75 m/s is the average speed of wind in the north west farms of table 6.4 and $E_o$=17,1 TJ is the relative energy production of one of those turbines. Conservatively, it was also assumed that only three quarters of this energy were actually available. It was also supposed that the turbines were part of a large energy plant located in the region of the dairy or rice farms, 1,05 turbins every hundred hectares, and that each holding shared a number of turbines proportional to the farm area (for this reason the turbine number is not integer).

Table 6.5 Power and energy data of the main wind farms in Missouri. Sources: NREL (2013) for the maps and NREL (2015) for the data.

| Wind farm | | Bluegrass | Lost creek | Conception | Cow Branch | Farmers City | Total | Average |
|---|---|---|---|---|---|---|---|---|
| Power | MW | 56,7 | 150 | 50,4 | 50,4 | 146 | 453,5 | - |
| Turbines | N | 27 | 100 | 24 | 24 | 73 | 248 | - |
| Specic power | MW | 2,1 | 1,5 | 2,1 | 2,1 | 2 | - | 1,96 |
| Production | TJ/yr | 483,3 | 146,1 | 445,3 | 424,3 | 1216,8 | 4030,2 | - |
| Producibility | h/yr | 2368 | 2705 | 2454 | 2338 | 2315 | - | 2436 |
| Energy/turbine | TJ//yr | 17,9 | 14,6 | 18,5 | 17,7 | 16,7 | - | 17,1 |
| Energy density | GJ/ha | 177 | 129 | 200 | 166 | 154 | - | 165 |
| Turbine density | N/100 ha | 0,99 | 0,88 | 1,08 | 0,88 | 1,85 | - | 1,05 |

Table 6.6 Wind energy potential for the surveyed missourian farms. See text for details

| Farms | Wind speed | Production factor | Farm Area | Turbines | Total Production | Specific production | |
|---|---|---|---|---|---|---|---|
| | m/s | % | ha | n | GJ | GJ/ha | MJ/kg |
| G1 | 6,5 | 44,2% | 36,57 | 0,38 | 2909,7 | 79,57 | 1,28 |
| G2 | 7 | 55,3% | 8,1 | 0,09 | 804,9 | 99,38 | 2,88 |
| P1 | 7 | 55,3% | 44 | 0,46 | 4372,5 | 99,38 | 6,88 |
| P2 | 6,25 | 39,3% | 160 | 1,68 | 11317,3 | 70,73 | 4,09 |
| OP1 | 6,5 | 44,2% | 59 | 0,62 | 4694,3 | 79,57 | 20,92 |
| OP2 | 7 | 55,3% | 33 | 0,35 | 3279,3 | 99,38 | 9,36 |
| OP3 | 6,5 | 44,2% | 23 | 0,24 | 1830,0 | 79,57 | 7,54 |
| C1 | 6 | 34,8% | 570 | 6,00 | 35670,7 | 62,58 | 6,71 |
| C2 | 6 | 34,8% | 142 | 1,49 | 8886,4 | 62,58 | 7,77 |
| C3 | 6 | 34,8% | 122 | 1,28 | 7634,8 | 62,58 | 7,79 |
| C4 | 6 | 34,8% | 1220 | 12,84 | 76348,0 | 62,58 | 7,12 |
| OR1 | 6 | 34,8% | 163 | 1,72 | 10200,5 | 62,58 | 8,33 |

The energy potential is very high, from four to six times greater than the hydroelectric potential of the italian farms. Possible application of this energy will be discusse in the next paragraphs. It is worth noting that also atpresent there are no wind farm in the Mississippi delta region, many italian on shore wind farms are located in zones where the average wind speed is 4 - 5 m/sec (Atlaeolico 2013) , while in the rice area the speed at 25 m is between 4,5-5 m/sec.

## 6.3 The shift towards electric power

Since most of the farms could produce more electrical energy that their current needs (paragraph 6.2.1), it is possible to think to shift towards electrical power other operations that are currently performed through combustion of fossil fuels. Two kind of operations will be considered in this paragraph, heating and engine for tractions, while its possible use for fertilizer manufacturing will be discussed in paragraph 6.5.

### *6.3.1 Heating with electrically powered heat pumps*

Propane and sometimes diesel fuel are typically used to heat ambients (offices and milk parlors) or for other farm operations like cheese making or rice drying. By using a heat pump powered by renewable energies it is possible to obtain the required heat without the combustion of non renewable fuels.

A heat pump is a machine that operates an inverse thermodynamic cycle by using mechanical work to pump heat from a low temperature environment (the “outside”) to a high temperature environment (the “inside”). Work must be spent on this cycle, because, according to second principle of thermodynamics, heat flows spontaneously only from high to low temperature bodies. It is possible to make a schematic representation of a heat pump by reversing the directions of the arrows of the left part of figure 6.1.

The coefficient of performance (COP) of a heat pump is defined by

$$COP=\frac{|Q_o|}{Q_i}=\frac{Q_i+W_i}{Q_i} \tag{6.3}$$

where $W_i$ is the work used in the system, $Q_i$ is the heat absorbed at low temperature $T_l$ and $Q_o$ the heat transfered at high temperature $T_h$. From the second identity (that follows from the first principle of thermodynamics) it is clear that COP is always greater than 1.

An ideal reversible heat pump would have a COP defined by

$$COP_{rev}=\frac{T_h}{T_h-T_l} \tag{6.4}$$

A real heat pump has a performance that is usually lower than $COP_{rev}$. Figure 6.4 shows the COP of 63 different models of heat pumps as a function of $T_h/(T_h-T_l)$. A linear fit of the data gives the following expression:

$$COP=0{,}335\frac{T_h}{T_h-T_l}+0{,}286 \quad . \tag{6.5}$$

According to eq (6.4), the COP for a heating system providing hot air at 35 °C is 3,2 if the outside temperature is 0 °C and 2,6 if it's -10 °C. COP are much better for rice drying, around 5,3, because rice is dried at about 30 °C and in september-october the outside temperature is usually above 10 °C.

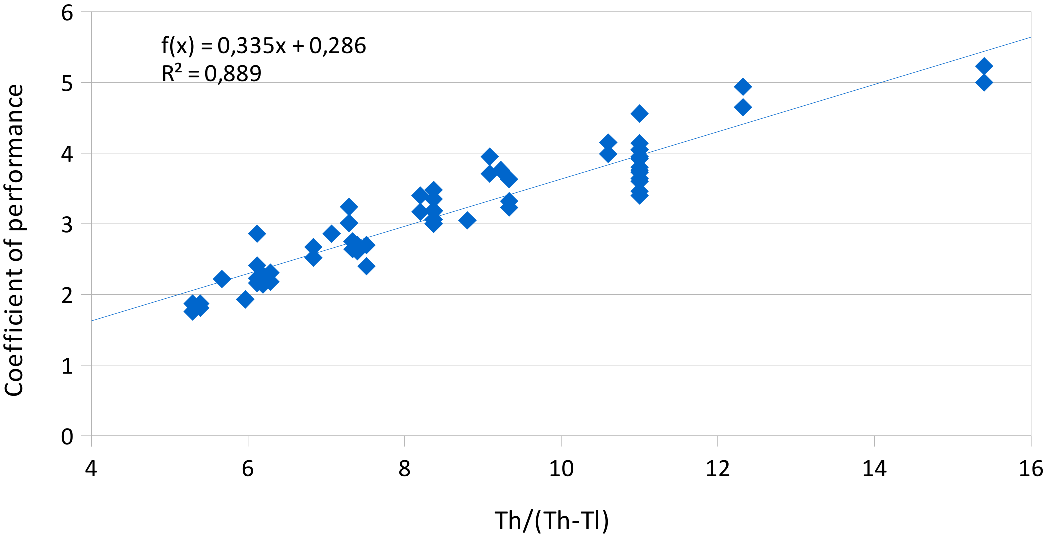

Figure 6.4 Coefficient of performance of different models of heat pumps vs $T_h/(T_h-T_l)$
Data from Staffel (2009)

Table 6.7 reports the propane and thermal energy consumption of selected farms (the ones that give disaggregated data on fuel consumption for ambient heating and traction). Requirements can be quite high, especially for rice drying. On the same table is reported the electrical energy consumption in order to deliver the thermal energy with a heat pump. To be conservative, COP was set equal to 3 for heating purpose and to 5 for rice drying, which is also in agreement with literature data (Best 1996). The last column shows the theoretical availability of extra electrical energy from PV panels, that is the production (3rd column of table 6.2 and 6.3) minus the current electrical consumption (4th column of same tables).

Is it possible to power a heat pump with solar energy? This kind of solution is not yet much diffused but it has been already tested (Zhang 2014) and is also commercially available (PennEnergy 2014). It is possible to couple PV electric production with thermal solar prodeuction to pre-heat the water. The use of lithium-ion batteires allows  to make it work also during the night. The system is quite efficient and requires only little input from the electric grid.

Rice drying can be perfomed mainly during the day, so that battery requirements are lower. Using the heat pump may be an interesting option for rice farms that do not have a mill, otherwise it would be probably more convenient to generate the heat from husks combustion (par 6.4.2). The same could be said for dairy farms that may have the opportunity of biogas production (par 6.4.1): the use of methane or byproduct heat from electricity generation may be more convenient .

Table 6.7 Current heating needs of dairy and rice farms and possible use of a heat pump

| Farm | Operation | Propane heating | | Heat pump | | Extra PV Energy available |
|---|---|---|---|---|---|---|
| | | Consumption | Energy | COP | Electrical energy | |
| | | liters | GJ | | GJ | GJ |
| G2 | cheese making | 7750 | 199,0 | 3 | 66,3 | 299 |
| G3 | heating | 8890 | 228,3 | 3 | 76,1 | 1266 |
| P1 | heating | 1937 | 49,7 | 3 | 16,6 | 449 |
| P4 | heating | 950 | 24,5 | 3 | 8,2 | 55 |
| C5 | rice drying | 32788 | 842,0 | 5 | 168,4 | 617 |
| C6 | rice drying | 8581 | 220,0 | 5 | 44,0 | 527 |
| C7 | rice drying | 3543 | 91,0 | 5 | 18,2 | 282 |
| C8 | rice drying | 10358 | 266,0 | 5 | 53,2 | 177 |
| OR2 | rice drying | 18000 | 462,0 | 5 | 92,4 | 104 |

### *6.3.2 Use of electric power for tractors: perspectives and limits*

The main limitation in the diffusion of electrical tractors is the same that is slowing down the development of electrical cars, that is power density. A state of the art Lithium-sulfur cell has a specific energy of 1,1 MJ/kg and energy density of 2,6 MJ/dm$^3$ (Oxisenergy 2014). By comparison, diesel fuel has a specific energy of 43,4 MJ/kg and a density of 36,1 MJ/dm$^3$.

A battery pack will thus occupy 14 times more volume than a diesel tank, and will weight 40 times more, posing challenges and limitations to the design and the performance of electric tractors.

On the other hand, an electric tractor would be more efficient, since almost all the power is delivered to the wheels, while in conventional tractors the mechanical efficiency is around 67% (90% of transmission efficiency times 75% of tractive efficiency, MacMillan 2002).

RAMSES is an interesting prototype of electric tractor, developed by an international team coordinated by the University of Florence (El Asmar etal. 2009). The tractor is powered by a 96 V, 12 kW electrical engine; an auxiliary engine of the same power is used for moving external agricultural equipment and the hydraulic system. The engine is fed by 16 lead-gel batteries with a total energy of about 17 kWh, that can give a 2-4 hours autonomy for field work or 80 km of displacement at a maximum speed of 45 km/h. The mass is 1700 kg and the useful load 1000 kg.

Batteries are recharged with a PV equipment of 12 kWp; the whole system is partifcularly designed to work in tropical countries, where solar energy is abundant and field work can be performed in a morning and afternoon sessions separate by the battery recharge.

A similar commercial model from an american-canadian company has a 18 kW engine with autonomy up to 9 hours and is especially designed for towing carts and mowing (Electric Tractor 2015).

An electric tractor has a good performance with respect to small diesel tractors of similar power (Heckeroth 2009). In order to increase the engine power  it would be necessary to scale up the batteries, with related costs increase.

A hypothetical 50 kW electric tractor (equivalent to a 75 kW diesel) may consume 250 kWh per day. This energy could be stored in one big Lithium battery pack that weighs one ton, occupy a volume of 430 liters and costs roughly 80 000 $, that is more than a complete diesel tractor of the same power. Designing a larger vehicle like a combine harvester that operates continuosly at high power rates would be even more difficult.

Moreover Lithium reserves are estimated to be around 13,5 million tonnes (USGS 2015), which means that even if all estimated Lithium would be recovered and used for agricultural purposes, it would be sufficient only to substitute 50% of the 27 million tractors in use in the world (FAOSTAT 2014).

It is however quite reasonable to assume that technological innovation in PV storage systems could reduce in the near future mass, volume and costs of batteries, making electric tractors more competitive on the market.  In this case, it would be interesting to evaluate if the farms could cover their power needs with PV production granted by panels on their rooftops.

As can be seen from tables  6.8 and 6.9, 18 over 27 surveyed farms would produce enough energy to power all the tractors currently in use. In the other 6 cases, the extra energy could be provided by supplementary PV panels occupying areas ranging from 40 to 500 m², equivalent to square fields with sides ranging from 6 to 22 m. These extra panels could be located in non cultivated or non productive areas, but even if they were located on good fertile land, they would occupy only a small fraction of the area required to produce the same energy with biofuels .

Wether biogas  or syngas production were available at the farms (par 6.4.1 and 6.4.2), their use as tractors fuel would be probably more convenient than the use  of Lithium cells for electrical engines.

Availability of cheap fossil fuels during the twentieth century drove the race towards more and more powerful and energy-thirsty machinery. Possible constraints and limitations from renewable energy supplies will be probably at the origin of a shift towards a low energy agricultural paradigm, as correctly stated by Bardi et al. (2013):

> «Clearly, a mechanized agriculture cannot work by simply replacing diesel powered vehicles with battery powered ones. In the long run, if we do not want to return to human powered farms, the only option is to restructure the agricultural process in such a way to reduce the need of heavy vehicles and high power operations, making it compatible with electric vehicles.
> An agriculture which makes less use of brute power is also an agriculture that is more respectful of the environment in the sense that it causes little degradation of the soil.»

One possible example of “less use of brute power” is the no-till farming practice, that avoids the most energy intensive operation of ploughing, with benefits in reduced machiney use and fuel consumption, together withh better soil conservation (Derpsch et al 2010); the benefits are increased when no-till is associated with organic farming (Rodale 2014). No-till farmin increased from 45 to 111 millions of hectares in the laste decade and is used not only for wheat and maize, but also for rice-soy rotation.

Table 6.8 Estimated energy requirements for electrical tractors use in the surveyed dairy farms and % coverage provided by PV panels installed on rooftops. If coverage is less than 100%, the extra energy and extra area for PV panels is indicated. Tractors are supposed to work for 400 hours a year. Electrical power is 2/3 of diesel power owing to higher transimission efficiency.

| Farm | Potential PV Production | Total power used at farm | | Required Energy | Coverage | Extra energy | Extra area for PV |
|---|---|---|---|---|---|---|---|
| | | Actual tractors | Electric equivalent | | | | |
| | GJ/y | kW | kW | GJ/y | % | GJ | m² |
| G1 | 1948 | 500 | 333 | 600 | 325% | | |
| G2 | 398 | 395 | 263 | 474 | 84% | 76 | 69 |
| G3 | 4708 | 738 | 492 | 886 | 531% | | |
| G4 | 2158 | 1145 | 763 | 1374 | 157% | | |
| G5 | 4684 | 1410 | 940 | 1692 | 277% | | |
| P1 | 642 | 234 | 156 | 281 | 229% | | |
| P2 | 432 | 200 | 133 | 240 | 180% | | |
| P3 | 487 | 390 | 260 | 468 | 104% | | |
| P4 | 474 | 302 | 201 | 362 | 131% | | |
| OP1 | 406 | 581 | 387 | 697 | 58% | 291 | 233 |
| OP2 | 546 | 139 | 93 | 167 | 327% | | |
| OP3 | 776 | 197 | 131 | 236 | 328% | | |
| OP4 | 61 | 100 | 67 | 120 | 51% | 59 | 57 |
| OP5 | 580 | 293 | 195 | 352 | 165% | | |
| OP6 | 1860 | 855 | 570 | 1026 | 181% | | |

Table 6.9 Estimated energy requirements for electrical tractors use in the surveyed farms and percent coverage provided by PV panels installed on rooftops. If coverage is less than 100%, the extra energy and extra area for PV panels is indicated. Tractors are supposed to work for 400 hours a year. Electrical power is 2/3 of diesel power owing to higher transimission efficiency. Combine harvesters are not included.

| Farm | Potential PV Production | Total power used at farm | | Required Energy | Coverage | Extra energy | Extra area for PV |
|---|---|---|---|---|---|---|---|
| | | Actual tractors | Electric equivalent | | | | |
| | GJ/y | kW | kW | GJ/y | % | GJ | m² |
| C1 | 3151 | 1327 | 885 | 1592 | 198% | | |
| C2 | 1332 | 1040 | 693 | 1248 | 107% | | |
| C3 | 382 | 895 | 597 | 1074 | 36% | 692 | 554 |
| C4 | 1384 | 900 | 600 | 1080 | 128% | | |
| C5 | 929 | 604 | 403 | 725 | 128% | | |
| C6 | 690 | 529 | 353 | 635 | 108% | | |
| C7 | 307 | 469 | 313 | 563 | 55% | 256 | 233 |
| C8 | 245 | 331 | 221 | 397 | 62% | 139 | 12 |
| C9 | 477 | 451 | 301 | 523 | 104% | | |
| C10 | 546 | 436 | 291 | 516 | 88% | 64 | 58 |
| OR1 | 238 | 430 | 287 | 516 | 46% | 278 | 222 |
| OR2 | 312 | 652 | 435 | 782 | 40% | 470 | 428 |

## 6.4 Renewable energies from farm internal resources

In the present paragraph, farm internal resources has to be intended as byproducts that could generate energy and still be used as fertilizers after energy production. We are not considering specifically grown crops for energy use, that will be discussed in paragraph 6.4.

### *6.4.1 Biogas from manure*

The production of biogas from cows manure can achieve three important results: *(i)* renewable fuel production (methane) with eventually consequent combined production of heat and electrical energy; *(ii)* reduction of methane and nitrous oxide emissions in the atmosphere; *(iii)* the digestate product can still be used as fertilizer.

*(i)* Anaerobic digestion allows to produce methane from manure with a mass yield ranging from 13,5 to 15,5% on a dry matter basis (Ahlgren et al 2009; Zhang and El Mashad 2010); total average methane

production for one cow is thus about 310 kg per year (0,85 kg/cow/day), corresponding to an available energy content of 17 GJ/cow/year (see table 6.10)

This value is related to dairy farms where the animals are confined and all the manure can be collected and processed in a digester. In pasture based farming, cows are pasturing most of the time and only about 10-15% of the manure can be collected when the animals are in the milking parlor (Dairy Australia 2008). In this case the exploitable energy would be lowered to about 2 GJ per cow.

Table 6.10 Methane production from cow manure. Methane volume at IUPAC standard conditions of 273 K and 100 kPa

| Reference | | Ahlgren et al 2009 | Zhang and El Mashad 2010 |
|---|---|---|---|
| Average values per cow per year | | | |
| Fresh matter | kg | 12450 | 16850 |
| Dry matter | kg | 1990 | 2342 |
| Methane | kg | 308 | 314 |
| Methane | $m^3$ | 438 | 447 |
| Energy | GJ | 17,1 | 16,9 |
| Average values per 1 kg of manure dry matter | | | |
| DM % | % | 15,98% | 13,90% |
| Methane | kg | 0,155 | 0,134 |
| Methane | liters | 220 | 190,7 |
| Energy | MJ | 8,61 | 7,24 |

As can be seen from figure 6.5, energy eventually produced from a biogas digester (red line) could satisfy all the fuel needs of the 8 dairy farms where the animals are confined and all manure is collected (bars with red edges); in the case of G2 it is also included propane for cheese making.

The other 7 dairy farms could produce less energy (light blue line) since the animals are pasturing on the field for most of the time and only part of the manure could be recovered. In three cases (P2, OP2 and OP4) they could nevertheless satisfy their low energy needs (bars with light blues edges). In the other holdings biogas could give from one third to one half of the needed fuel.

Methane powered tractors are already on the market; one model has 100 kW of power and a methane tank of 50 kg that could deliver about half a day of work (Farmer Guardian 2014). Since one cow can produce 300 kg of methane, a small herd of 16 cows could power this tractor for about 400 hours a year. Using methane as fuel for machinery could be complimentary or alternative to electric powered vehicles (paragraph 6.3.2).

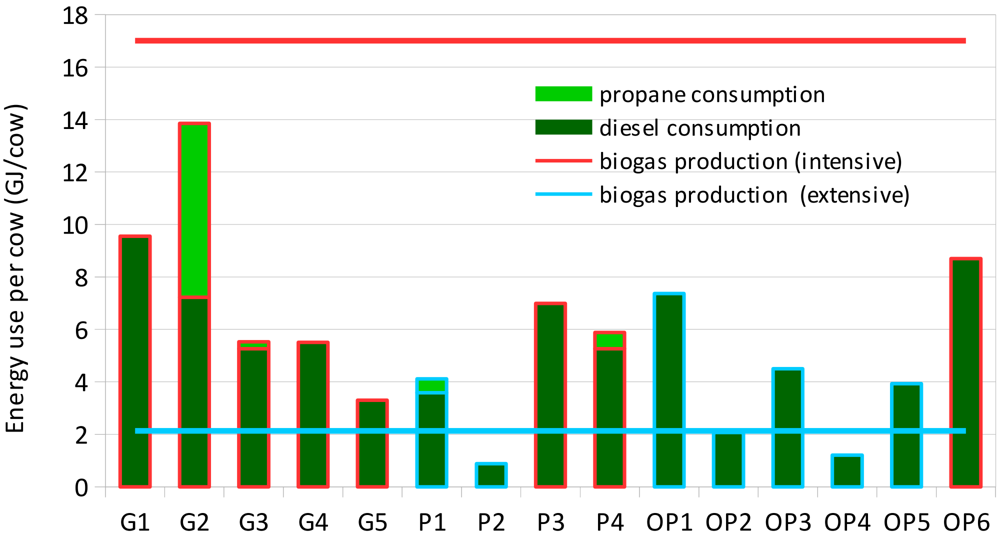

Figure 6.5 Specific per cow fuel energy production from biogas and consumption for traction and heating in the surveyed dairy farms. Red edge: confinement farms ; light blue edge: farms with cows on the fields

The optimum size for a digester is calibrated on the herd size and is typically in the range of 50-900 animals. Smaller sizes could increase fixed costs, while larger sizes , even if possible, would increase the transport cost of manure, methane and digestate (Persson et al. 1979; Fabbri and Piccinini 2012). If single farms in a region are too small to build a digester, they could consociate in order to optimize its size.

An alternative use of biogas is on site combustion for cogeneration of heat and electricity.

Since specific methane production is about 0,85 kg/cow day, with a related maximum energy production of 47 MJ/cow/day, the maximum theoretical thermal power attainable from combustion is 0,54 kW/cow. In practice, it is usually possible to obtain only 80% of this value, that is 0,43 kW/cow.

The efficiency $\eta$ of an electrical generator is typically in the range 25-40%, which means that specific electrical power would be in the range 0,11-0,17 kW/cow, while the rest of energy could be potentially delivered as heat. The amount of minimum and maximum electrical energy potential deliverable in the surveyed dairy farms is reported in table 6.11. In farms with field pasturing (denoted with an asterisk) generation is small or neglible, due to the limited amount of manure that can be collected. In confinement farms production can be quite significant, even if it it is smaller than the energy that can be generated from rooftop solar panels (last two columns of table 6.9).

The main drawback of in site use of biogas for cogeneration is that in most cases there is actually no cogeneration, but only production of electrical energy, while the thermal energy is simply *wasted*. This is the case of farm G4, that has a biogas plant with a total installed power of about 300 kW fueled by the methane produced from the manure of 587 cows plus the heifers: energy is sold to the grid, but heat is just spoiled and the same happens in other four surveyed digestors in Piemonte, where only 10% of the heat is used locally and the rest is wasted (Balsari and Dinuccio 2011) .

Heat is wasted mainly because the thermal requirements of farms are usually much smaller than the available thermal energy from the digester; possibility of using the heat for district heating is also limited by the distance of farms from town and villages.

Table 6.11 Minimum and maximum electrical energy deliverable at the surveyed dairy farms according to the herd size, as absolute value (GJ/y) and as % of the energy that could be produced by PV (see tables 6.2 and 6.3). Farms with (*) have no confinement, so manure recovery is limited to 15%.

| Farm | Electrical energy from biogas | | % of PV deliverable at farm | |
|---|---|---|---|---|
| | Min ($\eta$=25%) | Max ($\eta$=40%) | Min ($\eta$=25%) | Max ($\eta$=40%) |
| | GJ/year | GJ/year | GJ/year | GJ/year |
| G1 | 641 | 1025 | 27,3% | 43,6% |
| G2 | 103 | 165 | 21,4% | 34,3% |
| G3 | 2913 | 4661 | 46,4% | 74,3% |
| G4 | 1738 | 2780 | 60,4% | 96,6% |
| G5 | 4284 | 6854 | 68,6% | 109,8% |
| P1* | 41 | 65 | 5,3% | 8,4% |
| P2* | 234 | 375 | 44,9% | 71,9% |
| P3 | 110 | 175 | 16,9% | 27,0% |
| P4 | 134 | 214 | 21,1% | 33,8% |
| P5 | 21 | 34 | 25,8% | 41,3% |
| OP1* | 19 | 31 | 3,9% | 6,3% |
| OP2* | 29 | 46 | 4,4% | 7,0% |
| OP3* | 13 | 21 | 1,4% | 2,3% |
| OP4* | 16 | 26 | 2,1% | 3,4% |
| OP5 | 514 | 823 | 20,7% | 33,2% |

In Italy moreover most biogas plants were built in the last years in order to obtain the incentives accorded by the law for renewable electrical energy production energy, without too much worrying about the overall sustainability of the project (Mela and Canali 2014) .

Even if it were possible to recover all the heat produced by the methane combustion, it would be preferable to use directly the methane as fuel for the tractors, instead of using the electrical energy to power an electric vehicle: methane tanks are much cheaper than Lithium-ion batteries (paragraph 6.3.2) and adapting an internal combustion engine to methane is simpler than designing an electric tractor.

*(ii)* Conventional management of manure, that includes stokage and spread on the fields, is responsible of significant atmospheric emissions of Methane ($CH_4$) and Nitrous Oxide ($N_2O$), of the order of 42 g $CO_2$

$_{eq}$ per kg manure or 530 kg $CO_{2\ eq}$ per cow per year as detailed in table 6.12. This amount is equivalent to about 4000 km travelled by a new low emission car (130 g $CO_2$ /km), so that the emissions of five milking cows are equivalent to one US car that on the average travels about 20000 km per year (NHTS 2009).

Table 6.12 Greenhouse gas emissions related to biogas production and comparison with conventional manure management. Adapted from Ahlgren et al. (2009) using the latest IPCC values for the GWP of methane of 34 instead of the old value of 25 (Myhre et al. 2013).

| Greenhouse gas | Emissions from biogas production | | Emission from manure management | |
|---|---|---|---|---|
| | g $CO_{2\ eq}$/kg manure | kg $CO_{2\ eq}$/cow/y | g $CO_{2\ eq}$/kg manure | kg $CO_{2\ eq}$/cow/y |
| $CH_4$ | 2,37 | 29,5 | 7,73 | 96,2 |
| $N_2O$ | 1,78 | 22,1 | 33,72 | 419,9 |
| $CO_2$ | 1,79 | 22,3 | 1,10 | 13,7 |
| Total | 5,94 | 73,9 | 42,55 | 529,8 |

On the contrary, production of biogas reduces GHG emissions to about 86%; residual emissions are due to $CH_4$ and $N_2O$ leakage from the biogas plants, and we can reasonably assume that they could be furtherly reduced by properly redesigning the equipment. The $CO_2$ emissions from methane combustion aren't counted in table 6.8, because they are balanced by the carbon dioxide uptake during the growth phase of the feed used for the cows.

*(iii) T*he digestate product after the extraction of biogas contains substantially the same quantity of the main nutrients Nitrogen, Phosphate and Potash and also of other micronutrients like Magnesium, Calcium and Sulphur (Möller and Müller 2012). It is interesting to note that also the Carbon content of digestate is only slightly lower than the original manure, so that on the long term there is no substantial effect on the carbon balance. The digestion process seems also to improve the quality and availability of nutrients (Holm-Nielsen et al. 2009); digestate also have pesticide and fungicide effect which in some cases can be more effective than chemicals Ide Groot and Bogdanski 2013).

### *6.3.2 Syngas from rice husks*

Rice husks can be used as a source of renewable fuel. Even if the heat of combustion can reach 15 MJ/kg (Madhiyanon et al 2010) or even 16 MJ/kg under particular process conditions (Shen et al. 2012), a more proper choice would be the value of 14,3 MJ/kg reported by the International Rice Research Institute, which reflect the average yield of most of the burners (IRRI 2008). This caloric value is lower than other biomass fuels, owing to the high silica content of the husks, but it is nevertheless sufficient to grant a good supply of renewable energies to farms.

Rice husks represent approximatively 20% of the mass of paddy rice, so from 1 ton of as grown rice is possible to obtain 200 kg of husks, that could give up about 2800 MJ of energy. This amount could be used for drying a quantity of paddy rice ranging from 2,4 to 7 tons, depending on the specific energy inputs for drying (the range was 0,4 - 1,2 MJ/kg in the surveyed farms, table 5.5 and 5.6). The process could then be self sustained and extra energy would eventually be available for other farm use.

Since husk has a low density (from 70 to 110 kg/m³), it occupies a lot of storage space and tends to generate dust when moved. Husks could also be pelleted, but it would be more advisable to transform it in syngas through a gasification process: from one kg of husks it is possible to obtain 2 kg of syngas, whose heat of combustion of about 5MJ/kg is mainly due to its contents of hydrogen, carbon monoxide and methane (Ataei et al. 2012, Yoon et al 2012). The mass increase of the gas with respect to the husks is due to incorporation of Nitrogen (56% in volume) coming from the air supplied in the process and increase in Oxygen content, coming from air and steam supplied in the process.

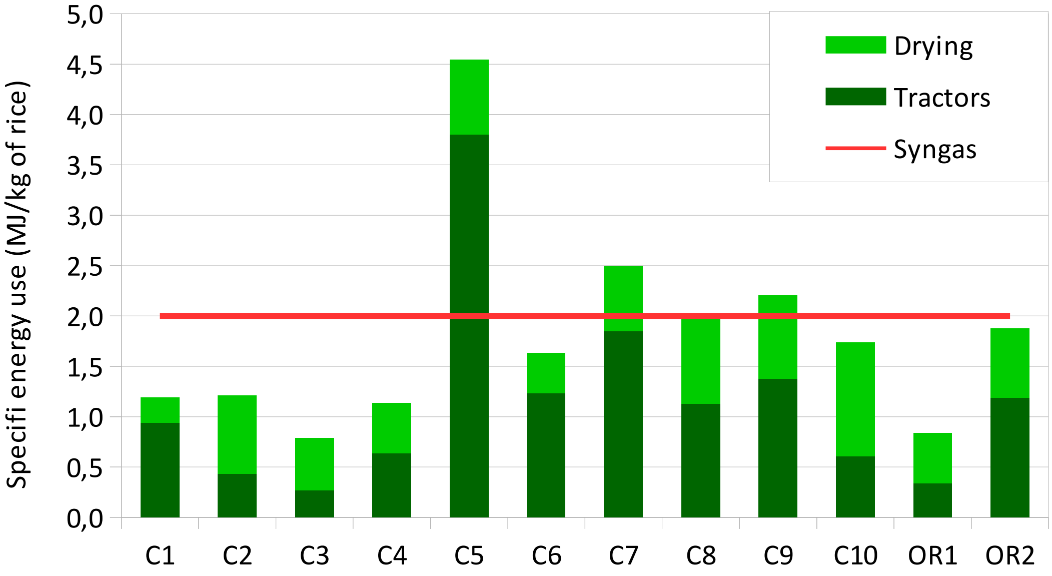

Figure 6.6 Specific per kg of paddy rice fuel energy production from syngas and consumption for traction and drying the surveyed rice farms.

The above mentioned figures gives a conversion rate of 0,4 kg of syngas per kg of paddy rice with a possible energy production of about 2 MJ/kg of rice. This specific value is compared in figure 6.6 with the specific fuel consumption of the surveyed rice farms.

Energy available from syngas would be more than sufficient for most farms with the exception of the ones with higher fuel consumption; particularly the fuel use of C5 may be overestimated , while C7 suffers of increased costs for its small size (paragraph 5.3.2).

The use of syngas for vehicle traction is the subject of research studies (Hagos et al 2014), while there are prototypes that are already used by farmers (ASA 2013, Farm Show 2014). Syngas can be stored and transported more easily than rice huks and small scale gasifier are available on the market at low price also for the needs of small-medium farms (Btek 2015).

Farms could transorm husks in syngas only if they are equipped with a rice mill, otherwise this operation could be perfomed at the mills

The only italian experience of husk energy use is a power station in the Vercelli province that collects the biomass from mills and farmers, like OR2. It treats 200 tons a day of husks producing 35 MW of thermal power and 8 of electric (Hydroblins 2015). This experience is not particularly smart because the efficiency of electricity generation is only 23% and all the heat generated is wasted since the plant is located in a small village of 400 inhabitants far from urban centers. The use of husks as a source for syngas is highly preferable.

The gasification process is carbon neutral, since the CO2 produced was previously absorbed from the atmosphere through photosynthesis.

Husk ashes after burning or gasification are quite abundant, about 20% of the original biomass, that is 4% of the original paddy rice mass, mainly composed by silica. They can be used as soil amendment (Rajor et al 2011) and significant crop yield increase was documented, but only at very high doses of 10 and 20 t/ha (Njoku and Mbah 2012).

## 6.5 Sustainable fertilization

The greatest environmental impact of fertilizers is linked to Nitrogen, that requires high energy inputs for its production in a suitable form for agriculture (Ammonia 38 MJ/kg N; urea 49 MJ/kg N, paragraph 3.4.3) and is responsible for important GHG emissions. According to recent research, N2O emission from soil treated with N fertilizers is not linear but exponential: doubling the application rate from 150 to 300 kg/ha has the effect of increasing the emission of a factor 2,5, from 660 to 1679 kg $CO_{2\ eq}$/ha (Shcherbak et al., 2014) .

Two alternative or complimentary paths will be considered: the practice of organic farming and the prodution of ammonia using renewable resources.

### *6.5.1 Organic Nitrogen*

In organic farming no synthetic nitrate fertilizers are used: this results in a significant reduction in global energy consumptions with only slight decrease in crop yields (paragraph 3.8.2 and 3.8.3). The actual experience of the surveyed dairy and rice farms show that it is possible to produce milk or rice without the use of synthetic Nitrogen.

In the surveyed organic italian dairy farms, nitrates are delivered to the soil only through cows manure self-fertilization, because most of the Nitrogen is biologically fixed by the leguminous alfalfa; american farms use less alfalfa and therefore most add other N sources from compost (OP1), chicken manure (OP2) and pigs slurry (OP3).

In rice farms, nitrates are delivered through pig slurry (OR1) or horn and hoof (OR2) or by crop rotation, alternating rice crops with soy of other pulses that fix nitrogen biologically.

These organic practices could significantly reduce energy input for fertilization, but their are subject to three main limitations: *(i)* not all soils are suitable for crop rotation, for instance heavy clayish soils are good only for rice ; *(ii)* the great availability of animal manure is mainly an effect of non organic industrial livestock farming; *(iii)* this farming uses synthetic nitrates in order to fertilize the crops used for feed.

There is an ongoing scientific debate about wether organic farming alone can (Badgley et al 2006) or cannot (de Ponti et al. 2012) feed the world; there is still no definite answer to this question, since crops yields are so sensitive to many different factors and it is almost impossible to generalize to all the planet the results of single localized studies.

Using a precautionary approach to the subject, it is reasonable to assume that it is not possible to rely only on organic farming and that it would be better to have other more sustainable sources for organic fertilizers.

### *6.5.2 SSAS: Nitrogen production from renewable sources*

Ammonia, the basic source for all nitrate fertilizers, is currently produced with the Haber-Bosch process at high temperatures and pressures in large industrial plants that make abundant use of methane not only as fuel to reach the reaction temperature, but also as reactant. For this reason this process is unsustainable by definition.

Solid State Ammonia Synthesis (SSAS) is a new and extremely promising technology that could be a real game changer both for agriculture and renewable energies (Ganley et al. 2004, Klinrisuk et al. 2015, Vasileiou et al. 2015).

SSAS operates through an electrolitic cell at atmospheric pressure where water is dissociated at 550 °C in gasesous $O_2$ and protons ($H^+$) that are adsorbed and then conducted by a membrane to the other side of the cell to react with $N_2$ to form $NH_3$.

SSAS has three main advantages with respect to the old Haber Bosch process: *(i)* it uses less energy about 32,8 MJ/kg N instrad of 38,6 MJ/kg N (Ganley et al 2007); *(ii)* it may be powered by renewable electricity and uses renewable reactants; *(iii)* the operation at atmospehric pressure and the cell structure allows also small- medium scale plants that could be eventually integrated in the farms.

In this way ammonia could be generated only by PV panels and could be also considered as an energy carrier, that is a way to store energy that could be used later in an ammonia fuel cell ( Ganley et al. 2004) or as fuel in properly designed engines (Saika 2000). With respect to hydrogen, ammonia is more portable and non flammable.

Urea produced from SSAS would require 43,8 MJ/kg, a 10% reduction with respect to the conventional process. Moreover, the urea synthesis reaction absorb on molecule of CO2 for every 2 molecules of $NH_3$ consumed, so there is a *net decrease of atmospheric* $CO_2$ of 1,4 kg per every kg of $NH_3$ consumed (the conventional Haber Bosch process for ammonia produces $CO_2$ that is later absorbed in the urea formation, so it is carbon neutral); the decrease is of 0,73 kg of $CO_2$ per every kg of urea produced.

Table 6.13 and 6.14 compare, for dairy and rice farms respectively, the energy required for producing urea from SSAS with the energy available from rooftop solar panels (for farm G1 it was indicated the indirect nitrogen content of the feed, while for OP2, OP3, OR1 and OR2 it was reported the nitrogen equivalent of organic fertilizer; other organic farms use compost or self fertilization from cows manure).

Table 6.13 Current Nitrogen fertilizer use in the surveyed dairy farms, energy needs for urea production through SSAS and energy availability from rooftop PV panels

| Farm | Milk | Nitrogen use | Energy required | Energy from PV | Coverage | Extra energy | Extra area |
|---|---|---|---|---|---|---|---|
| | t/y | t/y | GJ/y | GJ/y | % | GJ/y | m² |
| G1 | 2264 | 41,0 | 1795 | 1948 | 109% | - | - |
| G2 | 279 | 1,4 | 60 | 398 | 664% | - | - |
| G3 | 9634 | 29,7 | 1301 | 4708 | 362% | - | - |
| G4 | 5310 | 32,4 | 1421 | 2158 | 152% | - | - |
| G5 | 13688 | 23,1 | 1013 | 4684 | 462% | - | - |
| P1 | 636 | 2,3 | 99 | 642 | 645% | - | - |
| P2 | 2764 | 40,0 | 1752 | 432 | 25% | 1320 | 1056 |
| P3 | 246 | 1,8 | 79 | 487 | 618% | - | - |
| P4 | 271 | 1,9 | 83 | 474 | 5062% | - | - |
| OP2 | 350 | 1,03 | 45 | 546 | 1210% | - | - |
| OP3 | 243 | 9,555 | 418 | 776 | 185% | - | - |

Most farms would be self sufficient for N fertilizers production: this means that they would deliver to the grid more energy than it is needed for fertilizer synthesis, or eventually that they could produce the fertilizer by themselves, using the extra ammonia as energy storage.

Large farms, like P2, C1, C3 and C4 don't have enough rooftop area with respect to the land need for fertilizers; this could be provided by additional PV panel put on unproductive ground or by other renewable sources, like eolic energy.

Table 6.14Current Nitrogen fertilizer use in the surveyed rice farms, energy needs for urea production through SSAS and energy availability from rooftop PV panels

| Farm | Rice | Nitrogen use | Energy required | Energy from PV | Coverage | Extra energy | Extra area |
|---|---|---|---|---|---|---|---|
| | t/y | t/y | GJ/y | GJ/y | % | GJ/y | m² |
| C1 | 5315 | 266,6 | 11672 | 3151 | 27% | 8521 | 6817 |
| C2 | 1137 | 28,6 | 1251 | 1332 | 106% | - | - |
| C3 | 980 | 20,4 | 894 | 382 | 43% | 512 | 410 |
| C4 | 10716 | 353,8 | 15493 | 1384 | 9% | 14109 | 11287 |
| C5 | 1130 | 13,6 | 594 | 929 | 156% | - | - |
| C6 | 553 | 11,9 | 520 | 690 | 132% | - | - |
| C7 | 140 | 9,9 | 434 | 307 | 71% | 128 | 102 |
| C8 | 304 | 5,4 | 236 | 245 | 104% | - | - |
| C9 | 676 | 16,8 | 736 | 477 | 65% | 258 | 207 |
| C10 | 515 | 13,4 | 587 | 546 | 93% | 40 | 32 |
| OR1 | 1225 | 5,0 | 219 | 238 | 109% | - | - |
| OR2 | 675 | 4,0 | 175 | 312 | 178% | - | - |

# 7. Conclusions

> The transition to the solar age is really under way now, not merely in terms of new technologies but, in a broader sense, as a profound transformation of our entire society and culture. The shift from the mechanistic to the ecological paradigm is not something that will happen sometime in the future. It is happening right now in our sciences, in our individual and collective attitudes and values, and in our patterns of social organization. The new paradigm is better understood by individuals and small communities than by large academic and social institutions
> F. Capra, *The turning point. Science, society and the rising culture*, 1982, p, 337 (it. ed.)

## 7.1 Farming scenarios with renewable energies

The strong dependence of both dairy and rice farming on fossil energy inputs has been assessed in chapter 5, with the methodology defined in chapter 4. In chapter 6 were presented the possible alternatives to fossil fuels dependence, based on the existing or incoming renewable energy technologies.

It is now the time to summarize all these alternatives , trying to depict possible farming scenarios for the dairy and rice sectors. To what extent they can be powered by sustainable energy?

### *7.1.1 Dairy farms*

The best option for dairy farms is the use of photovoltaic and wind energy (Missouri only) in order to satisfy their needs for electrical energy (par. 6.3) and nitrogen fertilizer (par. 6.5), while fuel for machinery could be provided by biogas and/or by ammonia.

The comparison between current farm energy needs and the potential contribution from renewable energies is shown in figure 7.1 and 7.2, respectively for conventional and organic farms, and in table 7.1, together with the energy balances. The comparison is done in specific terms, that is in MJ per kg of energy corrected milk produced in one year, since the surveyed farms are characterized by significantly different sizes. All values were computed according to the production potentials defined in chapter 6.

All farms could in principle satisfy their basic energy needs for fuel, electricity and Nitrogen fertilizer with the use of renewable resources; in 9 cases over 15 they could also satisfy their total energy needs. In principie, it would be possible to free the dairy sector from its dependence on oil, gas and coal. A possible strategy for the transition is discusse in par. 7.2.

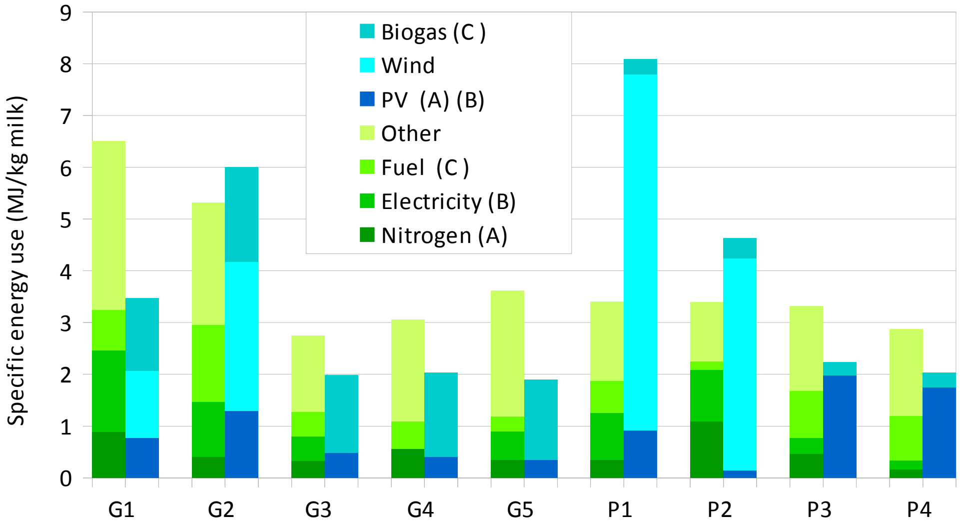

Figure 7.1 Conventional dairy farms energy needs (left bars in green tones) and renewable energy potentially available (right bars in blue tones)

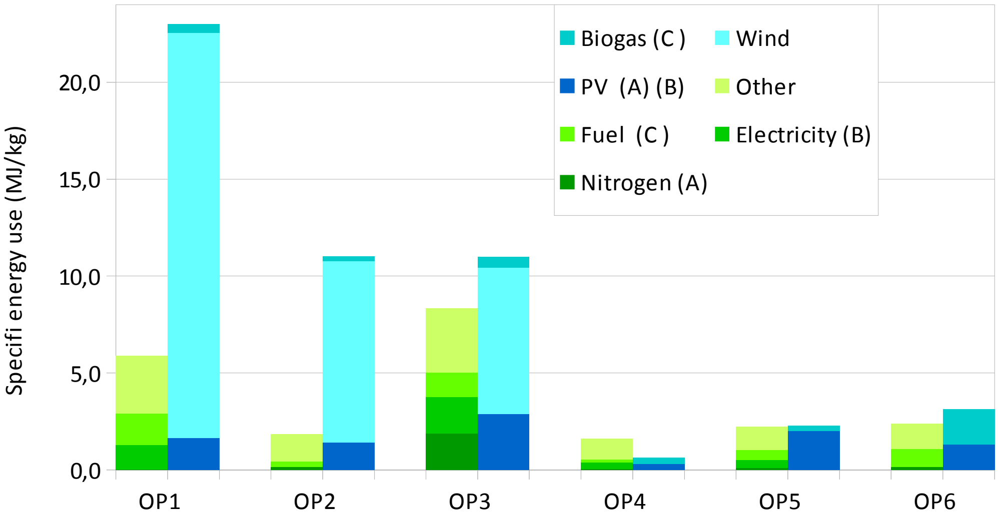

Figure 7.2 Organic dairy farms energy needs (left bars in green tones) and renewable energy potentially available (right bars in blue tones)

As can be seen from table 7.1, the smaller biogas production of pasture based and organic farms (par. 6.4.1) is more than compensated by the higher wind production, owing to greater land availability. This is tru particularly for farm OP1, that has more lando per animal.

The opposite can be said of intensive grain based farms, where the lower electricity production is more than compensated by methane digested from manure.

Farms with a total negative energy balance could reduce their intensive feeds/fertilizing inputs and/or deploy more PV panels on unproductive land.

The very high specifc energy production from wind energy of organic farms is simply explained by their lower milk productivity, since they are comparable with other farms in terms of energy produced per hectare.

Table 7.1 Comparison between dairy farm energy consumption and potential energy production.

Source: chapter 6. Units: MJ/kg of ECM milk

| Farm | Energy consumption | | | | Energy production | | | Energy balance | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H=E+G-A-B | I=F-C | H+I | H+I-D |
| | Nitrogen (SSAS) | Electric | Fuel | Other | PV | Biogas | Wind | Electric | Fuel | Electric & Fuel | Total |
| G1 | 0,89 | 1,57 | 0,79 | 3,26 | 0,86 | 1,40 | 1,28 | -0,31 | 0,61 | 0,30 | -2,96 |
| G2 | 0,40 | 1,06 | 1,49 | 2,37 | 1,42 | 1,83 | 2,88 | 2,84 | 0,34 | 3,18 | 0,82 |
| G3 | 0,34 | 0,46 | 0,48 | 1,47 | 0,49 | 1,50 | - | -0,31 | 1,02 | 0,71 | -0,76 |
| G4 | 0,56 | 0,00 | 0,53 | 1,96 | 0,41 | 1,62 | - | -0,15 | 1,09 | 0,94 | -1,02 |
| G5 | 0,35 | 0,54 | 0,30 | 2,43 | 0,34 | 1,55 | - | -0,55 | 1,25 | 0,70 | -1,73 |
| P1 | 0,35 | 0,91 | 0,62 | 1,53 | 1,01 | 0,30 | 6,88 | 6,63 | -0,32 | 6,31 | 4,78 |
| P2 | 1,09 | 0,99 | 0,17 | 1,15 | 0,16 | 0,40 | 4,09 | 2,17 | 0,23 | 2,39 | 1,25 |
| P3 | 0,46 | 0,31 | 0,91 | 1,64 | 1,98 | 0,26 | - | 1,21 | -0,65 | 0,56 | -1,08 |
| P4 | 0,16 | 0,18 | 0,85 | 1,68 | 1,75 | 0,29 | - | 1,41 | -0,56 | 0,85 | -0,83 |
| OP1 | 0,02 | 1,28 | 1,61 | 2,97 | 1,81 | 0,44 | 20,92 | 21,43 | -1,17 | 20,25 | 17,28 |
| OP2 | 0,17 | 0,00 | 0,27 | 1,42 | 1,56 | 0,26 | 9,36 | 10,75 | -0,01 | 10,74 | 9,32 |
| OP3 | 1,89 | 1,88 | 1,24 | 3,32 | 3,20 | 0,55 | 7,54 | 6,96 | -0,69 | 6,27 | 2,96 |
| OP4 | 0,06 | 0,31 | 0,19 | 1,06 | 0,32 | 0,33 | - | -0,05 | 0,14 | 0,09 | -0,97 |
| OP5 | 0,11 | 0,40 | 0,52 | 1,21 | 2,01 | 0,26 | - | 1,50 | -0,26 | 1,25 | 0,04 |
| OP6 | 0,16 | 0,00 | 0,93 | 1,31 | 1,33 | 1,82 | - | 1,17 | 0,89 | 2,05 | 0,74 |

### *7.1.2 Rice farms*

As before, the best option for rice farms is the use of photovoltaic, hydroelectric (Piemonte) or wind energy (Missouri) in order to satisfy their needs for electrical energy and Nitrogen fertilizer, while fuel for tractors and combine harvesters could be provided by syngas from rice husks gasification.

The comparison between current farm energy needs and the potential contribution from renewable energies is shown in figure 7.3 and 7.4 for Missouri and Piemonete respecively, while table table 7.2 reports the same values together with energy balances. As before, the comparison is done in specific terms, that is in MJ per kg of paddy rice at 12% moisture produced in one year, since the surveyed farms are characterized by significantly different sizes. All values were computed according to the production potentials defined in chapter 6.

All missourian farms could in principle satisfy all their energy needs with a large energy output that could be sold to the market, owing to the significant producibility of wind energy.

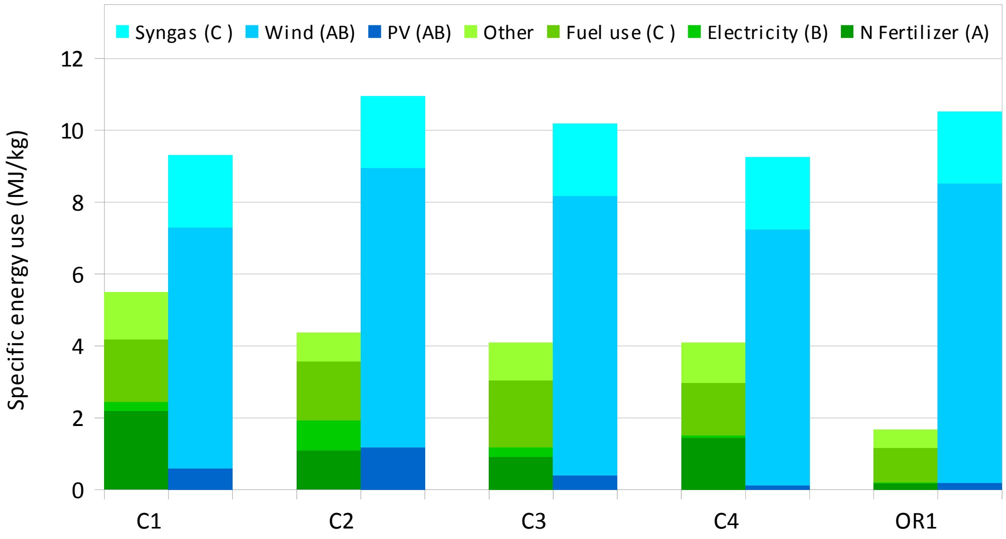

Figure 7.3 Rice farms energy needs (left bars in green tones) and renewable energy potentially available (right bars in blue tones) for rice farms in Missouri

The situation is sligltly less favorable in Piemonte, since the potential of hdroeletric is lower. Inorder to be more conservative, the values in figure 7.4 and table 7.2 were obtained by supposing an average specific energy from hydroelectric of 11,5 GJ/ha, which is assumes that only half of the unexploited canal sites would be really usable (see table 6.4).

Despite this fact, six farm over seven could satisfy their basics needs for Nitrogen, fuel and electricity and 4 could satisfy all energy consumption.

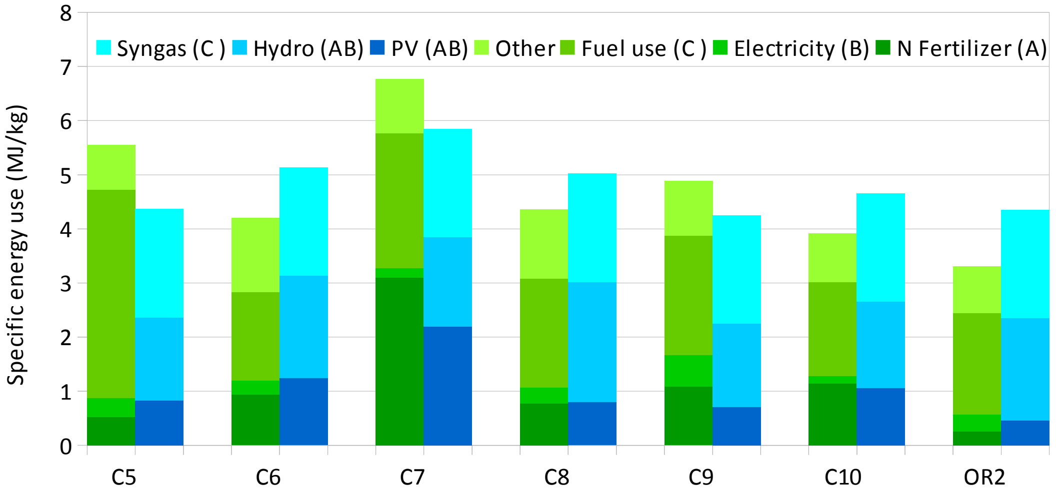

Figure 7.4 Rice farms energy needs (left bars in green tones) and renewable energy potentially available (right bars in blue tones) for rice farms in Piemonte

Table 7.2 Comparison between rice farm energy consumption and potential energy production.

Source: chapter 6. Units: MJ/kg of paddy rice at 12%

| Farm | Energy consumption | | | | Energy production | | | | Energy balance | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H | I=E+F+G-A-B | L=H-C | H+I | I+L-D |
| | Nitrogen (SSAS) | Electric | Fuel | Other | PV | Hydro | Wind | Syngas | Electric | Fuel | Electric & Fuel | Total |
| C1 | 2,20 | 0,25 | 1,73 | 1,31 | 0,59 | | 6,71 | 2,00 | 4,86 | -0,20 | 4,66 | 3,35 |
| C2 | 1,10 | 0,82 | 1,66 | 0,79 | 1,17 | | 7,77 | 2,00 | 7,03 | 0,90 | 7,92 | 7,14 |
| C3 | 0,91 | 0,26 | 1,87 | 1,05 | 0,39 | | 7,79 | 2,00 | 7,01 | 1,09 | 8,10 | 7,05 |
| C4 | 1,45 | 0,07 | 1,46 | 1,11 | 0,13 | | 7,12 | 2,00 | 5,74 | 0,55 | 6,29 | 5,18 |
| C5 | 0,53 | 0,35 | 3,85 | 0,82 | 0,82 | 1,54 | | 2,00 | 1,49 | 1,47 | 2,96 | 2,14 |
| C6 | 0,94 | 0,26 | 1,63 | 1,37 | 1,25 | 1,89 | | 2,00 | 1,94 | 1,06 | 2,99 | 1,63 |
| C7 | 3,10 | 0,17 | 2,49 | 1,01 | 2,19 | 1,65 | | 2,00 | 0,57 | -1,10 | -0,53 | -1,54 |
| C8 | 0,78 | 0,29 | 2,02 | 1,27 | 0,80 | 2,21 | | 2,00 | 1,95 | 1,22 | 3,17 | 1,90 |
| C9 | 1,09 | 0,58 | 2,21 | 1,01 | 1,57 | 1,4 | | 2,00 | 1,44 | 0,91 | 2,35 | 1,34 |
| C10 | 1,14 | 0,14 | 1,74 | 0,90 | 1,80 | 1,60 | | 2,00 | 2,12 | 0,86 | 2,98 | 2,08 |
| OR1 | 0,18 | 0,02 | 0,97 | 0,50 | 0,19 | | 8,33 | 2,00 | 8,32 | 1,82 | 10,14 | 9,64 |
| OR2 | 0,26 | 0,31 | 1,88 | 0,86 | 0,46 | 1,89 | | 2,00 | 1,78 | 1,74 | 3,52 | 2,66 |

## 7.2 Implementing renewable energies with community support

The results of the previous paragraph clearly indicates that renewable energy technologies could in principle cover most of the energy needs of rice and dairy farms. The cost of implementing these technologies is however quite high and not always affordable by farmers.

In order to evaluate a possible strategy for renewable energy implementation, it is possible to consider a generic american dairy farm of 100 ha of crops and pastures, with a herd of 100 cows, 1000 m² of rooftop suitable for PV and a production of 700 tons of milk a year.

It would be possible to install , with increasing costs, a methane digester (plus methane tractor), PV panels and a wind turbine with a total production of 1760 GJ from methane and 16130 GJ of electricity (see table 7.3).

The specific methane production would be of 2,4 MJ/kg of milk and would more than satisfy the farm fuel needs, which are on the average around 2 MJ/kg (par 5.1). The use of biogas would save about 48000 liters of diesel fuel with a cost reduction of 45000 dollars per year. The total investment would be 220000 dollars, half for the digester and half for the retrofit of an existing tractor. If a new tractor is needed, the extra cost for methane power with respect to traditional diesel would be about 80000 $.

Since the average electrical energy use is about 1 MJ/kg of milk (par 5.1), the total would be around 1000 GJ a year, so that about 15000 GJ (4200 MWh) could be sold to the grid. Considering a net price of 70 dollar per MWh (80 dollars is the average missouri price of electrical energy minus 10$ per Mwh of turbine maintenance), the annual revenues would be about 295000 dollars. Total revenues and fuel savings sum ip to 340000 $.

Looking at the cost side, the overall investment would be of the order of 4 million dollars; a 10 years loan with an annual interest rate of 3,5 % would require annual payments of about 475000 dollars. The net annual cost (payment minus revenues) would about 135000 dollars.

Supposing that there are no supporting policies for renewable introduction in the farms and everything would be just governed by the market, the effect of the investment on renewable technologies on the price of milk would be relatively small, that is 0,19 $ more per each kg of milk sold over the 10 years of the loan

This amount is not negligible with respect to the farm gate price of milk, that in 2014 was on the average 0,52 $/kg (CLAL 2014) ; implementing renewable energies would increase the cost of milk of about 36%. It is worth to note however that the retail price of milk was on the average on the same year 0,95 $/kg (Future AAE 2014).

If consumers are willing to pay a higher price of 0,44 $/kg, or 84% more, for milk to be processed, transported and advertized, it is reasonable to question if a consumer would be willing to pay an increase of 20% on the retail price, provided he or she is informerd that this milk is produced only with renewable energies.

Table 7.3 Estimation of the cost for the implementation of biogas, PV and wind power in an average dairy missourian farm.
Sources : (a) Straus (2015) (b) EPA (2015)

| Technology | Variable | Unit | Value |
|---|---|---|---|
| Biogas | Volume of methane | $m^3$/yr | 44 000 |
| | Energy from methane | GJ/yr | 1 670 |
| | Total cost (digester and tractor retrofit) | $ | 220 000 |
| PV | Peak power | kW | 150 |
| | Energy per year | GJ | 1030 |
| | Total cost (b) | $ | 330 000 |
| Wind | Power | MW | 2,1 |
| | Energy per year | GJ | 15 100 |
| | Total cost (b) | $ | 3 360 000 |
| | | | |
| Total fuel energy (self consumption) | | GJ | 1670 |
| Total electrical energy | | GJ | 16130 |
| Total cost | | $ | 3 900 000 |

According to an economic analysis based on surveys performed in the USA, consumers willingness to pay (WTP) for renewable energies was on the average 0,7 extra dollars of 2007 (equivalent to 0, 8 dollars of 2015) per month for a 1% increase in renewables (Murakami et al 2014).

Assuming that consumers would spend thie same just for for the food industry, it would reflect in a WTP of 0,09 $/month for milk products (12% of the total food sector, FAOSTAT 2014).

The WTP for 100% renewables in milk farming would therefore be of about 9 dollars per month, that is more than the extra cost of 5,48 $ derived from the increase of 0,26 $/kg times the monthly average consumption of 21 kg of milk.

This analysis is ectremely simplified, but gives just the idea that consumers are probably willing to pay more if they have good information on the total quality of the product they are buying,

Moreover, if the milk is sold at a local farmers market, the price for consumers could be lower than in supermarkets, even if it is increased by the investment cost of renewable energies. Farmers could greatly benefit from community supported agriculture not only for selling locally their products, but also to reach agreements on investments on sustainable energy.

Assuming that the average american per capita milk consumption is 250 kg per year (FAOSTAT 2014), the farm production of 700 t of milk per year could satisfy a community of 2800 people. That could be located jus near the farm or in the surrounding area. If the four million dollar loan would be provided by this community instead of a bank, it would cost less than 1430 dollars per capita, while annually everyone would receive back payments for 170 $.

The agreement would be even more interesting if the community people were payed back in term of energy and milk . The farm energy production is equivalent to 1500 kWh per every member of the community, which is more than enough for italian households (consumption 1100 kWh/y), while would cover one third of the american per capita average consumption of 4500 kWh/y. The value of this production would about 120 $ per capita, so the farmer instead of paying back 170$ could give the equivalent in electrical energy and the remainder of 50% as a discount of 20 cent per liter on the cost of milk.

Multiple advantages are present in this idea of community supported agriculture and sustainable energy.

- The credit is not given by an anonimous institution, but by real people, who are personally interested and committed not only to receive back their money, but also to drink good quality milk and use a renewable energy supply.
- The price of milk at the farm gate could be negotiated between the farmer and the community, in order to grant for the farmer and all farm workers a fair income.
- Having a local renewable energy supplier would protect the community from every national or international oscillation in the price of energy, making the community more resilient.
- The link between the farmer and the surrounding community would build a stronger awareness on the protection of the environment, the landscape and the cultural heritage.

The transition to a more sustainable farming could start from the bottom as a grassroot movement, that could enforce itself as it grows in numer and size. If this movement could mantain the characteristic of being a great network of small networks, it would remain under the control of the communities at local level, allowing a democratic control for large scale decisions, in order to avoid all the distortions and evil effects of the companies that are to large to fail and are just ruled by few stockholders.

In other words, sustainable energy and farming should also choose a sustainable organizational structure in order to grow and face all the challenges of food production in a world more and more crowded and polluted with less and less fossil resources.

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# 9. Annexes

## 9.1 Crops and forage data sheets

Specific input energy for 1 kg of animal feed has been computed for corn, soybeans, alfalfa, hay and silage; detailed calculations are reported in the following pages.

Energy for structures (silos and warehouses) has been computed allocating the appropriate factor (see paragraph 1.1).

Energy for fertilizers and pesticides has been accounted according to the procedure outlined in paragraphs 1.3 and 1.4.

Energy machinery has been computed using the per year embodied energy reported in table 4 of paragraph 1.2. For each crop the actual equipment used in the field was taken into account (FAPRI 2014), together with the average working time per hectare (column A). Dividing by the annual working time (column B), it is possible to define the time and energy fraction (column C) pertinent to one hectare of cultivation. Direct fuel consumption (FAPRI 2014, column F) has been multiplied by the energetic power of diesel fuel to obtain direct energy use (column G).

All input values expressed as MJ/ha have been converted to MJ/kg of product by dividing by the crop yield. For corn ilagem alfalfa and hay dried matter yield has been considered.

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| **Maize** | Yield | t/ha | 8,47 | kg/ha | 8473,34 |
| Machinery energy input per kg |  | 140 | MJ/kg machinery |  |  |
| Silos energy input per kg |  | 0,07 | MJ/kg maize |  |  |
| Seeds | 74147 | seeds/ha | 0,332 | G/seed |  |
|  | 24,61 | kg/ha | 2560 | MJ/ha |  |

|  | Mass input per unit land |  | Energy input |  |  |
|---|---|---|---|---|---|
|  | lbs/acre | kg/ha | MJ/kg a. i. | MJ/ha | MJ/kgp |
| Fertilizers |  |  |  |  | **0,99** |
| N | 140 | 156,92 | *43,30* | 6794,47 | 0,80 |
| P | 60 | 67,25 | *13* | 874,25 | 0,10 |
| K | 45 | 50,44 | *15* | 756,56 | 0,09 |
| Lime | 0,6 | 0,67 | 2,1 | 1,41 | 0,00 |
| Pesticides |  |  |  |  | **0,55** |
| Herbicides | 12,83 | 14,38 | *325,32* | 4678,18 | 0,55 |
| Insecticides | 0 | 0,00 | *310* | 0,00 | 0,00 |
| Fungicides | 0 | 0,00 | 220 | 0,00 | 0,00 |

| Machinery (MJ/kg) | Work time |  |  | Embodied energy |  | Direct energy |  |
|---|---|---|---|---|---|---|---|
|  | per hectare | annual total | Use fraction | per year | per yr & ha | Unit fuel use | Energy |
|  | A | B | C=A/B | D | E=C*D | F | G |
|  | hr/hectare | hr/year |  | MJ/yr | MJ/yr ha | liters/ha | MJ/ha |
| a Field cultivator (35 ft) | 0.098 | 100 | 9.79E-04 | 44333 | 43.40 | 5.17 | 185 |
| b -Ripper 30" O.C.. (17 ft) | 0.071 | 100 | 7.05E-04 | 60941 | 42.99 | 3.73 | 133 |
| c Split row no-till planter (16/31 row 30/15") | 0,132 | 130 | 1,02E-03 | 8470 | 8,63 | 4,51 | 162 |
| d Boom sprayer (30 ft) | 0.322 | 100 | 3.22E-03 | 4492 | 14.45 | 8.78 | 314 |
| e Anhydrous applicator (21 ft) | 0.221 | 250 | 8.82E-04 | 6347 | 5.60 | 7.52 | 269 |
| f Combine. corn head (8 row): | 0.277 | 200 | 1.39E-03 | 33495 | 46.45 | 13.01 | 466 |
| g Grain cart (500 bushel) | 0.139 | 200 | 6.93E-04 | 31173 | 21.62 | 4.73 | 169 |
| h Grain auger 10 in- 5000 bu/hr (70 ft) | 0,067 | 200 | 3,34E-04 | 19052 | 6,36 | 1,48 | 53 |
| Semi. tractor and trailer |  |  |  |  |  | 7.44 | 266 |
| Pickup truck |  |  |  |  |  | 3.68 | 132 |
| Tractor 100 kW used with h | 0.07 | 450 | 1.48E-04 | 42327 | 6.28 |  |  |
| Tractor 120 kW used with d | 0.32 | 500 | 6.43E-04 | 69020 | 44.40 |  |  |
| Tractor 150 kW used with c.e.g | 0.49 | 500 | 9.83E-04 | 69020 | 67.87 |  |  |
| Tractor 200 kW used with f | 0.28 | 300 | 9.25E-04 | 19619 | 18.14 |  |  |
| Tractor 230 kW used with a.b | 0.17 | 400 | 4.21E-04 | 39667 | 16.70 |  |  |
| Total | 2.65 |  |  |  | 342.86 | 60 | 2150 |

|  | (MJ/kg) |  |
|---|---|---|
| Structure | **0,07** | 3,16% |
| Machinery | **0,04** | 1,83% |
| Fuel | **0,25** | 11,47% |
| Fertilizers | **0,99** | 44,94% |
| Pestidices | **0,55** | 24,95% |
| Seeds | **0,30** | 13,65% |
| TOTAL ENERGY | **2,21** | 100,00% |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| **Soybeans** | Yield | t/ha | 3,03 | kg/ha | 3026 |
| Machinery energy input per kg |  | 140 | MJ/kg machinery |  |  |
| Flat store energy input per kg |  | 0,045 | MJ/kg soy |  |  |
| Seeds | 420064 | Seeds/ha | 0,164 | G/seed |  |
|  | 69,3 | Kg/ha | 2317 | MJ/ha |  |

|  | Mass input per unit land |  | Energy input |  |  |
|---|---|---|---|---|---|
|  | lbs/acre | kg/ha | MJ/kg a. i. | MJ/ha | MJ/kgp |
| Fertilizers |  |  |  |  | **0,58** |
| N | 0 | 0 | *43,3* | 0 | 0,00 |
| P | 40 | 44,83 | *13* | 582,83 | 0,19 |
| K | 70 | 78,46 | *15* | 1176,87 | 0,39 |
| Lime | 0,5 | 0,56 | 2,1 | 1,18 | 0,00 |
| Pesticides |  |  |  |  | **0,73** |
| Herbicides | 6,03 | 6,76 | *325,32* | 2198,71 | 0,73 |
| Insecticides | 0 | 0,00 | *310* | 0,00 | 0,00 |
| Fungicides | 0 | 0,00 | 220 | 0,00 | 0,00 |

| Machinery (MJ/kg) | Work time |  |  | Embodied energy |  | Direct energy |  |
|---|---|---|---|---|---|---|---|
|  | per hectare | annual total | Use fraction | per year | per yr & ha | Unit fuel use | Energy |
|  | A | B | C=A/B | D | E=C*D | F | G |
|  | hr/hectare | hr/year |  | MJ/yr | MJ/yr ha | liters/ha | MJ/ha |
| a Field cultivator (35 ft) | 0,098 | 100 | 9,79E-04 | 44333 | 43,40 | 5,17 | 185 |
| b Tandem disk (30 ft) | 0,142 | 100 | 1,42E-03 | 60941 | 86,27 | 7,48 | 268 |
| c Split row no-till planter (16/31 row 30/15") | 0,132 | 130 | 1,02E-03 | 8470 | 8,63 | 4,51 | 162 |
| d Boom sprayer (30 ft) | 0,322 | 100 | 3,22E-03 | 4492 | 14,45 | 8,78 | 314 |
| e Combine, flexible grain head (30 ft) | 0,185 | 120 | 1,54E-03 | 33670 | 51,82 | 8,67 | 310 |
| f Grain cart (500 bushel) | 0,116 | 200 | 5,78E-04 | 31173 | 18,01 | 3,94 | 141 |
| g Grain auger 10 in- 5000 bu/hr (70 ft) | 0,022 | 200 | 1,11E-04 | 19052 | 2,12 | 0,49 | 18 |
| Semi, tractor and trailer |  |  |  |  |  | 2,79 | 100 |
| Pickup truck |  |  |  |  |  | 2,76 | 99 |
| Tractor 100 kW used with d,g | 0,34 | 450 | 7,64E-04 | 42327 | 32,35 |  |  |
| Tractor 150 kW used with c,f | 0,25 | 500 | 4,96E-04 | 69020 | 34,23 |  |  |
| Tractor 200 kW used with e | 0,18 | 300 | 6,16E-04 | 19619 | 12,09 |  |  |
| Tractor 230 kW used with a,b | 0,24 | 400 | 5,99E-04 | 39667 | 23,75 |  |  |
| Total |  |  |  |  | 327,10 | 45 | 1597 |

|  | MJ/kg |  |
|---|---|---|
| Structure | **0,045** | 1,63% |
| Machinery | **0,11** | 3,92% |
| Fuel | **0,53** | 19,16% |
| Fertilizers | 0,58 | 21,11% |
| Pestidices | 0,73 | 26,8% |
| Seeds | **0,77** | 27,8% |
| TOTAL ENERGY | **2,75** | 100,00% |

## Alfalfa

| | | | | | | |
|---|---|---|---|---|---|---|
| | Yield DM | t/ha | 11,77 | kg/ha | 11768,52297<br>99852 | |
| | | | | MJ/kg | | |
| Machinery energy input per kg | | | 140 | machinery | | |
| Silos energy input per kg | | | 0,2 | MJ/kg alfalfa | | |
| Seeds | 6,8 | kg/ha | 1762 | MJ/ha | | |

| | Mass input per unit land | | Energy input | | |
|---|---|---|---|---|---|
| | lbs/acre | kg/ha | MJ/kg a. i. | MJ/ha | MJ/kgp |
| Fertilizers | | | | | **0,37** |
| N | 0 | 0 | *43,3* | 0 | 0,00 |
| P | 70 | 78,46 | *13* | 1019,96 | 0,09 |
| K | 200 | 224,17 | *15* | 3362,49 | 0,29 |
| Lime | 0,5 | 0,56 | 2,1 | 1,18 | 0,00 |
| Pesticides | | | | | **0,00** |
| Herbicides | 0 | 0,00 | *325,32* | 0,00 | 0,00 |
| Insecticides | 0 | 0,00 | *310* | 0,00 | 0,00 |
| Fungicides | 0 | 0,00 | 220 | 0,00 | 0,00 |

| Machinery | Work time | | | Embodied energy | | Direct energy | |
|---|---|---|---|---|---|---|---|
| | for unit land | Annual total | Use fraction | per year | per yr and ha | Unit fuel use | Energy |
| | A | B | C=A/B | D | E=C*D | F | G |
| | hr/hectare | hr/year | | MJ/yr | MJ/yr ha | liters/ha | MJ/ha |
| a Boom sprayer (30 ft) | 0.161 | 100 | 1.61E-03 | 30438 | 48.95 | 2.06 | 74 |
| b Disk mower-conditioner (9 ft) | 1,742 | 80 | 2,18E-02 | 43167 | 939,60 | 32,68 | 1170 |
| c Wheel rake. V hitch (8 wheel) | 0.498 | 80 | 6.23E-03 | 5367 | 33.42 | 6.37 | 228 |
| d Round baler. silage kit 1500lbs | 1.742 | 250 | 6.97E-03 | 26985 | 188.07 | 32.68 | 1170 |
| eRd bale wrapper haylage | 3.706 | 250 | 1.48E-02 | 21817 | 323.24 | 47.40 | 1697 |
| Pickup truck | | | | | | 5.52 | 198 |
| Tractor 55 kW used with a.c.e | 4.37 | 450 | 9.70E-03 | 19619 | 190.33 | | |
| Tractor 80 kW used with b. d | 3.48 | 450 | 7.74E-03 | 39667 | 307.17 | | |
| Total | | | | | 2030.79 | 127 | 4537 |

| | MJ/kg | |
|---|---|---|
| Structure | **0,2** | 15,62% |
| Machinery | **0,17** | 13,48% |
| Fuel | **0,39** | 30,11% |
| Fertilizers | **0,37** | 29,08% |
| Pestidices | **0,00** | 0,00% |
| Seeds | **0,15** | 11,71% |
| TOTAL ENERGY | **1,28** | 100,00% |

## Hay

Yield DM t/ha 6,75 kg/ha 6747

MJ/kg
Machinery energy input per kg 140 machinery
Silos energy input per kg 0,2 MJ/kg hay
Seeds 6,3 kg/ha 558 MJ/ha

| | Mass input per unit land | | Energy input | | |
|---|---|---|---|---|---|
| | lbs/acre | kg/ha | MJ/kg a. i. | MJ/ha | MJ/kgp |
| Fertilizers | | | | | **0,54** |
| N | 40 | 44,83 | *43,3* | 1941,27 | 0,29 |
| P | 46 | 51,56 | *13* | 670,26 | 0,10 |
| K | 60 | 67,25 | *15* | 1008,75 | 0,15 |
| Lime | 0,5 | 0,56 | 2,1 | 1,18 | 0,00 |
| Pesticides | | | | | **0,00** |
| Herbicides | 0 | 0,00 | *325,32* | 0,00 | 0,00 |
| Insecticides | 0 | 0,00 | *310* | 0,00 | 0,00 |
| Fungicides | 0 | 0,00 | 220 | 0,00 | 0,00 |

| Machinery | Work time | | | Embodied energy | | Direct energy | |
|---|---|---|---|---|---|---|---|
| | for unit land | Annual total | Use fraction | per year | per yr and ha | Unit fuel use | Energy |
| | A | B | C=A/B | D | E=C*D | F | G |
| | hr/hectare | hr/year | | MJ/yr | MJ/yr ha | liters/ha | MJ/ha |
| a Disk mower-conditioner (9 ft) | 0,445 | 80 | 5,56E-03 | 43167 | 239,86 | 9,67 | 346 |
| b Wheel rake, V hitch (8 wheel) | 0,124 | 80 | 1,54E-03 | 5367 | 8,29 | 1,63 | 58 |
| c Round baler, net wrap 1500lb | 0,395 | 250 | 1,58E-03 | 26985 | 42,67 | 8,62 | 309 |
| Pickup truck | | | | | | 2,78 | 99 |
| Tractor 55 kW used with b | 0,12 | 450 | 2,75E-04 | 19619 | 5,39 | | |
| Tractor100 kW used with a, c | 0,84 | 450 | 1,87E-03 | 39667 | 74,06 | | |
| Total | | | | | 370,26 | 23 | 812 |

| | MJ/kg | |
|---|---|---|
| Structure | **0,2** | 18,82% |
| Machinery | **0,05** | 5,16% |
| Fuel | **0,12** | 11,33% |
| Fertilizers | **0,54** | 50,48% |
| Pestidices | **0,00** | 0,00% |
| Seeds | **0,08** | 7,79% |
| TOTAL ENERGY | **1,06** | 100,00% |

| | | | | | |
|---|---|---|---|---|---|
| **Maize silage** | Yield | t/ha | 17,93 | kg/ha | 17932 |

| | | | | |
|---|---|---|---|---|
| Machinery energy input per kg | | | 140 | MJ/kg machinery |
| Silos energy input per kg | | | 0,21 | MJ/kg alfalfa |
| Seeds | 18,9 | kg/ha | 1962 | MJ/ha |

| | Mass input per unit land | | Energy input | | |
|---|---|---|---|---|---|
| | lbs/acre | kg/ha | MJ/kg a. i. | MJ/ha | MJ/kgp |
| Fertilizers | | | | | **0,33** |
| N | 100 | 112,08 | *43,3* | 4853,19 | 0,27 |
| P | 60 | 67,25 | *13* | 874,25 | 0,05 |
| K | 15 | 16,81 | *15* | 252,19 | 0,01 |
| Lime | 0,5 | 0,56 | 2,1 | 1,18 | 0,00 |
| Pesticides | | | | | **0,26** |
| Herbicides | 12,83 | 14,38 | *325,32* | 4678,18 | 0,26 |
| Insecticides | 0 | 0,00 | *310* | 0,00 | 0,00 |
| Fungicides | 0 | 0,00 | 220 | 0,00 | 0,00 |

| | Work time | | | Embodied energy | | Direct energy | |
|---|---|---|---|---|---|---|---|
| | for unit land | Annual total | Use fraction | per year | per yr and ha | Unit fuel use | Energy |
| | A | B | | D | E=C*D | F | G |
| Machinery | hr/hectare | hr/year | C=A/B | MJ/yr | MJ/yr ha | liters/ha | MJ/ha |
| a Field cultivator (18 ft) | 0,190 | 100 | 1,90E-03 | 30438 | 57,94 | 5,19 | 186 |
| bRow crop planter (6 row) | 0,353 | 80 | 4,41E-03 | 43167 | 190,36 | 7,82 | 280 |
| c Anhydrous applicator (21 ft) | 0,221 | 250 | 8,82E-04 | 6347 | 5,60 | 6,02 | 215 |
| d Silage Chopper, 2 row (5 ft) | 1,792 | 250 | 7,16E-03 | 12833 | 91,94 | 48,89 | 1750 |
| Pickup truck | | | | | | 5,52 | 198 |
| Tractor 100 kW used with b | 0,35 | 450 | 7,84E-04 | 42327 | 33,20 | | |
| Tractor 120 kW used with a, c, d | 2,20 | 450 | 4,90E-03 | 69020 | 337,91 | | |
| Total | | | | | 716,94 | 73 | 2630 |

| | MJ/kg | |
|---|---|---|
| Structure | **0,21** | 19,08% |
| Machinery | **0,04** | 3,63% |
| Fuel | **0,15** | 13,33% |
| Fertilizers | **0,33** | 30,30% |
| Pestidices | **0,26** | 23,71% |
| Seeds | **0,11** | 9,95% |
| TOTAL ENERGY | **1,10** | 100,00% |

## 9.2 Dairy farms data sheets

### Farm G1

G1 is a medium size modern grain based farm located in Missouri. Since the survey was performed in november 2014, collected data are related to year 2013.

General data

| | | |
|---|---|---|
| Average milking cows | | 188 |
| Average dry cows | | 26 |
| Calves born in year | | 167 |
| Average lactations | | 2,25 |
| Age at first delivery | years | 2 |
| Culling rate | % | 37% |
| Milk production | kg | 2 137 917 |
| Fat | % | 3,84% |
| Protein | % | 3,08% |
| ECM milk production | kg | 2 264 388 |
| Milk production per cow | kg | 11 408 |
| ECM milk production per cow | kg | 12 083 |

Nutritional inputs (kg/cow/day)

| Cow number | 125 | 56 | 27 |
|---|---|---|---|
| Daily ration | High production | Medium production | Dry |
| Soy plus rumen protected | 1,16 | | |
| Soy bean hulls | 1,30 | 1,74 | 1,25 |
| Soy bean meal 48% | 0,65 | 0,63 | 1,26 |
| Corn | 3,76 | 3,61 | |
| Corn silage | 24,44 | 19,99 | 13,02 |
| DDGS | 5,51 | 5,51 | |
| Premix | 3,50 | 3,21 | 1,44 |
| Alfalfa | 1,86 | 2,11 | |
| Hay | 9,14 | 9,95 | 13,02 |
| Premix composition | | | |
| Corn | 2,01 | 1,63 | 1,03 |
| Soy plus rumen protected | | 0,84 | |
| Other | 0,56 | 0,35 | 0,25 |
| Soy equivalent | 1,16 | 0,84 | 0,00 |
| Total Corn | 5,77 | 5,24 | 1,03 |
| Total | 51,33 | 46,75 | 29,99 |

## Machinery

| Tractors | kg |
|---|---|
| JD 6405 | 3783 |
| Massy | 4293 |
| JD 6115 | 5780 |
| 430 case (2x) | 2834 |
| Stall in milking parlor | 16 |

## Direct energy consumption

| | | |
|---|---|---|
| Diesel fuel | liters | 33 267 |
| Gasoline | liters | 15 305 |
| Electrical energy | kWh | 329 358 |

## Notes

No fertilizer consumption was recorded sonce the farm owns no land and buys all the feed from the market

# Farm G2

G2 is a small size traditional grain based farm located in Missouri that produces a hogh quality cheese. Since the survey was performed on december 5th 2014, collected data are related to year 2013.

## General data

| | | |
|---|---|---|
| Average milking cows | | 30 |
| Average dry cows | | 5 |
| Calves born in year | | 25 |
| Average lactations | | 3,5 |
| Age at first delivery | years | 2 |
| Culling rate | % | 23,5% |
| Milk production | kg | 198 673 |
| ECM milk production | kg | 279 076 |
| Fat | % | 5,9% |
| Protein | % | 4,1% |
| Milk production per cow | kg | 6 662 |
| ECM milk production per cow | kg | 9 303 |

## Nutritional inputs (kg/cow/day)

| Period duration (months) | 10 | 2 |
|---|---|---|
| Daily ration | Milking cows | Dry |
| Corn | 4,57 | |
| Corn silage | 8,16 | 3,63 |
| Premix | 3,63 | |
| Alfalfa | 9,98 | |
| Hay | | 4,54 |

| | | |
|---|---|---|
| Premix composition | | |
| Corn | 2,01 | |
| Soy | 1,61 | |
| Total | 26,31 | 8,16 |

## Machinery

| Tractors | kg |
|---|---|
| 2 110 hp | 4293 |
| 1 145 hp | 5780 |
| 1 165 hp | 6472 |
| Stall in milking parlor | 10 |

## Direct energy consumption

| | | |
|---|---|---|
| Diesel fuel | liters | 5 812 |
| Gasoline | liters | 15 305 |
| Electrical energy | kWh | 27 361 |

## Self forage production

| Crop | Area (ha) | Production (t) |
|---|---|---|
| Corn silage | 4,1 | 74 |
| Pasture | 4,1 | 26 |

## Fertilizer (kg/ha)

| | |
|---|---|
| N | 167,2 |
| P | 44,6 |
| K | 100,3 |

Notes

Electrical energy consumption was estimated vrom a monthly average cost of 600 $ and a specific energy cost for Missouri (2013) of 10,53 cent $/Kwh. The consumption related to farm activities is 40% of the total, the rest is cheesemaking and household

Energy embodied in corn silage wasn't allocated according to the Missouri average, since it is produced in farm and its cost is included in fertilizer and fuel

# Farm P1

P1 is a medium size modern pasture based farm located in Missouri. Since the survey was performed on december 12th 2014, collected data are related to year 2013.

## General data

| | | |
|---|---|---|
| Average milking cows | | 80 |
| Average dry cows | | seasonal |
| Calves born in year | | 90 |
| Average lactations | | 2,5 |
| Age at first delivery | years | 2 |
| Culling rate | % | 26% |

| | | |
|---|---|---|
| Milk production | kg | 554 364 |
| ECM milk production | kg | 653 667 |
| Fat | % | 4,38% |
| Protein | % | 3,3% |
| Milk production per cow | kg | 6 929 |
| ECM milk production per cow | kg | 7 946 |

## Nutritional inputs

| Daily ration | Yearly average |
|---|---|
| | kg/cow/day |
| Corn | 2,34 |
| Corn gluten feed | 0,22 |
| Corn silage | 2,14 |
| Brewers grain | 0,09 |
| Alfalfa | 2,61 |
| Total | 26,31 |

## Machinery

| Tractors | kg |
|---|---|
| 2 85 hp | 4293 |
| 1 145 hp | 5780 |
| Stall in milking parlor | 10 |

## Direct energy consumption

| | | |
|---|---|---|
| Diesel fuel | liters | 7 306 |
| Gasoline | liters | 1 915 |
| Propane | liters | 1 937 |
| Electrical energy | kWh | 53 354 |

## Self forage production

| Crop | Area (ha) | Production (t) |
|---|---|---|
| Alfalfa | 22,2 | 102 |
| Hay | 24,2 | 67 |
| Pasture | 36,3 | |

## Fertilizer (kg/ha)

| | |
|---|---|
| N | 154,9 |
| Turkey manure | 4460 |

## Notes

All cows follow the seasonal cycle so they went dry at the end of december
Electrical energy consumption was estimated from a monthly average cost of 468$ and an average specific energy cost for Missouri (2013) of 10,53 cent $/Kwh. Diesel consumption was estimated from a cost of 7000 $ and avegare price for Missouri (2013) of 0,98 $/liter. Gasoline consumption was estimated from a cost of 15571 $ and average price for Missouri (2013) of 0,84 $/liter.
Energy embodied in Turkey manure according to its N,P,K content is 1,467 MJ/kg manure.

Energy embodied in alfalfa wasn't allocated according to the Missouri average, since it is produced in farm and its cost is included in fertilizer and fuel

## Farm P2

P2 is a large size modern pasture based farm located in Missouri. The survey was performed on december 12th 2014 and the collected data are related to year 2014, from january to october. Projections were done for the other wo months

### General data

| | | |
|---|---|---|
| Average milking cows | | 547 |
| Average dry cows | | seasonal |
| Calves born in year | | 500 |
| Average lactations | | 4 |
| Age at first delivery | years | 2 |
| Culling rate | % | 25% |
| Milk production | kg | 2 390 132 |
| ECM milk production | kg | 2 764 451 |
| Fat | % | 4,51% |
| Protein | % | 3,21% |
| Milk production per cow | kg | 4 370 |
| ECM milk production per cow | kg | 5 054 |

### Nutritional inputs (kg/cow/day)

| Period duration (days in year) | 270 | 95 |
|---|---|---|
| Daily ration | Milking cows | Dry |
| Corn | 4,0 | |
| Corn silage | 2,0 | |
| Hay | 2,0 | 5,0 |
| Total | 8,0 | 5,0 |

### Machinery

| Tractors | kg |
|---|---|
| 2 145 hp | 5780 |
| Stall in milking parlor | 50 |

### Direct energy consumption

| | | |
|---|---|---|
| Diesel fuel | liters | 12961 |
| Electrical energy | kWh | 252 689 |

### Self forage production

| Crop | Area (ha) | Production (t) |
|---|---|---|
| Pasture | 160 | 1 920 |

### Fertilizer (kg/ha)

| | |
|---|---|
| N | 250,9 |
| K | 72,5 |

Notes
All cows follow the seasonal cycle so they went dry at the end of december
Electrical energy consumption was estimated from a jan-oct cost of 22921$ and an average specific energy cost for Missouri (2014) of 10,885 cent $/Kwh. Diesel consumption was estimated from a jan-oct cost of 10250 $ and average price for Missouri (2014) of 0,94 $/liter.
The farm has no barn

## Farm OP1

O1 is a smal size traditional pasture based organic farm located in Missouri that has also a creamery and sells cheese locally. Since the survey was performed on november 2014, collected data are related to year 2013.

### General data

| | | |
|---|---|---|
| Average milking cows | | 49 |
| Average dry cows | | 11 |
| Calves born in year | | 65 |
| Average lactations | | > 6 |
| Age at first delivery | years | 2 |
| Culling rate | % | 16% |
| Milk production | kg | 202 812 |
| ECM milk production | kg | 224 427 |
| Fat | % | 4,1% |
| Protein | % | 3,25% |
| Milk production per cow | kg | 4 139 |
| ECM milk production per cow | kg | 4 580 |

### Nutritional inputs

| Daily ration | Milking cows | Dry cows |
|---|---|---|
| | kg/cow/day | kg/cow/day |
| Pasture | - | - |
| Hay | - | 22,68 |
| Total | - | 22,68 |

### Machinery

| Tractors | kg |
|---|---|
| skidsteer | 3246 |
| 2 125 hp | 5780 |
| Stall in milking parlor | 18 |

### Direct energy consumption

| | | |
|---|---|---|
| Diesel fuel | liters | 9688 |
| Electrical energy | kWh | 26 640 |

### Fertilizer (kg/ha)

| | |
|---|---|
| Compost | 6 727 |
| Lime | 336 |

### Notes

Electrical energy consumption was estimated from a total consumption of 66000 kWh, subtracting the average missourian household consumption of 12770 kWh and dividing the result by two, since energy is used both in farming and in cheesemaking.
Energy embodied in compost from urban waste is assumed to be 0,41 MJ/kg compost.
Energy embodied in lime is assumed to be 2,1 MJ/kg.

## Farm OP2

O2 is a smal size traditional pasture based organic farm located in Missouri . Since the survey was performed on december 5th 2014, collected data are related to year 2013.

### General data

| | | |
|---|---|---|
| Average milking cows | | 45 |
| Average dry cows | | seasonal |
| Calves born in year | | 45 |
| Average lactations | | > 6 |
| Age at first delivery | years | |
| Culling rate | % | |
| Milk production | kg | 306 175 |
| ECM milk production | kg | 350 248 |
| Fat | % | 4,3% |
| Protein | % | 3,4% |
| Milk production per cow | kg | 6 804 |
| ECM milk production per cow | kg | 7 783 |

### Nutritional inputs

| Period in year (months) | 7 | 5 |
|---|---|---|
| Daily ration | High production | Medium - Dry |
| | kg/cow/day | kg/cow/day |
| Pasture | * | - |
| Corn | 5 | 3,6 |
| Corn silage | 6,8 | |
| Hay | - | 22,7 |
| Total | - | 26,3 |

### Machinery

| Tractors | kg |
|---|---|
| Tillage 150 hp | 1 500 |
| Hay mown 37 xp | 350 |
| Horses 7x | |
| Stall in milking parlor | 6 |

### Direct energy consumption

| | | |
|---|---|---|
| Diesel fuel | liters | 2 503 |
| Electrical energy | kWh | - |

### Self forage production

| Crop | Area (ha) | Production (t) |
|---|---|---|
| Pasture | 12,3 | - |
| Corn silage | 9 | 436 |
| Corn | 12,2 | 91,4 |

### Fertilizer (kg/ha)

| | |
|---|---|
| Pelleted chicken manure | 1 686 |
| Potash | 100 |

### Notes

This farm doesn't use electrical energy. Diesel fuel is used only for a tiller pulled by horses and a hay mowner. 7 horses are used, whose feed cost 27 MJ/day. Diesel consumption is estimated according to a monthly cost of 200$ and an average fuel price fo rMissouri (2013) of 0,98 $/liter. Energy embodied in corn and corn silage wasn't allocated according to the Missouri average, since it is produced in farm and its cost is included in fertilizer and fuel. Energy embodied in chicken manure is assumed to be 2,73 MJ/kg.

## Farm OP3

O3 is a smal size modern pasture based organic farm located in Missouri. Since the survey was performed on november 2014, collected data are related to year 2013.

### General data

| | | |
|---|---|---|
| Average milking cows | | 67 |
| Average dry cows | | seasonal |
| Calves born in year | | 75 |
| Average lactations | | 3 |
| Age at first delivery | years | |
| Culling rate | % | |
| Milk production | kg | 204 279 |
| ECM milk production | kg | 242 643 |
| Fat | % | 4,55% |
| Protein | % | 3,55% |
| Milk production per cow | kg | 3 049 |

| | | |
|---|---|---|
| ECM milk production per cow | kg | 3 621 |

## Nutritional inputs

| Period duration (days in year) | 204 | 84 | 77 |
|---|---|---|---|
| Daily ration | High production | Medium production | Dry |
| | kg/cow/day | kg/cow/day | kg/cow/day |
| Pasture | 19,96 | | |
| Sorghum silage | | 9,1 | 9,1 |
| DDGS | | | |
| Premix | | 2,27 | |
| Alfalfa | | | |
| Hay | | 9,1 | 9,1 |
| Premix composition | | | |
| Corn | | 1,26 | |
| Soy | | 1,01 | |
| Total | 19,96 | 20,41 | |

## Machinery

| Tractors | kg |
|---|---|
| skidsteer | 3 246 |
| 1 100 hp | 5 780 |
| 1 90 hp | 4 293 |
| Stall in milking parlor | 18 |

## D irect energy consumption

| | | |
|---|---|---|
| Diesel fuel | liters | 8 090 |
| Electrical energy | kWh | 63334 |

## Fertilizer

| | |
|---|---|
| Hog manure from near farm | 5808 m³ |

## Notes

All cows follow the seasonal cycle so they went dry at the end of december. Electrical energy consumption was estimated from a monthly average cost of 10256$ and an average specific energy cost for Missouri (2013) of 10,53 cent $/Kwh. Diesel consumption was estimated from a cost of 11934 $ and average price for Missouri (2013) of 0,98 $/liter. Energy embodied in hog manure is estimated according to its nutrient content. According to analysis of the farm lagoon: N 0,337%, P2O5 0,07%, K2O 0,285%.

# Farm G3

G3 is a large size modern grain based farm located in Emilia Romagna. Since the survey was performed on february 3rd 2015, collected data are related to year 2014.

## General data

| | | |
|---|---|---|
| Average milking cows | | 850 |
| Average dry cows | | 150 |
| Calves born in year | | 1191 |
| Average lactations | | 2,25 |
| Age at first delivery | years | 1,17 |
| Culling rate | % | 35% |
| Milk production | kg | 9 100 000 |
| Fat | % | 3,50% |
| Protein | % | 3,64% |
| ECM milk production | kg | 9 634 261 |
| Milk production per cow | kg | 10 706 |
| ECM milk production per cow | kg | 11 334 |

## Nutritional inputs

| Cow number | 400 | 450 | 150 |
|---|---|---|---|
| Daily ration | High production | Medium production | Dry |
| | kg/cow/day | kg/cow/day | kg/cow/day |
| Corn | 7,0 | 5,0 | 2,0 |
| Barley | 2,0 | 1,2 | |
| Premix | 3,0 | 2,5 | |
| Alfalfa | 7,0 | 5,0 | |
| Hay | 5,0 | 6,0 | 14,0 |
| Premix composition | | | |
| Soymeal | 1,5 | | |
| Sunflower | 1,5 | | |
| Total | 24,5 | 19,7 | 16,0 |

## Machinery

| Tractors/equipment | kg |
|---|---|
| 1x 180 hp | 7335 |
| 1x 140 hp | 8198 |
| 2x65 hp | 3452 |
| 3x120 hp | 2000 |
| 1x150 hp | 6472 |
| Stall in milking parlor | 40 |

## Direct energy consumption

| | | |
|---|---|---|
| Diesel fuel | liters | 120 000 |

| | | |
|---|---|---|
| Propane | liters | 8 889 |
| Electrical energy | kWh | 956 251 |

### Self forage production

| Crop | Area (ha) | Production (t) |
|---|---|---|
| Barley | 140 | 840 |
| Alfalfa | 680 | 5440 |

Notes
Electrical energy consumption was estimated froma total cost of 120 000 euros taking into account that the italian tariff is formed by a fixed cost (20,6784 euros) a cost per kW (15,173 euro/kWx100 kW) and a consumtion cost of 146,9 euros for the first 4400 kWh.

## Farm G4

G4 is a large size modern grain based farm located in Emilia Romagna. Since the survey was performed on february 3rd 2015, collected data are related to year 2014.

### General data

| | | |
|---|---|---|
| Average milking cows | | 507 |
| Average dry cows | | 80 |
| Calves born in year | | 575 |
| Average lactations | | 3,1 |
| Age at first delivery | years | 2,15 |
| Culling rate | % | 27% |
| Milk production | kg | 4 850 500 |
| Fat | % | 3,81% |
| Protein | % | 3,72% |
| ECM milk production | kg | 5 309 957 |
| Milk production per cow | kg | 9 478 |
| ECM milk production per cow | kg | 10 473 |

### Nutritional inputs

| Cow number | 507 | 80 |
|---|---|---|
| Daily ration | Milking | Dry |
| | kg/cow/day | kg/cow/day |
| Corn | 4,0 | 2,0 |
| Barley | 2,5 | |
| Premix | 3,0 | |
| Alfalfa | 9,0 | |
| Hay | 5,0 | 8,0 |
| Premix composition | | |
| Soymeal | 1,5 | |
| Sunflower | 1,5 | |

| | | |
|---|---|---|
| Total | 23,5 | 10,0 |

## Machinery

| Tractors/equipment | kg |
|---|---|
| 1x 135 hp | 5780 |
| 2x 70 hp | 2612 |
| 4x50 hp | 2200 |
| 1x30 hp | 1500 |
| 2x110 hp | 6472 |
| 2x160 hp | 4293 |
| Stall in milking parlor | 24+14+6 |

## Direct energy consumption

| | | |
|---|---|---|
| Diesel fuel | liters | 74 825 |
| Electrical energy | kWh | |

## Self forage production

| Crop | Area (ha) | Production (t) |
|---|---|---|
| Hay | 40 | 432 |
| Alfalfa | 360 | 3 888 |

# Farm G5

G5 is a very large size modern grain based farm located in Emilia Romagna. Since the survey was performed on february 3rd 2015, collected data are related to year 2014.

## General data

| | | |
|---|---|---|
| Average milking cows | | 1250 |
| Average dry cows | | 201 |
| Calves born in year | | 1647 |
| Average lactations | | 2,3 |
| Age at first delivery | years | 24,5 |
| Culling rate | % | 35% |
| Milk production | kg | 13 368 125 |
| Fat | % | 3,25% |
| Protein | % | 3,61% |
| ECM milk production | kg | 13 687 560 |
| Milk production per cow | kg | 10 694 |
| ECM milk production per cow | kg | 10 950 |

## Nutritional inputs (kg/cow/day)

| Cow number | 400 | 150 |
|---|---|---|
| Daily ration | High production | Dry |
| Wheat | 2 | |

| | | |
|---|---|---|
| Corn | 5,0 | |
| Sorghum | 2,0 | |
| Premix | 4,5 | |
| Alfalfa | 7,5 | |
| Hay | 2,5 | 10,0 |
| Premix composition | | |
| Soymeal | 2,25 | |
| Sunflower | 2,25 | |
| Total | 25,5 | 10,0 |

## Machinery

| Tractors/equipment | kg |
|---|---|
| 2x 160 hp | 9000 |
| 5x 110 hp | 4293 |
| 2x60 hp | 2298 |
| 4x35 hp | 1500 |
| 1x280 hp | 10609 |
| Stall in milking parlor | 40 |

## Direct energy consumption

| | | |
|---|---|---|
| Diesel fuel | liters | 110 766 |
| Electrical energy | kWh | 1 599 855 |

## Self forage production

| Crop | Area (ha) | Production (t) |
|---|---|---|
| Hay | 40 | 320 |
| Alfalfa | 75 | 750 |
| Sorghum | 50 | 350 |
| Wheat | 80 | 560 |

## Fertilizer (kg/ha)

| | |
|---|---|
| N | 30 (alfalfa) 200 (wheat) |
| P | 90 |
| K | 30 |

Notes

Electrical energy consumption was estimated froma total cost of 200 000 euros taking into account that the italian tariff is formed by a fixed cost (20,6784 euros) a cost per kW (15,173 euro/kWx100 kW) and a consumtion cost of 146,9 euros for the first 4400 kWh.

Diesel fuel was estimated from a cost of 109 00 eurosand a unit price of 0,984 euro/liter for 2014 (special price for farmers)

## Farm P3

P3 is a small size traditional pasture based farm located in Emilia Romagna. Since the survey was performed on february 4th 2015, collected data are related to year 2014.

### General data

| | | |
|---|---|---|
| Average milking cows | | 32 |
| Average dry cows | | 4 |
| Calves born in year | | 34 |
| Average lactations | | 2,97 |
| Age at first delivery | years | 2,33 |
| Culling rate | % | 24% |
| Milk production | kg | 230 000 |
| Fat | % | 3,88% |
| Protein | % | 3,13% |
| ECM milk production | kg | 245 848 |
| Milk production per cow | kg | 7 188 |
| ECM milk production per cow | kg | 7 683 |

### Nutritional inputs (kg/cow/day)

| Cow number | 32 | 4 |
|---|---|---|
| Daily ration | Milking | Dry |
| Premix | 5,0 | 2,5 |
| Alfalfa | 27,8 | 27,8 |
| Premix composition | | |
| Maize | 2,5 | |
| Barley | 2,5 | |
| Total | 32,8 | 27,8 |

### Machinery

| Tractors/equipment | kg |
|---|---|
| 1x 125 hp | 5036 |
| 1x 72 hp | 2612 |
| 2x60 hp | 2298 |
| 1x40 hp | 2000 |
| 2x30 hp | 1500 |
| Stall in milking parlor | 4 |

### Direct energy consumption

| | | |
|---|---|---|
| Diesel fuel | liters | 6 000 |
| Electrical energy | kWh | 16 623 |

### Self forage production

| Crop | Area (ha) | Production (t) |
|---|---|---|
| Hay | 4,4 | 86 |

| | | |
|---|---|---|
| Alfalfa | 13,3 | 237 |
| Maize | 1,6 | 15 |
| Wheat | 5,36 | 30 |

### Fertilizer (kg/ha)

| | |
|---|---|
| N | 36 |
| P | 48 |

## Farm P4

P4 is a small size traditional pasture based farm located in Emilia Romagna. Since the survey was performed on february 4th 2015, collected data are related to year 2014.

### General data

| | | |
|---|---|---|
| Average milking cows | | 45 |
| Average dry cows | | 6 |
| Calves born in year | | 38 |
| Average lactations | | 2,6 |
| Age at first delivery | years | 2,37 |
| Culling rate | % | 24% |
| Milk production | kg | 240 000 |
| Fat | % | 4,18% |
| Protein | % | 3,40% |
| ECM milk production | kg | 247 157 |
| Milk production per cow | kg | 6 154 |
| ECM milk production per cow | kg | 6 944 |

### Nutritional inputs (kg/cow/day)

| Cow number | 32 | 4 |
|---|---|---|
| Daily ration | Milking | Dry |
| Premix | 4,0 | 1,0 |
| Alfalfa | 8,0 | 5,0 |
| Hay | 6,0 | 7,0 |
| Premix composition | | |
| Maize | 2,0 | |
| Barley | 2,0 | |
| Total | 18,0 | 13,0 |

### Machinery

| Tractors/equipment | kg |
|---|---|
| 1x 90 hp | 4 200 |
| 2x 70 hp | 2600 |
| 2x50 hp | 2300 |
| 3x25 hp | 2000 |

| | |
|---|---|
| Stall in milking parlor | 4 |

## Direct energy consumption

| | | |
|---|---|---|
| Diesel fuel | liters | 5 500 |
| Methane | methane | 680 |
| Electrical energy | kWh | 10 560 |

## Self forage production

| Crop | Area (ha) | Production (t) |
|---|---|---|
| Hay | 5 | 86 |
| Alfalfa | 10 | 237 |
| Barley | 4,2 | 39 |

## Fertilizer (kg/ha)

| | |
|---|---|
| N | 51 |
| P | 66 |

# Farm OP4

OP4 is a small size traditional pasture based organic farm located in Emilia Romagna. Since the survey was performed on february 5th 2015, collected data are related to year 2014.

## General data

| | | |
|---|---|---|
| Average milking cows | | 31 |
| Average dry cows | | 11 |
| Calves born in year | | 29 |
| Average lactations | | 4 |
| Age at first delivery | years | 2 |
| Culling rate | % | 7,4% |
| Milk production | kg | 190 000 |
| Fat | % | 3,60% |
| Protein | % | 3,40% |
| ECM milk production | kg | 200 127 |
| Milk production per cow | kg | 6 129 |
| ECM milk production per cow | kg | 6 455 |

## Nutritional inputs (kg/cow/day)

| | | |
|---|---|---|
| Cow number | 31 | 11 |
| Daily ration | Milking | Dry |
| Premix | 3,7 | |
| Pasture | 10,7 | 10,7 |
| Hay | 8,35 | |
| Premix composition | | |
| Maize | 1,85 | |

| | | |
|---|---|---|
| Soy | 1,85 | |
| Total | 22,7 | 10,6 |

## Machinery

| Tractors/equipment | kg |
|---|---|
| 1x 100 hp | 4200 |
| Stall in milking parlor | 5 |

## Direct energy consumption

| | | |
|---|---|---|
| Diesel fuel | liters | 1 000 |
| Electrical energy | kWh | 1700 |

## Self forage production

| Crop | Area (ha) | Production (t) |
|---|---|---|
| Pasture | 19 | 163 |
| Hay | 6,7 | 114 |

# Farm OP5

OP5 is a small size traditional pasture based organic farm located in Emilia Romagna. Since the survey was performed on february 4th 2015, collected data are related to year 2014.

## General data

| | | |
|---|---|---|
| Average milking cows | | 38 |
| Average dry cows | | 10 |
| Calves born in year | | 45 |
| Average lactations | | 4,5 |
| Age at first delivery | years | 2,16 |
| Culling rate | % | 19,5% |
| Milk production | kg | 280 000 |
| Fat | % | 3,30% |
| Protein | % | 3,60% |
| ECM milk production | kg | 288 330 |
| Milk production per cow | kg | 7 368 |
| ECM milk production per cow | kg | 7 579 |

## Nutritional inputs (kg/cow/day)

| Cow number | 38 | 10 |
|---|---|---|
| Daily ration | Milking | Dry |
| Premix | 4,11 | |
| Alfalfa | 20,2 | 20,2 |
| Premix composition | | |
| Maize | 2,05 | |
| Barley | 2,05 | |
| Total | 24,3 | 20,2 |

### Machinery

| Tractors/equipment | kg |
|---|---|
| 1x 118 hp | 5036 |
| 1x 100 hp | 4200 |
| 1x 70 hp | 2612 |
| 1x60 hp | 2298 |
| 1x45hp | 1500 |
| Stall in milking parlor | 6 |

### Direct energy consumption

| | | |
|---|---|---|
| Diesel fuel | liters | 4 000 |
| Electrical energy | kWh | 7 986 |

### Self forage production

| Crop | Area (ha) | Production (t) |
|---|---|---|
| Pasture | 10 | 86 |
| Alfalfa | 26 | 250 |

### Fertilizer (kg/ha)

| | |
|---|---|
| N | |
| P | |

Notes

Electrical energy purchased form the network was 11409 kWh. Photovoltaics panel provide 3423 kWh of self consumption (not counted) and the same amount of power sold to the rate, that has been discounted from the purchased

## Farm OP6

OP6 is a medium size traditional organic farm located in Emilia Romagna. Since the survey was performed on february 4th 2015, collected data are related to year 2014.

### General data

| | | |
|---|---|---|
| Average milking cows | | 150 |
| Average dry cows | | 30 |
| Calves born in year | | 150 |
| Average lactations | | 3,5 |
| Age at first delivery | years | 2,04 |
| Culling rate | % | 23,55% |
| Milk production | kg | 1 368 750 |
| Fat | % | 3,48% |
| Protein | % | 3,24% |
| ECM milk production | kg | 1 403 890 |
| Milk production per cow | kg | 9 125 |

| | | |
|---|---|---|
| ECM milk production per cow | kg | 9 359 |

## Nutritional inputs (kg/cow/day)

| | | |
|---|---|---|
| Cow number | 38 | 10 |
| Daily ration | Milking | Dry |
| Soy | 2,0 | 1,5 |
| Maize | 7,0 | |
| Alfalfa | 4,0 | 4,0 |
| Hay | 11,0 | 10,0 |
| Total | 22,0 | 15,5 |

## Machinery

| Tractors/equipment | kg |
|---|---|
| 1x 145 hp | 6126 |
| 2x 100 hp | 4200 |
| 2x 90 hp | 3500 |
| 3x50 hp | 2200 |
| 1x70 hp | 1500 |
| 2x 55 hp | 2612 |
| Stall in milking parlor | 2200 |

## Direct energy consumption

| | | |
|---|---|---|
| Diesel fuel | liters | 35 000 |
| Electrical energy | kWh | |

## Self forage production

| Crop | Area (ha) | Production (t) |
|---|---|---|
| Hay | 140 | 1150 |

## Fertilizer (kg/ha)

| | |
|---|---|
| N | |
| P | |

## Notes

## 9.3 Rice farms data sheets

### Farm C1

C1 is a large size conventional farm located in Missouri. Since the survey was performed on december 8th 2014, collected data are related to year 2013.

#### General data

| | | |
|---|---|---|
| Rice area | ha | 569,5 |
| Total crop area | ha | 1 708,5 |
| Paddy rice Yield | Kg/ha | 9 332 |

#### Machinery

| Tractors/equipment | kg |
|---|---|
| 1x 420 hp | 17 052 |
| 3x 260 hp | 10 609 |
| 2x 290 hp | 11 000 |
| 2 combines | 15 600 |

#### Direct energy consumption

| | | |
|---|---|---|
| Diesel fuel for traction | liters | 134 140 |
| Irrigation | liters | 112 603 |

#### Fertilizer (kg/ha)

| | |
|---|---|
| Ammonium phosphate | 33,45 |
| Ammonia | 111,5 |
| Urea | 356,8 |
| Phosphate | 44,6 |
| Potash | 66,9 |

#### Pesticides (kg/ha)

| | |
|---|---|
| Glyphosate | 3,95 |
| Command | 0,91 |
| Quinclorac | 0,56 |
| Propanil | 11,63 |

#### Notes

### Farm C2

C2 is a medium size conventional farm located in Missouri. Since the survey was performed on december 8th 2014, collected data are related to year 2013.

#### General data

| | | |
|---|---|---|
| Rice area | ha | 142,4 |

| | | |
|---|---|---|
| Total crop area | ha | 849,9 |
| Paddy rice Yield | Kg/ha | 8 028 |

## Machinery

| Tractors/equipment | kg |
|---|---|
| 3x 175 hp | 7 000 |
| 2x 210 hp | 8 198 |
| 3x 150 hp | 6200 |
| 2 combines | 15 600 |

## Direct energy consumption

| | | |
|---|---|---|
| Diesel fuel for traction | liters | 59 614 |
| Irrigation (diesel) | liters | 37 258 |
| Irrigation (electric) | kWh | 299 812 |

## Fertilizer (kg/ha)

| | |
|---|---|
| Urea | 200,7 |
| Phosphate | 83,6 |
| Potash | 66,9 |

## Pesticides (kg/ha)

| | |
|---|---|
| Command | 1,75 |
| Clearpath | 0,28 |

## Notes

# Farm C3

C3 is a medium size conventional farm located in Missouri. Since the survey was performed on december 8th 2014, collected data are related to year 2013.

## General data

| | | |
|---|---|---|
| Rice area | ha | 122 |
| Paddy rice Yield | Kg/ha | 8 028 |

## Machinery

| Tractors/equipment | kg |
|---|---|
| 2x 175 hp | 13 642 |
| 2x 210 hp | 15 000 |
| 1 combines | 15 600 |

## Direct energy consumption

| | | |
|---|---|---|
| Diesel fuel for traction | liters | 5 677 |
| Irrigation (diesel) | liters | 16 836 |
| Irrigation (electric) | kWh | 71 347 |

## Fertilizer (kg/ha)

| | |
|---|---|
| Urea | 167,2 |
| 3-18-18 | 10,0 |
| Potash | 66,9 |

## Pesticides (kg/ha)

| | |
|---|---|
| Newpath | 0,56 |
| Clearpath | 0,56 |

## Notes

# Farm C4

C4 is a large size conventional farm located in Missouri. Since the survey was performed on december 9th 2014, collected data are related to year 2013.

## General data

| | | |
|---|---|---|
| Rice area | ha | 1220 |
| Total area | ha | 1708,5 |
| Paddy rice Yield | Kg/ha | 8 781 |

## Machinery

| Tractors/equipment | kg |
|---|---|
| 9x 130 hp | 6472 |
| 3 combines | 15 600 |

## Direct energy consumption

| | | |
|---|---|---|
| Diesel fuel for traction | liters | 183 145 |
| Irrigation (diesel) | liters | 91 572 |
| Irrigation (electric) | kWh | 280 711 |

## Fertilizer (kg/ha)

| | |
|---|---|
| Urea | 289,9 |
| Ammonium Sulphate | 11,5 |
| Phosphate | |
| Potash | 111,5 |

## Pesticides (kg/ha)

| | |
|---|---|
| Glyphosate | 0,09 |
| Ricebeaux | 1,46 |
| Gowan Permit | 0,01 |
| New Path | 0,02 |
| Rebel EX | 0,06 |

## Notes

## Farm OR1

OR1 is a medium size organic farm located in Missouri. Since the survey was performed on december 9th 2014, collected data are related to year 2013.

### General data

| | | |
|---|---|---|
| Rice area | ha | 163 |
| Total area | ha | 610 |
| Paddy rice Yield | Kg/ha | 7 526 |

### Machinery

| Tractors/equipment | kg |
|---|---|
| 2x 130 hp | 13642 |
| 1 combines | 15 600 |

### Direct energy consumption

| | | |
|---|---|---|
| Diesel fuel for traction | liters | 11 168 |
| Irrigation (diesel) | liters | 5 886 |
| Irrigation (electric) | kWh | 25 375 |

### Fertilizer (kg/ha)

| | |
|---|---|
| Hog manure | 9304 |
| Phosphate | |
| Potash | 33,45 |

### Pesticides (kg/ha)

| | |
|---|---|
| Flame weeding | 27,9 l/ha |
| Soybean dipeptide | 11,15 kg/ha |
| Soybean plasma | 53,9 kg/ha |

### Notes

Embodied energy of soybean dipeptide and plasma was estimated according to their N content in order to transform them in soy equivalent. Energy embodied in hog manure is estimated according to the average N,P,K nutrient content.

## Farm C5

C5 is a medium-large size conventional farm located in Italy. Since the survey was performed on february 6th 2015, collected data are related to year 2014.

### General data

| | | |
|---|---|---|
| Rice area | ha | 150,7 |
| Total area | ha | 182 |
| Paddy rice Yield | Kg/ha | 7 500 |

### Machinery

| Tractors/equipment | kg |
|---|---|

| | |
|---|---|
| 1x 190 hp | 8 000 |
| 1x 160 hp | 64 72 |
| 2x 130 hp | 5 780 |
| 2x 100 hp | 4 000 |
| 1 combines | 13 400 |

### Direct energy consumption

| | | |
|---|---|---|
| Diesel fuel for traction | liters | 93 856 |
| Electricl energy | kWh | 86 664 |
| Diesel fuel For Drying | liters | 22 600 |

### Fertilizer (kg/ha)

| | |
|---|---|
| Urea | 90 |
| Phosphate | |
| Potash | 170 |

### Pesticides (kg/ha)

| | |
|---|---|
| Glyphosate | 2,29 |
| Pendimetalin | 0,76 |
| Oxiadiazon | 0,08 |
| Viper | 1,3 |

Notes

Electrical energy consumption was estimated from a total cost of 11 000 euros taking into account that the italian tariff is formed by a fixed cost (20,6784 euros) a cost per kW (15,173 euro/kWx40 kW) and a consumption cost of 146,9 euros for the first 4400 kWh.

## Farm C6

C6 is a medium size conventional farm located in Italy. Since the survey was performed on february 6th 2015, collected data are related to year 2014.

### General data

| | | |
|---|---|---|
| Rice area | ha | 90 |
| Paddy rice Yield | Kg/ha | 6 139 |

### Machinery

| Tractors/equipment | kg |
|---|---|
| 3x 100 hp | 4 200 |
| 1x 140 hp | 5 780 |
| 1x 200 hp | 8 198 |
| 1x 70 hp | 2 600 |
| 1 combines | 13 400 |

### Direct energy consumption

| | | |
|---|---|---|
| Diesel fuel for traction | liters | 18 921 |

| | | |
|---|---|---|
| Propane for drying | liters | 8 581 |
| Electricl energy | kWh | 2942 |

### Fertilizer (kg/ha)

| | |
|---|---|
| Urea | 90 |
| Phosphate | |
| Potash | 170 |

### Pesticides (kg/ha)

| | |
|---|---|
| Glyphosate | 2,29 |
| Pendimetalin | 0,76 |
| Oxiadiazon | 0,08 |
| Viper | 1,3 |

Notes

Electrical energy consumption was estimated from a total cost of 11 000 euros taking into account that the italian tariff is formed by a fixed cost (20,6784 euros) a cost per kW (15,173 euro/kWx40 kW) and a consumtion cost of 146,9 euros for the first 4400 kWh. This value was discounted by the energy produced by the PV plant, 39 473 kWh.

Diesel fuel was estimated from a cost of 18000 eurosand a unit price of 0,984 euro/liter for 2014 (special price for farmers)

## Farm C7

C7 is a small size conventional farm located in Italy. Since the survey was performed on february 17th 2015, collected data are related to year 2014.

### General data

| | | |
|---|---|---|
| Rice area | ha | 20 |
| Paddy rice Yield | Kg/ha | 7 000 |

### Machinery

| Tractors/equipment | kg |
|---|---|
| 2x 90 hp | 4 028 |
| 2x 100 hp | 4200 |
| 1x 130 hp | 5 780 |
| 1x 120 hp | 5036 |
| 1 combines 450 hp | 20 142 |

### Direct energy consumption

| | | |
|---|---|---|
| Diesel fuel for traction | liters | 16 550 |
| Diesel fuel for drying | liters | 2 450 |
| Electricl energy | kWh | 6 657 |

### Fertilizer (kg/ha)

| | |
|---|---|
| Calcium Cyanamide | 153 |

|  |  |
|---|---|
| Urea | 344 |
| Phosphate | 150 |
| Potash | 344 |

## Pesticides (kg/ha)

|  |  |
|---|---|
| Oxiadiazon | 0,08 |
| Viper | 1,94 |

Notes

Electrical energy consumption was estimated from a total cost of 600 euros taking into account that the italian tariff is formed by a fixed cost (20,6784 euros) a cost per kW (15,173 euro/kWx40 kW) and a consumtion cost of 146,9 euros for the first 4400 kWh.

# Farm C8

C8 is a small-medium size conventional farm located in Italy. Since the survey was performed on february 23rd 2015, collected data are related to year 2014.

## General data

|  |  |  |
|---|---|---|
| Rice area | ha | 58 |
| Paddy rice Yield | Kg/ha | 5240 |

## Machinery

| Tractors/equipment | kg |
|---|---|
| 3x 130 hp | 5 818 |
| 1x 110 hp | 5 057 |
| 2x 100 hp | 4 476 |
| 2x 90 hp | 4028 |
| 1 combines 260 hp | 11 637 |

## Direct energy consumption

|  |  |  |
|---|---|---|
| Diesel fuel for traction | liters | 9 117 |
| Diesel fuel for drying | liters | 7 142 |
| Electricl energy | kWh | 18 892 |

## Fertilizer (kg/ha)

|  |  |
|---|---|
| Urea | 93 |
| Phosphate | 47 |
| Potash | 125 |

## Pesticides (kg/ha)

|  |  |
|---|---|
| Aura | 0,34 |
| Imazamox | 2,1 |
| Clincher | 1,57 |

Notes
Machinery is equally shared with another farm, so its embodied energy has been divided by two

## Farm C9

C9 is a small-medium size conventional farm located in Italy. Since the survey was performed on march 10th 2015, collected data are related to year 2014.

### General data

| | | |
|---|---|---|
| Rice area | ha | 90 |
| Paddy rice Yield | Kg/ha | 7 500 |

### Machinery

| Tractors/equipment | kg |
|---|---|
| 1x 175hp | 7 833 |
| 1x 200 hp | 8 952 |
| 1x 230 hp | 10 295 |
| 1 combines 290 kW | 17 400 |

### Direct energy consumption

| | | |
|---|---|---|
| Diesel fuel for traction | liters | 25 000 |
| Diesel fuel for drying | liters | 15 000 |
| Electricl energy | kWh | 85 060 |

### Fertilizer (kg/ha)

| | |
|---|---|
| Urea | 186,25 |
| Phosphate | 0 |
| Potash | 250 |

### Pesticides (kg/ha)

| | |
|---|---|
| Oxadiazon | 7,65 |
| Viper | 1,52 |

Notes
Combine is equally shared with another farm, so its embodied energy has been divided by two

## Farm C10

C10 is a small-medium size conventional farm located in Italy. Since the survey was performed on march 11th 2015, collected data are related to year 2014.

### General data

| | | |
|---|---|---|
| Rice area | ha | 71 |
| Paddy rice Yield | Kg/ha | 7245 |

## Machinery

| Tractors/equipment | kg |
|---|---|
| 2x 90 hp | 4 028 |
| 1x 165 hp | 7 385 |
| 2x 130 hp | 5 820 |
| 1x 110 hp | 4 920 |
| 1 combines 260 kW | 15 780 |

## Direct energy consumption

| | | |
|---|---|---|
| Diesel fuel for traction | liters | 8 400 |
| Diesel fuel for drying | liters | 15 600 |
| Electricl energy | kWh | 15 974 |

## Fertilizer (kg/ha)

| | |
|---|---|
| Urea | 188 |
| Phosphate | 0 |
| Potash | 127 |

## Pesticides (kg/ha)

| | |
|---|---|
| Oxadiazon | 1,37 |
| Stratos Ultra | 2 |
| Viper | 2 |

## Notes

# Farm OR2

OR2 is a medium size organic farm located in Italy. Since the survey was performed on february 25th 2015, collected data are related to year 2014.

## General data

| | | |
|---|---|---|
| Rice area | ha | 110 |
| Paddy rice Yield | Kg/ha | 6 136 |

## Machinery

| Tractors/equipment | kg |
|---|---|
| 1x 380 hp | 17 000 |
| 3x 130 hp | 5818 |
| 1x 100 hp | 4 252 |
| 2 combines 260 hp | 11 637 |

## Direct energy consumption

| | | |
|---|---|---|
| Diesel fuel for traction | liters | 21 382 |
| GPL fuel for drying | liters | 18 000 |

| | | |
|---|---|---|
| Electricl energy | kWh | 45 218 |

## Fertilizer (kg/ha)

| | |
|---|---|
| Horn and huffs | |
| N | 36 |
| P | 0 |
| K | 72 |

## Pesticides (kg/ha)

| | |
|---|---|
| | |
| | |

Notes

Electrical energy consumption was discounted by the energy produced in an energy plant that buys the husksfrom the farmer.

## 9.4 Survey for dairy farms

**1 Farm and Animal data**

Farm is
Confinement dairy Organic
Pasture-based dairy Non organic

All data should be related to one calendar year

| | | |
|---|---|---|
| 1.1 | Average number o milking cows | |
| 1.2 | Number of calves born | |
| 1.3 | Average age of herd | |
| 1.4 | Notes and specifications | |

**2 Forage production**

Inputs should be related only to the dairy activities, separating it from the global farm input, if necessary. All inputs should be related to one calendar year

| | | Cultivated area | | | Fertilizer use (lbs/acre) | | |
|---|---|---|---|---|---|---|---|
| | Forage | Acres | Yield | | Nitrogen | Phosphate | Potash |
| 2.1 | Corn silage | | | t/acre | | | |
| 2.2 | Corn | | | bsh/acre | | | |
| 2.3 | Barley | | | t/acre | | | |
| 2.4 | Pasture | | | t/acre | | | |
| 2.5 | Alfalfa | | | t/acre | | | |
| 2.6 | Other hay | | | t/acre | | | |
| 2.7 | Other (specify) | | | t/acre | | | |

| | | Pesticide use (lbs/acre) | | | Self production |
|---|---|---|---|---|---|
| | Forage | Herbicides | Insecticides | Fungicides | covers % of feed |
| 2.1 | Corn silage | | | | |
| 2.2 | Corn | | | | |
| 2.3 | Barley | | | | |
| 2.4 | Pasture | | | | |
| 2.5 | Alfalfa | | | | |
| 2.6 | Other hay | | | | |
| 2.7 | Other (specify) | | | | |

## 3 Feeding inputs (average daily ration per cow)

Inputs should be related only to the dairy activities, separating it from the total farm input, if necessary

| | | | Hi milk prod | Med milk prod | Dry period | Supplier, if any (*) |
|---|---|---|---|---|---|---|
| | Number of cows in group | | | | | |
| 3.1 | Corn silage | Pounds | | | | |
| 3.2 | Corn | Pounds | | | | |
| 3.3 | Barley | Pounds | | | | |
| 3.4 | Pasture (estimated) | Pounds | | | | |
| 3.5 | Alfalfa | Pounds | | | | |
| 3.6 | Other hay | Pounds | | | | |
| 3.7 | Soy Bean Meal | Pounds | | | | |
| 3.8 | DDG | Pounds | | | | |
| 3.9 | Premix (**) | Pounds | | | | |
| 3.10 | Other | Pounds | | | | |

**(*) Please indicate from whom purchased (e.g. local farmer, company, etc.)**
**(**) Please enclose list with premix composition with % ingredients by weight**

## 4 Direct energetic inputs (heating, mechanical operations, milking, etc.)

Inputs should be related only to the dairy activities,
separating it from the global farm input, if necessary
All inputs should be related to one calendar year

| | | | Total | self-produced fraction |
|---|---|---|---|---|
| 5.1 | Diesel fuel | gallons | | |
| 5.2 | Propane | gallons | | |
| 5.3 | Gasoline | gallons | | |
| 5.4 | Electrical energy | kWh | | |
| 5.5 | Wood | Pounds | | |
| 5.6 | Other (please specifiy) | | | |

## 5 Equipment and other inputs

All inputs should be related to one calendar year

*Dairy equipment*

| | | |
|---|---|---|
| 4.1 | Milking facility typology | |
| 4.2 | Number of stalls | |
| 4.3 | Daily working hours | |

Other inputs (materials for cattle bedding operations)

| | | | |
|---|---|---|---|
| 4.4 | | Pounds | |
| 4.5 | | Pounds | |
| 4.6 | | Pounds | |
| 4.7 | | Pounds | |

*Crop equipment*

List the most relevant equipment used for tillage, planting, maintenance harvesting, tractors included, specifying type and power

| | Type | Power |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

## 6 Outputs

All outputs should be related to one calendar year

| | | | |
|---|---|---|---|
| 6.1 | Total raw milk production | Pounds | |
| 6.1a | Milk density | Pound/gallon | |
| 6.1b | Butterfat fraction | % | |
| 6.1c | Protein fraction | % | |

| | | | |
|---|---|---|---|
| 6.2 | Number of calves sold | Number | |
| 6.3 | Average weight | Pounds | |
| 6.4 | Number of cows sold | Number | |
| 6.5 | Average weight | Pounds | |

## 7 Effluents (estimation)

| | | |
|---|---|---|
| 7.1 | Farmyard manure estimated volume | Gallons |
| 7.2 | Liquid manure estimated volume | Gallons |

## 9.5 Survey for rice farms

1. Land and farming

Data should be referred to one calendar year and only to operations related to rice production

| | Unit | |
|---|---|---|
| Cultivated area | acres | |
| Production | hundredweight | |

| | | Machine 1 | Machine 2 | Machine 3 |
|---|---|---|---|---|
| Tractors | | | | |
| Percent of possession (*) | % | | | |
| Weight of tractors in use or | Pounds | | | |
| Tractor model | Name | | | |
| Harvester – Thresherm (H-T) | | | | |
| Percent of possession (**) | % | | | |
| Weight of tractors in use or | Pounds | | | |
| H-T model | Name | | | |

| | | | | |
|---|---|---|---|---|
| *Nitrogen fertilizers* | | | | |
| ………… | Pounds | | | |
| ………… | Pounds | | | |
| ………… | Pounds | | | |
| *Phosphate fertilizers* | | | | |
| ………… | Pounds | | | |
| ………… | Pounds | | | |
| *Potash fertilizers* | | | | |
| ………… | Pounds | | | |
| ………… | Pounds | | | |
| *Organic fertilizers* | | | | |
| Manure | Pounds | | | |
| Green manure | Pounds | | | |
| Compost | Pounds | | | |

| | | | | |
|---|---|---|---|---|
| *Pesticides* | | | | |
| ………… | Pounds | | | |
| ………… | Pounds | | | |
| ………… | Pounds | | | |

## 2. Direct energy input

Data should be referred to one calendar year and only to operations related to rice production

| | Unit | Total | self-produced fraction |
|---|---|---|---|
| *Fuel* | | | |
| Yearly fuel consumption for tractors, H-T and other vehicles | gallons | | |
| Diesel fuel | gallons | | |
| Methane | gallons | | |
| Gasoline | gallons | | |
| Other (specify) | | | |
| *Electrical energy* | | | |
| Total consumption | kWh | | |

## 3. Post harvest operations

This section should be filled only if post harvest operations are occurring at farm

| Drying | Unit | Diesel | Natural gas | Other |
|---|---|---|---|---|
| Total Dryer(s) fuel consumprion | gallons | | | |

| | | |
|---|---|---|
| Hulling | | |
| Rice huller power | kW or Hp | |
| Lot processed mass | Pounds | |
| Lot process time | Hours | |
| Polishing | | |
| Rice polisher power | kW or Hp | |
| Lot processed mass | Pounds | |
| Lot process time | Hours | |

## 4. Packaging

This section should be filled only if packaging operations are occurring at farm

| | Unit | |
|---|---|---|
| Power or rice packing machine | kW or Hp | |
| Hourly package production | No. of hours | |
| Mass of rice in package | Pounds | |
| Package mass | Ounces | |
| Plastic type (PS, PE, PET…) | | |