LUISS

Dipartimento di
Impresa e Management

Cattedra: Energy markets and Industrial organization

The energy cost of food production: the case of agriculture and livestock

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Anno Accademico 2019/2020

Dedicated to my parents for supporting me,
to my sister, Michela, for always being by my side
and to Andrea for helping me believe in myself.
Dedicated to all those who believe in a better future, because there is no planet B

Contents

Introduction

The global community is warning us about the fact that our diet has a huge impact on the environment when it comes to energy consumption, environmental damages and of course climate change.

Worldwide food demand is increasing and so the energy demand of food sector and its greenhouse gases emission. Considering that in 2050 the world population will exceed nine billions of people and FAO projects a 70 percent increase in current food production it is clear we need to find new manners to producer food, increase the efficiency of the primary production and make new policies. The goal of this thesis is to analyse the energy demand of the agri-food chain, focusing on the common problem of energy efficiency and environmental damages.

To pursue this goal, we will go through data that represent the present situation across the world and that inform us about alternative production practices such as organic agriculture and greenhouse cultivation.

The first chapter focuses on how primary food production is one of the sectors with the greatest demand for energy. Specifically, the energy consumption of the agricultural sector compared to the annual domestic energy consumption can vary from 3 to 6 percent, depending on the country. In reality, as we will see in the first chapter, this number is strongly underestimated as it only considers direct inputs. The energy demand instead of the agri-food sector is also characterized by a series of indirect inputs which unfortunately cannot always be included in the calculations as in most of the studies and data collected these are included in other sectors.

As previously said, the development of alternative production practices is certainly one of the possible solutions for a more sustainable future. In particular, in Chapter 2, organic production will be dealt with, trying to understand if in terms of energy efficiency and environmental impact it is to be preferred to conventional production.

However, the heart of this thesis lies precisely in the analysis of energy consumption in agriculture and livestock. Starting from a broad study of modern agriculture, one immediately realizes that it is heavily dependent on fossil fuels. A strong environmental impact, a strong fluctuation in prices depending on oil prices, low energy efficiency are the consequences of this dependence.

However, in the world there are great differences between developing and developed countries on all fronts and therefore the same applies to the agri-food sector. The demand for energy and consequently energy efficiency depends on various factors linked to the location, firstly because of the differences across climates and secondly because of the different technologies available.

In addition to finding great differences between the various countries, there are also differences across the various types of crop and it is for this reason that various cereals and vegetables are taken into consideration in the report.

The consumption of animal products and derivatives such as meat and dairy products is still very high today and this has as a consequence a large spread of farms, especially intensive ones.

Obviously we are now aware of the environmental damage caused by intensive farming and for this reason it is of particular interest to understand why the production of animal products is so inefficient from an energy-consumption point of view and for its polluting potential. In fact, animals are defined as poor energy converters as before reaching man there are a series of energy inputs that are used precisely for the life and nutrition of the animal itself. Particularly then with regard to the milk industry in chapter four a case is considered in which the implementation of certain changes, such as carrying out certain agricultural practices only at certain times, can have a positive effect on energy demand.

In the final part of the thesis, on the other hand, there is a more environment-oriented approach and in fact the issues taken into consideration are the waste of energy during production and therefore the environmental impact of this possible approach. In particular, referring to food waste and its impact on the environment, considering the greenhouse gas emissions and subsequently the other reasons why the agri-food sector produces so many emissions. Finally, in addition to analyzing the current situation, we try to think of possible approaches for the future, especially through the use of renewable sources.

The agri-food industry is still too dependent on fossil fuels, however, there are several ways in which renewable energies are taking hold. In fact, they can be used both during production processes and there is the possibility of using the previously mentioned waste as a renewable energy source.

In the end according to the last topic of the course, the thesis aims to scan a variety of possible approaches for the future, introducing some ideas for the future such as technological innovations, implementation of present technology, the usage renewable resources, the improvement of energy access and the reduction of demand are the most important.

Last but not least, in the conclusion a few recommendation and suggestions that can be useful in order to combine the considerations about food, energy consumption and environment protection in a sustainable way are advanced.

1. An overview of energy demand for food primary production

In ancient Greek mythology, technology was seen as a gift from the gods.
The Promethean gift of fire allowed humans to elevate themselves above all the other forms of life, to begin design their world according to their own needs and desires. Anyway, this myth illustrates that there is a price to pay for the power gained: the Pandora's box.
Comparing the open of the Pandora's box, and the level of technology, it's clear that there is no going back. Human beings have become the dominant species on the planet, owing to their technological power, so on one hand, the exploitation of natural resources trough technology allows humankind to prosper, on the other hand our existence totally depends on technology.
Technology is an indispensable feature of our existence, so it would be in order to better manage it, studying the past and the present to avoid or at least limit unintended consequences.

1.1 A quick view on agriculture and food production

About 10 thousand years ago technologies start to be used in food production and from that moment agriculture has always played a substantial role in the society. The evolution of agriculture goes hand in hand with human technological development and the improvement of knowledge or cultivation techniques.
Humans had moved from subsistence agriculture to extensive controlled agriculture on large estates and crop rotation to intensive and specialized agriculture, increasingly mechanized, with the use of fertilizers and genetic engineering where technology plays a major role.
It is clear to all that technology needs energy in order to work and so does agriculture. In the past, human and animal labour, solar energy and rain were enough to allow humans to have food. Nowadays the demand of food is massive and so agriculture, which has always been a considerable consumer of energy, demands an even larger (direct and indirect) use of energy.
To meet the current level of demand, an adequate quantity and quality of agricultural production is needed. Considering the pace of population growth rate, then, without a change in world population diet there is no way humans requests for food is going to decrease, and as a consequence the consumption of energy made by food production sector is very likely to rise, too.
As mentioned before, we could summarized that the most relevant difference between past, present and future food production, is that, in the past in order to produce food humans relies nearly only on the efficient use of solar energy by photosynthesis, that is actually independent from them while now modern food production system can't work without energy sources that need humans in order to be used, as electricity or fossil fuel.
Due to the heavy impact of energy inputs on this sector, the key factor of food production is energy demand and efficiency.

Considering the demand, unfortunately food primary production relies on non-renewable resources for most of the steps, and in particular on fossil resources, either directly with the use of fuel or electricity or indirectly with the use of agricultural machineries, fertilizers or pesticides, cooling, storage and transportation of food.
It is not surprising, then, that the actual level of energy consumption of agriculture are underestimated and obviously, the main reason is that even tough when we consider energy use in agriculture we should track both direct energy use and indirect energy use associated with all kinds of inputs.
Unlikely, in most cases just direct energy inputs appear in data collected and used by studies on energy consumption by agriculture and food primary production.
Accordingly to the above, it is possible to find in the energy balance sheet of a nation that the energy required for the production of agricultural inputs and the fuels are not allocated entirely to the sector of "agriculture/forestry" e.g. production of fertilizers, consumption of fuels is reported in transportation sector.
This means that indirect energy demand is almost always considered in other sectors other than “agriculture/forestery”, meanwhile the energy use in agriculture is focused on direct energy use an so 50 % and more of the total energy use, which is related to the production of nitrogen fertilizer and other indirect energy uses, is omitted.
In particular, on-farm energy demand excluding human and animal power, is around 6EJ/yr.[1]
Where J is a derived unit of energy in the International System of Units, and EJ is exajoule, so 1 EJ=10^8 joule.
In addition to that, it is also useful to know that 1J= 1Ws, due to the common used of GWh in the next paragraphs as unit measurement.

1.2 General framework on energy efficiency and development of renewable energies for a sustainable future

Energy policies now play a central role in European strategies aimed at limiting the negative impact on the environment, in particular with regard to Greenhouse Gas (GHG) emissions due to anthropogenic activities and to promote a transition to a low-emission economy of carbon. The objectives to be achieved in the coming decades have been defined in the package "Climate-energy" (known as the 20-20-20 package) and considered an intermediate step compared to a longer-term horizon[2].
Energy efficiency and renewable energy development are therefore the themes that have taken on a central role in terms of European and international policy strategies, to ensure on the one hand concrete measures to deal with ongoing climate change, and on the other hand security in energy supply both at the European and global level.

[1] Data from IEA, 2010

[2] Communication from the Commission to the Council and the European Parliament of 22 November 2007: A European strategic energy technology plan. Towards a low carbon future, COM (2007) 723 final; URL: http://europa.eu/legislation_summaries/energy/european_energy_policy/l27079_en.htm).

The fight against climate change is tackled with various political instruments and international agreements, above all the Kyoto protocol, in which industrialized countries and countries whose economies are in transition pledged to reduce overall by 8% (5.2% in the first period of 2008-2012 compliance) the emission levels of the main greenhouse gases produced by anthropic activities, as compared to 1990 values. This objective has been revised with reference to the second implementation period (2013/2020) at 20%.

This agreement was based on the evidence of the framework drawn by the Intergovernmental panel on climate change (IPCC)[3] in his first report presented during the second Climate Conference in 1990, where it was shown that there was a very close link between climate change and human activities. The main causes of these influences, today as then, are represented by the use of fossil fuels with the related greenhouse gas emissions and the reduction of major carbon sinks in the world, mainly forests. Fossil fuels, in particular, are among the main causes of the increase in CO2, contributing 56.6% of all anthropogenic greenhouse gas (GHG) emissions

1.3 Energy consumption in agriculture: absolute and share value

In Italy, in 2017 direct energy consumption for the agricultural sector stands at around 2% of the overall energy consumed, which means about 31,354 GWh. This value is in line with the share of the total energy consumption by agriculture in Europe in 2017 (2,8%), with the highest share in Netherlands (8.2%) and Poland (5.6%), for an absolute value of 42,415 GWh and 45,569 GWh, respectively.[4] Actually the highest absolute value of agriculture energy consumption is reported in Turkey (51,678 GWh) and France (47,553 GWh).

Regarding non-european countries ,data on 2017 energy consumption can be found on IEA database. The original absolute value, from IEA are expressed in ktoe, but in order to be able to compare with European data, we need to use the same unit measurement and so a conversion has been done. (1ktoe= 11,63 GWh)

IEA reported all the data regarding the share of energy consumption by sector, from the begging of the century until 2017. In the last year reported (2017) in North America, activities related to agriculture and forestry consume around 369,764 GWh[5], which represent around 2,5 % of the total energy consumption, indeed dividing the region in Canada and United States, it is possible to observe that the Canadian share is 4% while it is 1% for the United States.

It is possible to find in IEA database, the same data regarding Central and South America. The amount of energy consumed by agriculture and forestry is 202.362 GWh plus around 3965 GWh for fishing (data on fishing are not available for North America). In Latin America there are a large amount of monocultures, such

[3] Independent intergovernmental group that proposes itself as a study group to inform public opinion and politicians about ongoing progress in research on the phenomenon of climate change, born in 1998 by the will of the Meteorological Organization World and UNEP (United Nations Environment Program

[4] Eurostat

[5] IEA data https://www.iea.org/data-and-statistics?country=WEONAM&fuel=Energy%20consumption&indicator=Total%20final%20consumption%20(TFC)%20by%20sector

as soy, palm, corn but also a lot of intensive farming, indeed focusing on countries like Brazil and Argentina we obverse a share of 5% and 6% and two absolute values of 121,650 GWh[6] and 53,498 GWh[7] in 2017.
Asian countries absolute values are completely different, while share values are quite similar to Western countries. Excluding China, the energy consumed in Asia is nearly 459,385 GWh and it represents around 3% of total energy consumption. The share of total energy consumption is about 2% in China, but the absolute value is obviously impressive, and amounting to 517,070 GWh - more than all the other Asian countries together. India, for example, one of the biggest producer of fruits, nuts and milk consumes 330,290 GWh, which means 5% of total consumption.

1.4 Energy efficiency in agriculture

Energy efficiency is defined in the recent Directive 2012/27/EU as "the relationship between a result in terms of performance, services, goods or energy and the input of energy".
First of all it is important to stress that the “Energy Union Strategy” [8] confirmed the energy efficiency target of 20% by 2020 first set out in Europe 2020. It adds that this is just the basis for moving forward to a reduction of at least 27% by 2030, having in mind a figure of 30 %. Since then Member States have made improved efforts to implement EU energy efficiency legislation and have set more ambitious energy efficiency targets. But when it comes to what it is actually the energy efficiency or how it can be measured, there are different ways. The best indicator to express energy efficiency are two, the ratio of energy use per cultivation area (GJ·ha-1) and energy use per unit of product (GJ t-1).
Generally, to evaluate the results achieved by a country in terms of energy efficiency, it is necessary to evaluate the increase or decrease in overall energy consumption from one year to the next. Unfortunately, data are not available for all the countries around the world and often the ones available just show a partial picture of the realty.
The energy efficiency of a production system can be affected by several factors: location, climate, level of technology, but in particular by the kind of resources and the final products.
As already mentioned, energy use includes both direct energy inputs and indirect energy inputs, and although it is not easy to perfectly identify them, we will try to analyse in detail both groups.
All these inputs are defined on an hectare basis (arable, greenhouse, and perennial crops), on the basis of a kg of meat (pigs, poultry) or on the basis of the quantity of milk in tons produced per livestock unit per year (dairy). Together with the total area in hectares per country or the total number of livestock units per country,

[6] https://www.iea.org/data-and statistics?country=BRAZIL&fuel=Energy%20consumption&indicator=Total%20final%20consumption%20(TFC)%20by%20sector
[7] https://www.iea.org/data-and-statistics?country=ARGENTINA&fuel=Energy%20consumption&indicator=Total%20final%20consumption%20(TFC)%20by%20sector
[8] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE, THE COMMITTEE OF THE REGIONS AND THE EUROPEAN INVESTMENT BANK A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy /* COM/2015/080 final */

this data can be used to present an estimate of the total energy consumption of the involved agricultural processes on a national or international level.

As mentioned before, modern agriculture consumes large quantities of energy, in particular fossil fuel for the production of both vegetable and animal food products. Comparing the ratio between the unit of energy input and the unit of energy obtained in the agricultural process, an average of 1 to 10 is reached. In practice, focusing on fossil fuel, it is like saying that the production of one kilocalorie of food requires 10 kilocalories of fuel in addition to the energy necessary for extraction, refining and transportation, while industrial production of 1 kg of beef raised on cereals requires 9 litres of fuel.[9]

If then the discussion is about the food supply chain the energy uses would be even more: not just energy consumption by agriculture, fisheries, animal feed production and meat and dairy industry and what it is used during the production as tractors, machinery, equipment, inorganic fertilizers and agri-chemicals, the building of infrastructure and post-harvest operations. Considering the energy demand even outside a farm would be very difficult. Food storage and processing, transport, distribution, retail, preparation and consumption are all activities that consume energy. Exactly for this reason the energy consumed from the agricultural system, that is going to be considered in the following chapter is the one used before the product live the farms.

Anyway, even restricting the analysis to the only "behind the gate energy use", there is the possibility to separate the totality of energy consumption in direct and indirect energy use.

Dividing in four categories the energy input inside a farm, there are: [10]

- Direct Energy Inputs – energy of fossils used in the agricultural process as the sum of consumed electricity, and solid, liquid and gaseous fuels ($GJ \cdot ha^{-1}$, GJ/LU);
- Indirect Energy Inputs – energy accumulated in the means of production consumed by the agricultural process ($GJ \cdot ha^{-1}$, GJ/LU);
- Total Energy Inputs – the sum of direct and indirect energy inputs for a unit of the agricultural production ($GJ \cdot ha^{-1}$, GJ/LU);
- Specific Input of Primary Energy– total primary energy use in the agricultural process per cultivation area (GJ·ha-1) and per ton of agricultural product (GJ t-1).

Energy is crucial for economic growth and a critical component in the ability of the agro-food sector to improve productivity, competitiveness and sustainability. Improving the efficiency of energy use – using less energy to provide the same level of output and service – is an important tool that policy makers can use to ensure a number of positive outcomes that can deliver several government priorities, from economic growth to greenhouse gas reduction to energy security and food security. To set the scene this Chapter discusses the

[9] I. Veermäe, J. Frorip, E. Kokin, J. Praks, V. Poikalainen, A. Ruus, L.Lepasalu Energy consumption in animal production
Estonian University of Life Sciences

[10] State of the Art on Energy Efficiency in Agriculture: Country data on energy consumption in different agro production sectors in the European countries https://edepot.wur.nl/278550

increasing demands for energy throughout the food chain. The synergy and overlapping policy goals between energy efficiency, food waste and GHG emissions mitigation agendas are noted, and conceptual and methodological issues involved in measuring energy use and efficiency are highlighted.

Increasing agricultural input use efficiency would have environmental benefits without necessitating dietary change. However, because the marginal environmental benefits of increasing agricultural input efficiency is larger in less efficient systems, special emphasis should be placed on improving efficiency in the least efficient agricultural systems, as livestock production and on improving people awareness on the impact of their food choice on our planet.

1.5 Direct energy inputs

Energy is consumed directly with the use of machinery, pumping water and the heating or cooling of livestock stables cultivating and harvesting crops, heating protected crops, drying and storage and heating greenhouses. Slightly over the half of the on-farm energy is consumed in OECD countries. Indeed fuel, lubricants and electrical energy are considered direct energy inputs depending on how they are consumed.

Electricity: (kWh per unit converted into MJ per unit)

Electricity is used in a variety of ways in on-farm agricultural production generally for pumping water for irrigation, grain drying, and storage ventilation but its use varies depending on the kind of food industry sector.

- Cereal crops: irrigation, electrically driven fans and/or heaters and then conditioning and storage.
- Potatoes, legumes: conditioning, ventilation in storage rooms.
- Dairy and livestock producers use electricity in vacuum pumping and cooling milk, feeding equipment, ventilation, water heating, animal-house heating and cooling, and lighting.
- Pig and broilers production: automatic feeding with complex rations preparation and automated rationing, controlled environment in buildings, farm management.
- Greenhouse producers use electricity for irrigation, heating, air circulation and ventilation fans, and supplemental lighting in particular in these cases all process control equipment.

Refined petroleum fuels (L per unit converted into MJ per unit)

- Diesel fuels and fuel oils, or distillates, are the dominant fuels consumed in both crop and livestock operations, in the field operations, heating and power generation, in farm machinery.
- Grain, root and perennial crops: field operation (tractors, self-propelled machines), heating (drying, crop stores), transportation (organic fertilizers and harvested crop), irrigation.
- Greenhouses: heating and power generation.
- Dairy, livestock, pig and poultry farm: transportation of feed, power generation.

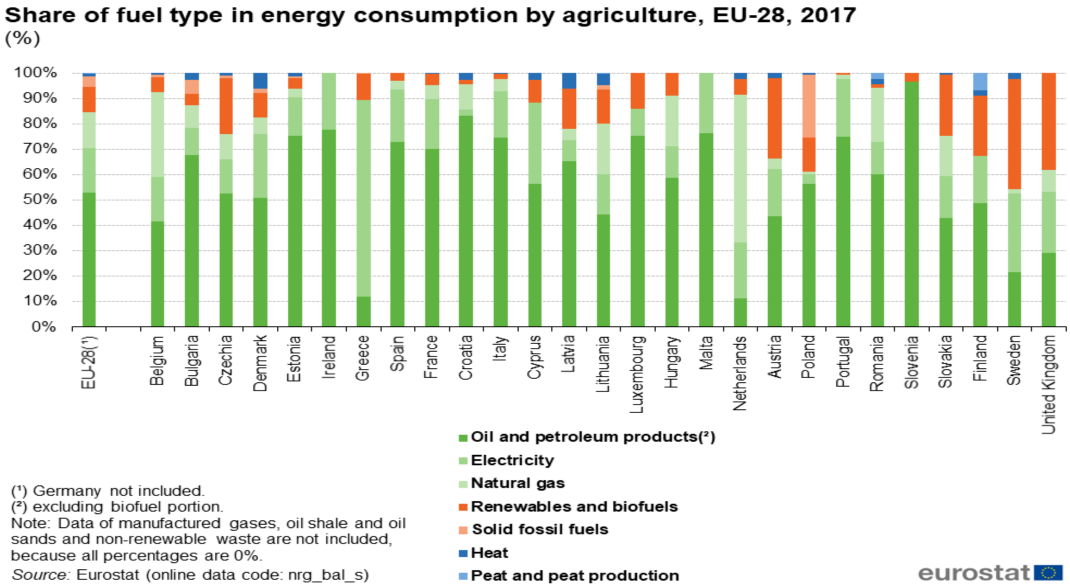
Natural Gas and Liquefied Petroleum (LP) Gas

Direct use of Natural Gas is relatively low compared to the amount of indirect natural gas used in ammonia-based nitrogen fertilizer production, that we are gone to analyse in the next section on the indirect energy inputs.

The only direct use of natural gas is to power facilities like crop dryers and irrigation equipment in greenhouse heating and grain drying, as well as for operating trucks, tractors, machinery, and irrigation water pumps[11] . According to the an USDA's report: " Producers of specialty crops, corn, poultry, and cotton had the largest average expenditures per farm for natural gas at $3,105, $2,906, $2,866, and $2,575, respectively. These producers benefit from the decline in natural gas prices due to the production of natural gas through horizontal drilling and hydraulic fracturing." [12]

Liquefied petroleum (LP) gas, which includes propane and butane, is a by-product of natural gas processing and crude oil refining[13]. Propane is used for a variety of farm operations, such as for powering irrigation systems, high-temperature dryers, building and water heating, flame

Figure 1 shows the 2017 energy mix for agriculture sector in the EU-28 in relative terms[14].



Source: Eurostat https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Figure3_Share_of_fuel_type_in_energy_consumption_by_agriculture_1997,2007,2017_EU-28.png

[11] U.S. Department of Energy, Energy Efficiency & Renewable Energy, Smith Dairy Deploys Natural Gas Vehicles and Fueling Infrastructure in the Midwest. Case Studies. Washington, DC.

[12] USDA/Trends in U.S. Agriculture's Consumption and Production of Energy: Renewable Power, Shale Energy, and Cellulosic Biomass, EIB-159 Economic Research Service

[13]U.S. Department of Energy, Energy Efficiency & Renewable Energy. Propane Fuel Basics. Alternative Fuels Data Center, Fuels & Vehicles: Propane Washington, DC.

[14] Eurostat https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Figure3_Share_of_fuel_type_in_energy_consumption_by_agriculture_1997,2007,2017_EU-28.png

1.6 Indirect Energy Inputs

This includes energy carriers used for manufacturing of production means, including fertilizers, pesticides, farm machinery and farm buildings as well as seeding material and feed. The indirect energy associated with the construction of farm buildings and farm machinery has been excluded from different studies and report but it should not be neglected.

Fertilizers and pesticides are one of the most energy intensive products used by agriculture. In the next chapter, it will be analysed how moving to an organic system and so avoid using these substances can reduce the energy use in a farm and so increase the energy efficiency.

Of course, inorganic fertilizer's use has contributed significantly to increasing crop yield in recent decades. and according to the demand of food, also the demand for inorganic fertilizers will probably continue to expand, mainly in low-GDP countries. In 2000, energy embedded in the production of inorganic fertilizer was around 7 EJ globally[15][16]. Nitrogen fertilizer production alone accounts for about half of the fossil fuels used in primary production and the amounts of nitrous oxide can be emitted during the production of nitrate is very high.

Not only indirect energy use but also the energy used in the production of fodder for livestock are not included, when studying energy used in farming.

The amount of energy needed to produce the feed and the raw materials (fresh and concentrated feed, feed additives) is high due to the fact that includes energy consumed by crops cultivation but also drying, storage and transportation from the monoculture to the intensive farming.

Other specific indirect energy inputs needed in the production process like straw for bedding, energy associated with water availability, building use, herd replacement, hatchery, milking etc, depending on the food.

1.7 A concise energy framework

The idea to have a unique method to calculate direct and indirect energy use is an interesting idea.

It is not easy to find out a unique method, considering that the only energy source that has a clear and consistent method for calculating demand, it is fossil fuels. In contrast, electricity, renewable energies, waste, nuclear energy, or imported electricity are not calculated according to a single consistent methodology. Instead, several approaches are available and used in practice.

In the future, a widely accepted method could be developed to calculate energy use in agriculture in a variety of situations, for example different farm sizes, farming intensities, husbandry practices and natural site potentials could be part of the model.

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[15]Smil V, 2008. Energy in nature and society- general energetic of complex systems, MIT Press, Cambridge, Massachusetts. 512 pages

[16] Giampietro M, 2002. Energy use in agriculture, Encyclopedia of Life Sciences, MacMillan Publishers, Nature Publishing Group, 15 pages. www.els.net

Nowadays the lack of data is a real problem, especially regarding certain areas of the world, or sectors. Colleting data or studies from, for example, Latin America or Southeast Asia is challenging, as it is difficult to collect data about commercial fishing or acquaculture. Therefore, an important task is to convince farmers, farmers' organisations or any food production industry owner about the benefits of providing data on farming activities for LCA purposes.

The enrichment of our diet has led to an increase in the complexity of farming: the number of products available are huge and so focussing on arable farming is not sufficient for final applications.

In addition to that animal products' consumption is increasing, especially in the developing countries and so the exchanges between arable farming and animal husbandry (e.g. animal feed, manure, straw) should be much more investigated. Indeed, in order to clearly understand the energy efficiency of a production some unsolved questions should be answered, e.g. how to quantify and to allocate substance flows and the energy consumption connected with organic fertilisers spread on arable land. Unfortunately, appropriate production schedules of different farm types still not yet provided reliable and representative data on agricultural energy use, direct as well as indirect.

However, the development of a clear and concise framework for energy budgeting in agriculture, able to meet the specific demands of agriculture, is actually a challenge within the sector for the next years but it should be at same time transparent and suitable for planning, for comparing and for marketing the agricultural production of food.

Finally, a common solution, used in particular in studies focus on environment and GHG, it's the Life-cycle assessment or life cycle assessment (LCA, also known as life-cycle analysis).

It is a methodology for assessing environmental impacts associated with all the stages of the life-cycle of a commercial product, process, or service. Assessments of the environmental impacts of what we are consuming are essential in evaluating their sustainability, and they are especially important in a material-, water- and energy-constrained world where energy affordability and environmental sustainability have to be balanced. " Life Cycle Assessment (LCA) can give a holistic picture of the total environmental impacts and costs to the society so that a comprehensive and balanced comparison can be obtained. LCA provides a framework for quantifying the potential environmental impacts of material and energy inputs and outputs of a process or product from 'cradle to grave' "[17]

[17] Vasilis Fthenakis , Marco Raugei "Life-Cycle Assessment of Energy Systems in Current and Evolving Grids" Prof.

2. Organic agriculture and its role in the food production system

Starting from the recognition of the role of natural capital in sustainable development due to its non-substitutability and irreversibility, beyond certain thresholds, of degradation processes, the idea of a green economy has made its way in recent years. Organic agriculture plays a big role in reducing environmental risks and ecological scarcity, in improving sustainable development. Furthermore, the green economy starts from the assumption that in order to achieve sustainability it is necessary to make the economy work properly, taking into account the value of all the resources used.

The challenge that agriculture is called to respond in terms of sustainable development and the green economy, is the satisfaction of a growing food demand from a growing world population, increasing productivity and efficiency, while reducing negative environmental externalities.

Speaking of sustainable agriculture, therefore, means referring to a system of objectives and a set of production techniques, organic farming is the most common one. Due to this it is important to analyze different type of food, understanding the real energy efficiency and the environmental impact of their production.

2.1 An overview on organic and conventional agriculture

Organic agriculture is a type of agriculture that exploits the natural fertility of the soil by promoting it with limited interventions, wants to promote the biodiversity of domestic species (both vegetable and animal), excludes the use of synthetic products and genetically modified organisms (GMOs).

Organic agriculture then indicates a type of agriculture based on a variety of practices and methods that take advantage of the natural fertility of the soil by promoting ecosystem management and conservation, limited interventions and product diversity.

The objective of organic agriculture is to produce sustainable and healthy food, respecting the natural biological and ecological processes. Indeed, organic agriculture essentially means using a cultivation technique and a way of producing food that respects natural life cycles. The anthropogenic impact is minimized. In addition to restricting or banning the use of chemical pesticides, synthetic fertilizers, antibiotics and genetically modified organisms (GMOs), crops are rotated so that on-site resources are used efficiently, plant and animal species resistant to diseases and adapted to the environment are used and cattle are raised in the open air and fed with organic fodder.

Organic agriculture emphasizes the use of management practices in preference to the use of off-farm inputs and it is generally closed cycle. For example, cattle provide manure to fertilize the soil which, in turn, produces food for humans and fodder for animals. The organic farm maintains the relationship with the surrounding environment, providing for the presence of uncultivated spaces to ensure the survival of insects, birds and small mammals, which it is also considered as a mechanism for controlling pests harmful to crops.

Organic agriculture can effectively combine productivity and environmental protection, as well as providing foods free of toxic residues and richer in flavour and nutrients. In the following paragraph, studies from different countries and focused on a variety of food provide evidence in order to support the statement written above.

Ultimately, an organic agricultural system is therefore designed to rely on renewable energy sourced as much as possible from on-farm or natural local systems. Although organic agriculture adheres to certifiable standards, farmers have the flexibility to enhance the ecological and sustainable practices of their farms beyond what the standards require.

In turn, "conventional agriculture" refers to any non-organic farming system and encompasses a wide range of agricultural methods including high external input agriculture, integrated production management, traditional pastoral systems, precision agriculture, and conservation agriculture, among others.

Conventional agriculture is a generally intensive cultivation method that involves the use of chemicals for fertilizing and defending plants. Residues (which must in any case be within the limits of the law) in the products and environmental problems linked to some practices as monoculture, continuous use of the same active ingredient, massive use of chemical pesticides, synthetic fertilizers, antibiotics and genetically modified organisms (GMOs).

Organic and non-organic food systems maintain separate supply and transport chains in most industrial countries and, increasingly, in developing countries.

The problems regarding energy efficiency, already anticipated in the previous chapter, and greenhouse gas emissions have become important talking points globally. Since organic agriculture has the potential to come with lower energy consumption and environmental impact than conventional agriculture, it has been experimented for several decades ad nowdays it seems to work as an alternative production system, because its adoption seems to give good results in Europe and the Mediterranean area.

Organic agriculture makes the reduction of the impact of agricultural activities a key point on his agenda.

From the data collected until today all over the world, the indications are goo[18] and so it seems useful to explore the potential offered by organic agriculture as a production system that makes long-term sustainability one of its major goals.

It would be crucial to extend the analysis of energy consumption beyond the harvest of the crop or animal product to examine distribution networks and the energy consumption therein. Cold supply chains, storage for seasonal crops, and shipment of agricultural products, all demand energy, and so packaging, transportation, storage and distribution, should be included in the energy footprint of food systems. Unfortunately, indirect energy demand is often neglected and so there are little comprehensive research comparing conventional and organic systems on indirect energy demand.

[18] J.W. Hoeppner, M.H. Entz, B.G. McConkey, R.P. Zentner, and C.N. Nagy
Energy use and efficiency in two Canadian organic and conventional crop production systems
Renewable Agriculture and Food Systems: 21(1); 60–67 DOI: 10.1079/RAF2005118

2.2 Synthetic fertilizers and pesticides: production and impact on energy demand

a. Nitrogen fertilizer

The main differences found while examining energy use in both agricultural systems are in the production process.

First of all, both growing crops and raising livestock use a large amount of energy and so in both cases we observe a big gap between the energy used in conventional and organic agriculture, so different production methods drastically alter the amount of energy needed.

Nitrogen fertilizer is the largest energy sink in non-organic production, indeed it is produced from raw materials and the conversion process into usable fertilizer is energy-intensive. In particular, the production of one ton of nitrogen fertilizer uses one to one and a half times of equivalent petrol.

Total energy (direct and indirect) demanded during the cultivation of cereals is high due to the production and constant application of synthetic nitrogen fertilizers. “Compared to these conventional production systems, the energy consumption in organic agriculture is therefore about half of the energy consumption in conventional agriculture” write Claude Aubert, agricultural engineer who contributed to the emergence of organic farming in France.

According to the Soil Association[19], the largest portion of energy used in conventional agriculture - on average 37 percent of total energy - is made up of synthetic pesticides and mineral fertilizers, especially nitrogen, and to a lesser extent, phosphorus and potassium. Overall, from 25 to 68 percent of total energy consumption in conventional agriculture comes from the use of fertilizers, the other major factors are the type of crop and growing conditions[20].

The main advantage of organic agriculture comes from the replacement of synthetic fertilizers with manure, legumes and other natural sources of nitrogen. Legumes fix atmospheric nitrogen naturally in their root nodules through the activity of microorganisms, enriching the soil. Water and other plant nutrients are provided through the active soil biology of organic system, in addition organic farms, animals produce part or all of the fertilizer necessary for agricultural production, energy costs are significantly reduced.

Due to its dependence on natural fertilizers, organic agriculture often performs relatively better in terms of energy efficiency (measured as the ratio of energy input per unit of agricultural production) despite lower yields. In most cases, the increase in yield for conventional production compared to organic production did not compensate for the energy used in the fertilizer to produce this gain[21]

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[19] Jodi Ziesemer , Energy use in organic food systems , Natural Resources Management and Environment Department Food and Agriculture Organization of the United Nations Rome, August 2007

[20] Refsgaard, K., Halberg, N., Kristensen, E. 1998. “Energy Utilization in Crop and Dairy Production in Organic and Conventional Livestock Production Systems.” Agriculture Systems 57(4): 599-630.

[21] Stolze, M., Piorr, A., Häring, A., Dabbert, S. 2000. “The Environmental Impacts of Organic Farming in Europe.” Organic Farming in Europe: Economics and Policy, Volume 6.
University of Hohenheim Department of Farm Economics, Stuttgart.

b. Pesticides and chemicals

Conventional agriculture uses a variety of chemicals in addition to nitrogen fertilizers such as pesticides, herbicides, fungicides and insecticides. Like all chemicals, their energy load mainly derives from their production and transportation, in addition to that due to the diversity of synthetic chemicals and the annual variation in their application, an incredible amount of energy is generally used[22].Although the energy consumption of fertilizers generally is the highest one, also chemicals in conventional systems contribute significantly to the energy inefficiency of many conventional operations.

2.3 Organic agriculture studies reviews

In a recent meta-analysis of a wide range of global organic vs. conventional comparisons, [23] WHO? Found that "lower energy consumption for organic farming both for unit of land (GJ ha−1), from 10% up to 70%, and per yield (GJ/t), from 15% to 45%. The main reasons for higher efficiency in the case of organic farming are:

Lack of input of synthetic N-fertilizers (which require a high energy consumption for production and transport and can account for more than 50% of the total energy input), low input of other mineral fertilizers (e.g., Posphorous and Potassium) , lower use of highly energy-consumptive foodstuffs (concentrates), and the ban on synthetic pesticides and herbicides".

In the study all the analyses show lower energy consumption, in organic production per unit of land, even if a few show higher energy consumption per unit of product in the organic systems, particularly for potatoes and apples. For these crops, knowledge of organic production has not been as well developed as field crops and dairying.

a. German meta-analyses on cropping system

A meta-analysis conducted in 81 commercial farms in Germany shows the great differences between organic and conventional farms. "The mean energy input in organic farms reaches 5.6 GJ ha-1 a-1. Due to differences in cropping structure und intensity, some farms exceed this level by up to 100%. In the conventional farms, mineral fertilizer and pesticide application cause markedly higher energy inputs (12.6 GJ ha-1 a-1). Yields and energy fixation in the eco-farms (28 to 192 GJ ha-1 a-1) reveal a wider variation than the corresponding values of the conventional farms (51 to 192 GJ ha-1 a-1). Energy fixation depends on the cropping system, site specific yield potentials and the use of the produced biomass. High energy fixation is achieved with a high harvest index, for example when the by-products and also catch crops are used. Organic farming consumes clearly less energy per unit area and reaches higher efficiency levels per unit product (output/input ratio,)" [24]

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[22] Saunders, C., Barber, A., Taylor, G. 2006. "Food Miles—Comparative Energy/Emissions Performance of New Zealand's Agriculture Industry." Research Report 285, Agribusiness & Economics Research Unit, Lincoln University, Lincoln.

[23] Gomiero, T.; Paoletti, M.; Pimentel, D. Energy and environmental issues in organic and conventional agriculture. Crit. Rev. Plant Sci. 2008, 27, 239–254.

[24] Küstermann, Hülsbergen, "Emission of Climate-Relevant Gases in Organic and Conventional Cropping Systems" .

b. Denmark: organic and conventional crop production

Another study regarding fossil energy use in agriculture comparing organic and conventional farming has been conducted in Denmark.

In this study, the crop production energy model is divided into: direct energy use of diesel, direct energy use other than diesel and indirect energy use. Thus, the total energy use (EU) for growing a specific crop can be expressed by

EU(crop)= EU(direct) + EU(indirect)= (EU(diesel) + EU(other))+ EU(indirect).

The EU(crop) was calculated for the following crop types: spring grain cereals, winter grain cereals, spring whole crop cereals, winter cereals, fodder beets, grass/clover and straw.

The energy efficiency (EE) was calculated as the yield (SFU ha−1) divided by the EU (MJ ha−1), it was generally higher in the organic system than in the conventional system (Fig. 1), but the yields were also lower. Consequently, conventional crop production had the highest net energy production, whereas organic crop production had the highest EE. A closer look at 1 showed that the highest EEs were found for the extensively grown crops (1.0–1.4 SFU MJ−1 for permanent grassland, and 1.1 SFU MJ−1 for organically grown grass/clover). On the contrary, the more intensively grown, rotational crops had a low EE (0.4–0.6 SFU MJ−1 for row crops, and 0.4–0.5 SFU MJ−1 for cereals).[25]

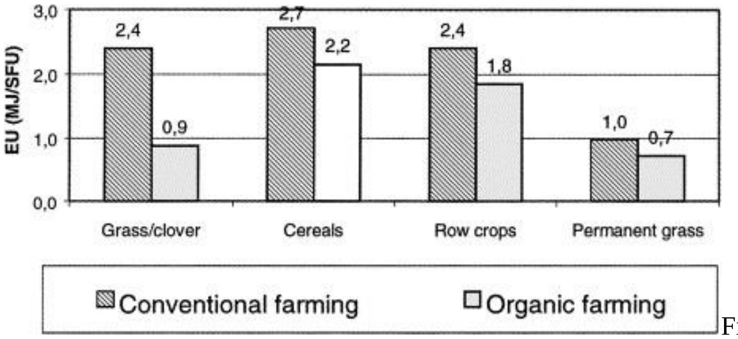

Fig 1

Source: A model for fossil energy use in Danish agriculture used to compare organic and conventional farming. Tommy Dalgaarda, Niels Halberga, John R.Porterb

c. North America

A very comprehensive comparative 12-year study[26] conducted in Canada investigated effects of two crop rotations and two crop production systems, using both organic versus conventional management, on energy use, energy output and energy-use efficiency. The grain-based rotation included wheat-pea-wheat-flax and wheat-alfalfa-alfalfa-flax.

Energy use was 50% lower with organic than with conventional management, and approximately 40% lower with integrated than with the grain-based rotation. Energy use across all treatments averaged 3420 MJ ha-1 yr-1. e. The integrated grain-forage rotation used 27% less energy than the grain-based rotation in this study.

[25] A model for fossil energy use in Danish agriculture used to compare organic and conventional farming. TommyDalgaarda, NielsHalberga, John R.Porterb

[26] See note 18.

Less energy input in the integrated rotation was attributed mostly to less N fertilizer. lax. Therefore, average rotational energy input attributed to Nitrogen fertilizer was 10,705 MJ ha-1 for the grain rotation and 6491 MJ ha-1 for the grain-forage rotation. Less pesticide (301 MJha-1 yr-1) and seed (354 Mjha-1 yr-1) use in the integrated rotation contributed to lower energy input.

The difference in energy input between production systems considering organic versus conventional was greater than the difference between crop-rotation types. Comparing the conventional and organic systems within rotations, the conventional system in the integrated rotation consumed 2.2 times the non-renewable energy as the organic system, while the conventional system in the grain-based rotation consumed 2.8 times the energy as the organic system. Obviously, fertilizer contributed most to the difference in energy input between conventional and organic systems, accounting for 51% and 43% of the total energy input of the conventional systems.

Moreover, also energy output was affected by rotation in more than half of the years and by organic or conventional management. Energy output was approximately 40% higher in conventional than in organic systems, in particular in the common wheat and flax crops. Among legume crops the energy output differences were fewer.

In the end, energy efficiency is always one of the best indicator in these studies. In particular only considering rotation effects, the integrated system seems to have an energy efficiency three times higher than the grain based. The problem is that alfa-alfa biomass is typically consumed by cattle, and animals are really bad convertors of energy, so "with a ratio 9:1 for energy conversion of forage to live animal gain" [27]there is no significant difference.

Indeed, comparing organic and conventional system, the differences are relevant. An increase of 175% in the integrated rotation system and of 152% in the grain-based rotation system.

Averaged across rotation, energy efficiency was 40% higher for the organic compared with the conventional system mainly due to lower energy input.

In conclusion, although organic systems are not able to perform the same energy output of conventional systems, so they are less productive, the fewer energy input are so much lower that in the end the energy efficiency of an organic system is higher than conventional systems.

d. Organic agriculture: summary

There are a lot of studies and data on the energy efficiency in organic agriculture.

From Central and North Europe to the Mediterranean area has been found that the energy costs in conventional production far exceeded the organic systems, because indirect energy costs in the production of chemical sprays and fertilizers reduce the energy efficiency. An example are the Greek olive groves: conventional forests compared to organic forests that use biological pest control are one third less efficient.[28]

[27] See note 18

[28] Dessane, D. 2003. "Energy Efficiency and Life Cycle Analysis of Organic and Conventional Olive Groves in the Messara Valley, Crete, Greece." Ecological Agriculture Master of Science Thesis, Wageningen University.

Another example is a research project conducted by the British Ministry of Agriculture, Fisheries and Food, which found that the energy intake per hectare in organic farming is 40 % of the energy intake in conventional agriculture for grain production, 54 percent for potatoes, 50 percent for carrots, 65 percent for onions, 27 percent for broccoli [29]

In conclusion nowadays organic farming covered 13.4 million hectares of agricultural land in the EU-28 in 2018. This corresponds to 7.5% of the total utilised agricultural area of the EU-28. The countries with the highest shares of organic land were Austria, Estonia and Sweden. In each of these countries the organic share was above 20% of the total agricultural land.

From 2012 to 2018, the share of total organic area in the total utilised agricultural area (UAA) within the EU rose from 5.6% to 7.5%.

These are all good signs, indeed the energy efficiency of most cropping systems can be enhanced through the adoption of organic management, and in addition to that, organic methods of food production can contribute substantially to feeding the current and future human population on the current agricultural land base, while maintaining soil fertility and high water quality.

According to an American research paper[30], there are a systematic underestimation of actual output on many organic farms, the advantages could be even more, and also there is scope for increased production on organic farms, since most agricultural research of the past 50 years has focused on conventional methods. Arguably, comparable efforts focused on organic practices would lead to further improvements.

2.4 Organic farming

When considering the energy consumption by organic and conventional systems, agriculture is not the only sector of food production that should be considered.

First of all, agricultural production in particular conventional production has an even greater extent since livestock is fed with cereals composed mainly of wheat, corn and soybeans.

As it will be discussed in Chapter 5, animals are very poor energy convertors, and their “diet” considerably reduces the energy efficiency of farming.

Generally, the major difference between farms follow conventional systems and organic ones is that in the first case concentrated feeds are purchased from external producers and therefore the energy used for transport must be added, while according to organic systems often the animals are free to feed or in any case the forage is produced directly on the farm.

This means that organic farms try to maintain a closed production and it has been observed that beef cattle fed with a mixture of cereals and grass fodder for life use twice the energy per kilocalorie of proteins produced

[29] MAFF. 2000. “Energy use in organic farming systems.” Report number OF0182. Retrieved on July 12, 2007 from http://www2.defra.gov.uk/research/project_data/More.asp?I=OF0182.

30 Badgley, Catherine, et al. “Organic Agriculture and the Global Food Supply.” Renewable Agriculture and Food Systems, vol. 22, no. 2, 2007, pp. 86–108. JSTOR, www.jstor.org/stable/44491441.

compared to grass-feed beef[31]. This happen for two reasons. First, due to the different conversion capacities of an animal in an intensive breeding rather than a grazing animal. Second, due to the impact of the energy used in the fodder production and distribution.

a. Beef and dairy

During these years a lot of assessments of energy use within beef and dairy production has been written.
Most of the studies take in consideration European or American countries, indeed data and studies regarding Asian countries are difficult to find.
In a German study[32], which compares intensive, extensive and organic grassland farming, using a life cycle assessment, finds that intensive farms are the worse in terms of fossil energy consumed; the main reason are grass drying industrial plants and Nitrogen fertilizer.
Instead, organic farms consumes only one-third of the intensive farms amount of chemicals.
Conventional farms in Germany use approximately 19.4 GJ ha−1 and organic farms around 6.8 GJ ha−1 of energy, while for mixed farming in the Hamburg region conventional farms uses 16.3 GJ ha−1 and organic farms 6.8 GJ ha−1 of energy.
Another interesting study is based on high quality Data collected from two relatively large dairy farms in the west of Sweden (e.g. all fodder is weighed), and also the farms are specialised milk producers, which means there are no other co-products except meat from the farms.
Considering the functional unit, 1000kg energy corrected milk ready to leave the farm, the results saw that there is a big difference in energy use based in the feeding strategy and so conventional or organic production. In particular, the use of primary *energy* was 3550 MJ per FU in the conventional system and 2511 MJ per FU in the organic system.
Another Danish investigation[33] shows that the energy consumption in organic dairy farms is less than in conventional ones: 2160 MJ/1000 kg milk in organic production and 3340 MJ/1000 kg milk in conventional production.
A Finnish study also found that the energy consumed by dairy cows was 4.4 gigajoules per 1000 litres of milk produced in biological systems and 6.4 gigajoules in conventional production[34]

b. Hogs

Pigs, even more than other animals, were farmed on many small mixed farms. Currently, most pigs are living on specialised farms, indeed intensive farming produce over 80% of pig meat. These pigs are fed with

[31] Pimentel, D. 2006. "Impacts of Organic Farming on the Efficiency of Energy Use in Agriculture." The Organic Center, Cornell University.
[32] Guido Haas, Frank Wetterich, Ulrich Köpke "Comparing intensive, extensive and organic grassland farming in southern Germany by process life cycle assessment" Institute of Organic Agriculture, University of Bonn, Katzenburgweg 3, D-53115 Bonn, Germany
[33] See not 20
[34] Grönroos, J., Seppäiä, J., Voutilainen, P., Seuri, P., Kolkkaiainen, K. 2006. "Energy use in conventional and organic milk and rye bread production in Finland." Agriculture, Ecosystems & Environment 117(2-3): 599-630.

concentrated feed "imported" from outside the farm and kept on concrete slatted floors, producing liquid manure. The move from a traditional to an intensive industrial production system has caused a huge increase in production and animal densities, which, in turn, contributed to an increase in pollution of water, soil and air.

In particular, organic hog production may be the least energy efficient of the major animal systems. A Swedish study[35] shows that conventional pork production uses less resources than other alternative production systems . Similar conclusions are reached by other studies like a Belgian research that compare organic, free-range and conventional system. GHG emission, as expected, were the lowest for the organic system, around 87% of the conventional or a British study that found lower emission but also lower energy use, around 13 % fewer total MJ.

In conclusion, comparing conventional and organic hog production it has been found that total footprint per 1000 kg of pig[36] in conventional systems doubles the organic systems one.

c. Poultry

An Italian study[37] compares conventional and organic poultry production in terms of energy analysis. The indicators are in favour of the organic ones, in particular the study reports : "higher efficiency in transforming the available inputs in final product; higher level of renewable inputs; higher level of local inputs; lower density of energy and matter flows"

In fact, the main differences are in the use of fertilizers to cultivate crop for the poultry diet instead of using Nitrogen fertilizer, saving 60% of energy and then the production cycle. Although the annual production is lower in terms of poultry weight in organic than in conventional (-206%), the advantages of an organic system are the sustainability, with a higher level of renewable inputs and an higher efficiency in general, transforming the inputs into the product ready to leave the farm.

2.5 Protected Agriculture: greenhouse crops

Greenhouse crops represent an important part of the agricultural sector worldwide, particularly in the Mediterranean area, and their diffusion is constantly growing. This agricultural technique, in fact, allows high efficiency in the use of resources and provides quality products all year round. Greenhouses are complex environments in which certain micro climatic conditions (temperature and humidity) must be respected to ensure correct production. Furthermore, consumers require different crops in all months of the year, even

[35] Kumm, K. "Sustainability of organic meat production under Swedish conditions." Agr. Ecosyst. Environ. 2002, 88, 95 101.

[36] Van der Werf, H.M.G.; Tzilivakis, J.; Lewis, K.; Basset-Mens, C. Environmental impacts of farm scenarios according to five assessment methods. Agr. Ecosyst. Environ. 2007, 118, 327-338.

[37] Cesare Castellinia, Simone Bastianoni, ClaudioGranai, Alessandro DalBosco, MauroBrunetti
Sustainability of poultry production using the emergy approach: Comparison of conventional and organic rearing systems.
Agriculture, Ecosystems & Environment Volume 114, Issues 2–4, June 2006, Pages 343-350

when some are completely out of season, this means that protected agriculture must face ever more challenges. In addition to that, the standards of quality expected are high, people buy more organic products than years ago but on the other hand, consumers ask for affordable products. As a result, farmers are focused on the containment of production costs, and of course energy consumption, heavily impact on the operating cost.

The use by farms of production models that guarantee the widest diversification of plant products and maximum efficiency, is based on renewable energies, are therefore essential to respond effectively to global competition.

In general, the objectives of the protected agriculture sector, as part of the agro-food chain, consist in fostering energy efficiency and environmental sustainability of technologies as a key element of competitiveness.

According to the most recent available estimates on protected agriculture glass and plastic greenhouses and tunnels cover 900,000 hectares of the world surface. The distribution is almost equal between Asia, especially China, Japan and Korea, which contribute with over 500,000 hectares of covered surface and the Mediterranean basin, where the spread of protected agriculture reaches 400,000 hectares. Italy, where there are between 35,000 and 40,000 hectares of greenhouses considering also non-permanent ones, is the protagonist of this sector together with Spain, Holland, France, Greece and Turkey and Egypt. Indeed, in Italy from an economic point of view, protected agriculture invoices over 3 billion euros in terms of gross production, which it is not a negligible amount considering that 31,9 billion euros is the value added of agriculture in Italy, according to ISTAT data.

The conformation of greenhouses sees the use of inexpensive flexible plastic films prevailing everywhere (70% of cases), mainly consisting of low density polyethylene. The polyethylene film, especially if in single thickness, boasts good transparency and mechanical resistance, but has a high thermal transmittance value ($U = 8.0\ W / m^2K$), for which it disperses heat. Rigid materials are also used in Mediterranean Europe, especially polymethylmethacrylate, PVC, polycarbonate and fiberglass materials with polyester. Glass is mainly used in Northern Europe. With regard to the heating systems of greenhouses, in many cases they are still diesel boilers.

a. Energy consumption of greenhouses

The energy requirement of greenhouse crops is mainly determined by the heating generated by boilers, with the diffusion of heat that occurs inside the ground or in the air. For this reason, protected agriculture in countries with colder climates, such as throughout Northern Europe, is characterized by significantly higher average consumption. The energy consumption in the Mediterranean countries is not less than 5-7 kg of oil equivalent per year per square meter of covered area, while for the countries of the Central-Northern Europe (Poland, Holland, Germany) consumption varies even between 40 and 80 kg per year per square meter. Similar values of energy consumption, however, are also found in some areas of greenhouse nursery production, especially in Liguria and Veneto. On average, in Italy, the incidence of direct energy consumption for heating greenhouses affects up to 30-40% (in relation to the volatility of the cost of energy) on total production costs. As far as the warmer months are concerned, the seasonal adjustment of greenhouse production and the demand for quality fresh products (especially by the large-scale retail trade) often requires the use of artificial cooling to maintain the quality characteristics of the products. Data regarding these systems are not available but it is calculated that they require power not less than 250 W per square meter and are responsible for up to 15% of total energy consumption.[38]

Considering warming system, which are much more common, if it is assumed an average value of 5-7 kgep per square meter per year, one surface reference of permanent greenhouses not inferior at 6,000 hectares, it is estimated a consumption of energy between 300,000 and 500,000 toe per year, in addition to an electrical consumption of at least 10,000 toe per year. To these must be added about 2.5 toe per year of energy in the form of fertilizers and pesticides which, together with energy consumption for materials plastics, which generally are not counted among the energy consumption of protected agriculture. For example, Polyethylene production are required 92-111 MJ / kg, for polyvinylchloride 85-107 MJ / kg, for polystyrene 118-160 MJ / kg, for polyester 170-222 MJ / kg to be produced.

b. Studies: greenhouse vegetable production and its energy use

A study conducted in Antalya province, which has a greenhouse area of about 13,337 ha , and is the centre of greenhouse farming in Turkey, puts forward the advantages for a farmer to take the route of greenhouse farming instead of conventional farming. The focus was on the energy efficiency so the energy output/input ratio.

Power requirements of the machines used in greenhouse operations were measured by using a computer based data acquisition system while according to the study, energy and economic variables (i.e. output–input ratio, specific energy, production cost, net return, etc.) are calculated by using the standard equations.

Tomato, pepper, cucumber and eggplant are the vegetables cultivated in the greenhouse considered. As a result, the operational energy and energy source requirements of the greenhouse vegetable production were found between the ranges of 23,883.5–28,034.7 and 45,763.3–49,978.8 MJ/1000 m^2, respectively. The energy ratio of greenhouse vegetables—tomato, pepper, cucumber and eggplant—was 0.32, 0.19, 0.31, 0.23, respectively and the energy

productivity (kg/MJ) are 0.40, 0.23, 0.39, 0.29.

From an economic point of view, given the sell price, decreasing the cost of energy is the best way to increase the net return of the vegetable production. It was found in the 595.6–2775.3 $/1000 m2 ranges and this show that among the greenhouse vegetables, tomato cultivation resulted in being the most profitable.

c. Crop farming in greenhouses

A study conducted in India examines that the energy requirement and energy input-output relationship of some field crops i.e. wheat, chickpea, soybean, mustard.

[38] Carlo Alberto Campiotti, Carlo Bibbiani , Francesca Dondi , Corinna Viola
Efficienza energetica e fonti rinnovabili per l'agricoltura protetta

According to what has been already showed chemical fertilizers consumed most of the energy for all crops. From 30% for chickpea, 45 % for soybeans, 57% for mustard to 60% for wheat.

Regarding the energy input-output relationship, the study shows that even if wheat produced higher grain and total biomass, the energy efficiency is higher in chickpea, followed by mustard, wheat and soybean. The net energy is respectively 33919 MJ/ha, 41252 MJ/ha, 64505 MJ/ha and 43067 MJ/ha but even more important are the energy productivity (kg/MJ). For chickpea 0.139, wheat 0.150, soybean 0.109 and mustard 0.112.

Economically speaking, the net return values varied from 2.39 to 27.0 $/1000 m^2.

d. Conclusions

Comparing the two studies is useful, and not very difficult, and doing it is possible to have a clear picture regarding greenhouse farming and when it is a good idea to adopt it.

First of all, the net return values of vegetable production in greenhouses (595.6–2775.3 $/1000 m2) were found significantly greater than the field crops.

In addition to that, other indicators can be used to better resume energy demand in greenhouse farming system, they are the energy productivity and the benefit/cost ratio.

Vegetables energy productivity goes from 0,23 to 0,40 while for crops from 0.109 to 0.150, these results must be considered in crop planning and energy requirements in agricultural farms.

Benefit/cost ratio are for tomato, pepper, cucumber and eggplant, respectively 1.57, 1.15, 1.29, 1,10 while for the crops: soybean, wheat, mustard and chickpea in order 1.10, 2.03, 1.98 and 2.30.

In conclusion, these results indicate that greenhouse industry for crops actually need to develop a systematic energy optimizing system to improve energy efficiency. The economic advantage of crops instead of vegetables has a price to pay: environmental damages and depletion of scarce and non-renewable energy sources.

2.6 In conclusion

On organic production

It is a fast-growing sector in many western nations, however it is still not the main production system.

The main reason is that it is a big investment converting a conventional system into an organic one, and even inf the second one have several advantages as: use 15% less energy , and have 37% higher eutrophication potential, 4% less greenhouse gas emissions 13% higher acidification potential in organic systems, respectively than conventional systems per unit of food. [39]

However there are also disadvantages, the first is that organic systems require 25%–110% more land use, and on a planet where population is increasing but the arable land is the same or it is even decreasing, the land use is a crucial factor.

[39] Michael Clark and David Tilman, Comparative analysis of environmental impacts of agricultural production systems, agricultural input efficiency, and food choice
2017 Environ. Res. Lett. 12 064016

It is, however, possible that the comparative environmental impacts of organic and conventional systems might differ at a regional, national, or global scale[40] . Additionally, while the overall pattern is for higher land use in organic systems, organic systems have similar land use for legumes and perennial crops while the land use difference between organic and conventional systems is smaller in rain-fed systems[41]

Organic foods have higher micronutrient concentrations[42][43] and lower pesticide residues [44] than conventional foods and so organic systems might offer health and environmental benefits we could not investigate with our data set.

On-farm and near-farm biodiversity[45] [46] tends to be higher in organic agricultural systems, probably because of its lower fertilizer, herbicide and pesticide inputs.

Conventional practices require more energy use and are reliant on high nutrient, herbicide, and pesticide inputs that can have negative impacts on human health and the environment [47] but it has a larger productivity considering water and land use.

Developing production systems that integrate the benefits of conventional, organic, and other agricultural systems is necessary for creating a more sustainable agricultural future.

Regarding protected agriculture[48]: the application and dissemination of systems and technical measures to increase energy efficiency and if on the one hand it requires a real cultural reconversion of the main players in the supply chain (producers, organizations, businesses, consumers), on the other it offers the opportunity to innovate traditional systems with new installations that ensure full compatibility with the needs of energy saving and environmental protection.

Furthermore, in the event that renewable resources are used as an energy source, the prospects for both entrepreneurial and socio-occupational development potentially associated with their use are not negligible, there is in fact the possibility of developing new production models, energy supply chains and entrepreneurial activities based on the application of local renewable resources (solar, geothermal and biomass).

In this regard, considering Italy, we find different solutions: the "Conto Energia", the Green Certificates (CV) and the Energy Efficiency Certificates (TEE), these represent economically viable and profitable options for greenhouse operators. The integration of innovation, the use of renewable energies, the acceptance of energy

[40] Bengtsson J, Ahnström J and Weibull A C 2005 The effects of organic agriculture on biodiversity and abundance: a metaanalysis J. Appl. Ecol. 42 261–9

[41] Seufert, V., Ramankutty, N. & Foley, J. Comparing the yields of organic and conventional agriculture. *Nature* **485,** 229–232 (2012). https://doi.org/10.1038/nature11069

[42] Hunter D, Foster M, McArthur J O, Ojha R, Petocz P and Samman S 2011 Evaluation of the micronutrient composition of plant foods produced by organic and conventional agricultural methods Crit. Rev. Food Sci. Nutr. 51 571–82

[43] Palupi E, Jayanegara A, Ploeger A and Kahl J 2012 Comparison of nutritional quality between conventional and organic dairy products: a meta-analysis J. Sci. Food Agric. 92 2774–81

[44] B P, Benbrook C M, Groth E and Lutz Benbrook K 2002 Pesticide residues in conventional, integrated pest management (IPM)-grown and organic foods: insights from three US data sets Food Addit. Contam. 19 427–46

[45] See note 40

[46] Hole D G, Perkins A J, Wilson J D, Alexander I H, Grice P V and Evans A D 2005 Does organic farming benefit biodiversity? Biol. Conserv. 122 113–30

[47] Vitousek P M et al 2009 Nutrient imbalances in agricultural development Science 324 1519–20

[48] See not 38

efficiency criteria represent both a definitive strategy to counter the volatility and the upward trend of traditional energy costs and a priority choice to maintain and improve competitiveness and the business economy of protected agriculture.

3. Products of the land: consumption of energy in Agriculture

Fluctuations in energy prices, technological advancements and changes in energy and environmental policies have transformed the relationship between energy consumption and the agriculture sectors.

Agriculture has always used energy products, especially fossil fuels, as inputs in production. Starting from the end of the 2000s, the use of renewable fuels has increased significantly but still not enough to replace non-renewable energy.

3.1 An overview on modern agriculture

For centuries, agriculture used energy both directly in the form of fuel and electricity and indirectly through the use of energy-intensive inputs, such as fertilizers and pesticides, as seen in chapter two.

The change in the economy and market policies has led farmers to adapt the agricultural raw materials to be produced, the relative quantity of production per material and how to produce them. The goal is to take advantage of the recent changes in energy prices and the technological improvements that have affected the agricultural sector.

Farmers have adapted to rising energy prices and changing policies by changing their use of energy-based agricultural inputs, altering energy-intensive production practices, and growing more crops for energy production purposes.

Farmers have expanded the production of agricultural products used as energy raw materials and as feed in particular, corn, soy and wheat, while the production of barley, oats and sorghum, cereals for human consumption has decreased.

In addition, there has been an adaptation to higher energy prices and related incentives for energy policy and conservation by shifting to more energy efficient production and input practices. Nonetheless, there are numerous studies that show that agriculture still requires a large amount of energy today.

Although farmers try to reduce fuel costs, through the maintenance of machinery and through the choice of more sustainable practices, energy efficiency is still a long way off.

What has just been said has had several positive consequences: there has been a reduction in costs for fertilizers, through the reduction of the quantity used or through the increase in the efficiency of use, or by converting the type of agriculture from conventional to organic, a process that is difficult but ongoing.

3.2 Economics of agricultural production

a. Economics of agricultural production

The economics of agricultural production is fundamental when considering the behaviours assumed by producers and the choices made.

The presumed goal of any manager of a business, even in agriculture, is to maximize profits, a measure of which is the difference between the yield from the sale of crops and the cost of producing these commodities. The former is strongly influenced by the selling price of the output and consequently also by the choice of the output to be produced, while the latter is strongly influenced by the cost of energy.

When choosing which outputs to produce, a farm manager faces a number of options regarding what to produce given the land, labor, and the production system available. Agricultural land may be more suitable for certain types of crops or livestock than other types.

Allocation of resources among the outputs

Once decisions have been made as to which commodity or commodity is to be produced, as the amount of labor and agricultural machinery on each farm is limited, the labor and machinery time must be allocated to each agricultural and livestock activity, in line with the general objective of the farmer.

b. Risk-taking and uncertainty

Production models in economics often assume that the manager knows with certainty the applicable production function, for example, the yield of a crop if a certain amount of fertilizer were applied, how much energy is needed and the cost of energy.

Price uncertainty is an inherent feature of virtually all agricultural products and production in agriculture takes time so working on costs is key to maximizing profit.

For this reason, research and technological advancement are essential to minimize costs, certainly one way is to make all production processes more efficient, thus avoiding waste and also minimizing the impact of food production on the environment.

Public funding of agricultural research is one way of promoting the growth of food supply. If supply increases do not keep pace with demand growth, food prices rise, drawing resources into food production. Understanding therefore which type of production system, which product is more energy efficient, profitable and sustainable is essential to guide the choices of consumers and lenders.

If we consider different countries, developing and developed, we find that the prices are very different. Similar comparisons will be made in the following paragraphs on the energy efficiency of the various crops in different locations around the world.

As far as corn is concerned, the cheapest is produced in the United States (8 ¢ / kg) while rice is produced cheaper in India (11 ¢ / kg) than in the United States (21 ¢). Wheat production costs are similar in the United States and India.

Despite the fact that agricultural wages are extremely low in developing countries, ranging from 6 ¢ to 50 ¢ per hour, labor is the main cost of food production in developing countries. The lack of mechanization has to be substituted with human labour and so a large number of hours are invested in production. Labor input in developing countries ranges from 600 to 1,800 hours per hectare[49].

Meanwhile the main costs of food crop production in the United States are for mechanization, fertilizers, and pesticides. When irrigation is used, the cost is 2 to 3 times the cost of all other inputs to food crop production in the United States[50]

3.3 Energy for primary production

The main technologies that consume energy for agricultural and livestock production and for fishing are different and there are great variations depending on the size of the company and its location and the type of food produced. The energy demand for producing similar food products in different production systems can be used to compare dependence on fossil fuels.

In 2005, the 27 million tractors operating in the world (about one third in low-GDP countries) consumed about 5 EJ of diesel for land development, transport and field operations . An additional 1.5 EJ / year was used for the production and maintenance of tractors and agricultural implements.

In the next paragraphs the difference between the levels of agricultural mechanization is highlighted, between the industrialized countries and the countries where agricultural cultivation is carried out using manual tools and technologies powered by animals.

An excellent example considered by the FAO in several reports is that which sees the installation of small mobile diesel engines in Bangladesh, with the aim of powering irrigation pumps, revolutionizing food production.

Irrigation is one of the activities that requires much of energy in agriculture. The mechanical pumping of water over about 10% of the world's arable land (about 300 Mha) consumes about 0.225 EJ / year to power the pumps. An additional 0.05 EJ / year of indirect energy is needed to produce and supply irrigation equipment[51].

Despite this, artificial irrigation is essential nowadays as these systems allow rain-fed systems to have double and triple crops and provide about 40% of the world supply of cereals (FAO, 2011a). In Africa, only 4 percent of cultivated land is irrigated, mainly due to the lack of funds. In India, irrigation systems have increased, having an impact on the environment and in particular on water resources.

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[49] Pimentel, D.; Doughty, R.; Carothers, C.; Lamberson, S.; Bora, N.; Lee, K. Energy inputs in crop production in developing and developed countries. In Food Security and Environmental Quality in the Developing World; Lal, R., Hansen, D., Uphoff, N., Slack, S., Eds.; CRC Press: Boca Raton, 2002; pp

[50] Pimentel, D.; Pimentel, M. Food, Energy and Society. CRC Press. Taylor and Francis Group: Boca Raton, Florida, 2008.

In fact, it must be considered that about two thirds of the global water resources used for irrigation come from underground aquifers and deep wells, and projections suggest that it will rise to 87% in 2050, as the reserves of shallower water will be depleted. Extraction rates currently exceed the reload rate.[52]

In the previous chapter, we focused on energy consumption deriving from the use of inorganic fertilizers, and it was shown how their use has significantly contributed to the increase in crop yields in recent decades, while also increasing the demand for energy in a more than proportional way.

In 2000, the energy incorporated in the production of inorganic fertilizers was around 7 EJ globally [53].

The production of nitrogen fertilizers alone accounts for about half of the fossil fuels used in primary production.

However, it must be kept in mind that the absorption of nitrogen, the main component of fertilizers, by crops tends to be ineffective. The absorption is about 28% for cereals and only 20% for vegetables and it is precisely for this reason that agricultural production, especially conventional production, is not energetically efficient

3.4 Agriculture and fossil fuel: a challenge for the future

Even though fossil fuels are a non-renewable resource, and likely to be depleted at current usage rates, we still use them as the main resource of energy in most of production activities.

Crude oil and natural gas make up a large portion of the energy that gets consumed in order to grow crops. The significant result of using fossil energy to increase yields, especially cereals, began in 1950 with the advent of the “Green Revolution”.

The Green Revolution of the 1960s and 1970s in fact helped in solving the problem of food scarcity through a better selection of plants, but above all by tripling the application of inorganic fertilizers, expanding the irrigated area and increasing energy supplies to provide additional services along the food chain.

Today, the situation is no longer the same, hunger, at least in industrialized and developing countries, is an almost totally solved problem and in addition to this, we reach saturation of arable land. The annual increases in the incremental yield of major cereal crops are decreasing and fossil fuels are becoming relatively scarcer and more expensive. In contrast to what happens in richer countries, about 2 billion people on earth live in poverty and these numbers are destined to increase because of the increase in population. It will be another necessary revolution in agricultural production to feed the future world's population, indeed, humanity is expected to expand to over 9 billion people by 2050. The "How to Feed the World by 2050" report[54] indicates that a 70% increase in food production from 2005-2007 production levels is needed to meet demand. This roughly requires the additional production of around 1,000 Mt of cereals per year by 2050. These production gains are expected to come largely from increased productivity of crops, livestock and fisheries. However, unlike the green revolution of the 1960s and 1970s, our ability to meet the goals may be limited in the future

[54] FAO, 2009a. How to feed the world in 2050, Food and Agriculture Organization of the United Nations, Rome. 35 pages. www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_ in_2050.pdf

by the lack of cheap fossil fuels and of course historical trends show that there is a clear link between food prices. and energy prices (Fig. 1).

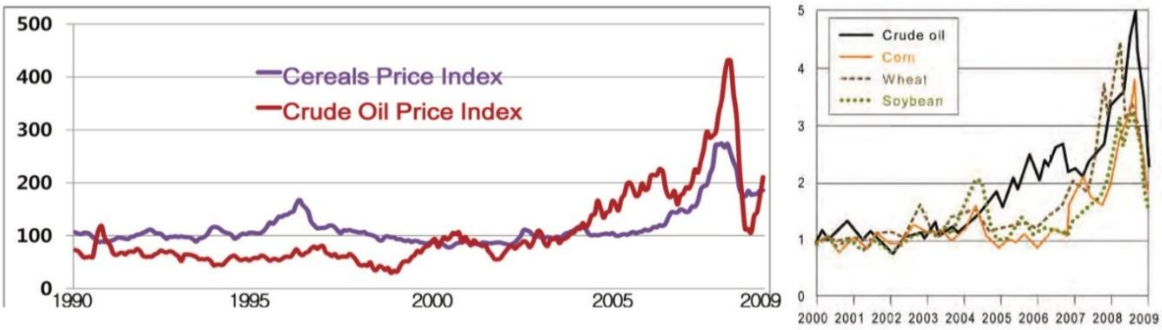

Figure 1. Comparative trends in commodity and oil price indices from 2000 to 2009 (Heinberg and Bomford, 2009) and from 1990 to 2009 (with 2004 as a reference) (Kim, 2010).

Reconnecting to what has just been said, it is therefore clear that the volatility of prices and the possible future scarcity of supply of fossil fuels and the strong dependence of the food industry on these non-renewable energy resources, raises concerns about the availability and economic accessibility of food. For example, consider the United States and its agricultural industry and observe that nearly 800 trillion British thermal units (Btu) of energy were used in 2012, or about the same primary energy as the entire state of Utah.

In addition to the availability of food, the problems linked to the strong dependence on an energy source such as fossil fuels are many. This energy source constitutes a significant part of the operating expenses for most crops, especially when considering the indirect energy costs for fertilizers, as fertilizer production is extremely energy-intensive. For some crops such as oats, maize, wheat and barley, energy and fertilizer expenses combined account for more than half of total operating expenses.

This means that there is and will be a major impact on the economic viability of some food-related businesses in the years to come. If fossil fuel prices continue to rise and carbon taxes are added to cover the costs of externalities of greenhouse gas emissions released during their combustion, costs of tractor fuel, chemicals and fertilizers, food processing and transport will all increase[55].

This situation could lead to a depletion of arable land and consequently to meet the global demand for agricultural products it will be necessary to increase the evening of the crops, in particular through the application of greater external energy inputs in less intensive systems.

For a future without greenhouse gas emissions or at least with a strong reduction of those, it is necessary to aim at an ever lower demand for fossil fuels and exploiting renewable energy and food waste as a resource (as discussed in chapters 5 and 6) is the best way to start.

[55] IPCC, 2007a. 4th Assessment Report - Mitigation, Chapter 1, Introduction, Working Group III, Intergovernmental Panel on Climate Change, www.ipcc.ch/publications_and_data/ar4/wg3/en/ch1. htm

3.5 Cereals, legumes and fruits

a. Corn

According to the Food and Agriculture Organization[56], among others, corn is among the leading grain crops in the world.

When environmental conditions are favorable, maize is one of the most productive crops per unit area and also one of the most energy efficient. In fact, through an analysis of energy inputs but also of energy yields, it is clear that the high yields of intensive corn production are in part linked to the large inputs of fertilizers, irrigation and pesticides.

There are different ways of producing corn, based on the hours of manpower required and the level of mechanization, the energy expenditure may vary. The country where corn is grown and therefore the level of industrialization of the domestic agricultural system means that there is different consumption of fossil energy and therefore the input: energy output ratio is different.

The production of corn in the United States today is widespread, and its cultivation takes place through intensive agriculture. The total human energy input is 11.4[57] hours per hectare.

In the US system, the total fossil fuel input is estimated to be 8.2 million kcal / ha. With a yield of about 9,400 kg / ha[58], or the equivalent of 34 million kcal / ha of food energy. This results in an input: output ratio of 1:4.11.

As a developing country, where therefore manual labour is still an important part of food production and where the level of mechanization is not that high, Indonesia is considered.

634 hours[59] of manpower and five hours of manpower per hectare are required, an energy expenditure of 4.0 million kcal. With a corn yield of 1,200 kg / ha that can be converted to 6.9 million kcal, the energy input: output ratio is 1: 1.08.

As far as the use of energy in the United States is concerned, it is noted that a large part of about 25% of the total energy is consumed in mechanization which reduces work. Precisely for this reason, the use of fossil energy inputs is very high and comes mainly from oil for machinery and natural gas for fertilizers.

As in any crop that involves the use of chemicals such as nitrogen fertilizers, there is a high demand for natural gas. The latter, in fact, represents the largest single input, about 30% of the total fossil energy inputs. While corn yields are higher in the intensive system than in hand-grown corn, the economic investment is $ 927 / ha, compared to less than $ 100 per hectare in the hand-grown system.

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[56] FAO. Quarterly Bulletin of Statistics. Food and Agriculture Organization, United Nations: Rome, Italy: 10, 1997.
Cereal. Cereal Production Table. http://www.answers.com/topic/cereal-3 (accessed on 6/4/08).

[57] NASS. National Agricultural Statistics Service, 2003. http://usda.mannlib.cornell.edu (accessed on 11/05/04).
[58] Pimentel, D.; Pimentel, M. Food, Energy and Society, Colorado University Press, Boulder, Colorado, 1996.
[59] Djauhari, A.; Djulin, A.; Soejono, I. Maize Production in Java: Prospects for Improved FarmLevel Production Technology. CGPRT Centre: Indonesia, 1988.

b. Wheat

The two most important cereals nowadays are wheat and rice, in particular the former is the most consumed cereal by humans compared to any other cereal. In addition, wheat is used as an energy source for the production of biofuels and is one of the main constituents of feed to feed livestock.

As for the production of corn, energy inputs and yields also vary according to the production system and obviously according to the place where it is grown.

Always taking as a reference the United States, one of the largest producers of wheat, it is observed that thanks to modernization, large machinery powered by fossil fuels replace the animal power used in the past or in developing and underdeveloped countries.

The wheat crops in this nation are monocultures with an extent impossible to cover without the use of the aforementioned large machinery and therefore a direct consequence is the drastic reduction in labour input to 7.8 hours[60.] In addition, the massive use of fertilizers and other production factors, typical of industrialized countries, has increased wheat yields to 2,990 kg / ha and therefore the input: output ratio for wheat production is approximately 1: 2.57.

The country, on the other hand, taken into consideration for a comparison is Kenya, in this case, the wheat farmers use human and animal energy and therefore the labour input is about 90 times that of the United States, with an amount of 684 hours[61]. The total energy input in this system is about 1.9 million kcal which provides a crop of about 6.4 million kcal in wheat, for an energy input: output ratio of about 1: 3.31.

Grain production in the United States requires more than double the fossil energy inputs than the Kenyan low-input production system (4.2 million kcal)

c. Rice

Rice has always been one a staple of human diet, today about 3 billion people live mainly by eating rice as the main carbohydrate, especially in developing countries. Precisely for this reason, the analysis of various rice production technologies is particularly relevant.

The biggest difference with other cereals, especially those analysed in the previous two paragraphs, is that while they are often transformed into biomass or feed, almost 80% of the rice produced is consumed directly by humans.

Rice is produced all over the world but Asian countries are the absolute leaders and the first producer is India. The rice production system practiced by Indian farmers, who use human labour and bullocks, requires 1,703 hours of human labour and 328 hours of beef labour. The energy inputs in this rice system amount to approximately 6.6 million kcal[62]. The total rice yield is 1,831 kg / ha (6.6 million kcal), with an input:output ratio of approximately 1:0.79.

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[60] See note 50.

[61] Hassan, R.M.; Mwangi, W.; Karanja. D. 1993 Wheat Supply in Kenya: Production Technologies, Sources of Inefficiency, and Potential for Productivity Growth, CIMMYT Economics Working Papers, 93-02, 1993.

[62] Tripathi, R.S.; Sah, V.K. Material and energy flows in high-hill, mid-hill and valley farming systems of Garhwal Himalaya. Agr. Ecosyst. Environ. 2001, 86, 75-91.

This energy ratio could be much higher if the energy for the bullocks were removed from the rating. This obviously cannot happen as the breeding of bullocks depends heavily on fossil energy; livestock farming, as we will see in the next chapter, is highly inefficient. The only way to make their impact negligible would be to have a pastoral farm, where the animals feed on forage and not on feed composed of other grains.

As with other grain production, the United States uses large fossil energy inputs to produce rice. The average yield is 7,616 kg / ha[63] (27 million kcal of food energy). The investment in fossil energy is approximately 19.3 million kcal, with an input:output ratio of 1:1.42. Although most of the energy is used for machinery and fuel to replace work, fertilizers represent a significant portion of the total input, about 13%. Human labor input is only 11 hours / ha[64] and is therefore much lower than that in India, but still relatively high compared to others american grains production as wheat.

d. Soybeans

Due to its high protein content (around 34%), soy is probably the most important protein crop in the world. Two-thirds of all soybeans produced are grown in the United States, China and Brazil. In the United States, relatively little of the soybean crop is used as human food. The uses of this bean are many. For example, this legume is transformed by obtaining oil and feed for livestock. Soybean and soy-based products in particular top the list of US agricultural exports[65].

In the United States, soybeans produce an average of 2,600 kg / ha to provide approximately 9.3 million kcal. Production inputs are equal to 2.5 million kcal / ha, with an input:output ratio of 1:3.71. The major inputs are machinery and fuel.

Legumes need less nitrogen than other crops because soybeans and other legumes biologically fix their nitrogen under most environmental conditions. The biological fixation process carried out by soil microbes uses about 5% of the light energy captured by soybean plants, but saves the energy that would otherwise be used for the production of nitrogen fertilizers. Providing 100 kg per hectare of commercial nitrogen fertilizer to replace the nitrogen fixed by soy would require the expenditure of 1.6 million kcal of fossil energy. Labor input in the United States was only 6 hours / ha[66] while in the Philippines, which is the developing countries considered due to the fact that it is the main producer of soybeans between developing countries, it is 744 hours[67].

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[63] USDA. Agricultural Statistics, 2006. U.S. Department of Agriculture. U.S. Government Printing Office: Washington, DC, 2006.

[64] Liveszey, J.; Foreman, L. Characteristics and Production Costs of U.S. Rice Farms. Electronic Report from the Economic Research Service, U.S. Department of Agriculture, Resource Economics Division: Washington, DC, 2004.

[65] See not 63

[66] Metzger, S. Preliminary report comparing tolerant and non-herbicide tolerant soybeans in eastcentral North Dakota, 2002. http://www.ag.ndsu.nodak.edu/carrt/ 03%20Annual%20Report/ Herbicide%20Tolerant%20andNon.htm

[67] Pimentel, D.; Doughty, R.; Carothers, C.; Lamberson, S.; Bora, N.; Lee, K. Energy inputs in crop production in developing and developed countries. In Food Security and Environmental Quality in the Developing World; Lal, R., Hansen, D., Uphoff, N., Slack, S., Eds.; CRC Press: Boca Raton, 2002; pp. 129-151

e. Potato

White potato is today one of the 15 most consumed plant foods in the world. Even in the United States, where a wide variety of vegetables is available, more potatoes are eaten than any other vegetable: about 22 kg[68] of potatoes per person per year. Potatoes contain proteins (1.5 to 2.5%), are rich in vitamin C and potassium and offer a good source of carbohydrates. If the protein content is considered, the protein production per hectare is 2 to 3 times higher than other crops.

If we consider the monoculture production system, we observe that the production of potatoes per hectare is many times higher than that of other crops that produce carbohydrates.

Based on US data, the largest inputs are for machinery[69] and fuel, hence fossil energy. The third largest input required is fertilizers. The total energy intake is about 15.0 million kcal / ha and the potato yield is nearly 44,000 kg / ha (25.2 million kcal of food energy).

The labour hours are higher than all other starches, 35 hrs[70]. The resulting input:output ratio is 1:2.76.[a]

f. Fruit

Tomato

Tomatoes are often erroneously considered a vegetable, because in fact they are a fruit, particularly appreciated from a nutritional point of view for their content of vitamin C (23 mg per 100 g of fresh tomato), vitamin A and iron. They are widely consumed, in many countries.

Always considering the United States as the reference country among the developed ones, we see that the labour input for tomatoes is high, about 184 hours / ha[71] often the harvest is done by hand. Most of the energy input is for machinery and fuel, and fertilizers are the third largest input. The tomato yield is 80,000 kg / ha[72], providing 16.0 million kcal of food energy. With a fossil energy input of 20.6 million kcal, the resulting input:output ratio is 1:0.78[73].

Oranges and apples

Oranges and apples are two of the most widely consumed fruits in Western countries, their cultures are very valuable – they are worth about $3,000 and $7,700 per hectare, respectively[74].

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[68] USDA. Agricultural Statistics, 2006. U.S. Department of Agriculture. U.S. Government Printing Office: Washington, DC, 2006.

[69] Patterson, P.E. Estimating cost of potato production in Idaho, 2002. http//www.ag.uidhao.edu/potao/research/files/Volume%2034/Volume%2034_9320Estimating%2 0Cost%20of%20Potato.pdf

[70] Pimentel, D.; Doughty, R.; Carothers, C.; Lamberson, S.; Bora, N.; Lee, K. Energy inputs in crop production in developing and developed countries. In Food Security and Environmental Quality in the Developing World; Lal, R., Hansen, D., Uphoff, N., Slack, S., Eds.; CRC Press: Boca Raton, 2002; pp. 129-151

[71] Kelly, T.C.; Lu, V.C.; Abdul-Baki, A.A.; Teasdale, J.R. Economics of a hairy vetch mulch system for producing fresh-market tomatoes in the mid-Atlantic region. J Am. Soc. Hortic. Sci. 1995, 120, 854-860

[72] See note 63

[73]David Pimentel , Energy Inputs in Food Crop Production in Developing and Developed Nations, ,5126 Comstock Hall, Cornell University, Ithaca, NY 14853, USA; doi:10.3390/en20100001

[74] See note 63

Oranges and other citrus fruits have a high content of vitamins and minerals and therefore are a highly nutritious food. At the same time, compared to other fruits, they have a much better energy yield.

Production requires 20.0 million kcal / ha of fossil energy and 200 hrs/ha[75] of labour. The return in food energy is 22.3 million kcal, with an input:output ratio of 1:1.11.

Apples, on the other hand, even more common than oranges, are not so beneficial from an energy point of view.

There is a very high degree of mechanization in apple orchards and therefore a large use of machinery is made for their production. The inputs for the latter, in fact, represent a large percentage of the total energy input. In the same way, apples are far more delicate than citrus fruits, therefore, to prevent the harvest from being ruined, pesticides are used extensively, the latter contributing almost 60% of the total energy consumption in apple production.

In addition, the labour input of 400 hours / ha[76] spent on apple production is also high compared to that of most other food crops grown in the United States. Particularly during the harvest. The total labour input is about 20.0 million kcal / ha. The total yield of apples is 54,000 kg / ha[77], providing 30.3 million kcal of food energy. The input: output ratio is 1: 0.18.[78][79]

Therefore, it is clear even just by comparing the input: output ratios of the two fruits or the labour hours that apple production is more energy-intensive than orange production.

In conclusion, it is possible to order the food considered above, based on the energy input:output ration. Corn is more efficient than other cereals, in both developed and developing countries. In US the ratio they are respectively 1:4.11 and 1:1.08, while for wheat they are 1:2.57 and 1:3.31 and for rice they are 1:1.42 and 1:0.79. Soybean is even more efficient than wheat but less than corn , with a ratio of 1:3.71 while potato is more to wheat with 1:2.76.

Meanwhile considering fruits oranges are much more sustainable than oranges, and tomato are more or less in the middle. The ratio are 1:1.11, 1:0.78 and 1:0.18.

3.6 Conclusion

Recognizing that a paradigm shift towards the sustainable intensification of agriculture is needed to ensure future global food security, FAO has created Sustainable Agricultural Production Intensification Program (SCPI).

[75] Reitz, H. Energy use in citrus production and harvesting. In Handbook of Energy Utilization in Agriculture. Pimentel, D., Ed.; CRC Press: Boca Raton, FL, 1980; pp. 285-289

[76] Mon, P.N.; Holland, D.W. Organic apple production in Washington State: an input-output analysis. Renewable Agric.Food Syst. 2005, 21, 134-141.

[77] USDA. Agricultural Statistics. U.S. Department of Agriculture. Government Printing Office: Washington, DC, 2007

[78] Scee not 73

[79] Save and Grow: A policymaker’s guide to the sustainable intensification of smallholder crop production. FAO Rome 2011

The idea behind all the analyses in this chapter and the goal for the future is to find solutions through an ecosystem approach, with appropriate external inputs applied at the right time and with the right amount. Achieving full energy efficiency in food production is the key to being able to feed a growing population, given the limited resources at our disposal.

This is the reason why a less fossil fuel-based input approach, which reduces producers' fuel costs and makes production more resilient to fluctuations in energy prices, is needed.

Better pest management and a more careful choice of output to be produced, considering more soil and climate, is the basis for ecosystem production, and therefore the reduction of fertilizers and other chemicals should give way to organic or conservation agriculture.

The technical principle of higher rates of efficiency in the use of key inputs, including water, nutrients, pesticides, energy, land and labour is the basis.

Here's why: “FAO's SCPI program works with member states to avoid machining; promote the judicious use of organic and inorganic fertilizer; incorporate integrated management of pests, diseases and weeds to reduce the need for pesticides; and encourage efficient water management. All these practices contribute to reducing the use of fossil fuels."[80]

4 Breathing the same air: consumption of energy in farming

4.1 Animal products

a. An overview on animal products consumption

The immense demand for all kind of animal product, meat, diary, eggs and fishes is growing according to human increase rate.

In order to guaranteed an average daily intake of 2772 kcal/ per person, without any significative change in our diet pattern, the production of food need to double, in particular considering animal products consumption is increasing in developing countries, future demand of meat, fish and dairy products can only been met t intensively-raised animal agriculture also known as factory farming or concentrated animal feeding operations (CAFOs).

As mentioned before, the increase of wealth in the industrialized countries had led to an increase in the demand of animal products.81 One of the strongest factors of how much meat people eat is their richness, but our planet can’t sustain the enormous global demand of animal protein. It is a threat for the availability of the already limited resources of the earth, as the oceans, the soil and the potable water.

Around 75% of the agriculture soil and the 80% of the drinking water are exploited to produce livestock and fishing cultures.

It is estimated that, until 2050 the amount of animal products demands will reach 465 million of tons, inevitably increasing the GHG emissions, deforestation and a general environmental degrade.

Nowadays, in several countries factory farming are the only solution, even though smaller, mixed farming systems are becoming more popular thanks to FAO projects or special subsidies , the most “humane” systems can’t meet current and growing demand even though they are slightly better, they still contribute to global warming. There is not a completely sustainable solution.

b. Livestock: meat consumption

Worldwide, similarly to other animal products also meat consumption is growing. Global production has doubled since the 1970s, mostly thanks to intensive farming systems. In the last thirty years, chicken breeding has grown 6 times; pigs tripled and cattle doubled. According to World Livestock 2001, by FAO, about 56

[81] H.C.J. Godfray, J.R. Beddington, I.R. Crute, L. Haddad, et al.Food security: the challenge of feeding 9 billion people Science, 327 (2010), pp. 812-818, 10.1126/science.1185383 New York, NY

billion animals are bred and slaughtered every year and meat consumption is expected to grow by 73% by 2050.

As mentioned in the previous paragraph, the increase in meat production is observed in particular in industrialized and developing countries where, historically, meat consumption was at fairly low levels.[82]

However, the use of data on farm animal populations requires some caution as there are difficulties in statistical collection as well as systemic comparison between the various regions of the world. The fragmentation of the available data leads to hypothesize the conservative nature of the available numbers and to believe that the animals used for the production of meat are actually much more than those detected by the official data.

Fortunately, in the last years, due to environmental and climate changes concern, several international institutions have conducted surveys on meat production and consumption, in order to identify its impacts, generally speaking FAO reports are the most comprehensive reports that provide valuable data;

First of all, Data collected by FAO show that meat production in the world has grown substantially since the 1960s, so much so that today the world livestock system exploits about 30% of the land that emerged on the planet[83] and 70% of the world's agricultural land. FAO reports that the global market is made up of 33% poultry (chickens), 36% pork, 24% beef and 5% sheep meat. The United Nations estimates that the human population in 2050 will amount to approximately 9.15 billion and therefore the impact on the planet could be devastating, in particular due to the expansion of the Western food model.

In 2005 the World Bank report 'Managing the Livestock Revolution[84]' estimated an average of annual global meat consumption of 36 kg per person in 1997, forecasting an increase in consumption to 45 kg per capita in 2020. In 2006, it was estimated an average consumption of 42.3 kg per person, with 87 kg per capita as an average for the inhabitants of industrialized countries, meanwhile according to data reported by P. H. Thornton as part of a research promoted by the International Livestock Research Institute, in 2050 the average annual meat consumption per capita will rise to 94 kg in industrialized countries and 44 kg for developing countries.

Focusing on the European Union, a publication of the European Commission estimated that in 2000 the consumption of meat in Europe (in the EU-15 countries) amounted to 35 million tons per year, equal to about 92 kg of meat per head.

According to ISMEA in Italy the current consumption of average meat per head is equal to 87.5 kg per year. Population growth, rising affluence and urbanization are the drivers for the rapid expansion of the sector in recent decades and demand for livestock products is expected to continue growing strongly through the middle

[82] D. Tilman, M. Clark Global diets link environmental sustainability and human health
Nature, 515 (2014), pp. 518-522, 10.1038/nature13959

[83] The World Bank Agriculture and Rural Development Department Pica-Ciamarra, U., & Otte, J. (2011). The 'Livestock Revolution': Rhetoric and Reality. Outlook on Agriculture, 40(1), 7–19. https://doi.org/10.5367/oa.2011.0030

[84] Managing the Livestock Revolution Policy and Technology to Address the Negative Impacts of a Fast-Growing Sector June 2005

of this century. “Decisive action is required if the sector is to satisfy this growth in ways that support society’s goals for poverty reduction and food security, environmental sustainability and improved human health”[85].

c Animals are just “poor” converter of energy

Animals do not create any kind of macronutrients or micronutrients, they just convert forages, crops and by-products.

Animal production is a poor converter of energy because it is based on a double energy transformation.

But what does it actually mean?

Solar energy and soil nutrients are converted into biomass by green plants. When the plants are fed to animals, a major share of energy intake is spent on keeping up body metabolism and only a small portion is used to produce meat and milk. As a result of the concentration effect the energy used per tonne of main outputs of animal production are substantially higher than crops.[86]

In addition to that, animal production can’t be considered sustainable due to the massive use of fossil fuel during all the stage of the production. The decrease in the costs of fossil fuels and the important mechanization of a variety of processes has led to enormous increases in the consumption of energy from fossil fuels and electricity in all food production processes, in particular in intensive farming.

For example fossil energy is the major input of livestock production systems, used mainly for the production, transport, storage and processing of feed. Depending on location (climate), season of the year and building facilities, energy is also needed for control of the thermal environment (cooling, heating or ventilation) and for animal waste collection and treatment.

In addition to that fertilizers and chemicals for agriculture have a high energy requirement for production and transport and contribute significantly to the energy inefficiencies of meat or other animal products.

Despite their unsustainability , the demand for meat and animal products has increasing leading to the intensification and industrialization of their production in general, therefore to the demand for large external inputs in order to achieve the high expected returns on investments in these systems.

Cereal crops are used in big percentages as feed, in the case of ruminants for example, the drastic dietary changes that have taken place in the past 60 years have caused alterations in ecology which have created a variety of ailments which in turn frequently necessitate more feed additives as antibiotics which means ore energy demand.[87]

For a general idea on the energy efficiency of meat production we must consider how many resources are used and the conversion rate between the energy used and the energy supplied by animal proteins.

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[85] Food and Agriculture Organisation (FAO): ‘Livestock in the balance’ (FAO, 2009)

[86] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2935130/

[87] Russell, J.B. and Rychlik, J.L. (2001) Factors That Alter Rumen Microbial Ecology. Science, 292, 1119-1122. https://doi.org/10.1126/science.1058830

Energy ratio, which, describes the relationship between the energy output of a system and energy inputs needed to operate the system, is a possibility. Energy ratio can be expressed as

ER = Eo/Ei, where Eo is energy output and Ei is energy input or it is possible to express the efficiency of the production procedure by the energy intensity which is estimated as the ratio of the energy inputs per mass of product. In the following table, instead of the most common ER, the kcal input/kcal protein is stressed.

Livestock	Grain (kg)	Forage (kg)	Kcal input/kcal protein
Lamb	21	30	57:1
Beef cattle	13	30	40:1
Eggs	11	-	39:1
Grass-fed beef cattle	-	200	20:1
Swine	5.9	-	14:1
Dairy (milk)	0.7	1	14:1
Turkeys	3.8	-	10:1
Broilers	2.3	-	4:1

Table 1. Grain and forage inputs per kilogram of animal product produced, and fossil energy inputs (kcals) required to produce 1 kcal of animal protein

Source: Energy consumption in animal production I. Veermäe, J. Frorip, E. Kokin, J. Praks, V. Poikalainen, A. Ruus, L.Lepasalu Estonian University of Life Sciences

4.2 Beef production

Depending on the type of feeding of the animals, there are different data, this derives precisely from the impact of the production of feed, the latter in fact can vary, as seen in chapter 2, different methods of food production, in this case feed, organic or conventional have different energy demands. An even greater difference in the case of breeding can be observed if instead of using concentrated feed, the animals eat in the pasture.[88] . Extended pastoral systems for ruminants tend to have lower energy inputs than intensive farming systems. Grass-fed farming systems obviously require a lower energy requirement due to the exclusion of the use of feed and consequently all machines dependent on fossil fuels, used in intensive farming processes. [89] For the feedlots beef there is and energy consumption on average of 90 MJ kg^{-1} , while for grass-fed is nearly half so 40 MJ kg^{-1}[90] .

tIt is therefore noted that among the various parts of the process in livestock production, the one that requires the most energy is the production and processing of concentrated feed.

It is also possible to observe great differences in energy consumption between countries, livestock species and types of production system. In the developing world, fossil fuels are seldom used.

[88] Barnett J. & Russell J. 2010. Energy Use on Dairy Farms. Environmental issues at dairy farm level. Bulletin of the International Dairy Federation. 443, 23-32.

[89] Kraatz S., & Berg W.E. 2009. Energy Efficiency in Raising Livestock at the Example of Dairy Farming. ASABE Annual International Meeting Grand Sierra Resort and Casino Reno, Nevada June 21 – June 24, An ASABE Meeting Presentation Paper Number: 096715 19 p.

[90] Pimentel, D. 2004. Livestock production and energy use. In, Encyclopedia of Energy, Matsumura, R. (ed.), Elsevier, San Diego, CA. pages 671-676.

it is widely recognized that a meat-rich and energy-intensive human diet based on animal products generally consume more energy resources than a human diet based on plants.

Observing the kcal input/kcal output ratio, it's clear that significant energy losses occur during the conversion of wheat calories into meat, in fact it has been estimated that over a third of world wheat production is currently used as animal feed.[91]

4.3 Poultry production

The US broiler sector is the largest in the world. Nearly 9 billion broilers are raised each year in the United States for meat production alone, thus excluding eggs. This corresponds to over 16 million tons of live weight with a farm-gate value of $ 21 billion . With an annual per capita consumption of 39 kg, broiler chicken was also the most consumed meat, accounting for 39% of meat consumption in the United States.

As all farms, also poultry plant have massive energy consumption. In poultry plants, the largest share of energy is consumed precisely for the regulation of the internal climate such as heating, cooling, ventilation, lighting and humidity control) and for the operation of production equipment used for food, hygiene and they are laying hens also for the production of eggs[92].

The interest in the consumption of energy in poultry in recent years has increased strongly for several reasons, the high price of energy but above all the need to reduce the environmental footprint.

According to international literature [93][94] energy consumption should vary between 12-16 MJ / head or 60-80 kWh / m2 / year depending on the location of the poultry farm and the level of technology used. According to the conclusions of the various studies, heating is one of the main energy consumers, even in the case of lowland farms, followed by cooling and ventilation where electricity is consumed and therefore one could think of a wall insulation system with the aim to reduce energy consumption.

The energy consumption results are based on energy audits in 2 broiler farms of 10,000 birds according to these energy audits the annual LPG consumption for a well insulated chicken coop was 188,000 kWh, which can increase up to 214,000 kWh in case a room is not well insulated. The annual electricity consumption is respectively 24,000 kWh and 20,000 kWh.[95]

The average final energy consumption varies from 46.38 kWh / m2, in companies with new technology, to 89.37 kWh / m2 for older companies. Even considering the individual warehouses, we see how wide the consumption range is, which can vary from 30 to 130kWh / m2. In terms of energy per mass of meat produced

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[91] Redefining agricultural yields: from tonnes to people nourished per hectare
Emily S Cassidy, Paul C West, James S Gerber and Jonathan A Foley
Institute on the Environment (IonE), University of Minnesota, Saint Paul, MN 55108, US

[92] E.M. Barber, H.L. Classen, P.A. Thacker. Energy use in the production and housing of poultry and swine – an overview, Canadian Journal of Animal Science, Vol. 69, 7-21.

[93] M. De Vries, I.J.M. De Boer. Comparing environmental impacts for livestock products: A review of life cycle assessments, Livestock Science, Vol. 128, 1-11.

[94] C. Baxevanou, D. Fidaros, Th. Bartzanas , C. Kittas. Energy consumption in poultries – energy audits in Greece, International Conference of Agricultural Engineering, AgEng 2014, C0623, 1-8, 2014.

[95] "Energy Consumption and Energy Saving Measures in Poultry " Catherine Baxevanou1, Dimitrios Fidaros, Thomas Bartzanas, Constantinos Kittas. Energy and Environmental Engineering 5(2): 29-36, 2017 http://www.hrpub.org DOI: 10.13189/eee.2017.050201

it ranges from 0.25 to 0.48 kWh / kg. Therefore, the case that requires the most energy are lowland farms with old technology with primary energy consumption of 0.69kWh / kg. However, when comparing poultry production with beef, we realize that it is largely convenient to raise chickens rather than cattle.

4.4 Dairy industry

a. Setting the scene

The dairy industry is one of the most important agriculture sectors: milk and dairy products are an important part of food tradition, more than 80 percent of the world's population, or about 6 billion people, regularly consume liquid milk or other dairy products. In 2014, the global dairy market was estimated at US $330 billion [96]

Milk are one of the most nutrient dense animal product consumed by human beings, it contains 87% of water and 13% of micro and macronutrients such as fats, proteins, vitamins and minerals.

More than one-quarter of 570 million farm-holdings worldwide, or more than 150 million farmers, are estimated to keep at least one milk animal, including cows, buffaloes, goats, and sheep. There are estimated to be 133 million holdings keeping dairy cattle, 28.5 million with buffaloes, and 41 and 19 million with goats and sheep, respectively[97]

Dairy sector have to face different challenges regarding milk production and distribution or its transformation in any dairy product. Indeed milk is a bulky and heavy good, high perishable, due to this its storage and transportation cost are high and in addition to that in order to produce a large amount of milk , an enormous amount of animals such as a cows, sheep and goats need to exploited.

As mentioned before dairy industry is not just milk, this raw material is used to produce a wide range of products, and dairies consumption, which has always been a staple in western countries is, nowadays, catching on in east countries. Increasing of dairy processing industry has driven to expansion of dairy factory farms, who replaced small and medium sized dairy farms in the developed countries, just to satisfy the increasing demand of dairy products.

b. Europe and milk production

Energy consumption in dairy farms is composed of direct use (energy consumption on the farm) and indirect use (energy required to produce farm inputs; eg Concentrated feed).

Precisely for this reason, similarly to cattle farms, the greater energy consumption is attributable to the consumption of fossil fuels used both as fuel for machinery and in the production of fertilizers used during

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[97] Energy Flow, Environment and Ethical Implications for Meat ProductionRobert A. KanalyLea Ivy O. ManzaneroGerard FoleySivanandam PanneerselvamDarryl Macer

the production process of concentrated feed. Obviously, in the case of dairy farms, electricity consumption can be even greater precisely due to the specific processes of the milk production chain.

To date, with an increase in milk production we observe an increase in energy consumption and this is inevitable unless major changes are made to the company's technologies and infrastructure.

Just as the farming system chosen for the production of meat influences consumption, the same applies to the extent and efficiency, that is the energy consumption per kg of milk produced or per capita, of energy consumption in farms. The possibility of choosing between pasture, confined, conventional, organic farming has a great impact on energy demand but is not the only factor to be taken into consideration. Since it is milk, it is not possible to consider milking and therefore the type of milking system, the time at which this occurs and the type of tariff. In fact, the chapter will discuss how the price structure influences the demand for electricity in this type of farms.

Through a meta-analysis that therefore exploits 36 studies to calculate the average energy consumption values (MJ kg - 1 energy corrected milk ECM) in 17 countries, it is found that the total primary energy consumption was 54% higher in conventional farms. compared to biological ones, data compatible with what has been said in chapter 2.

Among the studies that reported energy consumption (MJ kg - 1 ECM) in conventional dairy farms, an average of 4.1 MJ kg -1 ECM was calculated while for conventional confined farming systems they averaged 4. , 7 MJ kg - 1 ECM, while conventional grazing systems had an average of 2.8 MJ kg - 1 ECM.

On the other hand, seven studies have reported the use of energy in organic farms, an average of 2.7 MJ kg - 1 ECM has been calculated. If organic confined they had an average of 2.1 MJ kg - 1 ECM while studies on organic pasture systems have an average of 2.9 MJ kg - 1 ECM

According another survey carried out in 2009 on a sample of 60 dairy farms [98], the milking body is the most expensive user in terms of electricity consumption, with an average annual value of 420 kWh / cow in production and with a variability between 160 and 920 kWh / cow. Refrigeration of milk accounts for 43% of total consumption, followed by heating of the water (27%) and the vacuum pump (15%). For the management of manure, the average consumption is 34 kWh / cow per year, while for feeding it is 18 kWh / cow per year. Among the barn activities that require fuel, i.e. thermal energy, feeding is the most important item, with an average consumption of 45 litres / cow per year. At the end, on average, a total annual energy consumption of 884 kWh / cow, equal to 128 Wh / litres of milk, half attributable to the milking block (electricity consumption) and the remaining 50% to other stable operations (with prevailing heat consumption).

[98] Dolle J.B., Duyck J.B.. 2007. Les consommations d'ènergie en bâtiments d'èlevage bovin. Institut de l'Elevage. Chambres d'Agriculture de Bretagne et des Pays de la Loire, Compte rendu n° 050733008.

According to an analysis, conducted in Denmark[99], the most energy-consuming users are, in order, the vacuum pump, the compressor of the refrigeration tank, the electric boiler for the production of hot water and the automatic washing system of the milking system.

A German study[100] carried out on 41 farms reports, for the milking system as a whole, shows that annual electricity demand varying between 166 to 269 kWh / cow , equal to 2.58- 4.14 kWh / 100 kg of milk produced. The total average electricity consumption of the farms examined is thus 9 kWh / 100 kg of milk, 68% attributable to the milking parlor, 14% to the power supply, 8% to lighting and environmental control, 6% to the removal of effluents and 4% to other activities. From the analysis of the data collected in 4 German herds with very different consistency and production (from 60 to 400 cows and from 6,250 to 7,000 kg / cow per year), reports an energy consumption for heating technological water and for cleaning ranging from a minimum of 287 to a maximum of 350 kWh / cow per year, finally, the average total consumption of electricity for the various breeding activities, is equal to 5.2 kWh / 100 kg of milk produced.

In 2010 an Italian study[101] estimated the overall energy consumption of electricity and thermal energy of all operations relating to breeding in a Lombard dairy farm with a consistency of 195 lactating cows at 1,065 kWh / cow per year. This value is equivalent to 83.7 Wh / liters of milk, of which 25.4 attributable to milking. In conclusion the Table 2 summerize the direct and indirect energy inputs, including also soe kind of meat that were not discussed in the chapter.

Food product	Animal feed conversion	Direct and indirect energy inputs
Chicken	4.2 kg/edible meat	25-35 MJ/kg meat
Pork	10.7 kg/edible meat	25-70 MJ/kg meat
Beef (feedlots)	31.7 kg/edible meat	80-100 MJ/kg meat
Laying hens	4.2 kg/kg eggs	450-500 MJ/year
Dairy milk	0.7 kg/litre milk	5-7 MJ/litre of fresh milk

Table 2. Total on-farm energy inputs (including indirect energy for feed, buildings and equipment) per unit of animal food product[102]

4.5 Case study : Correlation between price structure and electricity demand

a. Introduction

The change in energy consumption and in particular that of electricity has been studied several times considering the changes in the price of electricity in dairy farms.

[99] Rasmussen J.B., Pedersen J. (2004) - Electricity and water consumption at milking. Danish Agricultural Advisory Service, National centre. Disponibile on line sul sito www.farmtest.dk

[100] Jäkel K. (2003) - Analyse der Elektroenergieanwendung und Einsparpotentiale am Beispiel sächsischer Milchviehanlagen (Analysis of the electrical energy input and
saving potentials at the example of Saxon dairy farms.). Forschungsbericht Agrartechnik, 414, Martin-Luther-Universität Halle/Saale.

[101] Zappavigna P. (2010) - Consumi di energia in stalla, quanto si può risparmiare. L'Informatore Agrario, 48 Suppl.: 40-43.

[102] See note 15

In particular, an Irish study[103] has shown the impact that changes in tariffs have on the consumption of electricity itself and therefore with the management of the farm, especially in dairy farms where the milking operation is moved to earlier or later than the day). A previously developed model[104] capable of simulating electricity consumption and costs in dairy farms (MECD) was used to simulate five different electricity tariffs (Flat, Day & Night, Time of Use Tariff 1 (TOU1), TOU2 and Real Time Pricing (RTP)) on three different types of dairy farms: a small farm (SF), a medium farm (MF) and a large farm (LF).

b.

Starting from the first "Flat" tariff for definition, the electricity price remained constant for all periods of time, the Day & Night tariff, consisted of two electricity prices, a high rate from 09:00 to 00:00 h and a low rate afterwards. Very similar to the tariff structure that divides daytime and night time was the TOU, divided into TOU1 and TOU2. The last RTP rate, however, varied dynamically based on the electricity demand on the national grid. The model takes into account different agricultural equipment, used in milk cooling systems, water heating system, milking system, lighting systems, water pumping systems and winter housing structures. The two different time slots for milking were taken into consideration, and the result obtained showed that the first hour of the day AM and the last hour PM had the least energy consumption.

In particular, focusing on the data, it is noted that the difference between the lowest and highest electricity consumption within a day and a farm was 7% for SF, 5% for MF and 5% for LF. This difference is due to the variation in the coefficient of performance of the milk cooling system

The two most common rates, flat and day and night, are used as a basis and as a reference point to show how the use of rates that expose the consumer the hourly rate in real time, is an efficient and effective tool in order to improve consumption. and therefore reduce costs.

In the Flat a price of € 0.16 / kW h was set throughout the year while in the Day & Night rate the implied prices were of € 0.16 / kW h from 09:00 to 00:00 h and of € 0.08 / kW from 00:00 to 09:00 h. The mean electricity price on the Day & Night Tariff, therefore, was € 0.13 / kW h

In the TOUs, on the other hand, there was the addition of a peak time band between 17:00 and 19:00, in this case with two different prices TOU1 € 0.15 / kW h (range 0.14–0.22 € / kW h) , the mean electricity price of TOU2 was € 0.13 / kW h (range 0.08–0.23 € / kW h).

Lastly. Real time pricing, or RTP, where electricity prices varied in real time, from hour to hour but also over the course of the days or months of the year.

In particular, the calculation was made[105]

103Upton, J. R., Murphy, M., Shalloo, L., Groot Koerkamp, P. W. G., & de Boer, I. J. M. (2015). Assessing the impact of changes in the electricity price structure on dairy farm energy costs. *Applied Energy*, *137*, 1-8. https://doi.org/10.1016/j.apenergy.2014.09.067

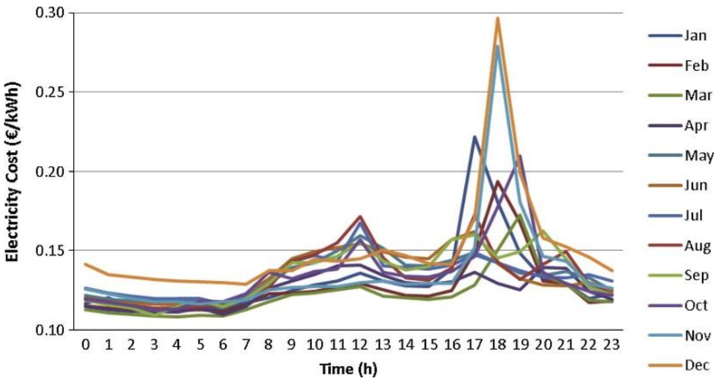
104 J. Upton, M. Murphy, L. Shalloo, P.W.G. Groot Koerkamp, I.J.M. De BoerA mechanistic model for electricity consumption on dairy farms: definition, validation and demonstration J Dairy Sci, 97 (8) (2014), pp. 4973-4984

105 Deane P, Fitzgerald J, Malaguzzi-Valeri L, Touhy A, Walsh D. Irish and British historical electricity prices and implications for the future. Working paper no. 452, Dublin (Ireland): Economic and Social Research Institute (ESRI); 2013

RTP (i, j) = SMP (i, j) + Tc + Bc + Dc + Rm

where RTP (i, j) is the real time price of electricity in month i (1–12) and hour j (1–24) (€ / kW h); Tc is transmission cost, taken as € 0.008 / kW h; Bc is balancing cost, taken as € 0.003 / kW h; Dc is distribution cost taken as € 0.051 / kW h and Rm is retail margin taken as € 0.017.

In conclusion, therefore, the mean electricity cost of the RTP was € 0.13 / kW h (range 0.11–0.30 € / kW h).



Returning to the above, energy in a dairy industry is used for different purposes and varies greatly according to size, in fact the results of the simulation model of this study show electricity costs per liter of milk were lowest for the SF, ie 33 W h / L and € 0.0037 / L. The corresponding figures for the MF were 41 W h / L, € 0.0044, whereas for the LF they were 42 W h / L, € 0.0046 € /

In particular, the consumption of simulated electricity varies according to size and settles at 8498 kW h in the SF, in the case of the MF 20,631 kW MF and in the case of the LF the simulated electrical consumption of 32,407 kW h.

As mentioned above, there is a change in electricity costs based on the milking start time and the reduction margins are different based on the type of tariff used.

The broadest scope for reducing total annual electricity costs by adjusting milking start times was TOU2 (39%, 34% and 33% of total annual electricity costs on SF, MF and LF) and the minimum rate for reductions using this method was the flat rate (7%, 5% and 7% of the total annual electricity costs).

The results show how the dimensions influence the potential for reducing the annual consumption of electricity and the related costs per liter of milk produced in fact in the LF the costs have a higher margin of reduction for the LF compared to SF or MF in all tariffs electric. Therefore, the increase in energy efficiency and forecasts on electricity costs in future tariff structures of electricity prices.

Therefore, we come to the conclusion that in the future it is necessary to make a wider choice available for electricity consumers in relation to the electricity tariff, not only private but above all in the industrial and production of goods sector, as in this case the producers of milk, in relation to the electricity tariff to which they subscribe. We therefore think about how to improve the decision-making process and make it more efficient, in order to use it to predict the energy costs of dairy farms in a variety of tariff environments for electricity, helping the farmer / consultant to choose the option best for a given farm. In fact, it shows how the electricity cost of the dairy farms is influenced by the time of the activity and therefore there is no more advantageous tariff in a general sense, but the farm may have to change the tariff if there is a change in the routine.

c. International contest

Limiting the results of previous study to Ireland alone, the country where it took place, is very reductive since the trend of electricity consumption and the relationship with the demand profile on domestic network are relevant aspects for the dairy industries of each industrialized country but above all they are aspects that also take on an international character.

At the residential level in the United Kingdom over 4.5 million residential consumers benefit from the TOU tariffs and therefore have a radio meter or remote switch connected to the load-shifting appliances. In other countries such as Estonia, Finland, France, Ireland, Italy, Malta, the Netherlands, Norway, Portugal, Spain, Sweden and the United Kingdom, there is a clear path towards intelligent measurement. Some countries, such as Australia[106] and New Zealand[107], have recognized intelligent measurement as a method of improving resource efficiency. The milk production industries of many countries are well established and therefore may be able to use smart grid infrastructure to their advantage. By observing the increases in electricity costs, a farmer could choose the best electricity tariff.

In conclusion, the analysis presented shows how the energy costs of dairy farms are influenced by the tariff at which the farm subscribes and how they can vary according to the routine of activity. However, technology and management can also play a significant role in reducing electricity costs.

Especially in all three farms, the costs were lower in the daytime and nightly rate and higher in the flat rate (between 19% and 51% more than the daytime and night-time rate). The highest maximum adjustment potential existed on TOU2, while the lowest maximum adjustment potential existed on the flat rate. LFs, which present room for improvement, can take advantage of dairy farms' energy cost forecasts in a variety of electricity tariff environments.

Finally, it was realized that regardless of the other variables choosing electricity tariffs with a low off-peak rate results in financial savings.

5.Energy waste in food production: environmental impact

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[106] DRET. Cost-benefit analysis of options for a national smart meter roll-out: phase two—regional and detailed analyses regulatory impact statement. Canberra (Australia): Department of Resources Energy and Tourism (DRET); 2008.

[107] Developing our energy potential New Zealand Energy Efficiency and Conservation Strategy, Energy Federation of New Zealand, Wellington (New Zealand) (2010

In the previous chapters, where the energy demand of the agricultural and livestock sector was analysed, an important concept came out clearly. It is clear that, like all industrial processes, even the production of food depends to a large extent on fossil energy[108].

Since the global energy crisis of the 1970s, dependence on fossil fuels and other non-renewable resources has been recognized as a structural limitation of the current socio-economic development model[109]. Therefore, considering the increase in world population that will take place by 2050 and the current model of exploitation of natural resources, we realize that it is not sustainable to live the modern and consumerist style of Western countries.

The excessive exploitation of nature is a great danger for the survival of the human species on earth, considering that the resources are not unlimited we should think of a transition towards an intelligent, equitable and sustainable use of energy, food and water[110].

A greater awareness in food production fits perfectly within this discussion, not only as a basis for human life, but also as one of the most energy-intensive economic activities.

In addition to having a very high demand for energy, the agri-food sector has a rather low energy efficiency: for example, in the United States, 10 kcal of energy from fossil fuels are required to produce one kcal of food[111]. A similar perspective allows us to estimate that the production of food of animal origin alone implies an 18% share of global greenhouse gas (GHG) emissions, equivalent to the industrial sector and higher than the transportation sector[112]. Therefore, changes in food choices could have an impact as important as changes in the way people travel[113].

The energy intensity of food systems is also the cause of important socio-economic phenomena. The recent food crisis has highlighted the profound interactions between food and energy markets[114,115]. During the first decade of the 21st century, global prices of basic foodstuffs followed almost immediately the prices of petroleum products[116] (a topic also analysed in Chapter 3). This pattern has placed serious pressure on food security in developing countries and has increased the vulnerability of production systems to energy costs, especially for smallholder farmers[117]. Despite this energy load, contemporary food systems involve an equally excessive creation of residual biomass. Part of this inefficiency is intrinsically linked to production processes,

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108 Georgescu-Roegen, N. The Entropy Law and the Economic Process; Harvard University: Cambridge, MA, USA, 1971.

109 Pieterse, J.N. Development Theory, Handbook of Research on Educational Communications and Technology; Sage Publications: London, UK, 2010.

110 Crutzen, P. Geology of mankind. Nature 2002, 415, doi:10.1038/415023a.

111 Cuéllar, A.D.; Webber, M.E. Wasted food, wasted energy: The embedded energy in food waste in the United States. Environ. Sci. Technol. 2 010, 44, 6

112 Steinfeld, H.; Gerber, P. Livestock's Long Shadow. Environmental Issues and Options; Food and Agricultural Organization: Rome, Italy, 2006.

113 Eshel, G.; Martin, P. Diet, energy, and global warming. Earth Interact. 2006, 10. [CrossRef]

114 Mitchell, D. A Note on Rising Food Prices. 2008. World Bank Policy Research Working Paper Series, 2008. Available online: http://ssrn.com/abstract=1233058

115 Trostle, R. Global Agricultural Supply and Demand: Factors Contributing to the Recent Increase in Food Commodity Prices; ERS USDA WRS-0801. Available online: http://www.ers.usda.gov/media/218027/wrs0801_1_.pdf

116 Heinberg, R.; Bomford, M. The Food & Farming Transition: Toward a Post-Carbon Food System; Post Carbon Institute: Sebastopol, CA, USA, 2009

117 Bush, R. Food riots: Poverty, power and protest. J. Agrar. Chang. 2010, 10, 119–129. [CrossRef]

as in the case of pruning, cultivation and processing by-products, inedible waste and potentially hazardous waste such as used vegetable oil. This often untapped biomass should be perceived as a systemic inefficiency contributing to the depletion of limited resources, such as water, land and fertilizers[118], as well as loss in economic value. In addition to this, the food waste of edible products must be considered.

5.1 Food waste is energy waste

About a third of the food produced is lost or wasted, this is a quantity of edible food products, which are lost along the entire food chain (FSC) equal to about 1,200 Mt per year.[119]

All this happens because in the world production of food exceeds the needs, because of the hyperalimentation habits that prevail in countries with fairly high GDP.

Suffice it to say that while in sub-Saharan Africa the food produced per day per capita is lower than the daily requirement of a person, in countries with high GDP[120] about 50% more food is produced than necessary.

All of this in addition to having harmful effects on people's health also has negative effects on the environment. Especially considering that large amounts of food are simply wasted. Food waste in European and North American countries is between 95 and 115 kg per capita per year[121], this amount is really high when compared with losses from 6 to 11 kg per capita per year which occur in sub-Saharan Africa, South Asia and Southeast Asia.

Some of the factors contributing to the accumulation of waste are:

- a misalignment between supply and demand;
- poor purchasing planning;
- imprudent preparation;
- the refusal of foods that do not meet rigorous quality standards or have passed the "use by" date.

Raising public awareness to avoid food losses and waste along the entire supply chain could benefit international goals of alleviating poverty and hunger but above all reducing energy inputs and greenhouse gas emissions[122].

Public awareness campaigns have begun to draw attention to the problem of food losses and waste. Public and private investment to reduce losses in crop, fish and livestock production systems would reduce risks to the supply chain, improve food quality and reduce GHG emissions per unit of consumption. Avoiding post-harvest losses would reduce food production costs and reduce greenhouse gas emissions from waste treatment and disposal of spoiled products.

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[118] Kummu, M.; de Moel, H.; Porkka, M.; Siebert, S.; Varis, O.; Ward, P.J. Lost food, wasted resources: Global food supply chain losses and their impacts on freshwater, cropland, and fertilizer use. Sci. Total Environ. 2012, 438, 477–489.

[119] Gustavsson J, Cederberg C, Sonesson U, Van Otterdijk R and Meybeck A, 2011. Global food losses and food wastes – extent, causes and prevention. Swedish Institute for Food and Biotechnology and the Rural Infrastructure and Agro-Industries Division, Food and Agriculture Organization of the United Nations, Rome. www.fao.org/ag/ags/ags-division/publications/publication/en/?dyna_ fef%5Buid%5D=74045.

[120]See note 15

[121] See not 120.

[122] UNEP, 2011. Towards a green economy: pathways to sustainable development and poverty eradication – a synthesis for policy makers. United Nations Environment Programme www.unep.org/greeneconomy.

Through the analysis of global quantified data on food losses and waste along the food chain compiled in different reports[123], it is possible to evaluate the energy waste that comes with food losses. When food is wasted, this embodied energy is also wasted, and the amount of this wasted energy is significant. From an energy point of view, food waste (FLW) can be considered a "double waste", because, on the one hand, the chemical energy contained in the food, and, on the other hand, the energy inputs of production are wasted together with the food[124].

However, although embodied energy is a fairly established concept, its application to food waste remains limited. Few recent studies[125,126] have attempted to estimate the resources incorporated in food waste[127] and only one has focused on energy[128].

Therefore, to elaborate a concept of "double waste" incorporated in FLW through the application of an analytical model for the evaluation of the energy incorporated in food waste in the FSC, which is characterized by a relevant use of energy [129] and by quantity considerable quantities of edible FLW along the entire chain .

In numerical terms, food losses in the United States account for about 2% of total annual energy consumption[130]. Overall, the energy embodied in global annual food losses is considered to be around 38% of the total final energy consumed by the entire food chain.

5.2 An Italian study on food waste

a. FSC energy demand

An Italian study[131] conducted by the University of Bologna in 2016, tried to calculate and describe in detail the double energy waste that comes from energy inefficiency and food waste.

Starting from the total energy use of the Italian FSC and considering that this peaked in 2002 at almost 1000 PJ and then decreased to 758 PJ in the maximum - annual variation between 2008 and 2009 (−7.2 %) in conjunction with the oil price shock[132], the variations in energy demand between 2002 and 2014 along different stages of production were considered.

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123 See note 119

124Cuéllar, A.D.; Webber, M.E. Wasted food, wasted energy: The embedded energy in food waste in the United States. Environ. Sci. Technol. 2 010, 44, 6

125 Grizzetti, B.; Pretato, U.; Lassaletta, L.; Billen, G.; Garnier, J. The contribution of food waste to global and European nitrogen pollution. Environ. Sci. Policy 2013, 33, 186–195.

126 Song, G.; Li, M.; Semakula, H.M.; Zhang, S. Food consumption and waste and the embedded carbon, water and ecological footprints of households in China. Sci. TotalEnviron. 2015,529,191–197.

127 See note 119

128Cuéllar, A.D.; Webber, M.E. Wasted food, wasted energy: The embedded energy in food waste in the United States. Environ. Sci. Technol. 2 010, 44, 6

129 Campiotti, C.; Viola, C.; Scoccianti, M.; Giagnacovo, G.; Lucerti, G.; Alonzo, G. Le Filiere del Sistema Agricolo per l'Energia e l'Efficienza Energetica. Report RT/2011/11/ENEA Rome. 2011. Available online: http://titano.sede.enea.it/Stampa/Files/cs2011/rapportotecnicocampiotti.pdf

130 Cuellar, A. D. and Weber, M. E. 2010. Wasted food, wasted energy: The embedded energy in food waste in the United States. Environ. Sci. Technol. 2010, 44, pp: 6464-6469. http://pubs.acs.org/doi/ pdfplus/10.1021/es100310d

131 The Hidden Burden of Food Waste: The Double Energy Waste in Italy
Matteo Vittuari , Fabio De Menna and Marco Pagani , Department of Agricultural and Food Sciences, University of Bologna, 19 August 2016

132 Hamilton,J.D.Causesandconsequencesoftheoilshockof2007–2008. InBrookingPapersonEconomicActivity. Spring 2009; pp. 215–259. Available online: http://www.brookings.edu/.ipcc

In agriculture, the strongest decrease occurred in the use of new machinery (-55%), fertilizers (-40%) and pesticides (-43%). Over the same period, the food processing sector recorded -21.6%, with the largest decrease in direct energy use (-35%), while the energy incorporated in packaging has changed by less (-11.2 %). Logistics contracted by 22%, with the largest reduction in exports (-55%). The distribution sector is in contrast, because in the same period it shows an increase in energy consumption of more than 60%. Over the whole period under review, the energy used in the FSC decreased faster than the total energy consumption (−14%), so the impact of the FSC on the total energy budget fell from 12.5% to 11% of the national energy budget[133].

However, the reduction in energy employment is mainly linked to a decrease in total production, which contracted from 100 to 78 Mt between 2000 and 2014, while energy intensity remained roughly the same. Considering 2011, for example, we see that the total production of nutritional energy of the FSC was equivalent to 323 PJ[134], the average input:output ratio can be estimated at 2.54 – that is, 2.54 MJ of primary energy was required to obtain 1 MJ of food before consumption.

It is also important to understand what caused this inefficiency and waste of energy. To do this, it is necessary to consider the average energy intensity for the different segments of the Italian FSC in the period 2000-2013. At farm level, 3.6 ± 0.3 MJ per kg of plant product were needed, while each kg of animal products requires an additional 7.8 ± 0.6 MJ of feed energy, for a total footprint of 11.4 ± 0.8 MJ (for the year 2011, the intensities of plant and animal agriculture were 3.28 and 10.79 MJ / kg respectively).

b. The double waste of energy

Using the FAO estimates for Europe[135], it is possible to construct an estimate the FLW relative to the Italian FSC, since reliable data with the same level of accuracy in the food categories were not available for the Italian territory. it was considered more prudent to rely on European averages.

Consider again year 2011. Mass food waste (FMW) was 17.9 Mt, so 17.3% of the total food supply S = P + I - O of 103 Mt[136] did not reach consumption. Considering that Italy has just over sixty million inhabitants, the FLW per capita was therefore equal to about 301 kg / year. This figure appears to be higher than the figure provided by a FAO report[137] for EU countries, but this is because feed was included in this calculation.

The greatest waste occurred for fruit and vegetables (two thirds of the global food waste), followed by cereals and tubers. This shows that the agricultural sector accounts for most of the waste.

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[133] MSE—MinisterodelloSviluppoEconomico,Dipartimentoperl’Energia. BilancioEnergeticoNazionale,Years from 2000 to 2014. Available online: http://dgerm.sviluppoeconomico.gov.it/dgerm/ben.asp (accessed on 12 May 2016).

[134] FAOSTAT. Food Balance Sheets. 2016. Available online: http://faostat3.fao.org/download/Q/QL/E (accessed on 12 May 2016).

[135] Gustavsson, J.; Cederberg, C.; Sonesson, U.; Emanuelsson, A. The Methodology of the FAO Study: Global Food LossesandFoodWaste—ExtentCausesandPrevention—FAO2011; SIK Report; No. 587, January 2013; Food and Agriculture Organization of the United Nations: Rome, Italy, 2013.

[136] FAOSTAT. Food Balance Sheets. 2016. Available online: http://faostat3.fao.org/download/Q/QL/E

[137] See not 120

5.3 GHG emissions of food production

Food chains around the world are responsible for the share of total (GHG) emissions., About 29% of global GHG emissions could be attributed to food alone and 18% to animal products alone. (EIPRO, 2006). This latest study analyzed the full life cycle of all goods consumed within the EU, i.e. including all imported and excluding goods produced within the EU and exported.

The impact of food on the climate depends on several factors. It must be taken into account that there are wide differences within the group of food production systems. The range of products is large and as a sequence also the production systems vary within the groups of products.

However, there are some common traits. For starters, fossil carbon dioxide (CO_2) emissions are less important than biogenic greenhouse gas emissions. For plant products, nitrous oxide (N_2O) is often the most important emission, as well as for the production of monogastric animals (pork, poultry), while for ruminants, methane (CH_4) is often the dominant gas. issued. Methane and nitrous oxide are very potent greenhouse gases, methane has a weighting factor of 25 times CO_2 and nitrous oxide 298.[138] For seafood, the correlation between energy consumption and climate impact is greater, especially for wild-caught fish. The climate impact of fishery products is dominated by fossil CO_2 emissions from the use of fuel on fishing vessels.

Products of animal origin, such as meat and dairy products, have on average higher emissions per kilogram than plant products, but there may be exceptions, like transport and packaging, which play an important role. Furthermore, as mentioned previously, food waste that ends up in landfills is also an important contributor to greenhouse gas emissions, in addition to the emissions that occur for their production, there is methane that is formed when food is degraded in anaerobic conditions in landfills.

A high land use per unit of food produced, i.e. a low yield, is also negative even if the direct emissions for the product could be lower. It should also be borne in mind that the way the land is used has a significant impact on other environmental impacts, such as eutrophication and biodiversity.

There is an ongoing debate on organic production, as compared to conventional production, regarding which system is more "climate friendly". The difference in terms of energy efficiency has already been addressed in the specific in Chapter 2. In short, it is worth summarizing here the opposite positions of the supporters of the two systems by saying that those who support conventional agriculture use the arguments of productive efficiency per hectare, while the supporters of organic agriculture emphasize the more resilient way of cultivate as an important aspect in the larger context.

However, a level of activities important from the point of view of GHG emissions we find that the two systems are similar, in fact even if the absolute levels of impact differ. Although as a general trend organic production is more efficient than conventional production, there are cases in which it is not so and that is why based on

[138] IPCC 2007, Climate Change 2007. IPCC Fourth Assessment Report. The Physical Science Basis. (http://www.ipcc.ch/ipccreports/ar4-wg1.htm)

the climatic impact of food production, what is produced and therefore our food choices matters more. than production systems.

a. LCA method

For a description of the climate impact of food production, the studies are mainly based on the Life Cycle Assessment (LCA) method. LCA is an ISO standardized method for the environmental assessment of products or services. In short, it can be said that LCA includes all the environmental impact caused by a product, from the "cradle to the grave", which means that all the flows necessary to produce, process and deliver the product are included in the analysis. Within the LCA approach, methods are used to allocate the emissions of individual substances into categories of environmental impact. Methods for defining system boundaries and allocating environmental burdens between products are somewhat blurred, so the results of LCA studies of similar systems may vary. These differences stem from the different methodological choices made by each study. Consequently, the results of the LCA must be interpreted as uncertain, but still useful for the identification of the most important parts of the production system taken in consideration in that moment and also for the identification and evaluation of potential for improvement. In food chains, the former parts (primary production and processing) of the chain differ significantly between product groups, while the latter parts are more similar. Therefore, the first part of the report covers the primary production of different product groups and the second part covers the post-farm activities of all product groups together.

5.4 GHG emissions: Livestock

To analyze GHG emissions from animal products, we divide them into two groups: monogastric animals and ruminants. For monogastric animals such as pigs and poultry feeding is the most important activity, followed by manure management. Emissions are dominated by nitrous oxide (N2O). For ruminants, such as cattle, sheep and goats, methane (CH4) emissions are often the most important. The second most important emission is nitrogen oxides from nitrogen turnover in feed production and manure management.
For all animal products, the subsequent stages of the chain such as transport, processing and packaging are less important in a relative sense.

a. Beef

At a global scale, beef is produced in extremely diverse production systems, but differences arise also within specific countries or regions. Beef is produced in "dedicated" herds, where meat is the main product, or as a by-product of dairy production, i.e. dairy calves are raised, and slaughtered cows are used for meat. The common factor of all these various systems is the high amount of methane produced.
In systems where a large share of feed is concentrated, such as wheat and soy, emissions from feed increase, both nitrous oxide and CO2. At the same time, methane emissions are lower if grazing cows are used.
An important explanation for the high GHG emissions related to beef production is the fact that it is necessary to add to the animal emissions those produced during the production processes of the feed, those produced by

manure and those produced to heat the stables. In addition to this the regeneration rate is very slow for cattle. Cows give birth to at most one calf per year, which means that all emissions during a cow year have to be transported more or less from the meat produced by the calf. In combined systems of milk and meat production, the cow produces both milk and a calf each year, which makes the beef produced by these systems less intense in terms of emissions. There are numerous LCA studies from different regions, the results for global warming and energy use are different.

The most recent studies, which are easily comparable with each other, have a tendency to show higher GHG emission than those of previous years. In particular, a CO2-equiv./kg bone-free meat is varies from 28[139], to 40[140], with two intermediate values of 30[141] and 32[142], for the first value the meat considered is also that deriving from calves and culled cows,

b. Dairy product

GHG emissions from production are similar to those from beef production, enteric fermentation and manure dominate with a contribution of 50-60% and nitrous oxides from feed production and manure management with about 30%[143]. There are differences however, dairy farming in developed countries is generally more intense with greater use of concentrated feed such as wheat and soy. Consequently, the feed supply is slightly more important.

Milk is one of the products most analysed by LCA. There are few studies from Europe, very few (if any) from developing countries. The results are quite similar and vary between 0.8-1.4 kg of CO2 equiv./kg of farmed milk. Since milk has a high water content (about 88%) it is reasonable to consider it compared to other animal products. Normalizing milk to 70% water means that greenhouse gas emissions are between 3.1 and 3.8 kg CO2 equiv./kg, on a meat-like dry matter basis.

c. Pigs

Pigs are monogastric animals and produce only a small amount of methane in the digestion of feed. However, it must be considered that pigs are fed with cereals and the like, feed that could be used directly as food by humans. The emissions during the life cycle of a pig are therefore normally dominated by agriculture and its inputs, in addition to unnecessary waste.

GHG emissions from pork are lower than those from beef and production is dominated by nitrous oxide - in fact, since no methane is formed in the digestion of the feed, the feed supply is the most important parameter

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[139] Cederberg et al. (2009b), "Average Swedish beef 2005"
[140] Cederberg et al. (2009a), "Average Brazilian beef"
[141] Verge, et al., (2008) , "Average Canadian beef
[142] Ogino et al. (2007) Japan
[143] Sevenster, M. & de Jong, F., 2009, A Sustainable Dairy Sector – Global, regional and life cycle facts and figures on greenhouse-gas emissions, Delft, CE, Publication number 08.7789.XX

and represents between 60 and 70% of total emissions up to the company gate. Total CO2-equiv./kg bone-free meat varies and we can find 6.4[144], 5.2[145] and 8[146].

Feed supply includes emissions caused by fertilizer production, nitrous oxide emissions to soil and energy used in arable agriculture and the rest of the emissions is mainly manure management.

d. Poultry

As regards this sector, the only LCA studies taken into consideration concern chicken, studies on ducks, geese or turkeys, in fact they are difficult to find and not very common in general.

Chicken is the absolutely dominant type of poultry globally and within the EU, but it is also the most consumed meat in the world.

Chickens are, like pigs, monogastric animals and have a high feed efficiency. At the same time, chickens have high demands on the composition of the feed and therefore the impact of feed on emissions is still significant. The high food efficiency leads to relatively low GHG emissions, compared to other farms. However, the stables must be heated to a greater extent than for cattle or sheep and this causes the emissions related to the management of the barn to increase. Particularly considering that in most of the EU fossil fuel predominates as a source. The total emissions are around 1.5 [147]

5.5 Vegetable products

a. Cereals

The climate impact of cereals has been studied extensively and it was realized that there are differences in the impact between the different cereals and energy crops, , however there is possible to identify which factors are the most important when it comes to greenhouse gas emissions.

As seen in Chapter 3, dedicated to the energy demand of agriculture, the production and application of nitrogen fertilizers is one of the activities with the greatest demand for energy, and since this energy is derived mainly from fossil fuels, it is easy to understand how the contribution to the overall climate impact of these nitrogen products is very high.

The production of nitrogen fertilizers generates fossil CO2, but also, and above all, nitrous oxide. The latter is in fact emitted both directly during the application of the fertilizer and indirectly as a consequence of the release of ammonia and the release of nitrate.

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[144] Williams, A.G., Audsley, E & Sanders, D.L., 2006, Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities, Main Report, Defra Research project IS0205, Bedford: Cranfield University and Defra, Available at www.silsoe.cranfield.ac.uk

[145] Cederberg, C., Sonesson, U., Davis, J. & Sund, V., 2009b, Greenhouse gas emissions from production of meat, milk and eggs in Sweden 1990 and 2005, SIK-Rapport 793, SIK – Institutet för Livsmedel och Bioteknik, Göteborg, ISBN 978-91-7290-284-8

[146] Basset-Mens, C. & van der Werf, H., 2003, Scenario-based environmental assessment of farming systems – the case of pig production in France, Agriculture, Ecosystems and Environment 1005, pp. 127-144

[147] Tynelius, G., 2008, Klimatpåverkan och förbättringsåtgärder för Lantmännens livsmedel – fallstudie Kronfågels slaktkyckling (Climate Impact and Improvement potentials for Lnatmännen’s chicken, in Swedish), Masters Thesis 2008, Dept. of Technology and Society, Environmental and Energy Systems Studies, Lund University, Lund, Sweden.

Secondly, there is the use of diesel for agricultural operations (plowing, harvesting, etc.) and for drying products, which contributes to the production of CO_2 emissions. However CO_2 is not the only GHG, nitrous oxide (N_2O) play a big role. Indeed, specific activities that contribute to N_2O emissions from agricultural lands include application of synthetic and organic fertilizers, the growth of nitrogen-fixing crops, the drainage of organic soils, and irrigation practices. Management of agricultural soils accounts for just over half of the N_2O emissions from the Agriculture economic sector. [148]

One of the most important foods globally is rice. Rice production in humid climates and where the fields are flooded is very different from dry or mountain rice production. The latter is in fact similar to other cereal crops from the point of view of climate impact, while the situation of paddy, rice grown in flooded fields, which is also the most important form of production globally, is totally different. A large amount of methane is formed under anaerobic conditions in flooded fields and in fact it is reported that rice represents 10-13% of global methane emissions globally[149]. Considering rice grown in Italy, for example,it was) calculated through an LCA that the total GHG emissions are 2.9 kg CO_2equiv./kg of white processed rice, which is six times higher than wheat flour[150].The main difference is its own field emissions, mainly methane, equal to about 70% of total emissions.

b. Legumes

In industrialized countries, legumes are often considered inferior as a protein source compared to animal sources - this is absolutely not correct. Legumes, in addition to having health advantages compared to animal proteins (insert study), have many advantages from an energy and environmental point of view. They are in fact much more efficient than animal proteins, i.e. they do not require the same amount of input per kg of protein compared to the inputs needed to produce 1 kg of animal protein.

One of the main advantages of legumes is the ability to fix nitrogen from the air and for this reason the use of nitrogen fertilizer is minimal or zero. This obviously leads to a reduction in the energy required for their production and benefits the climatic profile of these products.

There are various studies[151] evaluating the environmental impact of grain legumes, in particular by comparing different legumes, therefore with different origins and different processes. It is noted that most of the GHG emissions occur during cultivation as diesel is used. As for the subsequent processing, obviously if we consider canned products, packaging also plays an important role in greenhouse gas emissions compared to dried legumes.

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[148] *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2018* (published 2020), developed by the U.S. Government to meet annual U.S. commitments under the United Nations Framework Convention on Climate Change (UNFCCC).

[149] Neue, H.U., 1997, Fluxes of methane from rice fields and potential for mitigation, Soil use and management 13, pp. 258-267

[150] Blengini, G.A & Busto, M., 2009, The life cycle of rice: LCA of alternative agri-food chain management systems in Vercelli (Italy), Journal of Environmental Management 90, pp. 1512-1522

[151] Lagerberg Fogelberg C. & Carlsson-Kanyama, A. 2006. Environmental assessment of foods – an LCA inspired approach. In: Fuentes, C. & Carlsson-Kanyama, A. (reds.). Environmental information in the food supply system. Totalförsvarets forskningsinstitut (FOI), FOI-R-1903-SE. ISSN 1650-1942. Errata, available at www.cul.slu/forskning/forskare/charlottel.html

It is also interesting to consider the study by XX[152],which compares meals with different protein sources (similar content of protein, fat and energy). It shows that comparing a meal with a pea burger with a meal with a pork chop, we find a very large difference in the volume of GHG emissions. The former is associated with significantly less GHG than a pork chop meal.

c. Potatoes and root vegetables

Potatoes and other root vegetables are particularly efficient in growing, as the yield level is so high per hectare, resulting in low GHG emissions per kg of product. Emissions can vary depending on the type of soil. However, as cultivation is typically efficient, i.e. low inputs and emissions per unit produced, the energy used and emissions from the packaging or processing processes and to finish transport are important contributors to the overall carbon footprint for these types of products. .

d. Fruits and vegetables

When it comes to fresh fruit and vegetables, emissions are very limited and often concern only the use of fertilizers or pesticides, totally excluded when considering organic farming. The biggest problem with these products is that they are often sensitive to handling and have limited storage times, which can result in significant amounts of energy being used and also significant food waste.

Some fruits and some vegetables are often grown in heated greenhouses, in this case the emissions cannot be the same as a product grown in the field. In fact, the production of heat is the most important parameter for the carbon footprint of the product, where obviously the use of fossil fuels results in high greenhouse gas emissions. However, if biofuel was used instead of fossil fuels for heating, the emissions would be significantly different.

If we consider for example the production of tomatoes, often grown in greenhouses, we realize that the fossil-based heating system produces greenhouse gas emissions more than three times higher than tomatoes grown in a heated greenhouse with biofuels.

Emissions are even lower if we consider a country with a mild climate where tomatoes are grown in the open air. In Spain, for example, we find 0.35 kg CO2equiv./kg product for tomatoes grown in the open air, compared with 0.4 for Swedish greenhouses that use biofuels and 1.65 for those that use fossil fuels.[153]

5.6 Conclusion: revolution at the table

To conclude it can be said that the activities of the food system, including the production of food, the transport and storage of wasted food in landfills, produce greenhouse gas (GHG) emissions that contribute to climate change.

[152] Davis, J., Sonesson, U., Baumgartner, D. & Nemecek, T., 2009, Environmental impact of four meals with different protein sources - case studies in Spain and Sweden, accepted for publication August 2009, Food Research International

[153] Food Production and Emissions of Greenhouse Gases , An overview of the climate impact of different product groups Ulf Sonesson Jennifer Davis Friederike Ziegler

Of these sources, livestock production is the largest, accounting for approximately 14.5% of global greenhouse gas emissions from human activities[154]. A diet with a high presence of ruminant meat, such as cattle and goats, is particularly emissions-intensive[155] and therefore not very sustainable.

With the aim, therefore, of avoiding catastrophic climate change scenarios, of limiting the average increase in global temperature to 2° Celsius above pre-industrial levels, it is clear that an immediate change in human consumption habits is needed.

Imagining a scenario in 2050, when society will have finally abandoned non-renewable energy sources such as fossil fuels in favor of renewable sources such as wind and solar, where public policies and infrastructure investments have made traveling on foot, by bicycle and public transport the most accessible and popular forms of transportation and air transportation is used only as a last resort – one may think this is an idyllic situation. This is not the case: if global trends in meat and dairy intake continue, our chances of staying below the 2° Celsius threshold will still be extremely low[156]. This is why urgent and drastic reductions in consumption of meat and dairy products, are key to avoiding catastrophic climate change.

It is impossible to think that simple consumer education will suffice to change diets on an international scale, it will be necessary a policy intervention at the national and international level. Funding for animal husbandry and intensive livestock farming will have to be transformed into funding for farmers seeking ways of producing food in a more environmentally friendly and energy efficient way.

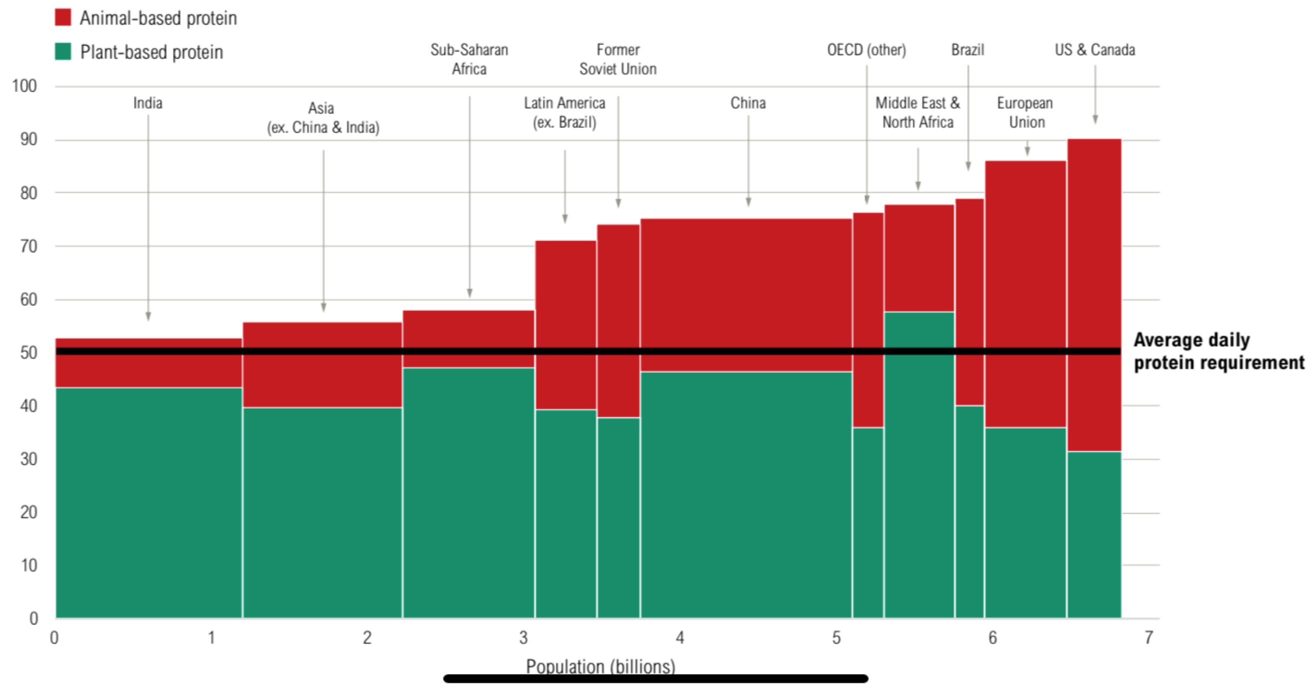
The possible shifts towards a more sustainable diet are therefore:

• A general reduction in calories intake: as mentioned in the previous paragraphs, overeating involves great waste of food, therefore double waste of energy and totally useless greenhouse gas emissions.

• Reduction in the consumption of proteins derived from animals. In reality, an over-consumption of protein occurs in every region of the world, in fact, as the GDP increases, the consumption of proteins, especially animals, increases.

In 2009, for example, considering that the average daily consumption recommended is 50g of protein, the average daily consumption reported is 68g of protein per day. Figure XXY shows how in the poorest countries almost all the protein requirement is covered by vegetable proteins, in the Middle East and North Africa, the dose of 50g per day is even exceeded. While the most developed countries double the necessary proteins and in particular in the US and Canada, the European Union and other OECD countries, protein consumption is well reaching 80-90g per day and the amount covered by vegetable proteins is less than 40g.

[154] Searchinger, T., C. Hanson, J. Ranganathan, B. Lipinski, R. Waite, R. Winterbottom, A. Dinshaw, and R. Heimlich. 2013. Creating a Sustainable Food Future: Interim Findings of the 2013–14 World Resources Report. Washington, DC: World Resources Institute.
[155] Keats, S., and S. Wiggins. 2014. "Future diets: implications for agriculture and food prices." London: Overseas Development Institute.
[156] Delgado, C., M. Rosegrant, H. Steinfeld, S. Ehui, and C. Courbois. 1999. "Livestock to 2020: The next food revolution." IFPRI Food, Agriculture, and the Environment Discussion Paper 28. Washington, DC: IFPRI (International Food Policy Research Institute).



Source: GlobAgri model with source data from FAO. Width of bars is proportional to each region's population. Average daily protein requirement of 50 g/day is based on an average adult body weight of 62 kg and recommended protein intake of 0.8 g/kg body weight/day (Paul 1989). Individuals' energy requirements vary depending on age, gender, height, weight, pregnancy/lactation, and level of physical activity

• Elimination of meat and dairy products. As previously mentioned, the largest source of emissions is the breeding of ruminates and consequently an elimination of their meat or derived products would have enormous benefits. In addition to this, obviously vegetarian or vegan diets can be considered, therefore partially plant-based or totally plat-based, in which case the emission reductions are 22% and 26% comparing to the emission of an average omnivore diet[157].

In addition to the diet, other conscious choices can be made to limit greenhouse gas emissions, such as avoiding industrial and highly processed foods, avoiding foods packaged especially in plastic, buying local and seasonal foods in order to avoid emissions deriving from conservation and transportation, buying seasonal produce and avoiding greenhouse products.

Obviously, changing eating habits is not easy, but through a process of education, through policies aimed at promoting the consumption of the right foods and discouraging that of highly unsustainable foods, a lot can be done.

[157] Scarborough, P., Appleby, P.N., Mizdrak, A. et al. Dietary greenhouse gas emissions of meat-eaters, fish-eaters, vegetarians and vegans in the UK. Climatic Change 125, 179–192 (2014). https://doi.org/10.1007/s10584-014-1169-1

6. Possible approaches for the future

Climate change poses many threats to agriculture, including production instability and the possibility of a decline in production. Obviously, this has an impact not only on the reduction of income in areas of the world that already have high levels of food insecurity but also limited means to cope with unexpected events or weather conditions caused by global change.

That is why it is absolutely necessary to find new approaches for the future. As remarked in the previous chapters, an increasing population in nations that are facing a changing climate is a threat to the natural resources of our planet.

FAO together with other partners, and especially the agriculture departments of different nations, promotes smart agriculture climate in order to sustainably increase productivity. Developing models to adapt to climate change, building resilience to shock and variability but above all reducing greenhouse gas emissions are therefore the objectives for the coming decade.

It must always be considered that during most of the processes of the agri-food chain, we find a very high use of fossil fuels and therefore agriculture itself contributes, together with the change of land use and forestry activities to about one third of emissions of greenhouse gases[158].

The technical mitigation potential of agriculture is high, the equivalent of 5.5-6 billion tons of carbon dioxide per year by 2030[159] and 70% of this potential could be realized in developing countries where agriculture is generally practiced by small farmers.[160]

6.1 Renewable energy supply options for the agri-food chain

The use of renewable energy resources along the entire agri-food chain is certainly one of the most valid alternatives to improve access to energy and reduce energy security problems linked to farming.

Indeed, one of the main objectives of the agriculture sector is precisely to reduce dependence on fossil fuels and the consequent greenhouse gas emissions, thus aiming to achieve the sustainable development goals also declared by the UN.

Certainly despite a variety of changes and the fact that the transition from fossil fuels to renewable energy systems has already begun, it will take time to have a total change and therefore we must think that to obtain a full effect (and renounce to the use of fossil fuels altogether) will be necessary to wait years, if not decades.

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[158] IEA, 2014. World Energy Outlook, 2014. International Energy Agency, OECD/IEA, Paris.

[159] IPCC, 2007. 4th Assessment Report - Mitigation, Chapter 7, Industry, Working Group III, Intergovernmental Panel on Climate Change. Available online at www.ipcc-wg3. de/publications/assessment-reports/ar4/.fi les-ar4/ Chapter07.pdf

[160] FAO, 2009. Small scale bioenergy initiatives – brief description and preliminary lessons on livelihood impacts from case studies in Asia, Latin America and Africa. Policy Innovation Systems for Clean Energy Security (PISCES), Practical Action, and FAO, Environment and Natural Resources Management working paper 31, 149 pages. Food and Agricultural Organization of the United Nations, Rome. Available online at http://www. fao.org/docrep/011/aj991e/aj991e00.htm

Considering, for example, the various alternatives such as biomass, wind, solar, hydroelectric, geothermal and ocean energy, we realize that the renewable energy resources available are many and this must be taken into strong consideration.

Although renewable energy satisfies about 13% of the global primary energy demand, almost half comes from traditional biomass used for cooking and heating and not from industrial use as food production.

In fact, focusing on renewable energy, in 2014 world renewable energy has reached a capacity of 103 GW and investments in this sector have increased. In particular, those that are strictly considered as renewable energies cover about 9.1% of world electricity production in 2014 and therefore bring a saving of 1.3 Gt of CO2[161]. Many scenarios show that modern renewable energies will increase to over 70% by 2050[162].

However in places where there is easy access to renewable energy resources such as wind, solar, micro-hydroelectric energy, farmers and agri-food companies can install their own technologies to generate the electricity necessary for the operation of the company itself. In addition, one can think of a collaboration between landowners and wind, geothermal or other renewable energy developers and obtain a share of the resulting electricity sales.

As for the current use of renewable energy, actually looking at the data and various case studies, we realize that it is already widely used throughout the agri-food sector, despite the fact that it is still dependent on fossil fuels. It is sometimes used directly to provide energy supplies on site or indirectly as a result of integration into the existing conventional energy supply system[163].

The geolocation of renewable energy sources dispersed in rural areas tends to be an advantage thanks to the possibility of providing a reliable and convenient energy supply, being closer to food production sites such as farms or crops.

The problem of the dependence of the agri-food system on fossil fuels would be almost totally eliminated if farms were therefore using renewable energy in all those processes in which it is possible to do so. For example, in agriculture, the selection of vegetables and irrigation are those processes that are more easily convertible than actions such as plowing or the production of fertilizers where fossil fuels cannot yet be ignored. In livestock farming, however, especially considering the milk industry, milking and cooling are the most easily convertible processes.

What has been said so far not only applies to industrialized countries but also to developing countries and emerging economies, which aiming to generate renewable energy for such productive uses offers the opportunity to also provide the much-needed bases for energy services.

The land area required for renewable energy projects is usually relatively small, with the exception of biomass energy crops (which we will consider more specifically in the next paragraphs). The total area of wind farms typically covers only 5% of the total agricultural area to which it refers, obviously the same is not true with large photovoltaic solar panels that can also use several hectares.

Even the hydroelectric power solution should not be totally excluded. Although it may seem more complicated to apply on site, there is the possibility of creating small hydro-river projects requiring only a small area of land for the turbine.

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161 UNEP, 2015. 9th Global Trends in Renewable Energy Investment 2015. Frankfurt School-UNEP Collaborating Centre for Climate & Sustainable Energy Finance and Bloomberg New Energy Finance. Available online at http://fs-unep-centre.org/publications/global-trendsrenewable-energy-investment-2015

162 IPCC, 2011a. Summary for Policy Makers, IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation, Cambridge University Press. Available online at http://srren.ipcc-wg3.de/report/IPCC_SRREN_SPM. pdf

163 Sims R, Mercado P, Krewitt W, Bhuyan G, Flynn D, Holttinen H, Jannuzzi G, Khennas S, Liu Y, O'Malley M, Nilsson L J, Ogden J, Ogimoto K, Outhred H, Ulleberg O, van Hulle F, 2011. Integration of Renewable Energy into Present and Future Energy Systems. Chapter 8 in IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation Cambridge University Press. Available online at http://srren.ipccwg3.de/report/IPCC_SRREN_Ch08.pdf

a. Wind power and solar photovoltaics

In the past the wind was used to drive windmills, so even before the introduction of clean energy, wind energy was exploited by man for various processes, particularly related to agriculture (pumping water) or food production (such as the grinding of wheat). Even today in some rural areas the mills are in operation for the production of flour.

As far as the production of electricity is concerned, there are wind turbines that generate electricity between 0.3 kW and 6 MW. The latter have now become reliable and economical.

The amount of electricity generated by a given production site depends on the availability of wind, and the power generated by a turbine is determined by the cube of the wind speed. For this reason, wind turbines are often strategically connected to ses with an excellent average annual wind speed of 10 m / second (capacity factor around 45% -50%). Taking this into consideration we have that the turbine will generate about three times more electricity in a year as if it were located on a good to medium site with an average speed of 7 m / s (capacity factor around 20% -25%)

As a general rule, wind turbines can be competitive when the average wind speed is 5 m / s or higher. As previously mentioned, usually the sites are preselected based on the map of wind but also considering the data collected in a previous period of time. Obviously, the choice must then be validated with on-site wind measurements before the development of a wind farm.

Technological developments in recent years have led all the technologies underlying the production of energy starting from renewable sources to be more efficient and reliable.

As it is the case with many other forms of renewable energy technologies, the benefits of wind turbines include the non-production of greenhouse gases, although obviously their production has its own carbon footprint, they can provide electricity to remote locations off the grid, requiring relatively little time for planning and construction compared to coal, gas and nuclear projects and finally wind power generation is characterized by great flexibility with respect to a growing energy demand as more turbines can easily be added to a park existing wind power.

In general, energy costs per kWh generated decrease with increasing turbine size, so smaller turbines are relatively expensive per kW of installed capacity. Micro wind turbines can be as small as 50W and only generate around 300 kWh / year.

Small turbines in low wind speed locations (4m/s-5m/s) could generate up to 1,500 kWh / year and save around 0.75t CO_2-eq if they replace diesel generation.

If, on the other hand, we consider turbines capable of satisfying the energy needs of commercial activities, there are small turbines of 20 kW and a rotor of 9 m in diameter that can produce about 20 MWh per year for use in farms and in small agri-food businesses.

Solar radiation, on the other hand, which is exploited as a source of energy by the whole plant kingdom, can also be exploited by man in a much broader way, by converting it into electricity using photovoltaic panels made up of solar cells.

The PV systems are modular and range from residential systems with power 0.25 kWp-10 kW, up to industrial scale PV systems with a capacity of over 1000 MW. A PV system with a nominal capacity of 1 kWp will occupy a roof or ground area of approximately 6 m^2 and generate approximately 1 kWh of electricity in an hour or more depending on cloud cover. Typically the higher the efficiency, the higher the cost / kWp. The installation point is fixed, there are panels that are equipped with a system that allows them to follow the sun, in order to have panels oriented towards the sun to absorb 30% compared to fixed panels[164].

b. Biomass

Food processing plants often use biomass by-products for heat and energy, the production is detailed in the next paragraph. As for the use by agriculture, the heat and electricity generated are typically used on site.

Obviously this is not a rule and given that biogas is used in a variety of processes and in a variety of sectors, there is also the possibility of selling the excess quantity or exporting it to the electricity grid as a source of additional revenue for the company.

Indeed biogas can also be used for a wide range of energy applications such as industrial burners (with a consumption of about 1,000 L / hour - 3,000 L / hour); gas refrigerators (30 L / h -75 L / h for 100 liters of capacity depending on the ambient temperature); co-powered biogas / diesel engines (500 L / h per kW). About 1 m3 of gas is needed to generate 1 kWh of electricity from biogas (or less if co-fired with diesel or petrol).[165]

6.2 Renewable energy supply options from the agri-food chain

a. Bioenergy

Biomass is certainly the most widely used form of renewable energy in the world and can be defined as "energy contained in living or recently living biological organisms" (fossil fuels are thus excluded). There are various sources from which biomass can be obtained: specially grown energy crops, by-products of agricultural production and food processing and end-use materials. In addition, the applications are different and it means that heat, electricity and fuel for transport can be supplied.

The most common varieties of solid biomass are vegetative herbaceous crops, forest residues, crop residues, walnut shells, rice husks, and other waste such as animal waste and urban waste.

Technologies for the thermochemical conversion of combustion, gasification and pyrolysis are largely mature, although improvements in conversion performance and efficiency are certainly something that can be worked on.

Two types of biomass that are very popular are liquid or gaseous biofuel. These are produced from biomass sources that are generally high in sugar (such as sugar cane, sugar beet, sweet sorghum), starch (such as corn and cassava) or oils (such as soy, canola, coconut, sunflower, and palm). The best examples are ethanol and biodiesel used for transportation. It is important to underline how global biofuel production has grown steadily over the last decade from 16 billion liters in 2000 to over 110 billion liters in 2013[166].

Biogas, instead, is produced by the digestion in anaerobic conditions of organic matter, for example all biodegradable raw materials, manure, crop residues, urban waste or food processes. In addition to the primary production of biogas in large plants, there is also the possibility of installing domestic biogas plants for the production of gas mainly used for cooking and heating homes.

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[164] Mehrtash M, Quesada G, Dutil Y, Rousse D, 2012. Performance evaluation of sun tracking photovoltaic systems in Canada. Available online at http://www.t3e. info/pdf/Publications/2012-ISME-%20Performance%20 Evaluation%20of%20Sun%20Tracking%20 Photovoltaic%20Systems%20in%20Canada.pdf

[165] Opportunities For Agri-Food Chains To Become Energy-Smart NOVEMBER 2015 R. SIMS, A. FLAMMINI, M. PURI, S. BRACCO

[166] IPCC, 2011b. Renewable Energy Sources and Climate Change Mitigation, IPCC Special Report, Cambridge University Press. Available online at http://srren.ipccwg3.de/report

Biogas is mainly composed of methane and carbon dioxide and can be burned for use as a fuel in any type of heat engine to generate mechanical or electrical energy. Other minor gases include hydrogen sulphide which forms corrosive sulfuric acid.

The heat lost from the engine can be usefully applied to provide combined heat and power, improving efficiency. Other gases, usable as biogas, produced from biomass are hydrogen and carbon monoxide.

Regarding the production of biomass from agriculture , it is possible to have biomass that can come from raw materials or waste, it should be emphasized that also a small-scale biogas plant should produce at least 10 m3 of biogas per day to be usable by the same farm that produced it.[167] For example, during sugar production, residual woody material can be used as a base, similarly, wet processing waste. All vegetable waste, discarded skins and in some cases even the pulp are excellent raw materials for anaerobic digestion plants for production.

Biogas can be used to generate heat and / or energy to be used on site, thus reducing the demand for energy, especially that linked to fossil fuels and consequently increasing the energy efficiency of a given production process. Alternatively, biogas can be placed in the electricity network. A very common example of renewable energy from agriculture is biomethane used as a fuel for vehicles.

b. Sustainable Biomass: examples

The shells of different types of nuts such as cashews and hazelnuts are rich in cellulose and fiber which can be used to make packaging and can be used as biofuels.

For example, the Italian chocolate company Ferrero, which uses about 25% of the world production of hazelnuts to produce 180 million kg of its Nutella cream per year, generates huge quantities of hazelnut shell as a residual by-product. Precisely for this reason, together with a renewable packaging company and a German research institute, a way is being studied to use hazelnut shells and cocoa skin as a raw material to produce packaging material for chocolates.

The same can be said for cashew shells, in this case in fact the residues, which are always inedible, can be transformed into bioplastic. The high cellulose content makes the shells also ideal as solid biomass for combustion to produce bioenergy (both thermal and electrical). In Africa and India, peanut and almond shells are used as solid fuels in coal-fired boilers and household stoves.

Another example is that of a large Australian walnut producer, Suncoast Gold Macadamias, which produces about 4,000 tons of macadamia shells per year and today, thanks to a waste-to-energy plant, generates about 9,500 MWh of renewable electricity by burning the residues. The transformation plant uses approximately 1,400 MWh of generation per year and resells any surplus to the grid[168].

These are examples of how to derive energy from food waste, however in some countries energy crops are grown specifically to provide biomass to be converted into liquid biofuels for transport (such as corn, sugar cane and rapeseed) but also for heat cogeneration and energy. This often places the emphasis on possible competition for land and water resources between food and biofuels, thus becoming a constant concern. Precisely for this reason, new varieties of crops are specially developed and attempts are made to improve the processes involving crops and reduce energy and water consumption.

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[167] NSCA, 2006. Biogas as a road transport fuel. National Society for Clean Air and Environmental Protection, Brighton, UK. ISBN 0 903 47461 1

[168]https://www.agl.com.au/~/media/agl/business/documents/large%20business/asset%20development/2008/october/a4_suncoast.pdf

A market analysis of 15 case studies across 12 countries in Latin America, Africa and Asia done by FAO in 2009 confirmed that bioenergy from small-scale on-farm projects can be used to produce heat, energy and biofuels for local use. contribute to domestic livelihood by reducing dependence on fossil fuels.

6.3 Renewable energy-agriculture-environment in BRICS

With almost half of the world population and thanks to rapid economic development, BRICS countries (Brazil, Russia, India, China and South Africa) have a strong impact on greenhouse gas emissions, about 40% of global emissions and this precisely because their non-renewable energy consumption represents more than 35% of the world total.

In accordance with the goal of reducing global emissions, in order to combat global warming, BRICS countries have also adopted several plans for reducing emissions.

Analyzing these countries individually, in 2016 during the Goa Declaration at the Eighth BRICS Summit, Brazil and South Africa committed to reduce emissions by 36-39% and 34% by 2020 while in relation to the intensity of GDP emissions, China and India announced a reduction of 40-45% and 20-25% by 2020, compared to the 2005 level. Russia is committed to a 10-25% reduction compared to the 1990s.[169]

As for the value of agricultural production in these countries, some figures are very high, in fact Chinese production was valued at around $656.9 billion, it is double that of India, the second classified. The production of Brazil is also high, amounting to around $100.9 billion. This explains why agricultural production in BRICS countries accounts for 40% of the global agricultural added value. According to the aforementioned summit, in addition to domestic objectives, joint declarations were issued underlining the importance of cooperation in agriculture.

Finally, as regards the process of converting production systems into systems powered by renewable resources, a series of loans from the New Development Bank (NDB) have been agreed to support projects focused on renewable energy.

The BRICS, in fact, are also the largest producers of renewable energy, over 35% of total renewable energy in the world, with a percentage contribution per nation that decreases in the following order: Brazil (74%), China (23%), Russia (16%), India (15%) and South Africa (6%).[170]

The main source of renewable energy in the BRICS countries is hydroelectricity: Russia (99.5%), China (82.5%), Brazil (70.5%), India (54.0%) and South Africa (50.5%). Hence, renewable energy generation must be diversified from the expansion of wind, solar and biomass electricity generation. In fact, BRICS countries are working hard to diversify renewable energy sources in recent years but the process is still long and in some cases strongly influenced by particular environmental and climatic conditions.

The results of various statistical tests show that a 1% increase in the use of non-renewable energy per capita or in agricultural added value added to the 0.997-0.998% or 0.408-0.431% increase in emissions. [171]

In fact, referring to the BRICS, in addition to non-renewable energy, agriculture also plays an important role in the environmental degradation of these countries.

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[169] Goa Declaration at Eighth BRICS Summit, 2016https://www.mea.gov.in/bilateral-documents.htm?dtl/27491/Goa+eclarationt+h+RICS+ummit

[170] New Development Bank, 2016.http://ieefa.org/wp-content/uploads/2016/10/New-Development-Bank-and-Role-in-BRICS-Renewable-Energy-Targets-October-2016.pdf.X. Liu et al.Applied Energy 204 (2017) 489–496490

[171] Dogan E, Seker F. The influence of real output, renewable and non-renewable energy, trade and financial development on carbon emissions in the top renewable energy countries. Renew Sustain Energy Rev 2016;60:1074–85.

The massive use of fertilizers, often in higher quantities than in Europe or North America, large monocultures and intensive farming are the main source of GHG in BRICS countries. In addition, the BRICS case is very interesting as these countries lack energy purification technologies for non-renewable energy.

Given that the development of renewable energy can improve environmental quality, in 2015, the NDB invested approximately $126 billion in the renewable energy sector of the BRICS and set a goal of increasing generation capacity of renewable electricity to 1251 gigawatts (GW) in 2020-2030. The long-run causality between production and emission suggests that reducing emissions will not negative affect economic development in the BRICS with short- and long-term government policies. In addition to expanding their economies, BRICS governments should invest more funds to increase non-renewable energy and develop renewable energy to replace non-renewable energy in order to improve the environment. In particular, considering that BRICS average proportion of renewable energy to total primary energy consumption was only about 10.87%, lower than the world average of 19.2% in 2014[172].

Compared to other parts of the world, modern agriculture in BRICS countries is heavily dependent on mechanization and petrochemicals, which increase the use of fossil fuels (non-renewable energy) and CO2 emissions. In Brazil, greenhouse gas emissions from agriculture and livestock represent approximately 26.6% of total emissions.[173] In China, about 15.0% of national CO2 emissions come from the agricultural sector and that number is increasing[174].

6.4 Mitigation and climate change impacts

The mitigation potential of replacing fossil fuels with renewable energy to provide heating, cooling, electricity and transportation fuels is enormous.

Obviously, like any industrial production, we find a carbon footprint due to the production, delivery and installation of a technology, therefore also those related to the production of clean energy. However, the carbon recovery period is usually of the order of months rather than years.

In addition to the greenhouse gas mitigation potential, various other collateral benefits of implementing renewable energy projects can be considered.

In fact, from a socio-economic point of view, the implementation of policies by local and national governments can create value in various respects; first of all the environment, in particular an improvement in air quality, then energy security, and finally the development of skills and job opportunities. All of these benefits are well documented in the IPCC 5th Assessment-Mitigation Report.[175]

In addition to the advantages that could result from a change of course, there are several documents drawn up by FAO or national departments such as USDA, which indicate how climate change will have a very strong impact on future food production and how therefore the agri-food sector will have to adapt. Investments to improve agricultural adaptation will inevitably favor some crops and regions over others. South Asia and Southern Africa are the regions

[172] REN21, 2016.http://www.ren21.net/status-of-renewables/global-status-report/.

[173] he GHG emissions pathways and targets in Brazil: 1970–2013, Agriculture and li-vestock.https://s3-sa-east-1.amazonaws.com/arquivos.gvces.com.br/arquivos_gvces/arquivos/372/Presentation_SEEG_2.0_-_Agriculture_-_COP_20_Side_Event.pdf.X. Liu et al.Applied Energy 204 (2017) 489–496494

[174] Decomposition of China's CO2 emissions from agriculture utilizing an improved Kaya identity W. Li, Q. Ou and Y. Chen Environ Sci Pollut Res Int, 21 (2014), pp. 13000-13006

[175] See note 166

that, without sufficient adaptation measures, are likely to experience the greatest negative impact on many of the staple crops on which their populations depend for food security".[176]

Finally, climate change is also likely to have a direct impact on the technical potential of renewable energy resources. A duller climate and greater rainfall could reduce the levels of solar radiation and therefore penalize photovoltaics, but thanks to rainfall the technical potential of a hydroelectric plant could increase. However, very drastic or sudden changes create more harm than good. For example, high periods of drought or floods, greatly damage agri-food production.

[176] Lobell D B, Burke M B, Tebaldi C, Mastrandrea M D, Falcon W P and Naylor R L, 2008. Prioritizing climate change adaptation needs for food security in 2030, Science, 319(5863), 607-610 DOI: 10.1126/ science.1152339

7. Conclusion: towards a sustainable agri-food chain production

Sustainability is one of the most used word in the last few years, it is clear that the co-benefits of climate change mitigation activities along the entire agri-food chain are key factors in policy development. Precisely for this reason, key factors such as health, air and water pollution, land use and of course greenhouse gas emissions should be taken into strong consideration during the development of support policies.

Detailed analyses of energy demand along the different selected value chains, between plant products and animal products and an assessment of the potential of clean energy are at the heart of the idea of developing a more sustainable food production system.

Indeed, the possibility of implementing in each value chain the use of clean energy or other techniques aimed at improving energy efficiency can be considered as the success factors from which to start.

Furthermore, just by taking into consideration different areas of the world and different products we realize that it is not possible to propose a single solution valid for all the challenges on the table. However, one thing in common to all is the possibility of starting with a phase of identification of the priorities.

One of the most obvious takeaway: do not waste food along the agri-food chain, as this can help reduce the overall demand for energy, water and land use.

Based on the analysis of the different food supply chains selected, energy efficiency opportunities exist to reduce energy demand, both on a large and small scale in all countries. The idea of creating an energy-smart food system involves providing sustainable energy for the food sector and generating sustainable energy from the sector.

The basic ways of moving in that direction are three:

- Increasing the efficiency of direct and indirect energy use so that the energy intensity (MJ/kg of food produced) decreases.

- Using more renewable energy as a substitute for fossil fuels without reducing food productivity. For example, a reduction in the use of fertilizers could be a way to achieve this goal.

- Improving access to modern energy services in order to reduce the energy efficiency gap between countries around the world.

Of course productivity is important, but it is important to increase it without increasing the demand of energy. In order to do it the energy efficiency in all production systems must improve.

Investments in improving energy efficiency and establishing renewable energy projects are increasing in the entire food sector. A combination of small-scale renewable energy systems and improved use of traditional biomass can provide access to reliable and affordable energy for many developing countries. However, where feasible, it would be preferable to leap-frog directly to renewable energy systems to avoid investments in technologies that will lock users into fossil fuels for the foreseeable future. The potential co-benefits of renewable energy on livelihoods, employment, health, rural development should be considered.

First of all, using renewable energy there is an increase in productivity and improvement of soil quality, but also e social advantages. Indeed, using sustainable farming practices, we have an increase in nutritional values, biodiversity protection, food safety all this often as a direct consequence of abandonment of fertilizers or other chemicals.

However, the current dependence on fossil fuels in the agri-food industry translates into approximately 7%-8% of global greenhouse gas emissions.

These CO2 emissions can be reduced by improving energy efficiency throughout the agri-food chain and by spreading the use of renewable energy instead of fossil fuels.

The challenge is to meet the growing demands for food through more sustainable production than through the thoughtful choice of what to produce.

Of course, as said before, a plant-based diet is much more sustainable than an omnivore diet, indeed crops are more efficient than livestock and consequently, changing diet is the biggest step towards improving the efficiency of food production. Unfortunately, it is not easy to change diet at a global scale, and so it is important to consider all the other many opportunities to reduce energy end-use inputs in food production.

Policies can be employed at various levels in order to ensure that the food sector can adapt to future energy supply constraints and to the impacts of climate change. Rapid deployment of energy efficiency and renewable energy technologies in the sector will require regulatory measures, financial incentives and micro-financing to overcome the high up-front capital costs of some technologies.

An international effort will be essential in order to implement solutions in a coherent and cost-effective way: increasing energy access with a focus on developing countries, improving energy efficiency at all stages of the food supply chain; and substituting fossil fuels with renewable energy systems in the food sector.

In conjunction with such a programme, national and local governments will need to consider policies and measures that support technological development in the agri-food chain, combine food security with energy security and a reduction in GHG emission.

Based on the analysis in this thesis, it is recommended to establish a public-private partnerships to promote energy-smart approaches in food production and trade and reduce the food sector's dependency on fossil fuels. At a national level, an idea could be to coordinate the formulation of energy-smart food policies between ministries responsible for food, agriculture, energy, health, transport, economic development and the environment while at international and global level there is the need to start cooperate more on climate-smart initiatives and GHG mitigation measures for the food sector.

References

B P, Benbrook C M, Groth E and Lutz Benbrook K 2002 Pesticide residues in conventional, integrated pest management (IPM)-grown and organic foods: insights from three US data sets Food Addit. Contam. 19 427–46

Badgley, Catherine, et al. “Organic Agriculture and the Global Food Supply.” Renewable Agriculture and Food Systems, vol. 22, no. 2, 2007, pp. 86–108. JSTOR, www.jstor.org/stable/44491441.

Barnett J. & Russell J. 2010. Energy Use on Dairy Farms. Environmental issues at dairy farm level. Bulletin of the International Dairy Federation. 443, 23-32.

Basset-Mens, C. & van der Werf, H., 2003, Scenario-based environmental assessment of farming systems – the case of pig production in France, Agriculture, Ecosystems and Environment 1005, pp. 127-144

Bengtsson J, Ahnström J and Weibull A C 2005 The effects of organic agriculture on biodiversity and abundance: a metaanalysis J. Appl. Ecol. 42 261–9

Blengini, G.A & Busto, M., 2009, The life cycle of rice: LCA of alternative agri-food chain management systems in Vercelli (Italy), Journal of Environmental Management 90, pp. 1512-1522

Bush, R. Food riots: Poverty, power and protest. J. Agrar. Chang. 2010, 10, 119–129. [CrossRef]

C. Baxevanou, D. Fidaros, Th. Bartzanas , C. Kittas. Energy consumption in poultries – energy audits in Greece, International Conference of Agricultural Engineering, AgEng 2014, C0623, 1-8, 2014.

Campiotti, C.; Viola, C.; Scoccianti, M.; Giagnacovo, G.; Lucerti, G.; Alonzo, G. Le Filiere del Sistema Agricolo per l’Energia e l’Efficienza Energetica. Report RT/2011/11/ENEA Rome. 2011. Available online: http://titano.sede.enea.it/Stampa/Files/cs2011/rapportotecnicocampiotti.pdf

Carlo Alberto Campiotti, Carlo Bibbiani , Francesca Dondi , Corinna Viola, Efficienza energetica e fonti rinnovabili per l’agricoltura protetta

Catherine Baxevanou1, Dimitrios Fidaros, Thomas Bartzanas, Constantinos Kittas.Energy Consumption and Energy Saving Measures in Poultry , Energy and Environmental Engineering 5(2): 29-36, 2017 http://www.hrpub.org DOI: 10.13189/eee.2017.050201, 2017 Environ. Res. Lett. 12 064016

Cederberg et al. (2009b), ”Average Swedish beef 2005”

Cederberg et al. 2009 ”Average Brazilian beef”

Cederberg, C., Sonesson, U., Davis, J. & Sund, V., 2009, Greenhouse gas emissions from production of meat, milk and eggs in Sweden 1990 and 2005, SIK-Rapport 793, SIK – Institutet för Livsmedel och Bioteknik, Göteborg, ISBN 978-91-7290-284-8
Cereal. Cereal Production Table. http://www.answers.com/topic/cereal-3 (accessed on 6/4/08).

Cesare Castellinia, Simone Bastianoni, ClaudioGranai, Alessandro DalBosco, MauroBrunetti , Sustainability of poultry production using the energy approach: Comparison of conventional and organic rearing systems.
Agriculture, Ecosystems & Environment Volume 114, Issues 2–4, June 2006, Pages 343-350

Crutzen, P. Geology of mankind. Nature 2002, 415, doi:10.1038/415023a.

Cuéllar, A.D.; Webber, M.E. Wasted food, wasted energy: The embedded energy in food waste in the United States. Environ. Sci. Technol. 2010, 44, 6

D. Tilman, M. Clark Global diets link environmental sustainability and human health, Nature, 515 (2014), pp. 518-522, 10.1038/nature13959

David Pimentel , Energy Inputs in Food Crop Production in Developing and Developed Nations, ,5126 Comstock Hall, Cornell University, Ithaca, NY 14853, USA; doi:10.3390/en20100001

Davis, J., Sonesson, U., Baumgartner, D. & Nemecek, T., 2009, Environmental impact of four meals with different protein sources - case studies in Spain and Sweden, accepted for publication August 2009, Food Research International

Deane P, Fitzgerald J, Malaguzzi-Valeri L, Touhy A, Walsh D. Irish and British historical electricity prices and implications for the future. Working paper no. 452, Dublin (Ireland): Economic and Social Research Institute (ESRI); 2013

Delgado, C., M. Rosegrant, H. Steinfeld, S. Ehui, and C. Courbois. 1999. “Livestock to 2020: The next food revolution.” IFPRI Food, Agriculture, and the Environment Discussion Paper 28. Washington, DC: IFPRI (International Food Policy Research Institute).

Dessane, D. 2003. “Energy Efficiency and Life Cycle Analysis of Organic and Conventional Olive Groves in the Messara Valley, Crete, Greece.” Ecological Agriculture Master of Science Thesis, Wageningen University.
Djauhari, A.; Djulin, A.; Soejono, I. Maize Production in Java: Prospects for Improved FarmLevel Production Technology. CGPRT Centre: Indonesia, 1988.

Dogan E, Seker F. The influence of real output, renewable and non-renewable energy, trade and financial development on carbon emissions in the top renewable energy countries. Renew Sustain Energy Rev 2016;60:1074–85.

Dolle J.B., Duyck J.B.. 2007. Les consommations d’ènergie en bâtiments d’èlevage bovin. Institut de l’Elevage. Chambres d’Agriculture de Bretagne et des Pays de la Loire, Compte rendu n° 050733008.

DRET. Cost-benefit analysis of options for a national smart meter roll-out: phase two—regional and detailed analyses regulatory impact statement. Canberra (Australia): Department of Resources Energy and Tourism (DRET); 2008.

E.M. Barber, H.L. Classen, P.A. Thacker. Energy use in the production and housing of poultry and swine – an overview, Canadian Journal of Animal Science, Vol. 69, 7-21.

Emily S Cassidy, Paul C West, James S Gerber and Jonathan A Foley, Redefining agricultural yields: from tonnes to people nourished per hectare, Institute on the Environment (IonE), University of Minnesota, Saint Paul, MN 55108, US
Energies 2020, 13(5), 1288; https://doi.org/10.3390/en13051288

Energy Federation of New Zealand Developing our energy potential New Zealand Energy Efficiency and Conservation Strategy, , Wellington (New Zealand) ,2010

Robert A. KanalyLea Ivy O. Manzanero Gerard Foley Sivanandam Panneerselvam Darryl Mace
Energy Flow, Environment and Ethical Implications for Meat Production

Eshel, G.; Martin, P. Diet, energy, and global warming. Earth Interact. 2006, 10. [CrossRef]

Eurostat https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Figure3_Share_of_fuel_type_in_energy_consumption_by_agriculture_1997,2007,2017_EU-28.png

FAO, 2009. Small scale bioenergy initiatives – brief description and preliminary lessons on livelihood impacts from case studies in Asia, Latin America and Africa. Policy Innovation Systems for Clean Energy Security (PISCES), Practical Action, and FAO, Environment and Natural Resources Management working paper 31, 149 pages. Food and Agricultural Organization of the United Nations, Rome. Available online at http://www. fao.org/docrep/011/aj991e/aj991e00.htm

FAO, 2009a. How to feed the world in 2050, Food and Agriculture Organization of the United Nations, Rome. 35 pages. www.fao.org/fi leadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_ in_2050.pdf

FAO. 2020. Dairy Market Review, March, 2020. FAO

FAO. Quarterly Bulletin of Statistics. Food and Agriculture Organization, United Nations: Rome, Italy: 10, 1997.

FAOSTAT. Food Balance Sheets. 2016. Available online: http://faostat3.fao.org/download/Q/QL/E .

Food and Agriculture Organisation (FAO): ‘Livestock in the balance’ (FAO, 2009)

Georgescu-Roegen, The Entropy Law and the Economic Process; Harvard University: Cambridge, MA, USA, 1971.

Giampietro M, 2002. Energy use in agriculture, Encyclopedia of Life Sciences, MacMillan Publishers, Nature Publishing Group, 15 pages. www.els.net

Goa Declaration at Eighth BRICS Summit, 2016 https://www.mea.gov.in/bilateraldocuments.htm?dtl/27491/Goa+eclarationt+h+RICS+ummit

Gomiero, T.; Paoletti, M.; Pimentel, D. Energy and environmental issues in organic and conventional agriculture. Crit. Rev. Plant Sci. 2008, 27, 239–254.

Grizzetti, B.; Pretato, U.; Lassaletta, L.; Billen, G.; Garnier, J. The contribution of food waste to global and European nitrogen pollution. Environ. Sci. Policy 2013, 33, 186–195.

Grönroos, J., Seppäiä, J., Voutilainen, P., Seuri, P., Kolkkaiainen, K. 2006. “Energy use in conventional and organic milk and rye bread production in Finland.” Agriculture, Ecosystems & Environment 117(2-3): 599-630.

Guido Haas, Frank Wetterich, Ulrich Köpke “Comparing intensive, extensive and organic grassland farming in southern Germany by process life cycle assessment” Institute of Organic Agriculture, University of Bonn, Katzenburgweg 3, D-53115 Bonn, Germany

Gustavsson J, Cederberg C, Sonesson U, Van Otterdijk R and Meybeck A, 2011. Global food losses and food wastes – extent, causes and prevention. Swedish Institute for Food and Biotechnology and the Rural Infrastructure and Agro-Industries Division, Food and Agriculture Organization of the United Nations, Rome. www.fao.org/ag/ags/ags-division/publications/publication/en/?dyna_ fef%5Buid%5D=74045.

Gustavsson, J.; Cederberg, C.; Sonesson, U.; Emanuelsson, A. The Methodology of the FAO Study: Global Food LossesandFoodWaste—ExtentCausesandPrevention—FAO2011; SIK Report; No. 587, January 2013; Food and Agriculture Organization of the United Nations: Rome, Italy, 2013.

Hamilton,J.D.Causesandconsequencesoftheoilshockof2007–2008. InBrookingPapersonEconomicActivity. Spring 2009; pp. 215–259. Available online: http://www.brookings.edu/.

Hassan, R.M.; Mwangi, W.; Karanja. D. 1993 Wheat Supply in Kenya: Production Technologies, Sources of Inefficiency, and Potential for Productivity Growth, CIMMYT Economics Working Papers, 93-02, 1993.

Heinberg, R.; Bomford, M. The Food & Farming Transition: Toward a Post-Carbon Food System; Post Carbon Institute: Sebastopol, CA, USA, 2009

Hole D G, Perkins A J, Wilson J D, Alexander I H, Grice P V and Evans A D 2005 Does organic farming benefit biodiversity? Biol. Conserv. 122 113–30

Hunter D, Foster M, McArthur J O, Ojha R, Petocz P and Samman S 2011 Evaluation of the micronutrient composition of plant foods produced by organic and conventional agricultural methods Crit. Rev. Food Sci. Nutr. 51 571–82

I. Veermäe, J. Frorip, E. Kokin, J. Praks, V. Poikalainen, A. Ruus, L.Lepasalu Energy consumption in animal production
IEA, 2014. World Energy Outlook, 2014. International Energy Agency, OECD/IEA, Paris.
Estonian University of Life Sciences

Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2018 (published 2020), developed by the U.S. Government to meet annual U.S. commitments under the United Nations Framework Convention on Climate Change (UNFCCC).

IPCC 2007, Climate Change 2007. IPCC Fourth Assessment Report. The Physical Science Basis. (http://www.ipcc.ch/ipccreports/ar4-wg1.htm)

IPCC, 2007. 4th Assessment Report - Mitigation, Chapter 1, Introduction, Working Group III, Intergovernmental Panel on Climate Change, www.ipcc.ch/publications_and_data/ar4/wg3/en/ch1. htm

IPCC, 2007. 4th Assessment Report - Mitigation, Chapter 7, Industry, Working Group III, Intergovernmental Panel on Climate Change. Available online at www.ipcc-wg3. de/publications/assessment-reports/ar4/.fi les-ar4/ Chapter07.pdf

IPCC, 2011. Renewable Energy Sources and Climate Change Mitigation, IPCC Special Report, Cambridge University Press. Available online at http://srren.ipccwg3.de/report
IPCC, 2011a. Summary for Policy Makers, IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation, Cambridge University Press. Available online at http://srren.ipcc-wg3.de/report/IPCC_SRREN_SPM. pdf
J. Upton, M. Murphy, L. Shalloo, P.W.G. Groot Koerkamp, I.J.M. De Boer A mechanistic model for electricity consumption on dairy farms: definition, validation and demonstration J Dairy Sci, 97 (8) (2014), pp. 4973-4984

J.W. Hoeppner, M.H. Entz, B.G. McConkey, R.P. Zentner, and C.N. Nagy , Energy use and efficiency in two Canadian organic and conventional crop production systems, Renewable Agriculture and Food Systems: 21(1); 60–67 DOI: 10.1079/RAF2005118

Jäkel K. (2003) - Analyse der Elektroenergieanwendung und Einsparpotentiale am Beispiel sächsischer Milchviehanlagen (Analysis of the electrical energy input and

Keats, S., and S. Wiggins. 2014. "Future diets: implications for agriculture and food prices." London: Overseas Development Institute.

Kelly, T.C.; Lu, V.C.; Abdul-Baki, A.A.; Teasdale, J.R. Economics of a hairy vetch mulch system for producing fresh-market tomatoes in the mid-Atlantic region. J Am. Soc. Hortic. Sci. 1995, 120, 854-860

Kraatz S., & Berg W.E. 2009. Energy Efficiency in Raising Livestock at the Example of Dairy Farming. ASABE Annual International Meeting Grand Sierra Resort and Casino Reno, Nevada June 21 – June 24, An ASABE Meeting Presentation Paper Number: 096715 19 p.

Kumm, K. "Sustainability of organic meat production under Swedish conditions." Agr. Ecosyst. Environ. 2002, 88, 95 101.

Kummu, M.; de Moel, H.; Porkka, M.; Siebert, S.; Varis, O.; Ward, P.J. Lost food, wasted resources: Global food supply chain losses and their impacts on freshwater, cropland, and fertilizer use. Sci. Total Environ. 2012, 438, 477–489.

Küstermann, Hülsbergen, "Emission of Climate-Relevant Gases in Organic and Conventional Cropping Systems" .

Lagerberg Fogelberg C. & Carlsson-Kanyama, A. 2006. Environmental assessment of foods – an LCA inspired approach. In: Fuentes, C. & Carlsson-Kanyama, A. (reds.). Environmental information in the food supply system. Totalförsvarets forskningsinstitut (FOI), FOI-R-1903-SE. ISSN 1650-1942. Errata, available at www.cul.slu/forskning/forskare/charlottel.html

Liveszey, J.; Foreman, L. Characteristics and Production Costs of U.S. Rice Farms. Electronic Report from the Economic Research Service, U.S. Department of Agriculture, Resource Economics Division: Washington, DC, 2004.

Lobell D B, Burke M B, Tebaldi C, Mastrandrea M D, Falcon W P and Naylor R L, 2008. Prioritizing climate change adaptation needs for food security in 2030, Science, 319(5863), 607-610 DOI: 10.1126/ science.1152339

M. De Vries, I.J.M. De Boer. Comparing environmental impacts for livestock products: A review of life cycle assessments, Livestock Science, Vol. 128, 1-11.

MAFF. 2000. "Energy use in organic farming systems." Report number OF0182. Retrieved on July 12, 2007 from http://www2.defra.gov.uk/research/project_data/More.asp?I=OF0182.

Matteo Vittuari , Fabio De Menna and Marco Pagani The Hidden Burden of Food Waste: The Double Energy Waste in Italy, Department of Agricultural and Food Sciences, University of Bologna, 19 August 2016

Mehrtash M, Quesada G, Dutil Y, Rousse D, 2012. Performance evaluation of sun tracking photovoltaic systems in Canada. Available online at http://www.t3e. info/pdf/Publications/2012-ISME-%20Performance%20 Evaluation%20of%20Sun%20Tracking%20 Photovoltaic%20Systems%20in%20Canada.pdf

Metzger, S. Preliminary report comparing tolerant and non-herbicide tolerant soybeans in eastcentral North Dakota, 2002. http://www.ag.ndsu.nodak.edu/carrt/ 03%20Annual%20Report/ Herbicide%20Tolerant%20andNon.htm

Michael Clark and David bengtan, Comparative analysis of environmental impacts of agricultural production systems, agricultural input efficiency, and food choice

Mitchell, D. A Note on Rising Food Prices. 2008. World Bank Policy Research Working Paper Series, 2008. Available online: http://ssrn.com/abstract=1233058

Mon, P.N.; Holland, D.W. Organic apple production in Washington State: an input-output analysis. Renewable Agric.Food Syst. 2005, 21, 134-141.

MSE—MinisterodelloSviluppoEconomico,Dipartimentoperl'Energia. BilancioEnergeticoNazionale,Years from 2000 to 2014. Available online: http://dgerm.sviluppoeconomico.gov.it/dgerm/ben.asp (accessed on 12 May 2016).

NASS. National Agricultural Statistics Service, 2003. http://usda.mannlib.cornell.edu (accessed on 11/05/04).
Neue, H.U., 1997, Fluxes of methane from rice fields and potential for mitigation, Soil use and management 13, pp. 258-267

New Development Bank, 2016.http://ieefa.org/wp-content/uploads/2016/10/New-Development-Bank-and-Role-in-BRICS-Renewable-Energy-Targets-October-2016.pdf.X. Liu et al.Applied Energy 204 (2017) 489–496490

NSCA, 2006. Biogas as a road transport fuel. National Society for Clean Air and Environmental Protection, Brighton, UK. ISBN 0 903 47461 1

Ogino et al. (2007) Japan

Palupi E, Jayanegara A, Ploeger A and Kahl J 2012 Comparison of nutritional quality between conventional and organic dairy products: a meta-analysis J. Sci. Food Agric. 92 2774–81

Patterson, P.E. Estimating cost of potato production in Idaho, 2002. http//www.ag.uidhao.edu/potao/research/files/Volume%2034/Volume%2034_9320Estimating%2 0Cost%20of%20Potato.pdf

Philip Shine .John Upton ,Paria Sefeedpari andMichael D. Murphy Energy Consumption on Dairy Farms: A Review of monitoring, Prediction Modelling, and Analyses

Pieterse, J.N. Development Theory, Handbook of Research on Educational Communications and Technology; Sage Publications: London, UK, 2010.

Pimentel, D. 2004. Livestock production and energy use. In, Encyclopedia of Energy, Matsumura, R. (ed.), Elsevier, San Diego, CA. pages 671-676.

Pimentel, D. 2006. "Impacts of Organic Farming on the Efficiency of Energy Use in Agriculture." The Organic Center, Cornell University.

Pimentel, D.; Doughty, R.; Carothers, C.; Lamberson, S.; Bora, N.; Lee, K. Energy inputs in crop production in developing and developed countries. In Food Security and Environmental Quality in the Developing World; Lal, R., Hansen, D., Uphoff, N., Slack, S., Eds.; CRC Press: Boca Raton, 2002; pp

Pimentel, D.; Doughty, R.; Carothers, C.; Lamberson, S.; Bora, N.; Lee, K. Energy inputs in crop production in developing and developed countries. In Food Security and Environmental Quality in the Developing World; Lal, R., Hansen, D., Uphoff, N., Slack, S., Eds.; CRC Press: Boca Raton, 2002; pp. 129-151

Pimentel, D.; Doughty, R.; Carothers, C.; Lamberson, S.; Bora, N.; Lee, K. Energy inputs in crop production in developing and developed countries. In Food Security and Environmental Quality in the Developing World; Lal, R., Hansen, D., Uphoff, N., Slack, S., Eds.; CRC Press: Boca Raton, 2002; pp. 129-151

Pimentel, D.; Pimentel, M. Food, Energy and Society, Colorado University Press, Boulder, Colorado, 1996.

Pimentel, D.; Pimentel, M. Food, Energy and Society. CRC Press. Taylor and Francis Group: Boca Raton, Florida, 2008.

R. Sims, A. Flammini, M. Puri, S. Bracco Opportunities For Agri-Food Chains To Become Energy-Smart NOVEMBER 2015

Rasmussen J.B., Pedersen J. (2004) - Electricity and water consumption at milking. Danish Agricultural Advisory Service, National centre. Disponibile on line sul sito www.farmtest.dk

Refsgaard, K., Halberg, N., Kristensen, E. 1998. "Energy Utilization in Crop and Dairy Production in Organic and Conventional Livestock Production Systems." Agriculture Systems 57(4): 599-630.

Reitz, H. Energy use in citrus production and harvesting. In Handbook of Energy Utilization in Agriculture. Pimentel, D., Ed.; CRC Press: Boca Raton, FL, 1980; pp. 285-289

REN21, 2016.http://www.ren21.net/status-of-renewables/global-status-report/.

Russell, J.B. and Rychlik, J.L. (2001) Factors That Alter Rumen Microbial Ecology. Science, 292, 1119-1122. https://doi.org/10.1126/science.1058830

Saunders, C., Barber, A., Taylor, G. 2006. "Food Miles—Comparative Energy/Emissions Performance of New Zealand's Agriculture Industry." Research Report 285, Agribusiness & Economics Research Unit, Lincoln University, Lincoln.

Save and Grow: A policymaker's guide to the sustainable intensification of smallholder crop production. FAO Rome 2011
saving potentials at the example of Saxon dairy farms.). Forschungsbericht Agrartechnik, 414, Martin-Luther-Universität Halle/Saale.

Scarborough, P., Appleby, P.N., Mizdrak, A. et al. Dietary greenhouse gas emissions of meat-eaters, fish-eaters, vegetarians and vegans in the UK. Climatic Change 125, 179–192 (2014). https://doi.org/10.1007/s10584-014-1169-1

Searchinger, T., C. Hanson, J. Ranganathan, B. Lipinski, R. Waite, R. Winterbottom, A. Dinshaw, and R. Heimlich. 2013. Creating a Sustainable Food Future: Interim Findings of the 2013–14 World Resources Report. Washington, DC: World Resources Institute.

Seufert, V., Ramankutty, N. & Foley, J. Comparing the yields of organic and conventional agriculture. *Nature* **485,** 229–232 (2012). https://doi.org/10.1038/nature11069

Sevenster, M. & de Jong, F., 2009, A Sustainable Dairy Sector – Global, regional and life cycle facts and figures on greenhouse-gas emissions, Delft, CE, Publication number 08.7789.XX

Sims R, Mercado P, Krewitt W, Bhuyan G, Flynn D, Holttinen H, Jannuzzi G, Khennas S, Liu Y, O'Malley M, Nilsson L J, Ogden J, Ogimoto K, Outhred H, Ulleberg O, van Hulle F, 2011. Integration of Renewable Energy into Present and Future Energy Systems. Chapter 8 in IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation Cambridge University Press. Available online at http://srren.ipccwg3.de/report/IPCC_SRREN_Ch08.pdf

Smil V, 2008. Energy in nature and society- general energetic of complex systems, MIT Press, Cambridge, Massachusetts. 512 pages

Sonesson Jennifer Davis Friederike Ziegler Food Production and Emissions of Greenhouse Gases , An overview of the climate impact of different product groups.

Song, G.; Li, M.; Semakula, H.M.; Zhang, S. Food consumption and waste and the embedded carbon, water and ecological footprints of households in China. Sci. TotalEnviron. 2015,529,191–197.

State of the Art on Energy Efficiency in Agriculture: Country data on energy consumption in different agro production sectors in the European countries https://edepot.wur.nl/278550

Steinfeld, H.; Gerber, P. Livestock's Long Shadow. Environmental Issues and Options; Food and Agricultural Organization: Rome, Italy, 2006.

Stolze, M., Piorr, A., Häring, A., Dabbert, S. 2000. "The Environmental Impacts of Organic Farming in Europe." Organic Farming in Europe: Economics and Policy, Volume 6. University of Hohenheim Department of Farm Economics, Stuttgart.

The World Bank Agriculture and Rural Development Department Pica-Ciamarra, U., & Otte, J. (2011). The 'Livestock Revolution': Rhetoric and Reality. Outlook on Agriculture, 40(1), 7–19. https://doi.org/10.5367/oa.2011.0030

TommyDalgaarda, NielsHalberga, John R.Porterb, A model for fossil energy use in Danish agriculture used to compare organic and conventional farming.

Tripathi, R.S.; Sah, V.K. Material and energy flows in high-hill, mid-hill and valley farming systems of Garhwal Himalaya. Agr. Ecosyst. Environ. 2001, 86, 75-91.

Trostle, R. Global Agricultural Supply and Demand: Factors Contributing to the Recent Increase in Food Commodity Prices; ERS USDA WRS-0801. Available online: http://www.ers.usda.gov/media/218027/wrs0801_1_.pdf

Tynelius, G., 2008, Klimatpåverkan och förbättringsåtgärder för Lantmännens livsmedel – fallstudie Kronfågels slaktkyckling (Climate Impact and Improvement potentials for Lnatmännen's chicken, in Swedish), Masters Thesis 2008, Dept. of Technology and Society, Environmental and Energy Systems Studies, Lund University, Lund, Sweden.

U.S. Department of Energy, Energy Efficiency & Renewable Energy, Smith Dairy Deploys Natural Gas Vehicles and Fueling Infrastructure in the Midwest. Case Studies. Washington, DC.

U.S. Department of Energy, Energy Efficiency & Renewable Energy. Propane Fuel Basics. Alternative Fuels Data Center, Fuels & Vehicles: Propane Washington, DC.

UNEP, 2011. Towards a green economy: pathways to sustainable development and poverty eradication – a synthesis for policy makers. United Nations Environment Programme www.unep.org/greeneconomy.

UNEP, 2015. 9th Global Trends in Renewable Energy Investment 2015. Frankfurt School-UNEP Collaborating Centre for Climate & Sustainable Energy Finance and Bloomberg New Energy Finance. Available online at http://fs-unep-centre.org/publications/global-trendsrenewable-energy-investment-2015

United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019: Highlights. ST/ESA/SER.A/423.

Upton, J. R., Murphy, M., Shalloo, L., Groot Koerkamp, P. W. G., & de Boer, I. J. M. (2015). Assessing the impact of changes in the electricity price structure on dairy farm energy costs. *Applied Energy*, *137*, 1-8. https://doi.org/10.1016/j.apenergy.2014.09.067

USDA. Agricultural Statistics, 2006. U.S. Department of Agriculture. U.S. Government Printing Office: Washington, DC, 2006.

USDA. Agricultural Statistics. U.S. Department of Agriculture. Government Printing Office: Washington, DC, 2007

USDA/Trends in U.S. Agriculture's Consumption and Production of Energy: Renewable Power, Shale Energy, and Cellulosic Biomass, EIB-159 Economic Research Service

Van der Werf, H.M.G.; Tzilivakis, J.; Lewis, K.; Basset-Mens, C. Environmental impacts of farm scenarios according to five assessment methods. Agr. Ecosyst. Environ. 2007, 118, 327-338.

Vasilis Fthenakis , Marco Raugei "Life-Cycle Assessment of Energy Systems in Current and Evolving Grids" Prof.

Verge, et al., (2008) , "Average Canadian beef

Vitousek P M et al 2009 Nutrient imbalances in agricultural development Science 324 1519–20

W. Li, Q. Ou and Y. Chen , Decomposition of China's CO2 emissions from agriculture utilizing an improved Kaya identity Environ Sci Pollut Res Int, 21 (2014), pp. 13000-13006

Williams, A.G., Audsley, E & Sanders, D.L., 2006, Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities, Main Report, Defra Research project IS0205, Bedford: Cranfield University and Defra, Available at www.silsoe.cranfield.ac.uk

World bank Managing the Livestock Revolution Policy and Technology to Address the Negative Impacts of a Fast-Growing Sector June 2005

Zappavigna P. (2010) - Consumi di energia in stalla, quanto si può risparmiare. L'Informatore Agrario, 48 Suppl.: 40-43.