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The role of agriculture in producing renewable energy

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To my parents, my sister, my grand-parents, my friends,

Professors M. B. Zolin and A. Basso

and everyone else whose lives have crossed path with mine by enriching my journey.

Thank you for being my companion.

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Abstract

The objective of this thesis is to investigate the role of agriculture in renewable energy production. The main finding suggests that the introduction of wind, solar and biomass energy production on farms, can lead to positive implications such as the mitigation of greenhouse gas emission and to an increase in the technical efficiency of farms.

Despite that, many practical challenges and barriers on renewable energy production on farms have been found, at economic/financial, technical, societal and regulatory level. The continuous development of technologies and the increase of collaboration between the agricultural and energy sectors can lead to positive results and to overcome these challenges.

Finally, an elaboration on Database Farm Accountancy Data Network (FADN) will be done, to analyse the relationship between agriculture and renewable energy production in Italy.

Introduction

The agricultural sector has an impact on climate change, and it has a role to play in mitigation of greenhouse gases emissions. In turn, it is also heavily affected by the impacts of climate change, as farming activities depend directly on climatic conditions. Due to fossil fuels and farming activities, the agricultural sector contributes substantially to greenhouse gas emissions.

Simultaneously, the agriculture sector, which accounts for the majority of land use in many areas, has significant potential for producing and using renewable energy.

Many different forms of renewable energy are produced in rural areas, ranging from solar, wind, hydro sources to different forms of bioenergy. Many installations provide opportunities for new cooperation in production, sales and distribution of renewable energy. They bring employment and economic development in rural areas, as well as the ability to substitute fossil fuels and contribute to energy stability.

Many technologies are available to meet energy use on the farm for heating, cooling and other energy functions. However, this large portfolio of options also create complex questions, because the potentials, performance and impacts of renewable energy technologies depend on natural conditions (climate), type of farm (small – large scale, management techniques), geographic conditions (including infrastructure), and socio economic factors as well as the surrounding energy system and energy infrastructure.

The main question of this thesis is understanding the role of agriculture in renewable energy production.

Its aims, in fact, to find an answer to the previous question, starting with a focus on fossil fuels production through an excursus on tendencies in the period 2000 – 2019. Attention will then be placed on renewable energies production: the different types of sources have been presented, with a specific focus on the main producing countries (Chapter I). After that, the integration of renewable energy production in agriculture will be treated in Chapter II, exposing the different possible solutions studied so far. The possible barriers and challenges that could arise, will be here discussed.

The focus would then be shift to the academic theory collected during the development of the VERA Academy project, with the aim of reviewing the literature on agriculture and renewable energy in a broad sense (Chapter III).

After discussing renewable energy production in agriculture at a general level, the last part of this thesis will be focused on the analysis of farms producing renewable energy in Italy, using the data gathered from the Farm Accountancy Data Network (FADN) database. Different aspects will be addressed, ranging from the number of farms producing renewable energy per region, numbers of farms producing renewable energy per type to managerial aspects, trying to give a complete picture of the situation regarding the production of renewable energy on Italian farms (Chapter IV).

CHAPTER I Energy sources: fossil fuels and renewable energies

Supply and usage of energy are essential for all the modern economies, in particular energy supports a wide range of crucial services and therefore it is of paramount importance for the humanity growth.

Energy resources can be classified into two types: non-renewable and renewable (RE).

Most non-renewable energy sources are fossil fuels are non-renewable sources; they are continually formed by natural processes but they take millions of years to form and they are extracted from the earth much faster than new ones are generated.

Nuclear energy is generally classified as non-renewable energy source. Even if nuclear energy itself is a renewable energy source, the material used in nuclear power plants is not.

In the first part of this chapter will be illustrated the fact that, these resources have been the most widely used type of energy in the modern era. The majority of our energy derives from fossil fuels, and we are overusing it year after year. Over the past 10 years, total production has increased from 116,214 to 136,761 TWh [1]. (Our World in Data, 2019)

Renewable resources, like wind, solar, geothermal and water, come from sources that regenerate as fast as they are consumed and are continuously available. During the beginning of the twenty-first century, since non-renewable sources started to deplete, renewable sources have become more popular. The energy produced from renewable sources grows year after year, in 2019 covered almost 27% of the power mix. (Global Energy Statistical Yearbook, 2020)

Renewable energy and agriculture are a winning combination because RE sources can be harvester forever and providing farmers with a long-terms source of income. In the second part of chapter one, we are going through renewable energy trends over the past years and how to combine it with agricultural sector.

[1] TeraWatt Hours

1.1 Fossil fuels: energy use and performance with relative consequences on the environment

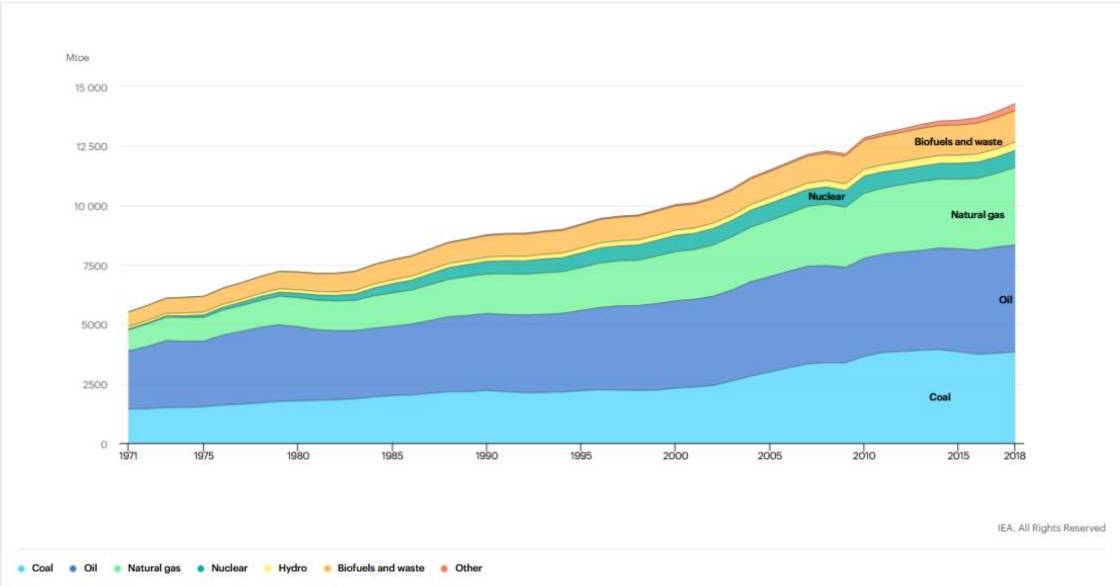
Fossil fuels, also known as hydrocarbons, are today the principal source of energy for the entire globe. They are divided into three types: oil, coal and natural gases including methane. Unfortunately, as we will see, these hydrocarbons are also the main source of greenhouse gases, which are responsible for important environmental phenomena such as the greenhouse effect, acid rain and global warming. Despite this, fossil fuels continue to be used on a massive scale.

Starting from the data collected by Enerdata (2020) and by the International Energy Agency (IEA) (2020), we are going to make an excursus on the tendencies in energy production in 2009 – 2019.

Global energy supply is still on rise. In effect, when we look back over the past 47 years, there are only a handful of years where energy production did not increase. For instance, 2009, the year following the financial crisis, is one of them (Figure 1.1).
Over the past 10 years world energy production continue to grow in average with a trend of 2%/year. The majority of the world's energy still come from fossil fuels, 84% in 2019 (Our World in Data) (Figure 1.1). Oil continues to be the dominant fossil fuels produced around the world (Figure 1.1), because it is the easiest to extract, process and transport. The top oil-producing country is United States, which accounts for 19% of the world's production (Investopedia, 2021). U.S. overtook Russia in 2012 for the second place and surpassed Saudi Arabia in 2013 to become the world's top oil producer. On the other hand, coal share has fluctuated significantly over the past years, growing constantly between 1999 and 2011 (Figure 1.1), influenced mainly by increased consumption in China. In 2011, it reached its highest level in the total energy supply by China. Since then, it has declined. In 2018, coal represents the 27% of world total energy supply (IEA, 2020). With the global economy slowing down and the common objective of having less carbon intensive power generation in the face of pollution and environmental concerns, coal production fell in United States and Europe in 2019. In contrast to that, the People's Republic of China produced what Europe and US did not, remaining the largest coal

producer, representing 47% of the global output (Our World in Data, 2019). Natural gas consolidates its third place, despite its combustion produces about half of CO_2 produced by coal and could therefore be used more, but it is present in less quantity than other fossil fuels. Since the financial crisis, natural gas production has been steadily increasing (Figure 1.1) at an annually compounded growth rate of 2.7% (IEA, 2020). The most substantial production was from Russia, globally the second largest producer after the United States.

Figure 1.1 World total energy supply by source, 1971-2018

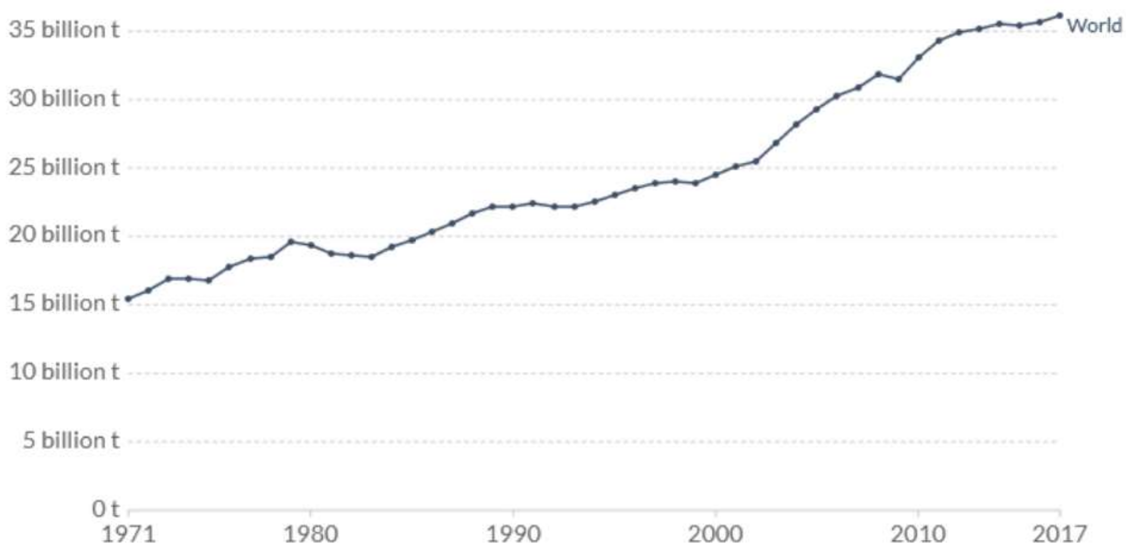


Source: IEA (2020)

As a result of the massive fossil fuel production, CO_2 emissions are increasing year by year (Figure 1.2). It is widely recognised that to avoid the worst impacts of climate change, the world needs urgently to reduce emissions. In the first half of 20th century, global emissions were dominated by Europe and the United States, but in the second half, we see a significant rise in emissions in the rest of the world, in particular across Asia, and most notably, China. Europe and United States now account for just less than one-third of emissions. Emissions growth has decreased over the last few years (since 2011) (Figure 1.2), but they have to reach their peak yet.

Since three-quarters of global greenhouse gases come from the burning of gas, coal and oil, we need to rapid switch to renewables.

Figure 1.2 Global Annual CO_2 emissions, 1900 - 2017



Source: Our world in data (2020)

The agricultural sector generate almost 10% of greenhouse gas emissions in the European Union (European Commission, 2018) mainly due to food production and transport. This is the consequence of an energy model primarily based on fossil fuel, which provides more than 70% of the total needs of the agricultural sector (Sutherland at al. 2018). Therefore, a fundamental change is necessary. Over the past years, significantly efforts have been made in the agricultural field trying to reduce this environmental footprint by increasing farm production and consumption of renewable energy. Many different forms of renewable energy are produced in rural areas, ranging from wind, solar, hydro and geothermal sources to different forms of bioenergy. Many small and medium scale installations provide opportunities for new cooperation in production, sales and distribution of renewable energy. In the next section different forms of RE combined with agriculture will be presented with their barriers and challenges.

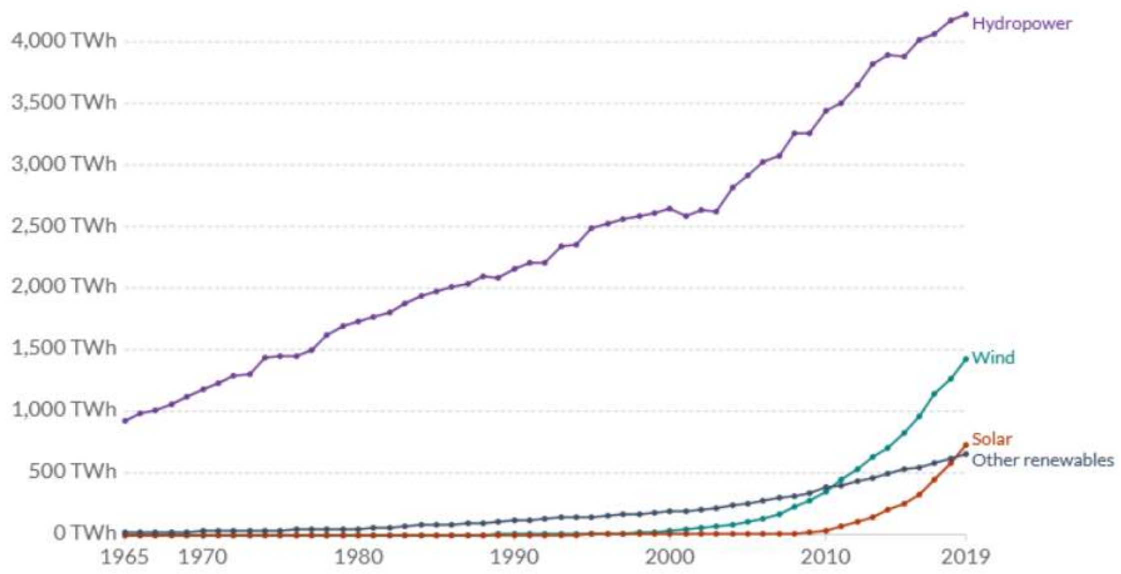
1.2 Renewable energies

Renewable energy is obtained from natural process that are renewed constantly. In 2019, global energy accounted for only 11% from renewables (Our World in Data, 2019), this share is increasing, but unfortunately, this progress is still slow. Evaluations about the concrete contribution that could be made by renewable energies in the next years showed that the level of financial support and the level of restriction on the conventional options influence everything. The renewable energy system to be noticed in the market that is still dominated by actual energy technologies, using oil, coal and gas, needs to continue to evolve and embrace new techniques.

The contribution of renewable energy has started almost 50 years ago with a low level; it was in the 1970s that the interest about renewable energies improved as a consequence of the oil price crisis (Figure 1.3). The type of energy selected has consequences that influence greenhouse gas emissions, equipment manufacturing and transportation, mineral consumption and water resource distribution. Nowadays experts in this field affirm that renewable energy technologies are more sustainable than the majority of the sources of energy that we are used to. There are two-principal reason why renewable energies are not adaptable to every area, the energy-use that depends on the culture of every single community and the distribution of the natural sources that depends on the geographical position.

Globally, hydropower is by far the largest modern renewable source, but also wind and solar power are both growing rapidly in the last decade (Figure 1.3).

Figure 1.3 Renewable energy generation by source, World, 1965 - 2019



Source: Our world in data (2020)

1.2.1 Hydroelectricity

Hydropower has emerged as one of the primary renewable energy sources that can help in reducing carbon emissions and the dependence on fossil fuels because it is produced by exploiting the mechanical energy of flowing water by forcing it through piping, which then turns a generator in order to produce electricity. Hydroelectric power has been one of world oldest and largest sources of renewable energies. Its generation scale dates back more than a century ago, and it is still the world largest renewable source, accounting for more than 60% of renewable generation. Overall, the world's hydropower capacity increased from 960.5GW in 2008 to 1,270.4GW in 2017, according to a report released by the International Renewable Energy Agency (IRENA). In 2019, around 7% of global energy came from hydropower (Our World in Data, 2019). However, the scale of hydroelectric power generation varies significantly across the world. China is the leading producer of hydropower in the world (Table 1.1) covering the 28,5 % of world total production, one of the reason is that the largest hydropower station in the world is located there due to China's insufficient reserves of fossil fuels and the government's preference for energy independence. Brazil is the world's second largest producer of hydropower, accounting for 9% of the world's total (Table 1.1). It is possible to note the large gap with respect to China's total output. Hydroelectricity provides more than 80% of energy generated in Brazil. It has the perfect geography for hydroelectricity production. Large rivers and elevation changes provide opportunities to build dams and use gravity to control the flow of water and the high levels of precipitation provide a consistent water flow.

On the other side, drawbacks of hydropower are: the expensive plant installation, the dependence on precipitation and the inability of having control over the weather, the involvement of stream regimens changes (affecting wildlife, plants and fish) and inundation of land, and the displacement of people living in the reservoir area. Moreover, another problem that is being experienced, in particular in Brazil, and that scientists are most concerned about is drought. Without water, it is impossible to produce energy, and Brazil is suffering a severe drought; the Sao Paolo reservoir has practically emptied in recent years due to climate change.

Table 1.1 Main producing countries of hydroelectricity, 2019

Producers	TWh	% of world total
People's Rep. of China	1 232	28.5
Brazil	389	9.0
Canada	386	8.9
United States	317	7.3
Russian Federation	193	4.5
India	151	3.5
Norway	140	3.2
Japan	88	2.0
Viet Nam	84	1.9
France	71	1.6
Rest of the world	1 274	29.6
World	**4 325**	**100.0**

Source: IEA 2020

1.2.2 Wind energy

Wind generation at scale, compared to hydropower, is a quite modern renewable energy source which is growing quickly in many countries around the world (Figure 1.3). In 2019, wind resources generate around 2% of global energy (Our World in Data, 2019). China and the US are the clear leaders in terms of nation-state performance: half of 2019 new wind capacity was installed in these two countries alone. In 2019, China and the US covered the 28,7% and 21,7%, respectively, of world total wind power production. (IEA, 2020) (Table 1.2). After this two leaders, Germany with nearly 30.000 wind turbines, more than anywhere else in Europe, cover the 8,6% of world total wind power production (Table 1.2). Germany gets 23,5% of its energy from wind in 2019; it is the biggest source of renewable energy for this country (Wind-watch, 2019). In the top ten producers, India is at the forth place. It has the second highest wind capacity in Asia and is the only Asian country, apart from China, to make the list, accounting the 5% of world total wind electricity produced (Table 1.2). The main problems of wind power are related to environmental constraints. First of all the majority of the windiest area are located far from the population where maintenance and transmission cost would be very high. Second the nature of the wind power is unpredictable this would limit its contribution to any region. Then, the presence of protected zone and forests puts a limitation on the location of the wind turbines. Last, wind farms are not attractive for tourist and neither for people living nearby which complain about noise, interference with radio and TV signal but also with migratory birds.

Table 1.2 Main producing countries of wind electricity, 2019

Producers	TWh	% of world total
People's Rep. of China	366	28.7
United States	276	21.7
Germany	110	8.6
India	64	5.0
United Kingdom	57	4.5
Spain	51	4.0
Brazil	48	3.8
Canada	33	2.6
France	29	2.2
Turkey	20	1.6
Rest of the world	220	17.3
World	**1 273**	**100.0**

Source: IEA 2020

1.2.3 Solar photovoltaic energy

Solar, like wind, is a quite modern renewable energy source compared to hydropower and it is growing quickly in many countries around the world (Figure 1.3). In 2019, solar resources generate around 1% of global energy (Our World in Data, 2019).

India is becoming always more and more important as producer of solar photovoltaic (PV) electricity, in fact, it covered the 7,2% of the world total production in 2019 (Table 1.3): this is in part due to a collaboration with the United States for developing the renewable energy sector of both the nations. The synergic effect of the technical knowhow of both countries will drive India towards innovation and investment in cheaper and more efficient renewable energy technology, this is the reason why many new companies have emerged in the last year to provide home solar system at an affordable price.

It is important for us, to note that Italy is among the top 10 in solar energy production (Table 1.3). Since 2007, when solar energy boomed in Italy, the growth has not stopped, in particular in 2019 solar photovoltaics accounted for 27% of electricity production from renewable sources. The sector has very good incentives, for example the 50% tax deduction for enterprises.

There is the other side of the coin: the problem of photovoltaic (PV) is the cost involved. Even though the progress on the technology of the panels makes them cheaper, the storage of the energy is required and this is the expensive part. Furthermore, solar energy collection depends predominantly on sunshine, which is the reason why even some cloudy days can have important effect on the energy system. Finally, solar energy is environmentally friendly until solar panels have reached the end of their lifetime, disposing of solar panels is hardly environmentally friendly due to heavy metals in solar cells, which can harm the natural environment if they are not recycled or disposed of properly.

Table 1.3 Producers of solar PV electricity

Producers	TWh	% of world total
People's Rep. of China	177	31.9
United States	81	14.7
Japan	63	11.3
Germany	46	8.3
India	40	7.2
Italy	23	4.1
United Kingdom	13	2.3
France	11	1.9
Australia	10	1.8
Korea	9	1.7
Rest of the world	81	14.8
World	**554**	**100.0**

Source: IEA 2020

1.2.4 Bioenergy

Bioenergy is another of the different resources available to meet our energy needs. It is a form of renewable energy derived from recently living organic materials known as biomass, which can be used to produce transportation fuels, heat, electricity, and products. Bioenergy can be as simple as a log fire or as complex as an advanced second-generation liquid biofuel. Studies show that bioenergy is the most widespread used renewable energy in the world. It provide around 10 % of the world's primary energy supplies (Victoria State Government, 2017).

Agricultural crops, algae, wood and organic residential/industrial waste, animal plant and waste are all sources of biomass. The type of biomass will determine the type and amount of bioenergy that can be produced and the type of technology that can be used to produce it. For instance, normally with wet wastes such as manure, biogas is produced through anaerobic digestion, which can be combusted to produce electricity and heat or upgraded into a transport fuel, bio methane. Instead, agricultural crops, such as canola and corn, can be used to produce liquid biofuels like ethanol and biodiesel.

Depending on the biomass material and the type of energy wishing to produce (heat, electricity or transportation fuels), there are many ways to produce bioenergy.

Processes include thermal, biochemical or mechanical either alone or in combination. Biomass can be converted to energy via a range of technologies from simple solid wood combustion heaters to boilers and bio digesters, which in turn produce gas for process steam for heat or for powering engines and turbines. The more commonly processes used to produce bioenergy are conventional combustion, gasification, pyrolysis and anaerobic digestion.

Direct combustion is the simplest and most widely used bioenergy technology for converting biomass to heat, which can then be used for space cooling or heating, for use in industrial process, to heat water or to produce electricity via a steam engine or turbine. Another option is the gasification, a thermos-chemical process that involves heating solid biomass to temperatures of around 800-1000°C in a gasifier with a limited supply of oxygen. Similar to gasification is pyrolysis, it involves thermal degradation of biomass heated in the absence of air (or with limited air or oxygen). It produces solid, liquid and/or gaseous products at ratios dependent on the speed and temperature of the pyrolysis process. Anaerobic digestion (AD) is another renewable energy technology that can transform organic matter into a bioenergy source. AD is a microbial decomposition of organic matter in an oxygen-free condition. Naturally, it occurs in marshes, wetlands and landfills, and inside the ruminant's stomach (Correa et al. 2018). The principal products of AD are biogas, a mixture of gases (mainly methane (CH_4) and carbon dioxide (CO_2)), and a nutrient effluent that can be used as a fertilizer (Korres et al. 2013). For decades, AD has been used as a waste stabilization process, but over the past years, it becomes more interest due to its potential for bioenergy production (Sawatdeenarunat et al. 2016). AD technology can produce both a fuel (biogas) that burns cleaner than combusting the biomass directly, and a fertilizer that can be land applied for agronomic benefits (KC et al. 2014).

1.2.5 Advantages and disadvantages of renewable energies

Starting from hydropower, which has a number of benefits over the most other forms of electricity generation. High reliability, proven technology, high performance, very low operational and maintenance costs, and the ability to quickly adapt to load changes are just a few of the benefits. Many hydropower plants are built next to reservoirs, which provide the city with water, flood control, and recreational opportunities. Furthermore, hydropower does not generate waste products that contribute to acid rain and greenhouse gas emissions.

High initial facility costs; reliance on precipitation (no control over amount of water available); changes in stream regimens that can impact fish, plants, and wildlife by increasing stream levels, flow patterns, and temperature; inundation of land and wildlife habitat (creation of reservoir); and displacement of people living in the reservoir area are some of the disadvantages of hydropower.

Wind energy, like other hydropower sources, has a number of advantages. It eliminates greenhouse gas emissions and lowers power costs by using wind turbines, which

generate energy and electricity when moved by the wind. All that is required for the turbines to operate is wind, which is simply air in motion, and air is found everywhere.
Wind energy generation, for a variety of reasons, will also promote domestic development. To begin with, the use of native materials in the construction of the turbines benefits the local economy. Second, wind turbines are a lucrative investment; technological advancements indicate a high potential return, and increased investment boosts the country's GDP.
Many of the world's windiest regions are far from population centres, such as northern Canada and Russia, where transmission and maintenance costs will be very expensive. Unless large-scale energy storage or intercontinental transmission are available, the intermittent and unpredictable nature of wind power will restrict its contribution to any country. Environmental constraints, such as the existence of forests and protected areas, as well as public approval, restrict the location of wind turbines. Wind farms are not always attractive, and they have generated concerns about noise, interference with radio and television signals, and interference to migratory birds.

Solar energy is non-polluting, because produces no greenhouse gases (as oil-based energy does). In comparison to other renewable energy sources such as wind and hydroelectric power, residential-sized solar energy systems have very little impact on the surrounding environment. Solar panels have no moving parts and need only routine cleaning beyond maintenance. Maintenance and repair costs are very low after the initial costs of installing the panels because there are no moving parts to break and restore.
The primary disadvantage of solar energy is its high cost. Despite technological advancements, solar panels remain costly. Even if the cost of the panels is ignored, the device required to store and use the energy can be very expensive. Even on the cloudiest days, some solar energy can be obtained, but solar energy collection requires sunlight. Even a few cloudy days can have a significant impact on an energy system, particularly when considering that solar energy cannot be collected at night. Moreover, deposing solar panels in not environmental friendly due to heavy metals in solar cells, which harm the environment if not recycled properly.

Finally, biomass energy has the ability to significantly reduce greenhouse gas emissions, reliance on foreign oil, landfills, and, most importantly, sustain local agricultural and forest-product industries. Another advantage of biomass is that, like crude oil, it can be converted into a variety of useful fuels, chemicals, materials, and goods.

However, attention should be paid to the crop choose for the production of biomass. Because it may cause harm for the environment. Moreover, In comparison to fossil fuels, biomass energy is an inadequate source of energy (ethanol vs gasoline). Growing and processing biomass feedstock, transporting feedstock to the power plant, and burning or gasifying the feedstock all have the potential to contribute significantly to global warming emissions. Another effect of biomass energy on the ecosystem is land degradation caused by the loss of green vegetation.

1.3 Renewable energy production and consumption trend in Italy

Italian electricity sector has undergone a revolution in recent years mainly due to a decline in energy consumption and the strong increase in renewable energy.

The Figure 1.4 shows the Gross inland electricity consumptions[2], given by the sum of the thermoelectric, the total renewable, the foreign balance and the nuclear. It represents the energy consumed in the country.

As can be seen, gross inland electricity consumption has had a very regular, almost linear trend in the past. It suffered significant drops in response to the crises of 2009 and 2013, just as in the global scenario. This downward trend cannot be attributed only to the immediate and direct consequences of the economic crisis, but also to a change in the structure of consumption, that has reduced the weight of energy-intensity activity. These changes, combined with policies to stimulate energy efficiency, have led to a real structural change in consumption.

The thermoelectric source also maintained an almost linear trend over time, until 2009, when there was a very marked drop due to two adverse conditions already mentioned, namely: the decline in consumption and the strong increase in renewables. The 2007

[2] Sum of the various gross inland productions, plus the foreign trade balance.

production peak (Figure 1.4), will never be reproduced again because renewable energy is set to grow over time and replace thermoelectric power.

Renewable energy production in Italy coincided for many years with natural hydropower - which considered only natural water inputs without bottom-up pumping used to store energy. The small difference that can be seen up to 2007 (Figure 1.4) between the dark-green line and blue line is represented by geothermal energy production, which is the only other historical renewable source. It was only in the early 1990s that the new renewable sources began to come together: bioenergy, wind power and photovoltaics. Since 2008, thanks to an improvement in incentive mechanisms and a decrease in the cost of technology, that the growth of these sources has increased dramatically.

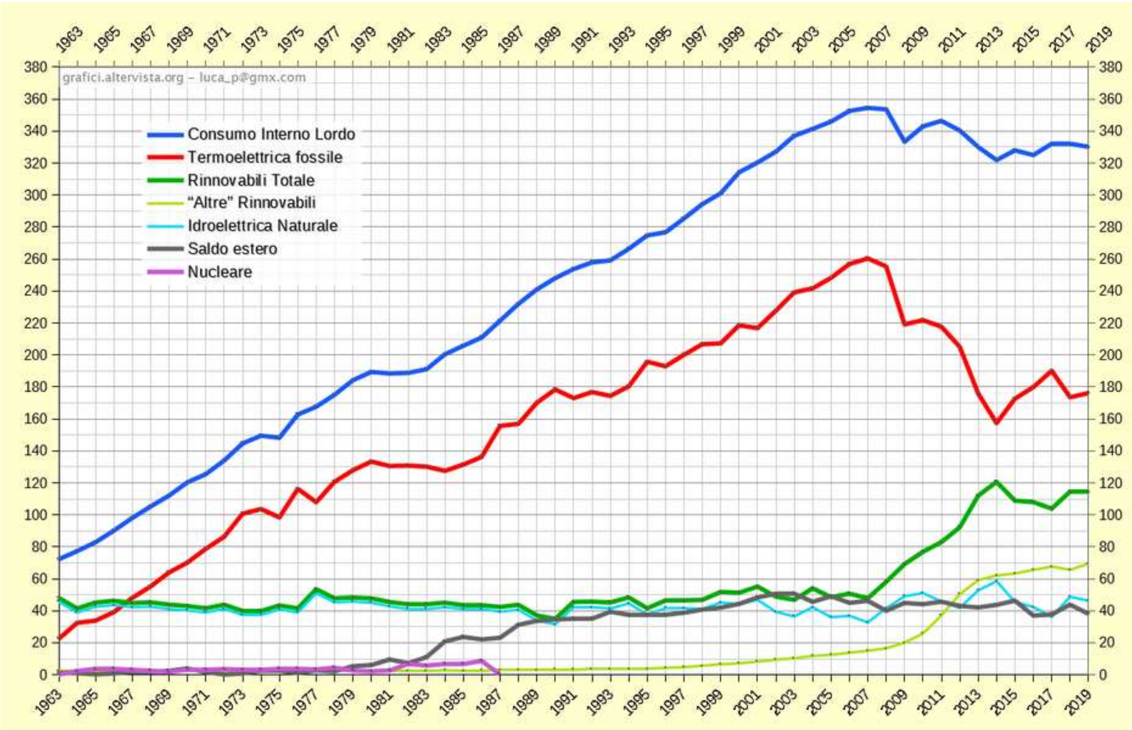
In fact, it is possible to note that the production of "other" renewable (light green line), that is new renewables and geothermal, has exceeded the traditional production of hydroelectric; an overtaking from which there will hardly be a return.

Actually, it is possible to see in the Figure 1.4 that the light blue line, representing the hydroelectric source shows no growth trends in the period 1063 – 2019. This is because the use of hydropower resources dates back to many years ago and all the best locations to build plants have already been exploited, as a result, the new plants are less productive and the old ones tend to lose their efficiency.

Energy production from “other” renewable sources has slowed down in recent years due to a decrease in incentive policies. On the other hand, at European level, targets have been set for 2030. In this context, each country is expected to propose a National Energy & Climate Plan (NECP) every 10 years. The Italian plan sets a target of 30% renewables in final energy consumption and 55.4% in electricity consumption by 2030.

In July 2019, a new system was launched to help achieve these goals in the medium-large plants – FER1 decree. This incentive system is focused on wind and photovoltaics, which are the most competitive renewable technologies.

Figure 1.4 Gross inland electricity consumptions by source in Italy (TWh)



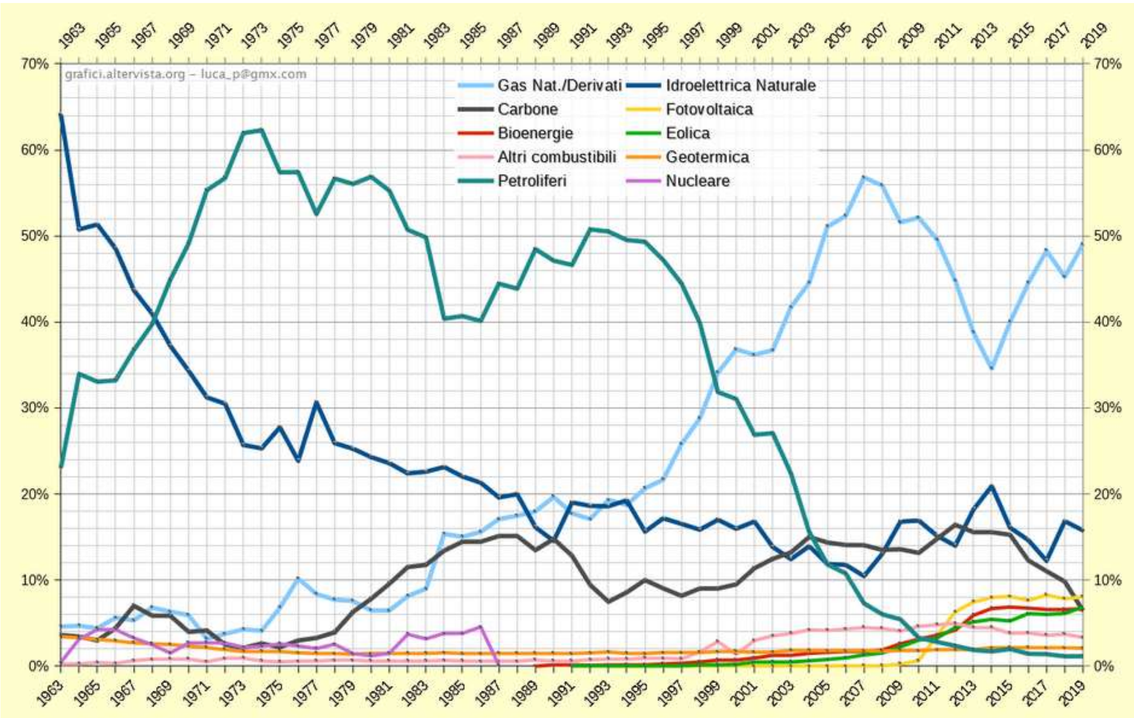
Source: Altervista (2019)

On the other side, electricity production sector has been very dynamic in recent decades.

It is possible to note in Figure 1.5 how before the 60s fossil fuels were prevalent over hydroelectric. Oil product first and then natural gas took over. On the contrary, coal has always been of secondary importance, with an upward trend until 2012 and then a downward one.

In the period 2009-2013, the new renewable sources emerged, thus replacing almost definitively the domain of natural gas. In recent years, however, the production of new renewables has almost stopped, but from 2020 is renewed growth thanks to new forms of support. By 2030, as mentioned above with regard to the NECP, renewables are destined to overtake fossil fuels, with photovoltaics set to become the leading renewable source.

Figure 1.5 Gross inland electricity production by source in Italy (percent)



Source: Altervista (2019)

CHAPTER II Renewable energy and agriculture

As already mentioned before, Renewable energies and agriculture is a winning combination because wind, solar, water and biomass energy can be harvested forever, providing farmers with a long-term source of income. Renewable energy can be used and produced on the farm replacing other fuels or sold as a “crash crop”.

To integrate energy generation into agricultural production process, a flexible approach is necessary. The on – farm energy systems need to be flexible in switching between the use of energy in agricultural production and supply of energy to the local grid including local neighbourhood. Each system has to be designed context – specifically. Flexibility is necessary regarding the use of resources for energy production (flexibility of input), the form of energy carrier provided (flexibility of output) and the on-farm use of energy (flexibility of energy use) (Christou, 2018). For each farm a deep analysis is required taking into account the land available, waste and residue streams, production profile, energy demand, natural resources available (such as water, solar radiation and wind), financial resources available and workforce. In addition, the options available to sell excess energy to customers, outside the company should be analysed. The aim is to explore the energy resources available on-farm and to adapt the energy production to farm energy demand. With regard to “flexibility of output”, the form of energy needed on the farms, the amount and the time of energy use, has to be taken into account. As regards the energy demand of farms, energy efficiency should be promoted through the analysis of farm options to reduce energy demand, replacing obsolete equipment and ensuring proper maintenance of those present in the company. On the energy demand side, flexibility is crucial for balancing energy supply and use. The solution that has been outlined is to shift the demand for energy into periods with a high availability of renewable energies (Christou, 2018). Many of those concepts could be improved by the use of energy storage systems.

In order to increase renewable energy production on farms, more farmers have to decide to produce renewable energy. However, this decision is not yet sufficiently taken by the individual farmer. However, during the last ten years, new actors have begun helping farmers providing them advice; in the meanwhile, existing Farm Advisory Services (FAS)[3] have developed specialized capability to provide advice.

There is a remarkable academic literature regarding farm business decision making. A subset of this literature deals with farm diversification and consequently the production of renewable energy. Commonly, farmers who are better educated, younger, owner-operators and operators of large land-bases are more likely to diversify (Villamil et al. 2008; Tranter et al. 2011; Tate et al. 2012; Frantal et al. 2016; Sutherland et al. 2016). Normally, diversification is taken into consideration by large companies as an “accumulation strategy” (accumulation of wealth), while smaller companies tend to use it as a “survival strategy” (Evans et al. 1993; Meert et al. 2005; Lopez et al. 2011).

For farmers, engaging in renewable energy production implies a big change in decision-making. Sutherland et al. (2012) developed a model to better understand when giving advice to farmers has the greatest impact. The model demonstrate that, the majority of the time, farms maintain the same trajectory, to making best use of existing resources, this is economically efficient. Recently, farmers make small changes and start to take in new information, but processing them passively. It is only after a trigger event (e.g. recognising that the farm is unprofitable or the need of a successor into the business) that the farmers start to consider new options. What this model emphasize is that many farmers may passively absorb information about renewable energy production for several years before a trigger event occurs. Advisors have a much greater role once farmers have decided to consider renewable energy production. Many times, the “other” farmers are the most common source of information for farmers (Garforth et al. 2003). A research of Sutherland et al. (2007) found out that these informal sources of information are the most important for small farmers, because they do not have found available to pay formal agricultural advice. This is the reason why, as renewable energy production on farms becomes more common, the pioneering farmers became active information providers, starting their own consultancies, combining their personal experience with other technical and legal knowledge.

[3] FAS helps farmers to better understand and meet the EU rules for environment, public and animal health, animal welfare and the good agricultural and environmental condition.

Taking into account the production of renewable energy, some types of renewable energy are more widespread: the largest resource for on-farm production of renewable electricity in Europe is wind energy, followed by biogas (European Parliament, 2016). Nevertheless, this depends on the country. For instance, among English farmers solar energy production is the most popular followed by wind energy production, (Bailey et al. 2008; Tate et al. 2012; Mbzibain et al. 2013), this is due to the ease of solar panel installation. Solar and wind are two options of passive energy production, once installed human intervention is minimal. On the contrary, bioenergy (anaerobic digesters) involve a significant "hassle factor". The majority of the advanced literature focuses on biomass and bioenergy crops production (Mola - Yudego et al. 2008; Villamil et al. 2008; Clancy et al. 2012; Huttunen, 2012).

Farmers mainly get involved in the production of renewable energy for economic reason. According to attitudinal tests, increasing farms profits is the main motivation that drives farmers to produce energy on-farm (Tranter et al. 2011), but this is not just about immediate profit. A study by Sutherland and Holstead found that Scottish farmers invest in wind energy production for the company's future, to help their future successors and to enable self-sufficiency in energy in the future. It represent also an opportunity for them to diversify, increase and stabilise their income, since farm incomes depends closely on fluctuating prices of their products. In addition, investing in the production of renewable resources would enable farmers to become less dependent on external energy supplies and to fulfil their desire to contribute to environmentally friendly energy production. An important role is also played by subsidy and feed-in taxes, farmers would be more encouraged to shift to environmentally friendly production and use of energy. Moreover, a positive contribution can be made at rural development and rural vitality level with the expansion of on-farm renewable energy activities. Farmers could have a higher, diversified and more stable income; technical infrastructure will be developed and it would have a positive impact on employment because more labour is needed on farms engaging in renewable energy production. Especially, bioenergy production often require additional local employment. Another positive aspect of renewable energy production is the reduction on greenhouse gas emissions. It was already mentioned at the beginning, that the agricultural sector contribute a lot to climate change, due to the fact that it generates a big slice of global greenhouse emission. This is why the introduction of renewable energies production could help, reducing the fossil fuels use.

The following are some ways to integrate renewable energy production in agriculture.

The mini-hydro is one of the multiple uses that can be made of irrigated water, to the benefit of agriculture penalized by energy costs also related to the most modern water-saving technologies. Mini hydro or micro – hydraulic systems are well connected in the agricultural world because they find the best possible application in sites where, there is an energy need to be met and a limited availability of water flow, as is typically the case with irrigation channels. Mechanical hydropower systems utilize the pressure of an irrigation system to spin the turbines and drive a hydraulic pump that is responsible for advancing the centre pivot around the field. Some studies demonstrate that Mechanical hydropower systems are the most common in Colorado because of their relatively low cost, independence from the larger power grid, and lower maintenance costs. (Osborn, 2017)

For long time, farms have used wind power to pump water and generate electricity. It is only over the past years that wind developers have installed large wind turbine on farms. Each turbine uses less than half an acre, in these way farmers can plant crops and graze livestock right to the turbine's base. The major obstacles encountered to turbines development are economic risks and transaction costs (Sutherland, 2014), some farmers avoid it by reducing turbine size or renting land to developers.

In agriculture, food production and photovoltaic systems mounted on the ground are perceived as being in conflict with each other. This conflict can be resolved with the concept of Agrophotovoltaic (APV), the opportunity to combine the crop production and generation of renewable electricity at the same plot (Beck et al. 2012). Research on plant growth under existing PV installations found that many species of natural plants grow quite well under these conditions, in particular shade tolerant crop. The APV method involves the installation of solar panels above the field with a larger space in between as compared to conventional ground system. (Beck et al. 2012; Majumdar et al. 2018; Marucci et al. 2018). Studies about its application have reported that it has a large global potential, in particular within arid climate zones (Beck et al. 2012).

Unlike other renewable resources, there are many ways to combine agriculture with bioenergy production. Creating a symbiosis between energy generation and the agricultural production process, brings advantages to both agriculture and energy sector. For instance, fermentation of livestock manures provides on-farm generated energy for farming operation. Advantages of manure digestion include improvement of nitrogen availability, improved physical properties (flow), reduction of odour and improved hygienic properties (Mirosz et al. 2015). Especially in large livestock farms, biogas technology has the potential to supply a significant share of electricity and heat needed on the farm (Paterson et al. 2016). Combined production of feed and biofuels is another example of how synergy effect could be created. In this case, oil crops like rapeseed are cultivated and processed in local oil mills. The vegetable oil is used as fuel for farm agricultural machinery. At the same time the oilseed cake supplies high value protein rich feed, replacing import of soybean (TFZ, 2017).

A lot of energy is consumed by farms; a large part of this is accumulated in biomass and organic residues such as straw, manure or wood residue, which can be used to generate energy. Many technologies are available to exploit these organic resources, but one of the main challenges is to exploit these resources without hampering food or feed production or install production systems with low sustainability. Options to combine crop production and energy provision are already developed and available (Souza et al. 2017), it is just a matter of putting them into practice.

2.1 Barriers and challenges to renewable energies production and consumption in agriculture

Accordingly to the large quantity of technical options and system solutions for renewable energy use on farms in combination with the different farm size and types (arable, livestock, etc.) settings (soil, infrastructure, climatic) ad regions (culture, system, innovation, policy), further growth of renewable energy use on farms is likely to take many forms and pathways. Positive trends and growth accelerators for renewable energy in agriculture and forestry can be noted, for example, increase in financial opportunities, decreasing cost of technology, gathering more experience and project development capacity. Nevertheless, for the development of bio energies, wind energy and solar parks, on a large scale, more and more support measures are required regarding infrastructure, spatial planning, different business models and market organisation, trends that are not all under control from farmers' perspective. Several support and research are needed to understand challenges and opportunities. Especially, identifying, developing and implementing integrated approaches and practices could help farmers adopt technologies that increase production of renewable energy in their farms.

Barriers and strengthening factors for the development of renewable energy technologies on farms have been identified and they can be grouped as: economic/financial, technical, societal and regulatory (Christou, 2019).

In general, renewable energy technologies (RETs) are more expensive compared to conventional alternatives (grid electricity, fossil fuels, etc.) this is why subsidies may be required to make them economically attractive. These incentives are uncertain due to policy changes, while stability in prices (e.g. feed-in tariffs, which touches on regulatory issues) is essential for farmers to avoid risks in their investment. In addition, capital is essential for investment projects.

Technical barriers deal with the reliability and complexity of technologies (functioning and maintenance), the service and capabilities of technology suppliers, divergence from projected performance due to specific local conditions. Systems integrating different components, such as the combination of solar, cooling devices, heat pumps or biomass use for energy like biogas could be examples of complex technologies at farm levels. In fact, biogas systems require specific skills and expertise because they often face fermentation problems that can be difficult to manage. On the other side, when technologies have good performance and require little maintenance, they are definitely an enabling factor. Solar energy and related batteries are not complex to use and problems with small-scale wind turbines may occur just in case of selection of unsuitable sites.

Obtaining authorizations to realize RET systems is quite hard and time consuming. Conflicts may arise between different regulations. Moreover, regulations on the sale of own-produced renewable electricity can have an influence on RET systems, especially on their profitability. On the other hand, there are many example of RETs on farm that have been successful thanks to the regulations; key role was played by the financial incentives.

The most common and widespread social aspects of the Renewable energy technologies implementation on farm and at community level are social acceptance. Social acceptance is evaluated against the following elements: personal attributes, psychological factors and contextual concepts (Hofman, 2015). Personal attributes refer to socio – demographic characteristics of farmers such as age, gender, level of education and income. The socio – demographic characteristics of farmers such as educational level, knowledge of innovative farming practices, economical status and age, gender structure of the household, influence their perception regarding the insertion of new technologies in farming. The old farmers tend to be more conservative and reluctant to use new technologies, this is probably due to the low education level or because they will not gain benefits of their investment before retirement. On the contrary, young farmers have access to technology breakthrough but they cannot afford it or they do not have financial credibility to get bank loans. The one who could potentially invest on renewable energy technologies in agriculture are the middle – aged farmers that have good education, history on adopting innovations and capital. (See chapter IV for Italian situation). Psychological factors concern the degree of awareness and understanding the political and environmental beliefs (Huijtsa et al. 2011) and the perceived fairness and trust (Musall, 2011). Farmer's awareness on global issues of concern (climate change, desertification, food safety, geo-environmental disasters) motivate them at a large extent in adopting low carbon practices in farming (non-tillage techniques, anaerobic management of wastes, rotation of crops) and implementing RES technologies on farm. Finally, contextual factors regard the social impact, namely the noise disturbance, emissions of track movements, odour problems (biomass plant), the aesthetic disturbance of the plant buildings (Chatziathanasiou et al. 2000), and the visual intrusion (wind park). Farmers' decisions to produce renewable energy is influenced to varying degrees by social norms and accepted standards of behaviour in their local community and/or community of practice. Local communities are increasingly objecting to renewable energy e.g. through lodging their concerns when planning permission is sought.

Each renewable energy alternative comes with specific issues concerning finance, technical, social, regulatory and competition for natural resources. Table 1.4 shows all the key issues identified by Christou et al. (2019) for each renewable energy technology alternative.

Table 1.4 Overview of the financial, technical, societal, regulatory, natural resource and other factors that enable or hamper the deployment of key renewable energy options on farms.

Solar power	
Economic/Financial	Electricity prices fluctuate frequently, putting solar power farms' productivity under constant pressure. Since large quantities of electricity are difficult to store, the amount of energy produced and fed into the grid must be carefully balanced to the system's ability to keep it running. Although small amounts of photovoltaic power can be integrated into the grid with minimal adjustments, larger-scale operations would necessitate the implementation of grid-monitoring technologies and more cost-effective energy storage systems, thus increasing the overall costs. It is important to have appropriate financial instruments available to encourage farmers to invest.
Technical	Farmers are often unaware of existing opportunities to improve the quality of their farm's energy usage. Important improvements in farm energy production can be made by profiling farm energy usage and using dedicated benchmarking.
Societal	The level of local government funding can have a significant impact on whether or not farmers invest in solar energy production. Wide solar parks on (agricultural) land can face challenges in gaining social acceptance..
Regulatory	In certain countries, grid balancing of energy supply and demand is not properly discussed. Feed-in tariffs could include market stability and long-term contracts, allowing further renewable energy projects to be funded.
Competition for natural resources	Solar power plants can compete with agricultural land and they ca have an effect on the landscape.
Wind	
Economic/Financial	On a cost basis, wind power must also compete with traditional generation sources. Despite the fact that the cost of wind power has decreased over the last decade, the technology still needs a significant initial investment, and appropriate financial instruments for farmers and farmer cooperatives are desirable. Stability of financial instruments, price certainty and stable long-term contracts are desirable.
Technical	Wind turbine electricity production is determined by wind intensity, so precise planning of energy output is impossible. The

	electricity supply system has to adapt to the wind energy production. However, efficient integration of wind energy into an existing power system requires an advanced management of the conventional power plant.
Societal	There are concerns about the rotor blades' noise as well as the visual effect on landscapes. These effects can have an impact on property values, although stronger societal support is obtained with more collective approaches.
Regulatory	Collaborative spatial planning is needed.
Competition for natural resources	Alternative uses for land that are more valuable than electricity generation can compete with land suitable for wind turbine installation.
Biomass heat, power, fuels	
Economic/Financial	Equipment and financing costs need to be reduced, particularly for advanced biofuels (large scale needed). Stable financial instruments and transparency are important. For biogas, support is needed for other services (e.g. manure treatment and recycling equipment). Business models on a regional scale are recommended (to obtain scale) and collective approaches could play an important role. Business models need to support multiple targets and achieve synergy with sustainable agriculture and land use goals.
Technical	Investment in biogas storage capacity is needed, hen the generation of electricity exceeds the consumption. Advanced biofuels and bio refining require sophisticated technologies. Matching the seasonality of biomass supplies and energy demand is difficult.
Societal	Social acceptance may be improved if benefits are demonstrated. Regional business models that are inclusive will help to boost support. The effects of the landscape must be considered..
Regulatory	Stability in regulatory frameworks is needed. A general structure for bioenergy development and agriculture sustainability is desirable.
Competition for natural resources	Sustainability of increased feedstock production is a key issue, including how to avoid competition with food production. There is a lack of knowledge about the economic potential of biomass.

Source: European Commission (2019)

Based on the information seen in Table 1.4, policy incentives and the R&D sector, with the goal of improving technologies, are the essential factors for the development of renewable energy technologies. This, combined with the development of integrated solutions and increased collaboration between energy and agriculture sectors are key areas that can lead to positive results. Renewable energy on farms need policy and incentives to accelerate the use, combined with collaboration between actors to address the various economic, technical and social barriers.

CHAPTER III Literature review

This chapter was the subject of an internship of the Venice centre in Economic and Risk Analytics for Public Policies (VERA) Academy. The VERA Academy is the advanced training programme that gives talented students of Master's Degree Courses of the Department of Economics the opportunity to work with the researchers of the VERA Centre on their research projects. The project involved the collection and analysis of the existing bibliography on renewable and non-renewable energy sources and on the relationship between renewable energy sources and agriculture. Then, recognition of existing sources and collection of data on energy from renewable sources in terms of production and consumption, with the construction of a final case study. The project was carried out between November 10, 2019 and February 29, 2020 with research tutors Antonella Basso and M. Bruna Zolin.

The work then focused more on the bibliographic collection and an approach to the Farm accountancy data network (FADN) DATABASE.

A systematic literature survey helps to identify those studies analysing the Agriculture and Renewable energy in a broad sense. To survey the existing literature, a set of key words closely related to the topic were selected: efficiency, Technical efficiency, DEA, agriculture and renewable energies.

The processing involved the analysis of 75 papers. Analysing the articles and taking into consideration the efficiency concept, the collection has expanded.

All the type of efficiency founded in literature will be summarised, with reference to the method used to measure it.

The academic literature collected, places a lot of attention on the efficiency profile, taking into consideration many aspects of efficiency, ranging from agriculture sector, irrigation, sustainability and energy.

The conventional definitions of efficiency used in the economics literature can be traced back to Farrel (1957). Farrell introduced a simple method of measuring the efficiency of a firm directly from observed data, in a single output (product) case, taking account of multiple inputs. Farrel proposed to decompose the economic efficiency of a firm into technical efficiency and allocative efficiency.

According to Farrel (1957), technical efficiency (TE) represents the ability of a decision making units (DMU) to produce maximum output given a set of inputs and technology (output-oriented) or, alternatively, to achieve maximum feasible reductions in input quantities given input prices and output(input-oriented).

It can be defined in terms of producing a maximum amount of output, given a set of inputs; or producing a given level of output with a minimum level of inputs; or a combination of the two. Either efficient farms use less input than others to produce a given quantity of output, or for a given set of inputs, they generate a greater output.

Whereas allocative efficiency reflects the ability of a production unit to use the inputs in optimal and efficient proportions, given their prices and the production technology used.

Efficiency in general concerns 64% of papers collected, and they can be divided according to the types of efficiency taken into account.

In technical efficiency contest, Banaeian et al. (2011) found that for Iranian greenhouse strawberry production, according to the technical efficiency, there is a suitable potential for more efficient and sustainable input utilization in production. Abruev et al. (2012) have examined the efficiency level of livestock production in the districts of Uzbekistan. They find out the overall efficiency was very low, due to the lack of organizational effectiveness in managing inputs under currently available technology. They suggest a series of measures and appropriate incentives, for example to increase farm size, in order to raise the efficiency of livestock production. Moutinho et al. (2018) estimate the technical agricultural efficiency of European countries. Okuyama et al. (2017) collected data of 66 farmers in the central region of Senegal and calculate the technical efficiency (TE) of the production of each crop. Finally, they identified factors that have positive impact on TE.

Sustainable efficiency or eco-efficiency is another type of efficiency analysed in the literature. Eco-efficiency is a management strategy of doing more with less (Glavič et al., 2012). Based on the concept of creating more goods and services, it uses fewer resources and produces less waste and pollution.

De Koeijer et al. took as sample Dutch sugar beet growers, researchers found a positive correlation between technical efficiency and sustainable efficiency. This lead to the conclusion that there is a considerable scope for improving the sustainability of arable farming by better management (De Koeijer et al. 2002). Martinez (2013), analysed eco-efficiency in terms of energy use and CO_2 emissions. The results suggest that increased energy taxes, investments and productivity generate higher eco-efficiency while higher fossil fuel consumption generate lower eco-efficiency.

The concept of sustainable efficiency is linked to the concept of energy efficiency, which simply means using less energy to accomplish the same goal – in other words, eliminating energy waste. Energy efficiency has a range of advantages, including lowering greenhouse gas emissions, reducing demand for energy imports, and reducing costs on a household and economy-wide level. Although renewable energy technology can help achieve these goals, improving energy efficiency is the most cost-effective – and often most urgent – way to minimize fossil fuel usage.

Researchers have been motivated to concentrate on energy efficiency by factors such as global warming, rising energy costs, reduced energy supply reliability, and the vision of sustainable development. Dogan al. (2015) study, estimates technical efficiency scores of G-20 countries in terms of electricity production for 1990, 1995, 2000, 2005, and 2011 periods. According to the findings, China and Russia are at the top of the energy efficiency rankings. France and the European Union, on the other hand, are inefficient in four of the five years. The importance of energy efficiency should be encouraged in order to achieve sustainable economic growth and climate stability today and in the near future (Pardo Martinez et al. 2015).

Another research have been done, in 23 developing countries during the period of 1980 – 2005 aiming at investigating the energy efficiency. Total – factor energy efficiency and change trends have been explored. During the entire research period, the empirical results show that Botswana, Mexico, and Panama perform the best in terms of energy efficiency, while Kenya, Sri Lanka, Syria, and the Philippines perform the worst. Seven countries' energy efficiency has remained relatively constant over time. Eleven countries' energy efficiency has been gradually decreasing. China was the fastest growing of the five countries with steady increases in total-factor energy efficiency (Zhang et al. 2011).

On the other hand, economic efficiency aims to minimize costs, which might or might not require fewer inputs. A research was done in the beekeeping sector in Greece, it comes out that given the technologies used, beekeepers could achieve the same amount of output by reducing their inputs. Finally, by reorganizing the used inputs and making the necessary adjustments, both efficiency and economic performance could increase (Makri et al. 2015). Vukelic et al. (2013) make a study which objective was to measure the economic efficiency of broiler farms in Vojvodina region. The results show that reducing the cost of production while attaining the same level of output is a good way to enhance the economic efficiency. Moreover, the distribution of efficiency scores shows that larger farms have higher efficiency scores that smaller ones.
Several studies have focus on the estimation and explanation of agricultural economic efficiency in developing countries. For example; Pakistan (Ali and Chaudhary 1990; Parikh et al. 1995; Battese et al. 1996), India (Battese and Coelli 1992; Battese and Tessema 1993), Bangladesh (Wadud and White 2000), China (Wang et al. 1996; Xu and Jeffrey 1998) Philippines (Dawson et al. 1991; Kalirajan 1991). These studies show substantial inefficiency and identify the potential to improve the productivity of agricultural production in developing agriculture. Dhungana et al. (2004) conclude that benchmarking using the efficient farms would be helpful for setting targets and finding the weakness of the current practices.

Among the papers dealing with efficiency, only one consider renewable energy consumption. Chien et al. (2007) analysed the effects of renewable energy on the technical efficiency of 45 economies during the 2001 - 2002 period. It results that the increase of renewable energy use improve also the technical efficiency of an economy. Increasing conventional energy input, on the other hand, reduces technological efficiency. It was also verified that the use of renewable energy is different in developed economies and developing economies. The status of Organization for the Economic Co-operation and Development (OECD) and non-OECD economies was used as a proxy variable for developed and developing economies respectively. The OECD economies have higher technical efficiency and a higher share of renewable energy from geothermal, solar, tide, and wind compared to non-OECD economies

The collected literature can also be classified under others two lines. The first one is composed of studies based on a microanalysis (company perspective). For instance, Wei et al., 2007; Mukherjee, 2008; Martinez, 2015. Increased energy intensity is the element that reduces energy efficiency, according to the findings of these studies.

The second line includes studies based on a macro analysis, which deal with energy efficiency problem in regional and/or international perspectives.

Hu and Wang (2006) calculate the total-factor energy efficiency index and analyse energy efficiencies in 29 Chinese administrative regions from 1995 to 2002. According to the findings, China's central region has the lowest energy efficiency and its total adjustment of energy consumption amount is over half of China’s total. However, with the exception of the western part of the country, China's regional index of total-factor energy efficiency improved from 1995 to 2002. Chang and Hu (2010), evaluate the energy productivity change of regions in China with a total-factor framework by using 29 provincial level data from 2000 to 2004. Shi et al. (2010) analyse the overall energy-saving capacity in 28 administrative regions in China for the period 2000 - 2006, taking into account undesirable outputs and minimization of energy consumption in measuring Chinese industrial energy efficiency, and conclude that industries in the east have the best average energy efficiency, followed by those in the central area. Zhang et al. (2011) analyse energy efficiency in 23 developing countries from 1980 to 2005 using a total-factor framework. According to the findings, Botswana, Mexico, and Panama have the highest energy efficiency, while Kenya, Sri Lanka, Syria, and the Philippines have the worst. Furthermore, seven countries' energy efficiency has remained stable over time, although eleven countries' energy efficiency has continued to decline. Finally, among five countries witnessing continuous increase in total-factor energy efficiency, China experienced the most rapid rise. Zhou et al. (2012) estimate economy-wide energy efficiency performance from a production point of view by focusing on energy efficiency calculation at a macro-level and proposing a parametric frontier method for 21 OECD countries, finding that Ireland, Italy and Norway are the most efficient countries, while Canada, New Zealand and Belgium have the lowest efficiency ratings. Finally, Dogan et al., (2015) study energy efficiency of G-20 countries in term of energy use.

As already mentioned, all the papers collected aim at measuring efficiency that was the main objective of this research. Several approaches are used to measure it.
Farrell's (1957), has led to the development of several techniques for the measurement of technical efficiency. These techniques can be classified into two basic types: parametric and non-parametric.
The parametric stochastic frontier production function (SFP) approach (Aigner et al. 1977) and the nonparametric mathematical programming approach, commonly referred to data envelopment analysis (DEA) (Charnes et al. 1978), are the two most popular techniques used in efficiency analysis.
Wadud and White (2000) indicate that in most empirical studies the selection of the methodology used to measure Technical Efficiency (TE) is arbitrary and mainly based on the objective of the study, the data available and the personal preference of the researcher.
The most commonly used methods in the academic literature collected is the Data Envelopment Analysis (DEA), (60% of the papers).
In the original research, Charnes, Cooper and Rhodes (1978) described DEA as a "mathematical programming model applied to observational data that provides a new way of obtaining empirical estimates of relations – such as the production functions and/or efficient production possibility surfaces – that are cornerstones of modern economies".
This non-parametric research technique is based on a mathematical optimization method. The method has been used in various sectors of the economy and at various levels (companies, counties, regions, etc.) since its inception in 1978.
Regarding the energy sector efficiency evaluation, it should be noted that papers that are based on DEA methodology are increasing from 2000. As the first remarkable effort employing DEA in energy efficiency assessment is the paper of Ramanathan (2000) who used DEA to assess the differences between the energy efficiency of rail and road transportation nodes.
Many studies (Fraser et al. 1999, Shafiq et al. 2000, Lansink et al, 2004) have estimated technical efficiency applying DEA with basis data on several inputs and outputs.
The main advantages of DEA approach is its flexibility, since it adapts multiple-output technologies and imposes less restrictive assumption about production technology.

Due to the high advantages of DEA, there are several applications of this technique to determine the efficiency in agricultural sector (Fraser et al. 1999, Fraser et al. 2001, Chambers et al. 2011, Abruev et al. 2012). Moreover, Dhungana et al. (2004) used the DEA method to investigate the economic inefficiency of Nepalese rice farms. They found that the significant variations in the level of inefficiency across sample farms were attributed to the variations in the use of resources such as seed, labour, fertilizers and mechanical power. Finally, Mousavi-Avval et al. (2011) used this technique to examine the technical efficiency of apple producers with respect to the energy and cost data for apple production in Tehran province of Iran.

Many researchers have used the DEA as a tool to create benchmarks to assess efficiency or inefficiency in different sectors. (Cooper et al. 2006; Fraser et al. 1999; Syp et al. 2015; Malana, 2006; Mohammadi et al. 2013; Mohammadi et al. 2015; Vukelic, 2013). For example, studies of benchmarking activities with DEA have exposed a slew of inefficiencies in some of the most profitable companies (Cooper et al. 2006). Błażejczyk-Majka, L. (2017), presents how DEA is used to develop agricultural production efficiency rankings in the EU member states.

Many times the researchers divide the countries or the companies of the sector under consideration in subgroups. For instance, researchers for a study made in Vojvodina, Serbia, to measure the economic efficiency of agricultural production, considered all the broiler farms and then classified them onto three categories according to their production capacity (Vukelic et al. 2013). In a study of Nassiri et al. (2010), India was divided in zone to calculate the technical efficiency of each zone. Toma et al. (2015), divided the sample of thirty-six countries into three categories based on their geographical main characteristics: group I, with 50 - 100% plain areas (20 countries); group II, with 50 % - 80% hill areas (8 countries) and group III, 50 - 80% mountain areas (8 countries) In terms of production factors (work, property, and mechanization) allocation and outputs, this empirical research shows that there are strong differences in performance between areas with similar geographical characteristics. Only 14 countries achieve DEA efficiency, the other countries need to change their input combination to reach a higher efficiency.

In Poland, DEA methodologies were used to benchmark the degree of operational efficiency of 55 winter wheat farms, ranging in size from small to large (Syp et al. 2015).

In Australia, DEA was used to benchmark the dairy industry, which is constantly striving to improve its productivity efficiency (Fraser et al. 1999). DEA uses a systems approach, in that it considers the relationship between all inputs and outputs at the same time (Fraser et al. 1999).

Furthermore, DEA provides a relative measure of efficiency and defines certain inputs and/or outputs that are underutilized. From the perspective of extension, this is highly valuable knowledge because it can help define industry best practices (Fraser et al. 1999).

In addition to the DEA methodology, there are other approaches useful to measure efficiency.

Some authors, such as Charnes et al. (1990) and Banker et al. (1994) suggest using more than one method to compare the results obtained from the estimation method, in order to benefit from the advantages of both.

Iráizoz et al. (2003) compare two estimation methods, one parametric and another non-parametric for the technical efficiency of a sample of Spanish farms producing tomato and asparagus. Considering the methods used, strong similarities was found between the two estimates for technical efficiency. From an efficiency analysis point of view, the results so far indicate a wide difference in efficiency across the farms. The obtained measures of efficiency indicate the potential that exists for improving farm income by improving productive efficiency.

In many studies, DEA is compared to other methods for the efficiency calculation. For instance, Alene et al. (2006), compare the empirical outputs of the stochastic frontier production function (SFP), parametric distance functions (PDF), and data envelopment analysis (DEA) in measuring the efficiency of intercropping systems of annual and perennial crops production in southern Ethiopia. The results of the multi-output PDF and DEA approaches showed that the systems were substantially more effective than the single output SFP approach. In multi-output agriculture involving intercropping of annual and perennial crops, researchers find that both DEA and PDF are relevant. Single-output measures of productivity and efficiency may thus underestimate resource use efficiency of intercropping systems.

Kimhi et al. (2018) use two alternative empirical models to estimate farm efficiency changes after the diary policy reforms in Israeli. The Stochastic Frontier Analysis (SFA) (Aigner et al. 1977) that use a statistical model to separate random deviation from maximum efficiency and permanent efficiency gap, and DEA. They found that the dairy industry in the post-reform era is composed of larger and more efficient farms compared to earlier years. Moutinho et al. (2018) use DEA and SFA too, to estimate the technical efficiency of European countries. Alene et al. (2005) compares the empirical performance of parametric (PDF) and non-parametric distance function (DEA) methodologies with applications to improved production technology adopters in eastern Ethiopia. Technical efficiencies obtained from the two approaches are positively and significantly correlated. Pardo Matrtìnez, C. I. (2015) used DEA and Panel data analysis to study the comparative performance of German and Colombian energy-intensive sectors between 1998 and 2005. The DEA's findings show that during the sample era, the vast majority of energy-intensive sectors improved, showing that energy input is a significant variable in the production structure and a key element in technology growth. In a second point, regression analysis using panel data analysis shows that a variety of variables, including labour productivity, electricity share, expenditures, and enterprise size, influence the energy efficiency disparities between German and Colombian energy-intensive sectors.

Mohammadi et al. (2015) use a combination of Life cycle assessment (LCA) and DEA to examine the environmental and economic performance of multiple similar entities. A total of 82 rice paddy fields for spring and summer growing seasons in north of Iran were assessed using a LCA and DEA methodology to estimate the technical efficiency of each farm.

The orientation of bibliographic research has also taken into consideration the consumption and production of energy.

Majority of the papers focus on energy consumption. Mukherjee (2008) make a study to measure the energy use efficiency in the U.S. manufacturing sector. Mousavi-Avval et al. (2011) focus on agriculture, researchers studied the optimization of energy consumption for apple production in Iran, trying to identify wasteful uses of energy in order to optimize the energy inputs. Singh et al. (1990) focused their research on paddy and wheat, the major crops produced in Punjab, India and consuming most of the energy used in the farms. A farmers' survey was conducted, using a multistage stratified methodology to investigate energy consumption for paddy-wheat rotation. Irrigation used the most resources out of all the farm activities for both paddy and wheat. The solution suggested is an alternative crop rotation, which require less energy. Shi et al. (2010) study Chinese industrial energy efficiency and investigate how to minimize the energy consumption in 28 administrative regions in China.

Only one paper, that it was already mentioned, Chien et al. (2007) analyse the renewable energy consumption, concluding that increasing the use of renewable energy improves an economy’s technical efficiency.

The number of papers analysing energy production is much smaller. Chang et al. (2010) research has as main purpose to evaluate the energy productivity change of regions in China with a total-factor framework during 2000 – 2004. The results shows a decline in productivity. Only one paper considers renewable energy production. Dalgaard et al. (2001) analyse the role of energy crops in reducing fossil fuel energy use and greenhouse emission. Researchers developed a tool to improve decision making on the use of crops for producing bioenergy. The results lead to the consideration that agricultural knowledge is important for optimizing bioenergy development chains' outputs.

In conclusion, majority of the papers are focused on achieving efficiency whether economic and/or technical. What is possible to understand is that to achieve this result, it is necessary to apply calculation methods and, through the results obtained, understand how to improve through the decrease or increase of input or output. The collected papers also tend to show that it is possible to achieve a good level of efficiency between agriculture and energy.

As it was possible to observe, the best method for calculating efficiency is the DEA method, which also compared with other methods leads to results that are more truthful.

Finally, more attention should be paid in the field of energy production, in particular the production of renewable energy since it would lead to an improvement in efficiency and in environment.

CHAPTER IV An analysis of farms producing renewable energy in Italy

The Farm Accountancy Data Network (FADN) is an EU tool for analysing the agricultural economic situation in Europe and programming/evaluating the Common Agricultural Policy (CAP – partnership between agriculture and society, and between Europe and its farmers). The FADN is a sample survey carried out in all of the European Union's member states. It is the only European source for farm management that is harmonised.

The FADN survey does not represent the entire range of farms surveyed in a given area, but only those that, due to their economic size, can be considered professional and market-oriented. The methodology adopted aims to provide representative data on three dimensions: regional economic and type of farming

For each farm in the sample, information is collected covering about 1000 variables and the Community farm return is compiled, outlined in its basic structure by specific regulatory measures of the Commission. Over time, it has undergone several changes and additions, in response to the increased need for information developed over the past years. The variables measured concern:

- Physical and structural data (location, area, livestock size, farm manpower, services offered, etc.)
- Economic data (revenues from sales, final stocks, purchases of technical equipment, etc.)
- Financial data and assets (debts, credits, public aids, production rights, acquisition and disposal of assets, etc.)

The Italian FADN (Rete di informazione contabile Agricola – RICA) information system is more structured than the European one, and it can meet knowledge needs not only at the farm level, but also at the territorial level for scientific and/or sectoral planning purposes.

Allows analyses to be carried out on various issues ranging from farms productivity to production costs, from environmental sustainability to the role of the farm family.

This third chapter will focus on analysing the main characteristics of the farms that was part of the FADN database in 2018, in order to extract at farm level the characteristics of farms producing energy from renewable sources.

The data then, extracted from the database, have been reported in an excel worksheet for easier comparison and analysis.

The database presents information on 10.387 farms located throughout Italy.

The part of the sample that will be taken into account for the analyses will be the farms that, in addition to the main production, produce simultaneously energy from renewable sources. The farms that produce renewable energy in Italy are 426 (Table 3.1).

It is possible to note in Figure 3.1 that the region with farms most inclined to produce renewable energy is Friuli Venezia Giulia in the first place, followed by Valle d'Aosta and Veneto, with 76, 54 and 52 farms producing renewable energy, respectively (Table 3.1). This is due to the fact that, these regions generally produce a lot of energy through renewable sources. In Friuli Venezia Giulia, 101 municipalities are 100% renewables for the electricity part. Renewable energy sources account for 27,1% of overall energy demand, with 31.040 plants distributed across all municipalities (Legambiente, 2018). Valle d'Aosta, on the side of the electricity production, can be defined as "100% renewable". This is because plants that exploit renewable sources generate about 99% of the electricity. In Veneto in recent years, the growth of renewable energy has been significant both in terms of installed power and in terms of energy production. Today 44% of total energy consumption is covered by renewable sources (Legambiente, 2018). On the other side, the regions where the number of farms producing renewable energy is lower are Trentino Alto Adige, Abruzzo and Molise (Table 3.1 and Figure 3.1).

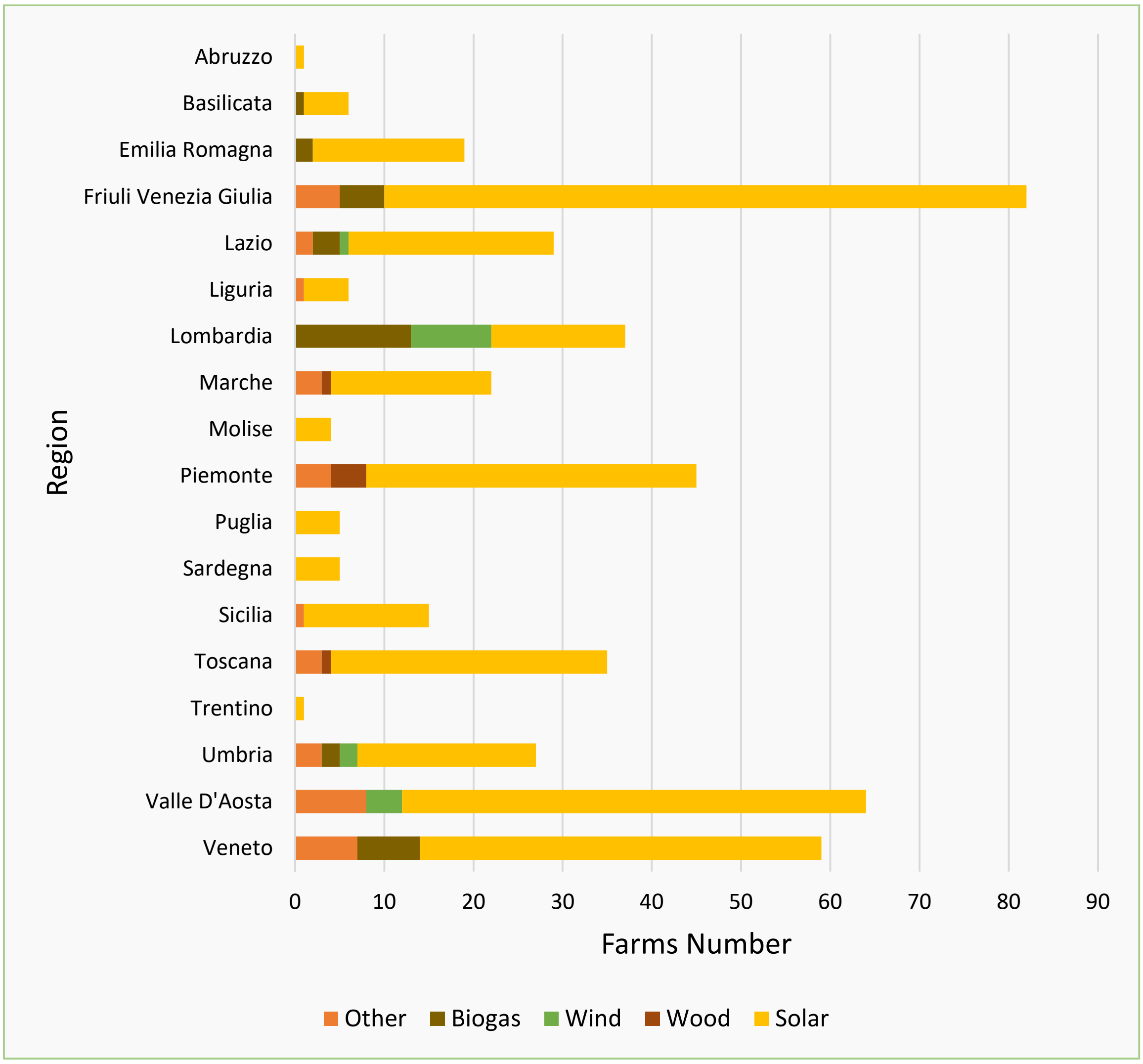
Figure 3.1 shows very clearly the difference between regions where the number of farms producing renewable energy is high and regions where the number of farms producing RE is low. Moreover, in this figure, it is possible to notice the type of renewable energy that is most common in Italian farms, solar energy.

Table 3.1 Number of farms producing Renewable Energy per region

REGION	NUMBER OF FARMS
ABRUZZO	1
BASILICATA	5
EMILIA ROMAGNA	19
FRIULI VENEZIA GIULIA	76
LAZIO	25
LIGURIA	5
LOMBARDIA	37
MARCHE	19
MOLISE	4
PIEMONTE	42
PUGLIA	5
SARDEGNA	5
SICILIA	14
TOSCANA	33
TRENTINO	1
UMBRIA	24
VALLE D’AOSTA	57
VENETO	54
TOTAL	**426**

Source: elaboration on Database RICA data

Figure 3.1 Number of farms producing Renewable Energy per region by type



Source: elaboration on Database RICA data

In fact, according to the data collected, the farms that use sunlight to produce electricity are 370, many more than the farms that use the other types of renewable resources.

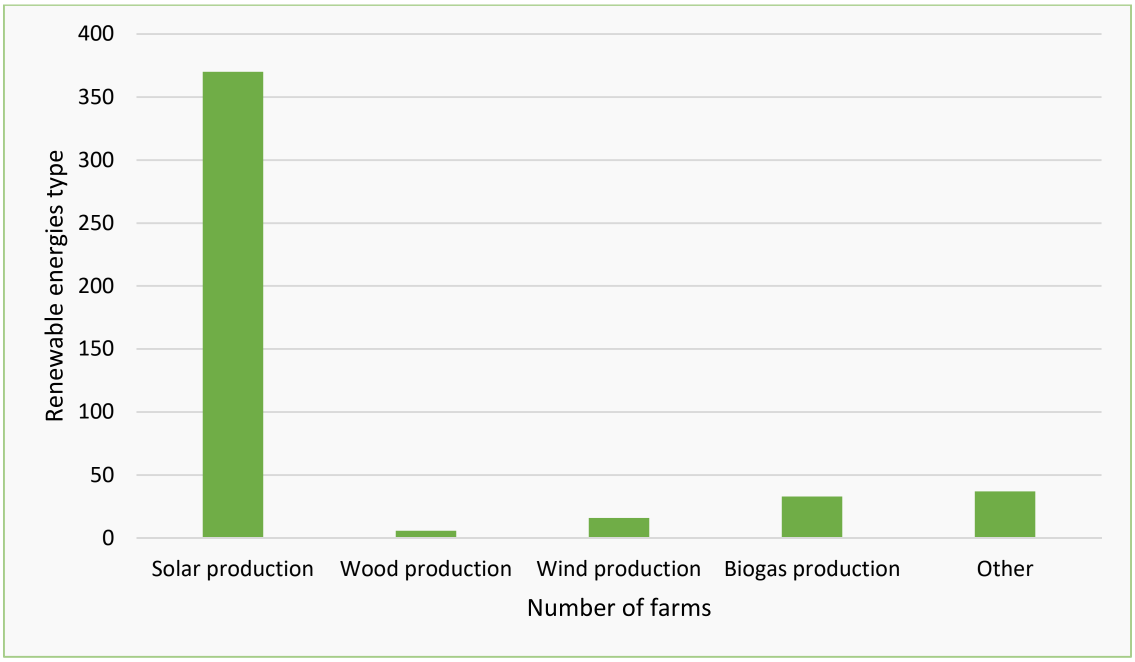
This is because photovoltaic systems, as already mentioned in Chapter 1, do not require much maintenance and incentives are provided. In addition, the sun is a constant almost daily, the same cannot be said of other types of resources, such as wind, which is much more unpredictable in Italy.

Table 3.2 Number of farms producing Renewable Energy per type

RENEWABLE ENERGY TYPE	NUMBER OF FARMS
SOLAR ENERGY PRODUCTION	370
WOOD ENERGY PRODUCTION	6
WIND ENERGY PRODUCTION	16
BIOGAS ENERGY PRODUCTION	33
OTHER	37

Source: elaboration on Database RICA data

Figure 3.2 Number of farms producing Renewable Energy per type



Source: elaboration on Database RICA data

From a management perspective, Table 3.3 shows the types of management in farms that produce renewable energy.

Mainly, farmers prefer direct management with prevalence of family members, only family members, and prevalence of extra-family, 201, 142, and 63 are the number of farms respectively. Far fewer are the farms managed by employee and contracting.

Table 3.3 Management type of farms producing renewable energy

MANAGEMENT OF THE FARM	
DIRECT HOLDING WITH A PREVALENCE OF FAMILY MEMBERS	201
DIRECT HOLDING WITH ONLY FAMILY MEMBERS	142
DIRECT HOLDING WITH PREVALENCE OF EXTRA FAMILY	63
WITH EMPLOYEES	18
CONTRACTING	2

Source: elaboration on Database RICA data

Looking at the district level the productivity by type of renewable energy shows very wide differences (Figure 3.4).

In the northwest, all types of renewable resources are used by farms for energy production, the same occurs in central Italy, albeit with less frequency.

In the North East, however, many more farms focus on solar energy production, leaving out wind and wood.

Even in the south and in the islands, the production of wind energy is totally neglected in farms, despite the fact that these areas of Italy are known for the high concentration of plants for the production of wind energy (Legambiente, 2018).

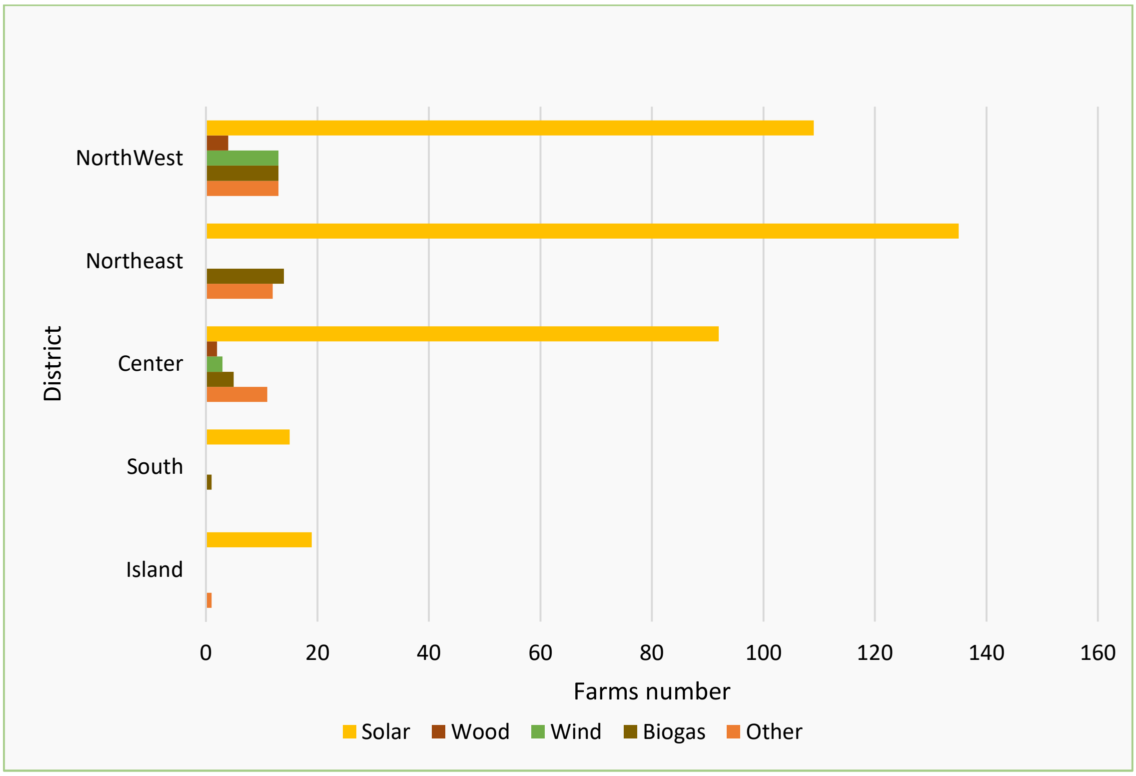
Overall, it can be seen that, even analysing Italy by districts, the source of renewable energy most produced by farms is solar energy.

Table 3.4 Number of farms producing Renewable Energy per district by type

DISTRICT	SOLAR	WOOD	WIND	BIOGAS	OTHER
NORTH WEST	109	4	13	13	13
NORTH EAST	135	0	0	14	12
CENTER	92	2	3	5	11
SOUTH	15	0	0	1	0
ISLAND	19	0	0	0	1
TOTAL	**370**	**6**	**16**	**33**	**37**

Source: elaboration on Database RICA data

Figure 3.3 Number of farms producing Renewable Energy per district by type



Source: elaboration on Database RICA data

In relation to the physical location of farms, it is possible to notice discrepancies between the Italian areas (Figure 3.4).

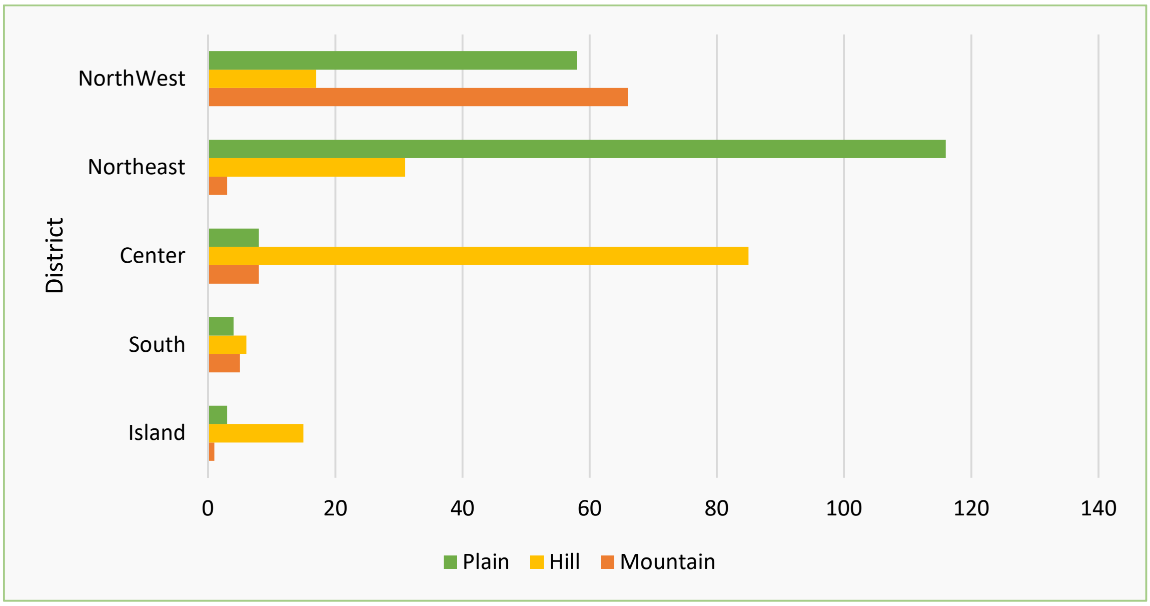
In the North West, farms producing renewable energy are concentrated mainly in the mountains and plains, unlike the North East, where almost all farms are located in the plain. In centre and southern Italy and the islands, however, farms are concentrated in the hilly part of the regions. These differences are mainly due to the different physical characteristics of the Italian areas.

Table 3.5 Number of farm producing Renewable energy per altitude zone

DISTRICT	PLAIN	HILL	MOUNTAIN
NORTH WEST	58	17	66
NORTH EAST	116	31	3
CENTER	8	85	8
SOUTH	4	6	5
ISLAND	3	15	1
TOTAL	**189**	**154**	**83**

Source: elaboration on Database RICA data

Figure 3.4 Number of farms producing Renewable energy per altitude zone



Source: elaboration on Database RICA data

According to data processing, Table 3.6 shows that renewable energy production is more widespread among farms located in the plains rather than in the hill or mountain zone. In fact, 6,3% of farms located in the lowlands produce renewable energy, almost twice the percentage of farms located in the hills and mountains.
Examining in detail the production of solar energy, it is possible to note that it is also more widespread in the lowlands – 4,8% compared to 3% and 3,1% in hill and mountain, respectively (Table 3.7).

Table 3.6 Number and percentage farms producing Renewable Energy per altitude zone by type

	SOLAR	WOOD	WIND	BIOGAS	OTHER	TOTAL	FADN	%
PLAIN	152	1	9	26	11	199	3171	6,3%
HILL	144	2	2	6	17	171	4831	3,5%
MOUNTAIN	74	3	5	1	9	92	2384	3,9%

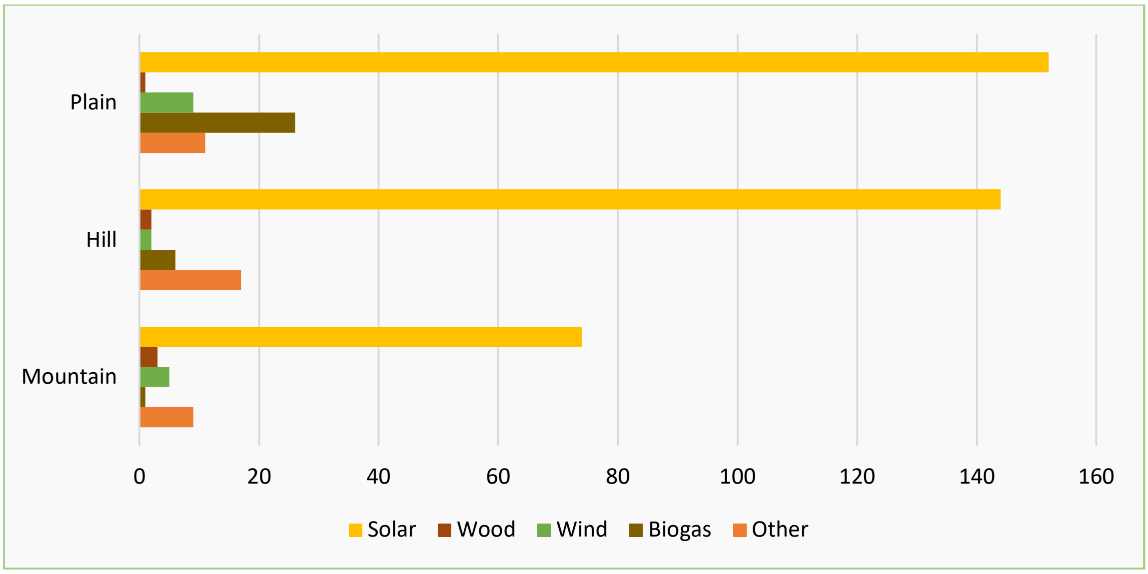
Source: elaboration on Database RICA data

Table 3.7 Percentage of farms producing Solar Energy per altitude zone

	SOLAR	TOTAL FADN	%
PLAIN	152	3171	4,8%
HILL	144	4831	3,0%
MOUNTAIN	74	2384	3,1%

Source: elaboration on Database RICA data

Figure 3.5 Number of farms producing Renewable Energy per altitude zone by type



Source: elaboration on Database RICA data

Table 3.8 shows that farms whose main activity is crop production are those that invest most in the production of renewable energy. In fact, crop-producing companies are 214, while livestock companies are 186. These data are motivated by the fact that the production of renewable energy fits more easily with crops production from a physical point of view. It is in fact more difficult to combine the production of renewable energy with livestock farming, although as already mentioned in Chapter 1, the combination of wind energy production and livestock has already been tested, creating higher turbines with smaller and quieter blades, the animals can graze along the base.

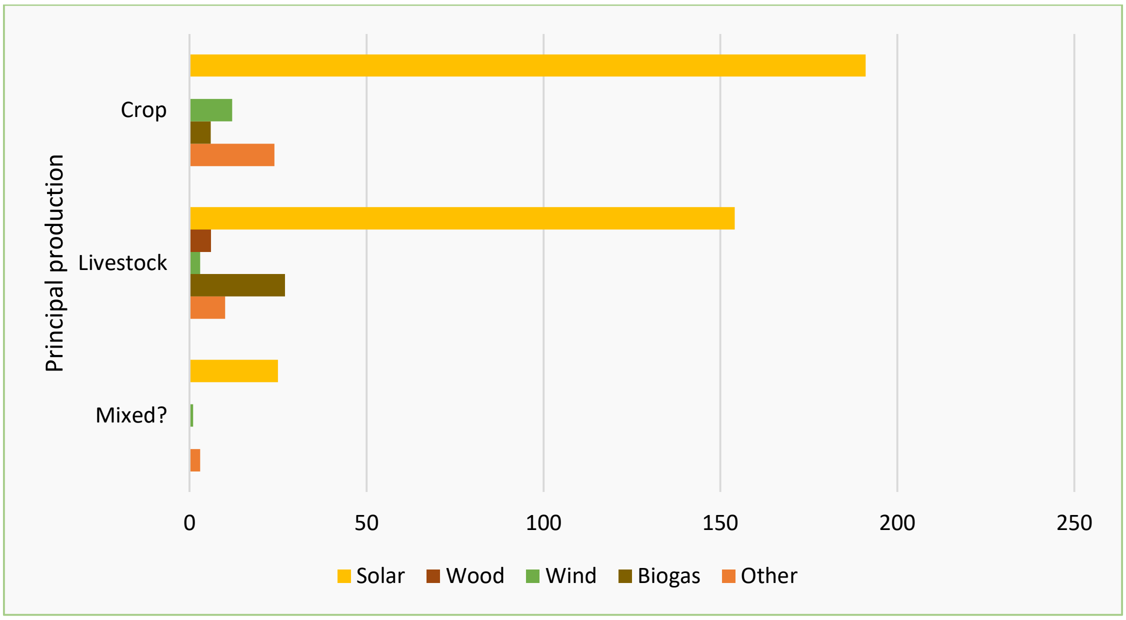
On the contrary, in figure 3.6 it can be noted that in livestock companies the biogas production is very high. This is because the production of biogas is based on organic waste from plant or animal waste. Livestock farms use waste from their animals, so they do not need to occupy additional land, as it happens for crop companies to get plant residues.

Table 3.8 Main production of farms that produce renewable energy

NUMBER OF FARMS PRODUCING RE AND MAIN PRODUCTION	
CROP	214
LIVESTOCK	186
MIXED	26
TOTAL	**426**

Source: elaboration on Database RICA data

Figure 3.6 Type of renewable energy according to farm main production



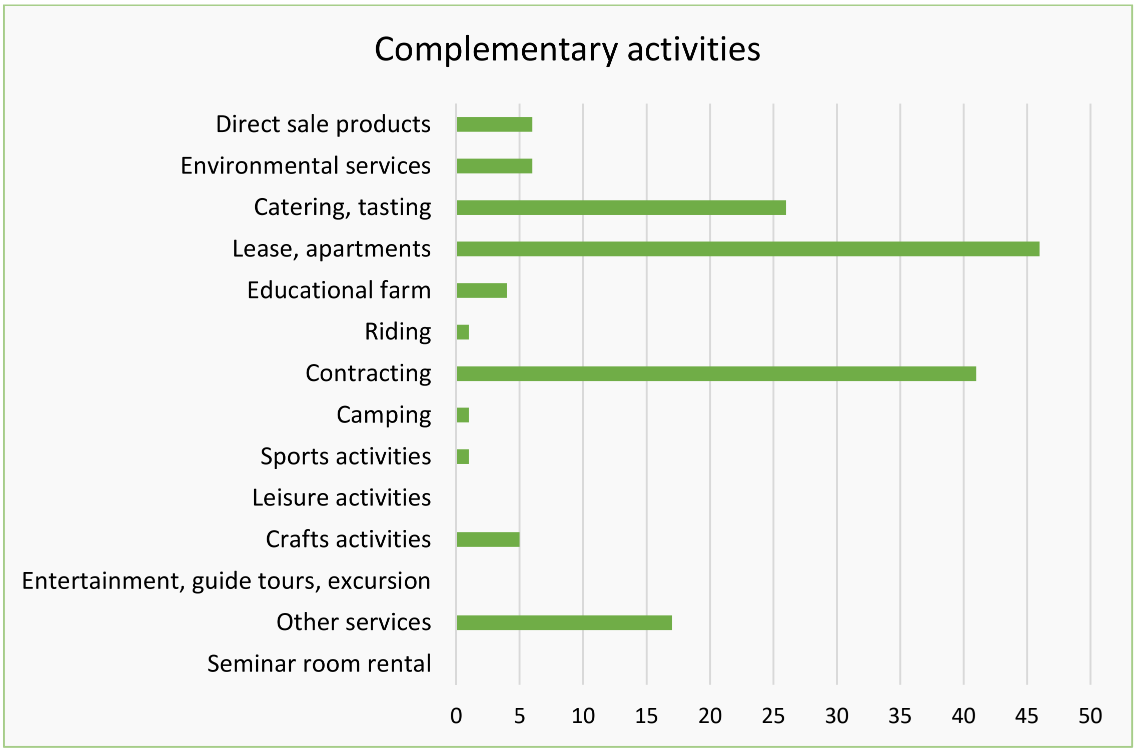
Source: elaboration on Database RICA data

The 426 agricultural holdings taken into account for these analyses, in addition to renewable energy production, are involved in other activities, known as complementary activities, listed in Figure 3.7.

Apartment rentals and active contracting are the most popular complementary activities among farms that produce renewable energy. Only one farm offer camping, because the companies are located in places that are more suitable for renting apartments.

There are also few companies dealing with environmental services.

Figure 3.7 Complementary activities to Renewable energy production



Source: elaboration on Database RICA data

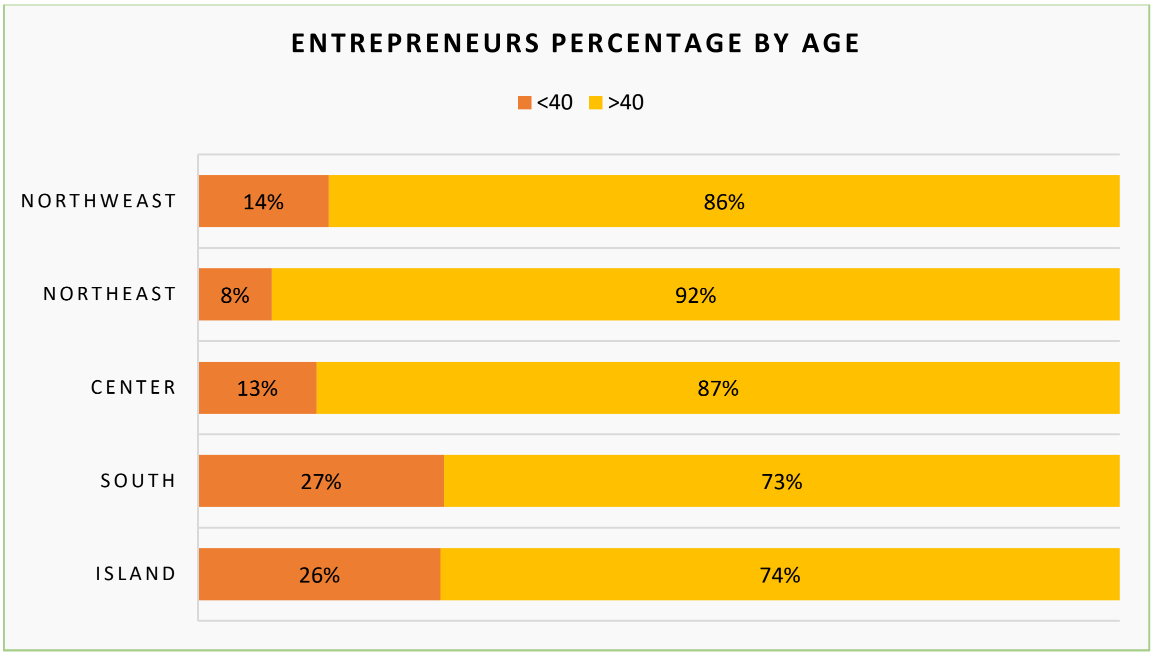
Let us now look at some characteristics of renewable energy farm entrepreneurs.
The data collected show that, focusing on entrepreneurs age, and dividing them into two groups – entrepreneurs under the age of 40, and entrepreneurs over the age of 40, the majority of entrepreneurs whose farms produce renewable energy are over 40 years old (Table 3.9).
As already mentioned in Chapter I, there are explanations for these data. Despite the fact that younger entrepreneurs have more access to technology breakthrough and smart agriculture, they cannot invest on new technologies, either because they cannot afford it or because they do not have the financial credibility to get granted the necessary bank loans and other financial aids. Middle-aged farmers, with good education level, with history on adopting innovations and with capital to support joint ventures are the ones who invest on renewable energies technologies in agriculture.
From the territorial point of view, taking into consideration the age division of farmers, there are no discrepancies between northern, central and southern Italy. The gap between the two groups remains very marked in all Italian areas, even if the percentage of young entrepreneurs in southern Italy and in the island is higher compared to the Northern and centre of Italy.
It should also be taken into account that sometimes the land remains in the name of the parent until the son inherits it. Thus, it could happen that the land is in the name of the elderly parent, but it is worked by the son. Therefore, if a young person has the land in his name, it is definitely him who takes care of it, but if the land is in the name of the parent, it is not excluded that the son takes care of it. This type of effect is not detected in Table 3.9, so there may be farms in the name of elderly parents, but worked by their son who decide to produce renewable energy.

Table 3.9 Number of entrepreneurs with farms producing renewable energy by age

DISTRICT	<40	>40
NORTH WEST	20	121
NORTH EAST	12	138
CENTER	13	88
SOUTH	4	11
ISLAND	5	14
TOTAL	**54**	**372**

Source: elaboration on Database RICA data

Figure 3.8 Number of entrepreneurs, with renewable energy companies by age



Source: elaboration on Database RICA data

The same situation occurs by analysing entrepreneurs based on gender. The number of farms headed by a male entrepreneur far exceeds those headed by a female entrepreneur.

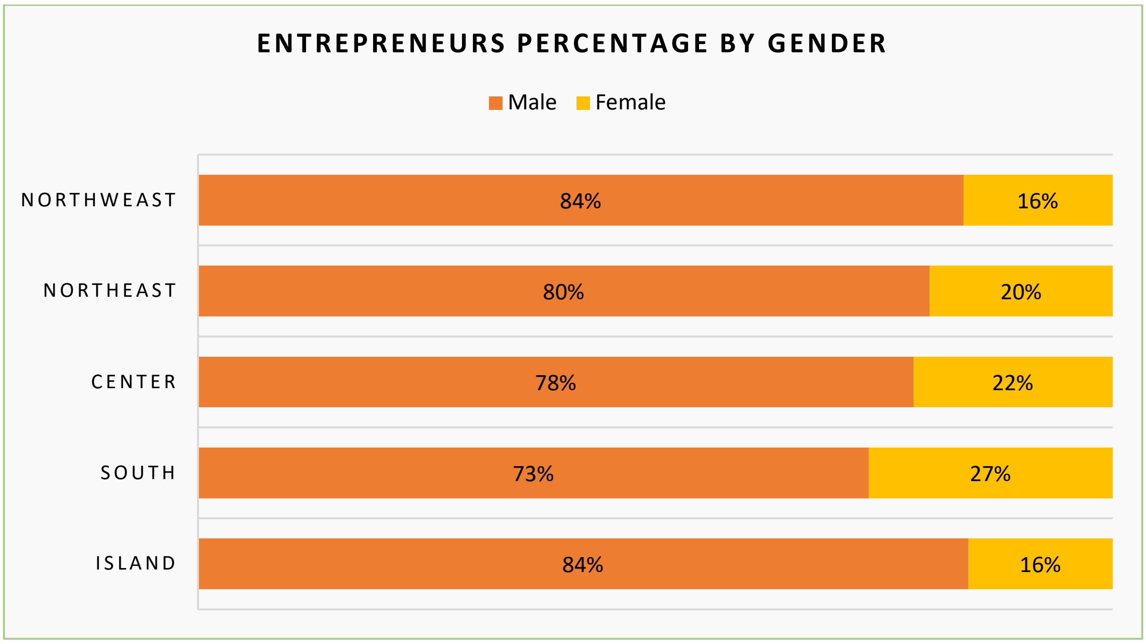
Southern Italy (excluding islands) is the area where the percentage of female entrepreneurs seems the highest, 27%, but in reality, the sample of farms producing renewable energy is smaller compared to north and centre of Italy.

Table 3.10 Number of entrepreneurs, with renewable energy companies by gender

DISTRICT	MALE	FEMALE
NORTH WEST	118	23
NORTH EAST	120	30
CENTER	79	22
SOUTH	11	4
ISLAND	16	3
TOTAL	**344**	**82**

Source: elaboration on Database RICA data

Figure 3.9 Number of entrepreneurs, with renewable energy companies by gender



Source: elaboration on Database RICA data

Finally, an analysis has been done comparing the Utilised Agricultural Area (UAA) of all the farms in the FADN sample, and the farms producing renewable energies.

As can be seen in Figure 3.10 and 3.11, farms with a small agricultural area (between 0 and 25) are much more than large farms.

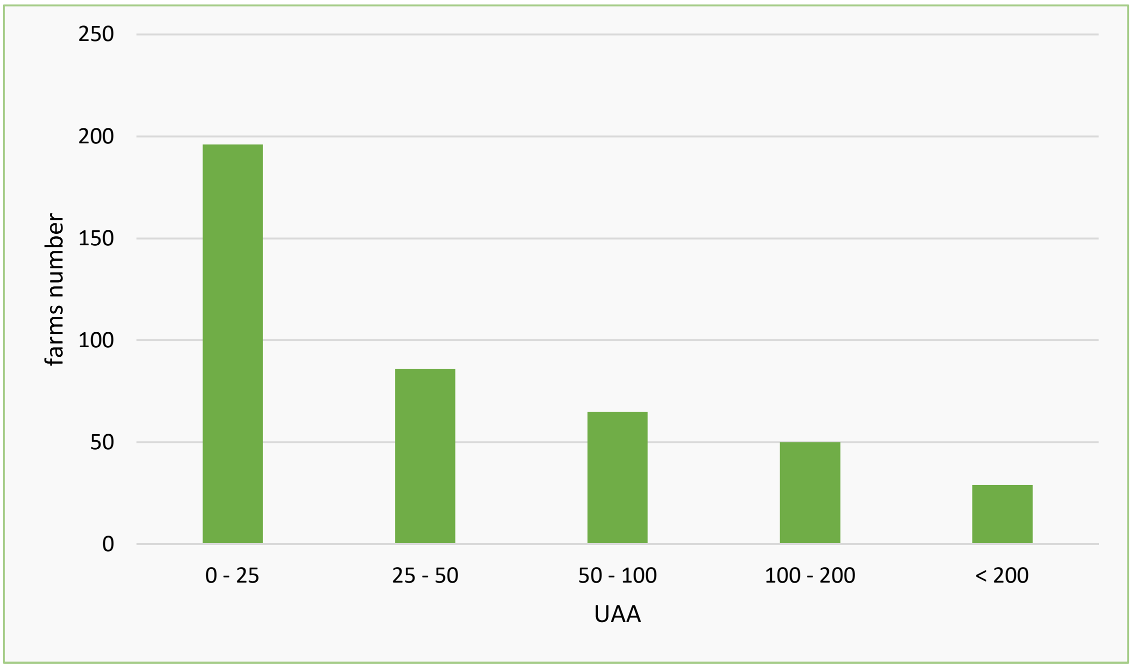
Furthermore, in Table 3.11 it can be noted that the total farms in the FADN sample, with a small Utilised Agricultural Area (UAA), are many, but only a few have introduced renewable energy production, only 2,93% of the total farms in the FADN sample. By contrast, farms with a high UAA that produce renewable energy, are many more, 13,49% of the farms in the total RICA sample.

Table 3.11 Percentage comparison between renewable energy producers and total FADN sample

UAA	RENEWABLE ENERGY PRODUCERS	FADN SAMPLE	PERCENTAGE RENEWABLE OUT OF TOTAL
0 - 25	196	6685	2,93%
25 - 50	86	1802	4,77%
50 - 100	65	1120	5,80%
100 - 200	50	564	8,87%
< 200	29	215	13,49%

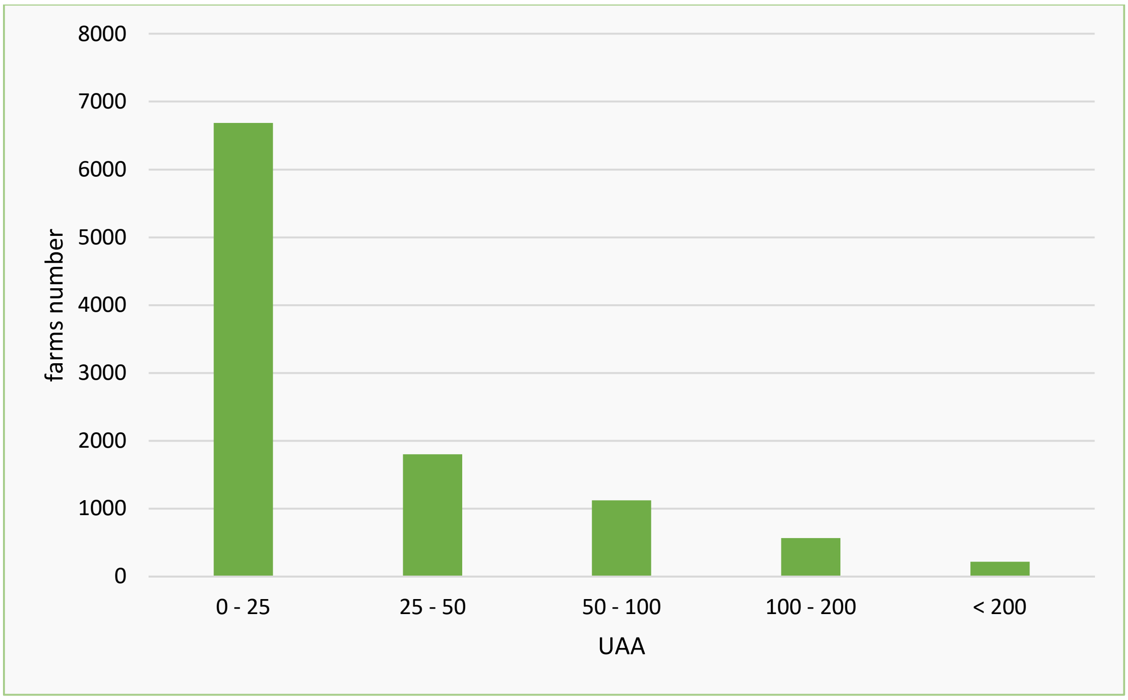
Source: elaboration on Database RICA data

Figure 3.10 Farms producing Renewable energy divided by UAA



Source: elaboration on Database RICA data

Figure 3.11 Italian Farms of FADN sample divided by UAA



Source: elaboration on Database RICA data

Conclusion

The European Commission sets the aim of achieving climate neutrality in Europe by 2050 in the European Green Deal that includes an action plan to promote resource efficiency by moving to a clean and circular economy and by restoring biodiversity and reducing pollution (European Commission, 2020).

The guidelines set out in the Green Deal should be applied in European Union programmes. In particular, the Rural Development Plan will have to foresee specific measures towards the production of renewable energy throw the agricultural sector.

A power sector, focused primarily on renewable energy sources, will be created, with coal phasing out and gas decarbonisation occurring as quickly as possible. The renewable energy aspect is one of the most important; in fact, renewable energy sources will play an essential role in the future. Smart incorporation of renewables, energy efficiency, and other sustainable technologies across industries would aid in achieving decarbonisation at the lowest cost possible.

Therefore, we must be careful. Normally we are led to think that everything related to renewable energy has positive implications but producing energy from renewable sources generates pollution too. The problem does not lie in switching from non-renewable energy to renewable energy, but it is about the efficiency in their production.

Both of the above problems are addressed in the thesis:

- the issue related to renewable energy production in the agricultural sector, a sector that on the one hand suffers from climate change, but on the other feeds it;
- the problem that we must move towards efficiency

Thus, the thesis points out that, despite the fact that renewable energies occupy a prominent place in the energy field discussion, for what concern the primary sector, we are still lagging behind and we still have much further to go.

Indeed, in the survey, which was carried out using the data processed by the FADN database (Chapter IV), it was found that, out of 10.368 farms, only 426 introduced renewable energy production as of today.

For this reason, it is no longer enough just to increase the production of renewable energy but it is necessary to focus on some aspects and some sectors in particular.

For example, the livestock industries, which are considered the most polluting, should be more encouraged to produce renewable energy, concentrating more on biogas, since the existing ones are very few.
Bioenergy production is the most easily adapting to the agricultural sector, although it is quite complex to produce, because it allows to dispose of a waste part that would otherwise be polluting. Solar systems, on the contrary, despite being more used, even in Italy, are generally placed in agricultural land, thus taking away space from the main crops of farms and also producing pollution in the disposal phase.
Finally, renewable energy and agriculture are a winning combination that we must continue to develop to make it as efficient as possible.

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Annex: List of academic literature with abstract

1) Abruev, A., Theocharopoulos, A., & Aggelopoulos, S. (2012). Technical efficiency and management of livestock production: the case of republic of Uzbekistan. In 2nd Advances in Hospitality & Tourism Marketing and Management Conference (AHTMMC) (pp. 1-7).

Abstract: The research data and information regarding the efficiency level of livestock production in the districts of Uzbekistan are limited. The objective of this paper is to investigate the efficiency and management of livestock production in certain districts of Samarkand Province, Republic of Uzbekistan. Data Envelopment Analysis (DEA) is applied in order to investigate if the livestock production districts use effectively their inputs and to investigate whether the scale of operation affects their efficiency. Research results can assist policy makers concerned with livestock production to take the necessary measures to increase its efficiency with apparent benefits for agricultural income and economic development.
Key Words: livestock production, efficiency, DEA, Uzbekistan, inputs, outputs.

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2) Ahmadabad, H. F., Mohtasebi, S. S., Mousavi-Avval, S. H., & Marjani, M. R. (2013). Application of Data Envelopment Analysis Approach to Improve Economical Productivity of Apple Fridges. International Research Journal of Applied and Basic Sciences, 4(6), 1603-1607.

Abstract: This study utilizes non-parametric technique of data envelopment analysis to examine the efficiencies of apple fridges using production and cost data for individual units. Data used in this study were obtained from 18 apple fridges in Tehran province, Iran. The results revealed that, total cost of production was averagely as 59.6 $ per 1000 kg of processed product. Also the results of efficiency analysis with data envelopment analysis (DEA) showed that, 5 units were recognized as efficient units on the basis of variable returns to scale assumptions. The technical, pure technical and scale efficiencies of units were found to be 0.76, 0.84 and 0.89, respectively. Moreover, total cost in target condition was calculated as 1295.70 MJ ha-1; accordingly, about 13% from total cost in present condition could be saved if the units follow the input package recommended by the study. From total cost saving, the highest share was obtained by labor (68%), followed by building rent (20%) and depreciation of equipments (8%), respectively. Applying a better machinery management technique to reduce human labor requirement may help to save the input costs for apple fridges and to improve the economical productivity of units.
Key words: Input cost; Technical efficiency; DEA; Apple fridges; Tehran

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3) Aigner, D., Lovell, C. K., & Schmidt, P. (1977). Formulation and estimation of stochastic frontier production function models. Journal of econometrics, 6(1), 21-37.

Abstract: Previous studies of the so-called frontier production function have not utilized an adequate characterization of the disturbance term for such a model. In this paper we provide an appropriate specification, by defining the disturbance term as the sum of symmetric normal and (negative) half-normal random variables. Various aspects of maximum-likelihood estimation for the coefficients of a production function with an additive disturbance term of this sort are then considered.

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4) Aldaz, N., & MillÁN, J. A. (2003). Regional productivity of Spanish agriculture in a panel DEA framework. Applied Economics Letters, 10(2), 87-90.

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5) Alene, A. D., & Zeller, M. (2005). Technology adoption and farmer efficiency in multiple crops production in eastern Ethiopia: A comparison of parametric and non-parametric distance functions. Agricultural economics review, 6(389-2016-23429), 5-17.

Abstract: This study compares the empirical performances of the parametric distance functions(PDF) and data envelopment analysis (DEA) with applications to adopters of improved cereal production technology in eastern Ethiopia. The results from both approaches revealed substantial technical inefficiencies of production among the sample farmers. Technical efficiency estimates obtained from the two approaches are positively and significantly correlated. However, the DEA approach is shown to be very sensitive to outliers as well as to the choice of orientation. The PDF results are relatively more robust. The results from the preferred PDF approach revealed that adopters of improved technology have average technical efficiencies of 79%, implying that they could potentially raise their food crop production by an average 21% through full exploitation of the potentials of improved varieties and mineral fertilizer. The results confirm that food production even under improved technology involves substantial inefficiency. The paper concludes with a discussion of potential underlying factors influencing farmer efficiency under improved technology, such as poor extension, education, credit, and input supply systems.
Keywords: Multiple outputs; Distance functions; DEA; Technical efficiency; Ethiopia

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6) Alene, A. D., Manyong, V. M., & Gockowski, J. (2006). The production efficiency of intercropping annual and perennial crops in southern Ethiopia: A comparison of distance functions and production frontiers. Agricultural systems, 91(1-2), 51-70.

Abstract: This study measures the efficiency of intercropping systems of annual and perennial crops production in southern Ethiopia using the stochastic frontier production function (SFP), parametric distance functions (PDF), and data envelopment analysis (DEA), and compares the empirical performances of the three methods. The results from the multi-output PDF and DEA approaches have revealed significantly higher efficiency of the systems than the singleoutput SFP approach. We find that both DEA and PDF are appropriate in multi-output agriculture involving intercropping of annual and perennial crops. Single-output measures of productivity and efficiency may thus underestimate resource use efficiency of intercropping systems. Based on the geometric mean technical efficiency predictions for each data point using the preferred PDF and DEA approaches, the sample farmers in southern Ethiopia have an average technical efficiency of 91%. The results confirm farmers'

efficient use of land and other resources through innovative cropping systems. Technologies that are appropriate to such systems may thus be needed for greater intensification.
Keywords: Distance functions; Intercropping; Stochastic frontiers; DEA; Ethiopia

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7) Bakhshoodeh, M., & Thomson, K. J. (2001). Input and output technical efficiencies of wheat production in Kerman, Iran. Agricultural Economics, 24(3), 307-313.

Abstract: The Iranian government encourages farmers to produce wheat (a common agricultural enterprise) by increasing farm productivity and efficiency. In this paper, using a Cobb–Douglas frontier production function, a simple relationship between a farm-level output-based technical efficiency measure (the Timmer index) and an input-based measure (the Kopp index) is first developed. Then, using 1995 data from 164 farms in Kerman province, Iran, the average Timmer and Kopp indexes were estimated at 0.93 and 0.91, respectively, and were found to be similarly affected by farm size (positively up to about 9 ha) and by input ratios, though with rather small explanatory power. Thus, there seems some but limited scope to increase the profitability of Iranian wheat production either by increasing the product, given input levels, or by decreasing inputs for the current level of wheat production. However, since wheat producers may be able to adapt their production process more easily and quickly by implementing new techniques, i.e. by more efficient combination of inputs, than by adopting new technology, correction of input over-use can be regarded as a policy with speedy if limited effect in this case.
Keywords: Technical efficiency; Timmer index; Kopp index; Wheat; Iran

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8) Banaeian, N., Omid, M., & Ahmadi, H. (2011). Improvement of cost efficiency in strawberry greenhouses by data envelopment analysis. Agricultura Tropica et Subtropica, 44, 3.

Abstract: In recent years, Data Envelopment Analysis (DEA) has become a central technique in productivity and efficiency analysis used in different aspects of economics and management sciences. The aim of this study is using the DEA technique to investigate the technical and scale efficiency of Iranian greenhouse strawberry production. Also this research focused on comparing and optimizing the performance of greenhouses. Required data were collected using face to face questionnaire from personnel of 25 greenhouses. Analyzes were based on the amount of four important inputs: human labour (h ha-1), fertilizers (kg ha-1), capital ($ ha-1) and other expenses ($ ha-1) as input, and gross return of produced strawberries ($ ha-1) as output. According to the average technical (0.73) and pure technical (0.96) efficiency, there is a suitable potential for more efficient and sustainable input utilization in production. Comparison between the present and target amount of inputs demonstrated that the differences caused by the lack of inputs consumption management and calculate that on average 54716.65 $ ha-1, interpreting that if greenhouse holders follow the recommendation and use the projected amount of inputs can save 45716.65 $ ha-1. Analysis showed that the most wastage of cost is fertilizers and greenhouses can save 29% of that by improving management practices.

Keywords: Data envelopment analysis; fertilizers; cost saving; management practices

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9) Banker, R. D., Charnes, A., & Cooper, W. W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. Management science, 30(9), 1078-1092.

Abstract: In management contexts, mathematical programming is usually used to evaluate a collection of possible alternative courses of action en route to selecting one which is best. In this capacity, mathematical programming serves as a planning aid to management. Data Envelopment Analysis reverses this role and employs mathematical programming to obtain ex post facto evaluations of the relative efficiency of management accomplishments, however they may have been planned or executed. Mathematical programming is thereby extended for use as a tool for control and evaluation of past accomplishments as well as a tool to aid in planning future activities. The CCR ratio form introduced by Charnes, Cooper and Rhodes, as part of their Data Envelopment Analysis approach, comprehends both technical and scale inefficiencies via the optimal value of the ratio form, as obtained directly from the data without requiring a priori specification of weights and/or explicit delineation of assumed functional forms of relations between inputs and outputs. A separation into technical and scale efficiencies is accomplished by the methods developed in this paper without altering the latter conditions for use of DEA directly on observational data. Technical inefficiencies are identified with failures to achieve best possible output levels and/or usage of excessive amounts of inputs. Methods for identifying and correcting the magnitudes of these inefficiencies, as supplied in prior work, are illustrated. In the present paper, a new separate variable is introduced which makes it possible to determine whether operations were conducted in regions of increasing, constant or decreasing returns to scale (in multiple input and multiple output situations). The results are discussed and related not only to classical (single output) economics but also to more modern versions of economics which are identified with "contestable market theories

Keywords: efficiency; technical inefficiency; returns to scale; mathematical programming; linear programming

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10) Bartolini, F., Bazzani, G. M., Gallerani, V., Raggi, M., & Viaggi, D. (2007). The impact of water and agriculture policy scenarios on irrigated farming systems in Italy: An analysis based on farm level multi-attribute linear programming models. Agricultural systems, 93(1-3), 90-114.

Abstract: The objective of this paper is to evaluate the impacts of agriculture and water policy scenarios on the sustainability of selected irrigated farming systems in Italy, in the context of the forthcoming implementation of the directive EC 60/2000. Directive EC 60/2000 (Water Framework Directive) is intended to represent the reference norm regulating water use throughout Europe. Five main scenarios were developed reflecting aspects of agricultural policy, markets and technologies: Agenda 2000, world market, global sustainability, provincial agriculture and local community. These were combined with two water price levels, representing stylised scenarios for water policy. The effects of the scenarios on irrigated systems were simulated using

multi-attribute linear programming models representing the reactions of the farms to external variables defined by each scenario. The output of the models consists of economic, social and environmental indicators aimed at quantifying the impact of the scenarios on different aspects of sustainability relevant for irrigated farming systems. Five Italian irrigated farming systems were considered: cereal, rice, fruit, vegetables and citrus. The results show the diversity of irrigated systems and the different effects that water pricing policy may produce depending on the agricultural policy, market and technological scenarios. They also highlight a clear trade-off between socio-economic sustainability and environmental (water, nitrogen, pesticide) sustainability. Water pricing will have, in most cases, less impact than agricultural markets and policy scenarios, though it appears to be an effective instrument for water regulation in the least intensive irrigated systems considered. This emphasises the need for a differentiated application of the Water Framework Directive at the local level as well as a more careful balance of water conservation, agricultural policy and rural development objectives.
Keywords: Water Framework Directive, Common Agricultural Policy, Irrigation, Multi-Attribute Analysis, Linear programming, Sustainability indicators

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11) Berry, P. M., Kindred, D. R., Olesen, J. E., Jorgensen, L. N., & Paveley, N. D. (2010). Quantifying the effect of interactions between disease control, nitrogen supply and land use change on the greenhouse gas emissions associated with wheat production. Plant Pathology, 59(4), 753-763.

Abstract: A method for calculating the effect of disease control on greenhouse gas (GHG) emissions associated with wheat production, reported previously, was developed further to account for effects of disease control on the amount of fertilizer nitrogen (N) which should be applied and on changes in land use. Data from nine randomized and replicated field experiments from the UK and Denmark showed that the economic optimum N input to winter wheat was greater if diseases were controlled by fungicides, than for untreated wheat. The GHGs associated with this additional N largely negated the benefit to emissions per tonne of grain resulting from disease control. However, the mean grain yield obtained without fungicide treatment was 6Æ71 t ha)1, compared to 8Æ88 t ha)1 with fungicide treatment, if N input was optimal for each situation. In the absence of disease control by fungicides, and assuming that the optimum N rate was used, an additional 481 kha of wheat would be required to maintain UK wheat production at the current level. If the additional land area came from converting temperate grassland to arable production, the GHG emissions caused by ploughing grassland would cause emissions to rise from 503 to 713 kg CO2e per tonne of grain produced. This would result in an additional 3Æ15 Mt CO2e per year to produce the typical UK annual production of 15 Mt. This analysis reinforces the importance of winning the ‘arms race’ against pathogen evolution towards fungicide insensitivity and virulence.
Keywords: Blumeria graminis tritici, disease resistance, fungicides, Mycosphaerella graminicola, Puccinia striiformis, Puccinia triticina

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12) Błażejczyk-Majka, L. (2017). Application of DEA for evaluating the efficiency of economic policy as exemplified by EU agriculture. Studia Historiae Oeconomicae, 35(1), 163-176.

Abstract: The article presents how DEA is used to develop agricultural production efficiency rankings in the EU member states, which can be used as the starting point for evaluating the performance of currently used instruments of economic policy. In the article, statistical data from the FADN were used. Agricultural production was compared for three types of output and four types of input involved. The performed study demonstrated that in 18 out of 28 states, agricultural production had been run efficiently on a macro level. The applied approach also allowed for identifying the causes of inefficiency in the remaining ten states, providing indications for recommended changes in in the way economic instruments are used.

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13) Boyd, G. A., Tolley, G., & Pang, J. (2002). Plant level productivity, efficiency, and environmental performance of the container glass industry. Environmental and Resource Economics, 23(1), 29-43.

Abstract: This paper presents a methodology and empirical results based on the Malmquistproductivity index. We measure productivity while treating pollution as an undesirable output. Ourestimates show that technical change has contributed to productivity and environmental performancegrowth in the container glass industry, an energy and pollution intensive sector. Changes in inter-plant efficiency over time have made this productivity growth more rapid than otherwise would haveoccurred with the underlying technical change. The efficiency estimates show that there are bothopportunities to improve productivity and reduce pollution in this industry, as well as productivitylosses associated with the emissions control. The shadow prices for NOx, the undesirable output weanalyze, is quite high compared to other regulated sectors.

Keywords: malmquist index, marginal abatement costs, productivity

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14) Bravo-Ureta, B. E., Solís, D., López, V. H. M., Maripani, J. F., Thiam, A., & Rivas, T. (2007). Technical efficiency in farming: a meta-regression analysis. Journal of productivity Analysis, 27(1), 57-72.

Abstract: A meta-regression analysis including 167 farm level technical efficiency (TE) studies of developing and developed countries was undertaken. The econometric results suggest that stochastic frontier models generate lower mean TE (MTE) estimates than non-parametric deterministic models, while parametric deterministic frontier models yield lower estimates than the stochastic approach. The primal approach is the most common technological representation. In addition, frontier models based on cross-sectional data produce lower estimates than those based on panel data whereas the relationship between functional form and MTE is inconclusive. On average, studies for animal production show a higher MTE than crop farming. The results also suggest that the studies for countries in Western Europe and Oceania present, on average, the highest levels of MTE among all regions after accounting for various methodological features. In contrast, studies for Eastern

European countries exhibit the lowest estimate followed by those from Asian, African, Latin American, and North American countries. Additional analysis reveals that MTEs are positively and significantly related to the average income of the countries in the data set but this pattern is broken by the upper middle income group which displays the lowest MTE.
Keywords: Meta-Regression, Frontier Models, Technical Efficiency, International Agriculture

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15) Brennan, N., Ryan, M., Hennessy, T., Cullen, P., & Dillon, E. (2016). Going beyond FADN: The use of additional data to gain insights into extension service use across European Union Member States. Studies in Agricultural Economics, 118(3), 145-153.

Abstract: This paper examines the use of extension services by farm households across eight European Union (EU) Member States, exploring the type of extension service engaged with, the degree of engagement and the type of information sought. The impact of extension on economic, environmental and social sustainability is also considered. European data utilised are those collected from a pilot sample of 820 households in 2015/2016 as part of the EU Framework 7 project FLINT, from which the Irish results are incorporated further with Irish Farm Accountancy Data Network data. The results outline the key contrasts across the countries investigated and suggest that the degree to which households engage with extension services is primarily infl uenced by national policies. In addition, this analysis indicates that the extent of this engagement has implications for sustainability at the farm level. The fi nal conclusions and policy recommendations in this paper support the development of a large-scale version of the FLINT pilot survey.
Keywords: agricultural sustainability, extension use by farmers

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16) Chambers, R. G., Hailu, A., & Quiggin, J. (2011). Event-specific data envelopment models and efficiency analysis. Australian Journal of Agricultural and Resource Economics, 55(1), 90-106.

Abstract: Most, if not all, production technologies are stochastic. This article demonstrates how data envelopment analysis (DEA) methods can be adapted to accommodate stochastic elements in a state-contingent setting. Specifically, we show how observations on a random input, not under the control of the producer and not known at the time that variable input decisions are made, can be used to partition the state space in a fashion that permits DEA models to approximate an event-specific production technology. The approach proposed in this article uses observed data on random inputs and is easy to implement. After developing the event-specific DEA representation, we apply it to a data set for Western Australian barley production data. Our results highlight the need for acknowledging stochastic elements in efficiency analysis.

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17) Chang, T. P., & Hu, J. L. (2010). Total-factor energy productivity growth, technical progress, and efficiency change: An empirical study of China. Applied Energy, 87(10), 3262-3270.

Abstract: This article introduces total-factor energy productivity change index (TFEPI) based on the concept of total-factor energy efficiency and the Luenberger productivity index to evaluate the energy productivity change of regions in China with a total-factor framework. Moreover, the TFEPI can be decomposed into change in energy efficiency and shift in the energy use technology. According to the computation results, China's energy productivity was decreasing by 1.4% per year during 2000–2004. The average total-factor energy efficiency improves about 0.6% per year, while total-factor energy technical change declines progressively 2% annually. The factors affecting TFEPI are also examined: (1) The east area has a higher TFEPI than the central and west area; (2) increasing the development status and electricity share of energy consumption will improve the region's TFEPI performance, while increasing the proportion of GDP generated by the secondary industry deteriorates TFEPI of a region.
Keywords: Total-factor energy productivity Efficiency changeTechnical change Total-factor energy efficiency Directional distance function China

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18) Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. European journal of operational research, 2(6), 429-444.

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19) Charnes, A., Cooper, W., Lewin, A. Y., & Seiford, L. M. (1997). Data envelopment analysis theory, methodology and applications. Journal of the Operational Research society, 48(3), 332-333.

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20) Chien, T., & Hu, J. L. (2007). Renewable energy and macroeconomic efficiency of OECD and non-OECD economies. Energy Policy, 35(7), 3606-3615.

Abstract: This article analyzes the effects of renewable energy on the technical efficiency of 45 economies during the 2001–2002 period through data envelopment analysis (DEA). In our DEA model, labor, capital stock, and energy consumption are the three inputs and real GDP is the single output. Increasing the use of renewable energy improves an economy's technical efficiency. Conversely, increasing the input of traditional energy decreases technical efficiency. Compared to non-OECD economies, OECD economies have higher technical efficiency and a higher share of geothermal, solar, tide, and wind fuels in renewable energy. However, non-OECD economies have a higher share of renewable energy in their total energy supply than OECD economies.
Keywords: Data envelopment analysis; Technical efficiency; Renewable energy

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21) Cooper, W. W., Seiford, L. M., & Tone, K. (2006). Introduction to data envelopment analysis and its uses: with DEA-solver software and references. Springer Science & Business Media.

Abstract: Recent years have seen a great variety of applications of DEA (Data Envelopment Analysis) for use in evaluating the performances of many different kinds of entities engaged in many different activities in many different contexts in many different countries. One reason is that DEA has opened up possibilities for use in cases which have been resistant to other approaches because of the complex (often unknown) nature of the relations between the multiple inputs and multiple outputs involved in many of these activities (which are often reported in non-commeasurable units). Examples include the maintenance activities of U.S. Air Force bases in different geographic locations, or police force sin England and Wales as well as performances of branch banks in Cyprus and Canada and the efficiency of universities in performing their education and research functions in the U.S., England and France. These kinds of applications extend to evaluating the performances of cities, regions and countries with many different kinds of inputs and outputs that include “social” and “safety-net” expenditures as inputs and various “quality-of-life” dimensions as outputs. DEA has also been used to supply new insights into activities (and entities) that have previously been evaluated by other methods. For instance, studies of benchmarking practices with DEA have identified numerous sources of inefficiency in some of the most profitable firms — firms that served as benchmarks by reference to their (profitability) criterion. DEA studies of the efficiency of different legal-organizations forms as in “stock” vs. “mutual” insurance companies have shown that previous studies have fallen short in their attempts to evaluate the potentials of these different forms of organizations. (See below.) Similarly, a use of DEA has suggested reconsideration of previous studies of the efficiency with which pre- and post-merger activities have been conducted in banks that were studied by DEA.

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22) Cooper, W. W., Seiford, L. M., & Zhu, J. (2011). Data envelopment analysis: History, models, and interpretations. In Handbook on data envelopment analysis (pp. 1-39). Springer, Boston, MA.

Abstract: In a relatively short period of time Data Envelopment Analysis (DEA) has grown into a powerful quantitative, analytical tool for measuring and evaluating performance. DEA has been successfully applied to a host of different types of entities engaged in a wide variety of activities in many contexts worldwide. This chapter discusses the fundamental DEA models and some of their extensions.
Key words: Data envelopment analysis (DEA); Efficiency; Performance

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23) Dalgaard, T., Halberg, N., & Porter, J. R. (2001). A model for fossil energy use in Danish agriculture used to compare organic and conventional farming. Agriculture, Ecosystems & Environment, 87(1), 51-65.

Abstract: The role of energy crops in reducing fossil energy use and greenhouse gas emission is much debated. To improve decision making on the use of crops for producing bioenergy, a tool (Energy Crop Simulation Model or E-CROP) has been

developed to calculate 1) sustainable crop dry matter yield levels as function of agricultural inputs, and 2) gross and net energy yield and greenhouse gas emission reduction, covering the entire bioenergy production chain from sowing to distribution of bioenergy. E-CROP can be applied to a wide range of crops, soils, climatic conditions, management choices, and conversion technologies. This paper describes E-CROP and focuses on its application on four arable crops, as cultivated on two contrasting sites in the Netherlands (potato and sugar beet for bioethanol, winter oilseed rape for biodiesel and silage maize for bioelectricity) and on the effect of crop management (viz. irrigation and nitrogen fertilisation). In all situations, gross energy output exceeded total energy input. Calculated for an average situation, net energy yield ranged from 45 to 140 GJ.ha-1. Lowering irrigation and/or fertilisation input levels generally resulted in a reduction of net energy yields. The net reduction of greenhouse gas emissions in the average situation ranged from 0.60 to 6.5 t CO2-eq.ha-1. In general, N2O emission from nitrogen fertiliser caused large variations in the net reduction of greenhouse gas emission, which even became negative in some situations. Lowering nitrogen fertilisation to levels that are suboptimal for net energy yields enhanced the net reduction in greenhouse gas emission, implicating that both goals cannot be optimised simultaneously. Agricultural knowledge is important for optimising the outputs of bioenergy production chains.
Keywords: Energy Crops, Biodiesel, Bioethanol, Bioelectricity, Sustainable Production, Energy Yield, Greenhouse Gas Emission

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24) De Koeijer, T. J., Wossink, G. A. A., Struik, P. C., & Renkema, J. A. (2002). Measuring agricultural sustainability in terms of efficiency: the case of Dutch sugar beet growers. Journal of environmental management, 66(1), 9-18.

Abstract: Sustainability embraces socio-economic and bio-ecological dimensions or attributes. This paper presents a conceptual framework for quantifying sustainability on the basis of efficiency theory commonly used in economics. The conceptual model is implemented using Data Envelopment Analysis (DEA). Sustainability is measured for a sample of Dutch sugar beet growers. The average technical efficiency was only 50%. A positive correlation was found between technical efficiency and sustainable efficiency. Differences in efficiency among farmers were persistent within and between years. We conclude that there is considerable scope for improving the sustainability of arable farming by better management.
Keywords: sustainability, environmental efficiency, technical efficiency, economic efficiency, profit efficiency, data envelopment analysis.

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25) Dercon, S., Gilligan, D. O., Hoddinott, J., & Woldehanna, T. (2009). The impact of agricultural extension and roads on poverty and consumption growth in fifteen Ethiopian villages. American Journal of Agricultural Economics, 91(4), 1007-1021.

Abstract: This article investigates whether public investments that led to improvements in road quality and increased access to agricultural extension services led to faster consumption growth and lower rates of poverty in rural Ethiopia. Estimating an Instrumental Variables model using Generalized Methods of

Moments and controlling for household fixed effects, we find evidence of positive impacts with meaningful magnitudes. Receiving at least one extension visit reduces headcount poverty by 9.8 percentage points and increases consumption growth by 7.1 percentage points. Access to all-weather roads reduces poverty by 6.9 percentage points and increases consumption growth by 16.3 percentage points. These results are robust to changes in model specification and estimation methods.
Keywords: Ethiopia, extension, growth, poverty, roads.

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26) Dhungana, B. R., Nuthall, P. L., & Nartea, G. V. (2004). Measuring the economic inefficiency of Nepalese rice farms using data envelopment analysis. Australian Journal of Agricultural and Resource Economics, 48(2), 347-369.

Abstract: A data envelopment analysis of a sample of 76 Nepalese rice farmers reveals average relative economic, allocative, technical, pure technical and scale inefficiencies as 34, 13, 24, 18 and 7 per cent, respectively. The significant variations in the level of inefficiency across sample farms are attributed to the variations in the 'use intensities' of resources such as seed, labour, fertilisers and mechanical power. In addition, a second stage Tobit regression shows the variation is also related to farm-specific attributes such as the farmers' level of risk attitude, the farm manager's gender, age, education and family labour endowment. Based on the empirical findings, policy implications and development strategies for improving efficiency of Nepalese rice farms are briefly discussed.

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27) Díaz, J. R., Poyato, E. C., & Luque, R. L. (2004). Applying benchmarking and data envelopment analysis (DEA) techniques to irrigation districts in Spain. Irrigation and Drainage: The journal of the International Commission on Irrigation and Drainage, 53(2), 135-143.

Abstract: In this research, the application of data envelopment analysis (DEA) is proposed as a methodology to overcome the problems related to the lack of methodology to assign the correct weightings for the calculation of indexes and to the subjectivity of the interpretations of results. DEA is a linear programming technique to determine the relative efficiencies of a company when the inputs and outputs of production units within the company are known, but the productive process itself is not. In this way, quantitative efficiencies and the weighting of any performance indicator can be assessed and compared, permitting managers to obtain a well-defined performance ranking. This is especially important when managers dispose of a limited budget. The results of the application of this methodology to Andalusian irrigation districts (Spain) are presented and discussed here. This study was used to select the most representative irrigation districts in Andalusia which were then studied in greater depth by applying the performance indicators selected by IPTRID for use by the benchmarking international program.
Key words: performance indicators; benchmarking; DEA

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28) Dogan, N. O., & Tugcu, C. T. (2015). Energy efficiency in electricity production: a data envelopment analysis (DEA) approach for the G-20 countries. International Journal of Energy Economics and Policy, 5(1), 246-252.

Abstract: Factors such as global warming, increased energy prices, decreased security of energy supply and the vision of sustainable development have inspired researchers to focus on energyefficiency. In this context, this study adopts input oriented DEA based on the Charnes, Cooper and Rhodes (CCR) model and estimates technical and super efficiency scores of G-20 countries in terms of electricity production for the periods 1990, 1995, 2000, 2005 and 2011. Findings reveal that China and Russia appear at the top of energy efficiency rankings. On the other hand, France and the European Union are inefficient in four of five periods. Besides, the way that the United States follows for recent electricity production seems inefficient. This implies that the world has been experiencing an important transformation in terms of efficient electricity production and policy makers should be aware of this progress in order to avoid unexpected outcomes for the energy future.
Keywords: Energy efficiency; Data Envelopment Analysis; G-20 countries

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29) Falavigna, G., Manello, A., & Pavone, S. (2013). Environmental efficiency, productivity and public funds: The case of the Italian agricultural industry. Agricultural Systems, 121, 73-80.

Abstract: The present paper aims at evaluating the effect of regional policies in the agricultural field, with a specific focus on the Italian case. Provincial systems are evaluated through the Directional Output Distance Function (DODF) that is an extension of the Data Envelopment Analysis technique (DEA). The DODF approach allows authors to consider pollutant emissions as undesirable output and to redefine productivity and efficiency indicators, considering also the contraction of emissions from the fertilizer’s use. Results show that there is a considerable difference for environmental performances among Italian regions and that productivity estimates differ when emissions are included. The amount of public funds granted by the Rural Development Programs (RDP) over the period 2000–2006 is in general assigned to the more disadvantaged areas. Nevertheless, obtained results suggest that TFP growth does not exactly follow the direction of public funds and some policy’s implications are provided.
Keywords: Agricultural systems Directional distance function, Malmquist–Luenberger productivity, indexes, Rural Development Programs

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30) Farrell, M. J. (1957). The measurement of productive efficiency. Journal of the Royal Statistical Society: Series A (General), 120(3), 253-281.

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31) Fraser, I., & Cordina, D. (1999). An application of data envelopment analysis to irrigated dairy farms in Northern Victoria, Australia. Agricultural Systems, 59(3), 267-282.

Abstract: In this paper, data envelopment analysis (DEA) is used to assess the technical efficiency of a sample of irrigated dairy farms in Northern Victoria, Australia. It is proposed that DEA is a useful tool in helping to benchmark the dairy industry, which is continually striving to improve its productive efficiency. DEA takes a systems approach in that it takes account of the relationship between all inputs and outputs simultaneously. DEA yields a more consistent measure of efficiency than the more frequently reported partial indicators of farm efficiency. In addition, DEA yields a relative measure of efficiency and it identifies those inputs and/or outputs that are being under-utilised. From an extension perspective this is extremely useful information as it can assist in identifying industry best-practice.
Keywords: Data envelopment analysis, DEA Technical efficiency Benchmarking Best-practice

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32) Halberg, N., Verschuur, G., & Goodlass, G. (2005). Farm level environmental indicators; are they useful?: an overview of green accounting systems for European farms. Agriculture, ecosystems & environment, 105(1-2), 195-212.

Abstract: Green accounts or input–output accounting systems (IOA) have been developed in countries with intensive agricultural production to facilitate voluntary improvements in farm environmental performance. There is a need for an overview of indicators used and a review of results and experiences reported. Ten IOA systems covering the topics of the farm's use of nutrients, pesticides and energy were selected from a survey of 55 systems and compared in this paper. The approaches and indicators used vary from systems based on good agricultural practices (GAP) to accounts based systems that use physical input–output units. Many IOA systems use farm gate nutrient balances, pesticide use per hectare and energy use per kilogram product. These indicators are easy to calculate but the resulting value needs separate interpretation for the farmer. Other systems include modeled emissions and rate the yearly farm results using closed scales, which allows for easy interpretation but builds on implicit normative assumptions of best practices. Participating farmers were most often reported to be motivated for the use of IOA but empirical evidence of improved environmental farm performance was scarce. IOA systems should be linked with production planning tools used by the advisory services. Farmers and advisors needs better reference values to evaluate the indicator levels (environmental performance) on the individual farm possibly based on analysis of a larger number of farms. The statistical properties of IOA indicators need to be researched regarding: (1) the relation between changed management practice and changes in indicator values on a given farm over a period of time; (2) the relative importance of systematic versus coincidental differences in environmental performance of a set of farms. It is concluded that IOA systems could become effective tools for agri-environmental improvement of European farms given further development and standardization.
Keywords: Green account; Input–output accounting; Farm management; Indicators; Environmental impact assessment; Nutrient balance; Energy; Pesticides

33) Hoang, V. N. (2011). Measuring and decomposing changes in agricultural productivity, nitrogen use efficiency and cumulative exergy efficiency: Application to OECD agriculture. Ecological Modelling, 222(1), 164-175.

Abstract: This paper uses an aggregate quantity space to decompose the temporal changes in nitrogen use efficiency and cumulative exergy use efficiency into changes of Moorsteen–Bjurek (MB) Total Factor Productivity (TFP) changes and changes in the aggregate nitrogen and cumulative exergy contents. Changes in productivity can be broken into technical change and changes in various efficiency measures such as technical efficiency, scale efficiency and residual mix efficiency. Changes in the aggregate nitrogen and cumulative exergy contents can be driven by changes in the quality of inputs and outputs and changes in the mixes of inputs and outputs. Also with cumulative exergy content analysis, changes in the efficiency in input production can increase or decrease the cumulative exergy transformity of agricultural production. The empirical study in 30 member countries of the Organisation for Economic Co-operation Development from 1990 to 2003 yielded some important findings. The production technology progressed but there were reductions in technical efficiency, scale efficiency and residual mix efficiency levels. This result suggests that the production frontier had shifted up but there existed lags in the responses of member countries to the technological change. Given TFP growth, improvements in nutrient use efficiency and cumulative exergy use efficiency were counteracted by reductions in the changes of the aggregate nitrogen contents ratio and aggregate cumulative exergy contents ratio. The empirical results also confirmed that different combinations of inputs and outputs as well as the quality of inputs and outputs could have more influence on the growth of nutrient and cumulative exergy use efficiency than factors that had driven productivity change.
Keywords: Nutrient use efficiency, Cumulative exergy use efficiency, Thermodynamic efficiency change, Productivity growth, OECD agriculture, Sustainability

34) Hoang, V. N., & Alauddin, M. (2010). Assessing the eco-environmental performance of agricultural production in OECD countries: the use of nitrogen flows and balance. Nutrient cycling in agroecosystems, 87(3), 353-368.

Abstract: Nitrogen balance is increasingly used as an indicator of the environmental performance of agricultural sector in national, international, and global contexts. There are three main methods of accounting the national nitrogen balance: farm gate, soil surface, and soil system. Some studies have provided the comparison among these methods and the conclusion is mixed. The present paper combines these three methods to provide a more detailed auditing of the nitrogen flows and balance. The proposed combination gives more useful information than the individual methods do, especially for the use of nitrogen flows and balance in international comparison of environmental performance. The study investigated the nitrogen flows and balance of OECD countries for years from 1985 to 2003 and used different indicators to assess relative environmental performance of these

countries. Some important findings emerge from the empirical exercise. First, on the whole OECD countries had decreased their nitrogen surplus by around 10% between 1990 and 2003. Secondly, OECD nitrogen surplus intensity was still higher than the world level. Thirdly, the environmental performance in the crop sector was better than the livestock sector. Fourthly, the performance varied greatly among member countries and these differences were correlated with many factors such as the use of land and domestic support. Fifthly, the rankings varied depending on the indicators used.
Keywords Agricultural production , Eco-environmental performance, Farm gate , OECD, Nitrogen balance, Nutrient auditing, Soil system, Soil surface

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35) Hu, J. L., & Wang, S. C. (2006). Total-factor energy efficiency of regions in China. Energy policy, 34(17), 3206-3217.

Abstract: This paper analyzes energy efficiencies of 29 administrative regions in China for the period 1995–2002 with a newly introduced index. Most existing studies of regional productivity and efficiency neglect energy inputs. We use the data envelopment analysis (DEA) to find the target energy input of each region in China at each particular year. The index of total-factor energy efficiency (TFEE) then divides the target energy input by the actual energy input. In our DEA model, labor, capital stock, energy consumption, and total sown area of farm crops used as a proxy of biomass energy are the four inputs and real GDP is the single output. The conventional energy productivity ratio regarded as a partial-factor energy efficiency index is computed for comparison in contrast to TFEE; our index is found fitting better to the real case. According to the TFEE index rankings, the central area of China has the worst energy efficiency and its total adjustmentof energy consumption amount is over half of China's total. Regional TFEE in China generally improved during the research period except for the western area. A U-shape relation between the area'sTFEE and per capita income in the areas of China is found, confirming the scenario that energy efficiency eventually improves with economic growth.
Keywords: Data envelopment analysis; Total-factor energy efficiency (TFEE); China economy

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36) Huerta, J. H., Alvear, E. M., & Navarro, R. M. (2012). Evaluation of two production methods of Chilean wheat by life cycle assessment (LCA). IDESIA (Chile), 30(2), 101-110.

Abstract: Agricultural production is an activity that generates environmental impacts, primarily associated with the use of machinery and chemical inputs. For this reason it is expected that cultural practices and technological levels will influence significantly the environmental impacts of different production systems. In this study we evaluated conventional and organic methods using life cycle assessment (LCA). The results identified soil management as the stage of conventional production that generates the greatest environmental impact; the most affected impact categories were acidification, with 15.28 kg SO2 equivalent per ton of grain produced, and eutrophication, with 4.83 kg PO4 eq/ton of grain. The category most affected by organic production was soil management, mainly due to the Diesel fuel used in

agricultural machinery. In this production method the category of abiotic resource depletion had the greatest impact, with 0.89 kg Sb eq/ton of grain. The use of compost as a strategy fixed important amounts of biogenic carbon, generating environmental benefits in the impact category of climate change –4.39 kg CO_2 eq/ton of grain.
Key words: conventional production, organic production, environmental impact.

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37) Iráizoz, B., Rapún, M., & Zabaleta, I. (2003). Assessing the technical efficiency of horticultural production in Navarra, Spain. Agricultural Systems, 78(3), 387-403.

Abstract: The objective of this paper is to estimate technical efficiency in the horticultural production sector in Navarra (Spain). Tomato and asparagus production are analysed separately. Both a non-parametric and a parametric approach to a frontier production function are used and the differences in the results are discussed. In a second stage we examine the degree to which the calculated efficiency correlates with a set of explanatory variables representing different features of farms such as size, factorial returns and economic performance. The results indicated that both tomato and asparagus production are relatively inefficient, with potential in both cases for reducing input or increasing output. These results hold regardless of whether the frontier was parametric or non-parametric. The estimated measures of technical efficiency were positively related with the partial productivity indices and negatively related with the cultivation costs per hectare. No conclusive results were obtained for the relation between size and efficiency.
Keywords: Horticultural products; Technical efficiency; Frontier production function

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38) Kanellopoulos, A., Reidsma, P., Wolf, J., & Van Ittersum, M. K. (2014). Assessing climate change and associated socio-economic scenarios for arable farming in the Netherlands: An application of benchmarking and bio-economic farm modelling. European journal of agronomy, 52, 69-80.

Abstract: Future farming systems are challenged to adapt to the changing socio-economic and bio-physical envi- ronment in order to remain competitive and to meet the increasing requirements for food and fibres. The scientific challenge is to evaluate the consequences of predefined scenarios, identify current “best” practices and explore future adaptation strategies at farm level. The objective of this article is to assess the impact of different climate change and socio-economic scenarios on arable farming systems in Flevoland (the Netherlands) and to explore possible adaptation strategies. Data Envelopment Analysis was used to identify these current “best” practices while bio-economic modelling was used to calculate a number of important economic and environmental indicators in scenarios for 2050. Relative differences between yields with and without climate change and technological change were simulated with a crop bio-physical model and used as a correction factors for the observed crop yields of current “best” practices. We demonstrated the capacity of the proposed methodology to explore multiple scenarios by analysing the importance of drivers of change, while accounting for variation between individual farms. It was found that farmers in Flevoland are in general technically efficient and

a substantial share of the arable land is currently under profit maximization. We found that climate change increased productivity in all tested scenarios. However, the effects of different socio-economic scenarios (globalized and regionalized economies) on the economic and environmental performance of the farms were variable. Scenarios of a globalized economy where the prices of outputs were simulated to increase substantially might result in increased average gross margin and lower average (per ha) applications of crop protection and fertilizers. However, the effects might differ between different farm types. It was found that, the abolishment of sugar beet quota and changes of future prices of agricultural inputs and outputs in such socio-economic sce- nario (i.e. globalized economy) caused a decrease in gross margins of smaller (in terms of economic size) farms, while gross margin of larger farms increased. In scenarios where more regionalized economies and a moderate climate change are assumed, the future price ratios between inputs and outputs are shown to be the key factors for the viability of arable farms in our simulations.
Keywords: Integrated assessment Data EnvelopmentAnalysis Farm adaptation Farm model Technical efficiency

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39) Khademvatani, A., & Gordon, D. V. (2013). A marginal measure of energy efficiency: The shadow value. Energy Economics, 38, 153-159.

Abstract: Economists are well aware of the importance of marginal versus average measures of energy efficiency. Yet in the energy literature, there is no consensus on the appropriate method for defining and measuring energy efficiency. This paper sets out the shadow value of energy as a proper and meaningful marginal energy efficiency index. A restricted profit function is used to model the shadow value. We explore four scenarios to characterize and evaluate the shadow value of energy; a within country comparison of different production processes with different energy requirements, a comparison of different countries with different resource endowment, a government policy to impose a tax to alter the shadow value to address environmental issues and a within country comparison of externalities arising from two sources of energy. A comparative static analysis is carried out to sign the functional arguments defined for the shadow value.
Keywords: Energy efficiency Marginal index Shadow value

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40) Khoshnevisan, B., Rafiee, S., Omid, M., Yousefi, M., & Movahedi, M. (2013). Modeling of energy consumption and GHG (greenhouse gas) emissions in wheat production in Esfahan province of Iran using artificial neural networks. Energy, 52, 333-338.

Abstract: This study was carried out in Esfahan province of Iran. Data were collected from 260 farms in Fereydonshahr city with face to face questionnaire method. The objective of this study was to predict wheat production yield and (greenhouse gas) GHG emissions on the basis of energy inputs. Accordingly, several (artificial neural network) ANN models were developed and the prediction accuracy of them was evaluated using the quality parameters. The results illustrated that average total input and output energy of wheat production were 80.1 and 38 GJ ha_1, respectively. Electricity, chemical fertilizers and water for irrigation were the most

influential factors in energy consumption with amount of 39.5, 23.3 and 6.17 GJ ha_1, respectively. Energy use efficiency and energy productivity were 0.032 GJ kg_1 and 34.1 kg GJ_1, respectively. The ANN model with 11-3-2 structure was the best one for predicting the wheat yield and GHG emissions. The coefficients of determination (R2) of the best topology were 0.99 and 0.998 for wheat yield and GHG emissions, respectively.
Keywords: Artificial neural networks, Energy, GHG emissions, Prediction, Wheat production

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41) Kimhi, A. (2009). Heterogeneity, specialization and social cohesion in Israeli Moshav cooperatives. Journal of rural Cooperation, 37(886-2016-64689), 125-137.

Abstract: The Israeli Moshav cooperative was designed as a group of homogeneous family farms, all equal in size and resources. Over the years, processes of selective migration and specialization have increased heterogeneity within each Moshav. This has led to destabilization of the social and economic viability of the cooperative, and was one of the reasons for the financial crisis of 1985. This paper investigates the process of heterogeneity and specialization and examines its consequences in the post-crisis period. In particular, it documents the aggregate trends of decreasing number of active farms, increasing farm size, increased farm specialization, and increased reliance on off-farm income. All these lead to increased heterogeneity and polarization within and between Moshav cooperatives, raising concerns about the future economic and social viability of these cooperatives.
Keywords: Cooperatives; Heterogeneity; Structural change.

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42) Kimhi, A., & Reznik, A. (2018). Efficiency Implications of the Dairy Farm Policy Reform in Israel (No. 888-2019-2202).

Abstract: The dairy branch is one of the most regulated branches of agriculture in Israel. The dairy farm policy reform, initiated in 1999, enabled Israeli dairy farmers, for the first time, to trade production quotas, and encouraged capital investments through financial incentives. The consequence is a rapid exit of producers, an increase in the size of existing producers either through purchasing quotas or through mergers, and an improvement of production efficiency and milk quality. This paper uses Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) to estimate the changes in production efficiency and their determinants, using data from the dairy farm profitability surveys of 2003, 2005, 2007 and 2009. We found that partnerships in the Kibbutz sector are the most efficient farms by all standards examined, mostly due to exploiting economies of scale. Results also suggest that dairy production is characterized by increasing returns to scale, and the gradual increase found in scale efficiency over time for small farms, and mainly for family farms, can be used as evidence for the success of the reform. Overall, we found that the dairy industry in the post-reform era is composed of larger and more efficient farms in compared to the earlier years. Production methods, capital structure and size still differ substantially across farms, hence efficiency is still quite variable, and there is scope for further improvements. Continued policies aimed at further concentration of production in fewer and larger farms are found to be of limited

potential. Efforts should focus on helping less efficient farmers to utilize the best available production methods and adopt efficient production techniques.

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43) Kimhi, A., & Rubin, O. D. (2006). Assessing the response of farm households to dairy policy reform in Israel (No. 888-2016-65099).

Abstract: After nearly fifty years of stability and stagnation of dairy market regulations in Israel, a dramatic policy reform has been enacted in 1999. The reform enabled farm households, for the first time, to trade production quotas. In addition, the reform signaled to farmers that milk prices will gradually go down in real terms, and therefore only producers who expand and become more efficient will prevail. The reform allowed for generous financial support for investment in expansion, but also required the adoption of environmental regulations which could be costly to many farm families. This paper uses data from a census of small family-operated dairy enterprises that was conducted in 2001, in order to analyze the response of farm households to the reform. The results imply that the reform was particularly attractive for already strong producers. Weaker producers are less attracted by the reform and will likely fade away by default in the long run. Another finding is that intergenerational succession is an important element of decision making of milk producers. Hence, the response of farm households to changes in the economic environment cannot be disentangled from the occupational decisions of their offspring. These findings imply that the desired structural change in the family-farm milk production sector will take much longer than expected, essentially as long as the current generation of producers is around. This requires, perhaps, an extension of the reform period or a change in incentives in favor of the smaller and older producers.
Key words: milk policy reform; technology adoption; intergenerational succession.

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44) Makri, P., Papanagiotou, P., & Papanagiotou, E. (2015). Efficiency and economic analysis of Greek beekeeping farms. Bulgarian Journal of Agricultural Science, 21(3), 479-484.

Abstract: Beekeeping is an economic activity, not only because of the products it offers, but also for being environmentally friendly. Greece is a significant honey producing country, given its limited population and area. Thus, the present study attempts to perform an important economic analysis of the Greek beekeeping sector, and explore the efficiency of beekeeping farms by applying the Data Envelopment Analysis (DEA) method. According to the results, significant inefficiencies have been identified, despite the fact that beekeeping seems to be a profitable sector. More precisely, beekeepers could achieve the same level of output by reducing their inputs by 34% for the short-run and by 43% for the long-run, on average, given the technology adopted. In addition, the majority of beekeepers should make important changes to their scale of operation. Finally, the reorganisation of the used inputs along with the appropriate adjustments, could lead to the improvement of both: efficiency and economic performance.
Key words: economic results, Data Envelopment Analysis, beekeeping, Greece

45) Malana, N. M., & Malano, H. M. (2006). Benchmarking productive efficiency of selected wheat areas in Pakistan and India using data envelopment analysis. Irrigation and Drainage: The journal of the International Commission on Irrigation and Drainage, 55(4), 383-394.

Abstract: Food demand is bound to increase significantly in future as a result of a growing world population. As a large proportion of the available land and water resources have been developed, there is limited scope for further increase in the use of these resources. Thus, future increases in food production will originate from improvements in performance of existing agriculture rather than development of new resources. It is anticipated that wheat demand in the South Asia will rise significantly in future. In order to increase production and overcome diminishing water availability for irrigation, performance of wheat farms must increase. This paper describes the process of benchmarking the productive efficiency of wheat in selected areas of Pakistan and India. Data envelopment analysis (DEA) is used to evaluate and rank productivity performance of wheat growing areas in both countries based on three inputs: irrigation (m3 ha_1), seed (kg ha_1) and fertiliser use (kg ha_1). The results of analysis show that DEA is an effective tool for analysing and benchmarking productive efficiency of agricultural units. Ranking of productive efficiency based on three inputs is also shown to differ significantly from that based on a single resource (irrigation). Copyright # 2006 John Wiley & Sons, Ltd.
Key words: DEA; benchmarking; irrigation productivity; productive efficiency; wheat; Pakistan; India

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46) Markovits-Somogyi, R. (2011). Ranking efficient and inefficient decision making units in Data Envelopment Analysis. International Journal for Traffic & Transport Engineering, 1(4).

Abstract: Data envelopment analysis is a non-parametric linear programming method capable of the efficiency evaluation of decision making units (e.g. public transport companies). It is very often used in the transport sector for the efficiency assessment of airports, ports, railways and public transportcompanies. However, the original DEA method does not differentiate the efficient firms and thus, does not create full ranking. To overcome this problem, several methods have been developed with the aim of enlarging the distinguishing power of DEA. The present article aims to review these methods with a special emphasis on the ones elaborated in the last decade.
Keywords: data envelopment analysis, full ranking, different techniques.

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47) Martínez, C. I. P. (2013). An analysis of eco-efficiency in energy use and CO2 emissions in the Swedish service industries. Socio-Economic Planning Sciences, 47(2), 120-130.

Abstract: This study determines the trends in energy efficiency and CO2 emissions of the Swedish service sector using data at the 2-digit level of aggregation for the Swedish service industry over the period 1993 e2008, this empirical study examines eco-efficiency in terms of energy efficiency and CO2 emissions based on a number

of models. The results show that Swedish service industries increased energy consumption and CO2 emissions during the sample period, whereas energy and CO2 emission intensities have shown a decrease in recent years. Eco-efficiency models based on the Malmquist data envelopment analysis model suggest that Swedish service industries have an excellent potential to increase energy efficiency and reduce CO2 emissions. Second-stage panel data techniques show that energy taxes, investments and labour productive have a significant and positive influence on energy and CO2 emission intensities implying that increasing these variables lead to higher energy efficiency and lower CO2 emission intensity. This analysis demonstrates the importance of designing and applying adequate energy policies that encourage better energy use and management in this industrial sector for the goal of achieving a low carbon economy.
Keywords: Swedish service industries, CO2 emissions, Energy efficiency, Data envelopment analysis, The Malmquist productivity index, Panel data model

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48) Mohammadi, A., Rafiee, S., Jafari, A., Dalgaard, T., Knudsen, M. T., Keyhani, A., ... & Hermansen, J. E. (2013). Potential greenhouse gas emission reductions in soybean farming: a combined use of life cycle assessment and data envelopment analysis. Journal of Cleaner Production, 54, 89-100.

Abstract: Joint implementation of Life Cycle Assessment (LCA) and Data Envelopment Analysis (DEA) has recently showed to be a suitable tool for measuring efficiency in agri-food systems. In the present study, LCA þ DEA methodologies were applied for a total of 94 soybean farms in Iran to benchmark the level of operational input efficiency of each farmer. Likewise, potential reductions in the consumption levels of the physical inputs were determined, while estimating the environmental improvements linked to these reduction targets. Our results indicate that 46% of the farms studied operated efficient. The estimated Global Warming Potential (GWP) reduction for the whole sample was obtainedw11% according to DEA model results. Among the field operations, the contribution of irrigation to the total GWP reduction was the highest (63%) followed by fertilization (34%). The results also revealed that farms which burnt crop residue in the field generate significantly more greenhouse gas emissions than other farms. The raising of operational input efficiency and limiting of crop residue burning in the field are recommended options to ensure more environmental friendly soybean farming systems in the region.
Keywords: Global warming potential, LCA þ DEA method, Soybean Irrigation, Crop residue

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49) Mohammadi, A., Rafiee, S., Jafari, A., Keyhani, A., Dalgaard, T., Knudsen, M. T., ... & Hermansen, J. E. (2015). Joint life cycle assessment and data envelopment analysis for the benchmarking of environmental impacts in rice paddy production. Journal of Cleaner Production, 106, 521-532.

Abstract: The combined implementation of Life Cycle Assessment (LCA) and Data Envelopment Analysis (DEA) has been identified as a suitable tool for the evaluation of the environmental and economic performance of multiple similar entities. In this study, a total of 82 rice paddy fields for spring and summer growing seasons in north

of Iran were assessed using a combined LCA and DEA methodology to estimate the technical efficiency of each farmer. Furthermore, the environmental consequences of operational inefficiencies were quantified and target performance values benchmarked for inefficient units so that ecoefficiency criteria were verified. Results showed average reduction levels of up to 20% and 25% per material input for spring and summer systems, leading to impact reductions which ranged from 8% to 11% for spring farms and 19% to 25% for summer farms depending on the chosen impact category. Additionally, the potential economic savings from efficient farming operations were also determined. The economic results indicate that an added annual gross margin of 0.045 $ per 1 kg rice paddy could be achieved if inefficient units converted to an efficient operation.

Keywords: Life Cycle Assessment (LCA), Data Envelopment Analysis (DEA), Rice paddy, Growing season, Technical efficiency, Economic savings

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50) Moudrý Jr, J., Jelínková, Z., Plch, R., Moudrý, J., Konvalina, P., & Hyšpler, R. (2013). The emissions of greenhouse gases produced during growing and processing of wheat products in the Czech Republic. J Food Agric Environ, 11(1), 1133-1136.

Abstract: The Czech Republic's climate and energy policy strongly focuses on nuclear power, while originally high political support to renewable energy is in decline. *GHG target*: Non-ETS emissions in 2011 were below of the 2013 target and according to the latest national projections the Czech Republic is expected to overachieve its 2020 target. *Policy development*: On 1 January 2013, the new Act on Supported Energy Sources came into effect, and stricter energy efficiency rules for buildings were introduced.

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51) Mousavi-Avval, S. H., Rafiee, S., & Mohammadi, A. (2011). Optimization of energy consumption and input costs for apple production in Iran using data envelopment analysis. Energy, 36(2), 909-916.

Abstract: In this study a non-parametric method of data envelopment analysis (DEA) was applied to analyze the efficiency of farmers, discriminate efficient farmers from inefficient ones and to identify wasteful uses of energy in order to optimize the energy inputs for apple production in Tehran province, Iran. From this study the following results were obtained: from the total of 56 farmers, considered for the analysis, 34% and 54% were found to be technically and pure technically efficient, respectively. The technical, pure technical and scale efficiency scores of farmers were 0.7857, 0.8982 and 0.8666, respectively. Optimum energy requirement was found to be 37993.15 MJ ha_1; indicating that 11.29% of total energy input could be saved if the recommendations of this study are followed. From total energy saving, the contribution of electrical energy was the highest; it followed by chemicals energy inputs; implying that there was a great scope for saving energy inputs by improving the use pattern of these inputs. The results of economical analysis showed that the total costs of production could decreased from 8227.70 to 7570.01 $ ha_1; also the benefit to cost ratio and productivity improved from 1.24 to 1.34 and 2.52 to 2.74, respectively.

Keywords: Energy saving. Technical efficiency, Electrical energy, Economical analysis

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52) Moutinho, V., Madaleno, M., Macedo, P., Robaina, M., & Marques, C. (2018). Efficiency in the European agricultural sector: environment and resources. Environmental Science and Pollution Research, 25(18), 17927-17941.

Abstract
This article intends to compute agriculture technical efficiency scores of 27 European countries during the period 2005–2012, using both data envelopment analysis (DEA) and stochastic frontier analysis (SFA) with a generalized cross-entropy (GCE) approach, for comparison purposes. Afterwards, by using the scores as dependent variable, we apply quantile regressions using a set of possible influencing variables within the agricultural sector able to explain technical efficiency scores. Results allow us to conclude that although DEA and SFA are quite distinguishable methodologies, and despite attained results are different in terms of technical efficiency scores, both are able to identify analogously the worst and better countries. They also suggest that it is important to include resources productivity and subsidies in determining technical efficiency due to its positive and significant exerted influence.

Keywords Agriculture resources productivity · European subsidies · Common agricultural policy (CAP) · Data envelopment analysis (DEA) · Stochastic frontier analysis (SFA) · Generalized cross-entropy (GCE)

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53) Mukherjee, K. (2008). Energy use efficiency in US manufacturing: A nonparametric analysis. Energy Economics, 30(1), 76-96.

Abstract: This study approaches the measurement of energy use efficiency in the U.S. manufacturing sector from a production theoretic perspective. The method of Data Envelopment Analysis is utilized to analyze the energy efficiency for the aggregate manufacturing sector as well as for the six highest energy consuming 2-digit sectors for the period 1970–2001, and several alternative models are proposed. The new measures of energy efficiency suggested in this study do provide some additional insights and could be helpful if used alongside the traditional measure of energy efficiency based on energy intensity.
Keywords: Data Envelopment Analysis; Energy efficiency; Manufacturing

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54) Nassiri, S. M., & Singh, S. (2010). A comparative study of parametric and non-parametric energy use efficiency in paddy production.

Abstract: In the present study an attempt has been made to use a non-parametric method Data Envelopment Analysis (DEA) for assessing source-wise and operation-wise the Technical Efficiency (TE) and Return-to-Scale (RTS) for paddy production in four zones of the state of Punjab, India. The results were then compared to corresponding ones already obtained from a parametric method (Cobb-Douglas production function). The data from farmers growing rice in four zones including labor-h, machine-h, power source, horse power and hours used, kind of machinery used, physical inputs such as seed, fertilizers and pesticides (as inputs) and the yield (as output) were transformed into energy terms (MJ ha-1). The results revealed that farmers in zone 2 with a source-wise TE of 0.91, have consumed energy from more efficient sources, followed by zone 4 (0.90) and then zones 3 and 5 (0.85). No significant correlation could be established between the parametric and nonparametric *TE* for source-wise energy inputs. According to the DEA results, it was observed that 55.6% and 64.1% of inefficient farmers had an increasing *RTS* for operation-wise and source-wise energy inputs, respectively. However, a constant *RTS* had been reported by the parametric frontier function.

Keywords*:* Data envelopment analysis, Energy efficiency, Paddy, Pure technical efficiency, Return-to-scale, Scale efficiency, Technical efficiency.

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55) Nassiri, S. M., & Singh, S. (2010). Non-parametric energy use efficiency, energy ratio and specific energy for irrigated wheat crop production. Iran Agricultural Research, 27(1.2), 27-38.

Abstract: In this paper, non parametric Data Envelopment Analysis (DEA) was subjected to the energy data of wheat producers in Punjab state, India, and technical, pure technical and scale efficiencies were calculated for farms both category wise and zone wise. The main objective was to determine the strength of the correlation between non-parametric efficiencies and indices such as energy ratio and specific energy. Results revealed that larger farms had a higher energy ratio and lower specific energy as compared to smaller ones. Frequency distribution of technical efficiency scores revealed that large farms were more consistent on efficiency scores, and the dispersion of technical efficiency was highest on medium farms followed by semi Medium and small farms. The correlation coefficients between energy ratio and each technical, pure and scale efficiency, as well as those between specific energy and each technical, pure and scale efficiency showed that energy ratio and specific energy are not appropriate indices for explaining farm efficiencies in different farm categories and zones.

Keywords: Data Envelopment Analysis, Energy-ratio, Specific energy, Technical efficiency, Wheat.

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56) Okuyama, Y., Maruyama, A., Takagaki, M., & Kikuchi, M. (2017). Technical efficiency and production potential of selected cereal crops in Senegal. Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS), 118(2), 187-197.

Abstract: This study focused on the production outcomes for five crops cultivated in Senegal: upland rice, lowland rice, groundnut, maize, and pearl millet. Technical efficiency (TE) of the production of each crop was estimated using data envelopment analysis, and the determinants of TEs were assessed using generalised linear regression analyses. Data were collected in face-to-face interviews with 66 farmers in the Kaolack region of Central Senegal during November 2011–February 2012. Average TEs for upland rice, lowland rice, groundnut, maize, and pearl millet were estimated as 0.76, 0.88, 0.89, 0.94, and 0.90, respectively. The identified factors that had a positive impact on TE were years of cultivation experience, amount of nitrogen fertiliser applied, and participation in a farmers' association. Weeding hours, seeding rate, size of the cultivated area, and delays in sowing time were negatively associated with TE. The factors that significantly affected TE differed among the crops. Optimising these factors could enable potential yield increase of upland rice, lowland rice, groundnut, maize, and pearl millet by 24, 12, 11, 6, and 10 %, respectively.

Keywords: production function, agricultural extension, data envelopment analysis (DEA), rice, West Africa

57) Pardo Martínez, C. I. (2015). Estimating and analyzing energy efficiency in German and Colombian manufacturing industries using DEA and data panel analysis. Part I: Energy-intensive Sectors. Energy Sources, Part B: Economics, Planning, and Policy, 10(3), 322-331.

Abstract: In this article, data envelopment analysis (DEA) is employed to study the comparative performance of German and Colombian energy-intensive sectors between 1998 and 2005. The results of the DEA indicate that the great majority of energy-intensive sectors improved on this index during the sample period, demonstrating that energy input is an important variable within the production structure and a key element in technology development. At a second stage, regression analysis using panel data analysis reveals that several factors, including labor productivity, the share of electricity, investments and enterprise size can be considered determinants of differences in energy efficiency among German and Colombian energy-intensive sectors. Our results also show that different energy policies should apply, and that they should encourage the importance of energy efficiency in order to achieve a sustainable economic development and climate stabilization today and in the near future.
Keywords: data envelopment analysis, data panel analysis, energy efficiency, energy intensive sectors

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58) Picazo-Tadeo, A. J., & Prior, D. (2009). Environmental externalities and efficiency measurement. Journal of environmental management, 90(11), 3332-3339.

Abstract: Production of desirable outputs often produces by-products that have harmful effects on the environment. This paper investigates technologies where the biggest good output producer is not the greatest polluter, i.e. technologies located on the downward-sloping segment of the frontier depicted in Färe et al. (1989). Directional distance functions and Data Envelopment Analysis techniques are used to define an algorithm that allows them to be identified empirically. Furthermore, we show that in such situations producers can contribute social goods, i.e. reducing polluting wastes, without limiting their capacity to maximise production of marketable output. Finally, we illustrate our methodology with an empirical application to a sample of Spanish ceramic tile producers.
Keywords: Efficiency measurement, Environmental efficiency, Environmental externalities

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59) Reig-Martínez, E., & Picazo-Tadeo, A. J. (2004). Analysing farming systems with Data Envelopment Analysis: citrus farming in Spain. Agricultural Systems, 82(1), 17-30.

Abstract: Farming systems in the Mediterranean agricultural areas of Spain are frequently characterised by the small size of the production units and a widespread strategy of externalisation of many growing tasks which could be seen as a way of allowing farms to remain competitive. In this paper, we suggest Data Envelopment Analysis as an appropriate analytical tool to explore the possibilities of short-term viability of individual farms, after eliminating current inefficient practices. From a

sample of Spanish citrus farms, we identify the efficient production units that determine the technological or best practice frontier, and we compare their characteristics with those of the average farm. Best practice farms have higher yields than the average farm and are also further advanced in the process of substituting wage-earning labour for family labour. Cutting the employment of the household_s labour on its own farm is linked to a strategy of externalisation of citrus growing tasks, in an attempt to surmount the problems posed by the small average size of farms. Finally, we compute an overall efficiency measure and several indicators of short-run competitiveness that compare the ability of farms to generate net income under both current and efficient production plans. Our results show that there is a substantial fall in the number of farms judged economically non-viable after inefficiency has been removed.
Keywords: Citrus farming; Competitiveness; Productive efficiency; Data Envelopment Analysis

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60) Sadjadi, S. J., Omrani, H., Abdollahzadeh, S., Alinaghian, M., & Mohammadi, H. (2011). A robust super-efficiency data envelopment analysis model for ranking of provincial gas companies in Iran. Expert Systems with Applications, 38(9), 10875-10881.

Abstract: Conventional super-efficiency data envelopment analysis (DEA) models require the exact information of inputs or outputs. However, in many real world applications this simple assumption does not hold. Stochastic super-efficiency is one of recent methods which could handle uncertainty in data. Stochastic super-efficiency DEA models are normally formulated based on chance constraint programming. The method is used to estimate the efficiency of various decision making units (DMUs). In stochastic chance constraint super-efficiency DEA, the distinction of probability distribution function for input/output data is difficult and also, in several cases, there is not enough data for estimating of distribution function. We present a new method which incorporates the robust counterpart of super-efficiency DEA. The perturbation and uncertainty in data is assumed as ellipsoidal set and the robust super-efficiency DEA model is extended. The implementation of the proposed method of this paper is applied for ranking different gas companies in Iran.
Keywords: Data envelopment analysis, Robust optimization, Uncertainty, Rank

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61) Salvati, L., & Carlucci, M. (2011). The economic and environmental performances of rural districts in Italy: are competitiveness and sustainability compatible targets?. Ecological Economics, 70(12), 2446-2453.

Abstract: This paper analyses the economic performances of the rural system and the level of land sensitivity to degradation in Italy. Three indicators (district value added, share of agriculture on total product, and a composite index of land sensitivity) were used to classify 784 Italian local districts into eight performance classes. Four classes share a combination of high environmental quality (in terms of land degradation), high (or low) economic performances, and high (or low) productivity of the primary sector. The remaining four are characterised by a combination of low (and declining) environmental quality, high (or low) economic performances, and high (or low) productivity of the primary sector. The eight classes

were grouped into four 'environmental quality' types and four 'target performance' categories to discriminate among high- and low-performance districts by considering twelve additional variables within a Discriminant Function Analysis (DFA). 148 high environmental performance districts (18% of total) were identified mainly across the Alps and Apennine while 314 districts (41%) were classified in the lowest performance class and concentrated in flat areas of southern Italy. The districts with high environmental performances were characterised, on average, by medium to low district value added, moderately low economic weight of the primary sector, and tourism specialisation. Districts with high economic performances and low environmental performances were characterised by high sensitivity to LD, low district value added, high share of agriculture in total product, and the lowest productivity of labour in all economic sectors. In these districts the risk of entering a downward spiral of rural poverty and environmental degradation is potentially high.

Keywords: Economic performances, Environmental sustainability, Land vulnerability, Rural development, Local district, Italy

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62) Salvati, L., & Zitti, M. (2008). Regional convergence of environmental variables: empirical evidences from land degradation. Ecological Economics, 68(1-2), 162-168.

Abstract: Studies on regional convergence in environmental variables may provide useful information to drive policies regarding complex processes featured by the interaction of ecological and economic factors. In order to provide empirically observed evidences on regional convergence in environmental phenomena, we chose Land Degradation (LD) as the study variable because it represents a key topic in both environmental projections and policy strategies. This paper explores the temporal variation (1990–2000) of a synthetic index of vulnerability to LD, called ESAI (Environmental Sensitive Area Index), calculated on the whole Italian territory. Convergence in land vulnerability was analysed on three different geographical scales: NUTS-2 regions, NUTS-3 provinces, and local labour systems (LLSs). Different convergence patterns were identified and discussed according to the level of LD estimated over the national territory and the economic characteristics of these areas.

Keywords: Land degradation, Vulnerability, Regional analysis, Convergence, Composite index, Italy

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63) Shi, G. M., Bi, J., & Wang, J. N. (2010). Chinese regional industrial energy efficiency evaluation based on a DEA model of fixing non-energy inputs. Energy policy, 38(10), 6172-6179.

Abstract: Data envelopment analysis (DEA) has recently become a popular method in measuring energy efficiency at the macro-economy level. However, previous studies are limited in that they failed to consider the issues of undesirable outputs and minimisation of energy consumption. Thus, this study considers both factors in measuring Chinese industrial energy efficiency and investigates the maximum energy-saving potential in 28 administrative regions in China. The results show that industries in the east area have the best average energy efficiency for the period

2000–2006, followed by the central area. Further, after comparing the industrial energy overall efficiency, pure technical efficiency (IEPTE), and scale efficiency of the 28 administrative regions examined, the study finds that in most regions of this study, the two main reasons causing the wastage of a large amount of energy during the industrial production process are that the industrial structure of most regions still relies on the massive use of energy in order to support the industrial-based economy and the IEPTE is too low. Based on these findings, this paper correspondingly proposes some policies to improve regional industrial energy efficiency.
Keywords: Chinese industrial energy efficiency Undesirable outputs Minimising energyconsumption

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64) Singh, S., Singh, M. P., & Bakhshi, R. (1990). Unit energy consumption for paddy-wheat rotation. Energy Conversion and Management, 30(2), 121-125.

Abstract: Paddy and wheat are two major crops of the state of Punjab (India) and are grown in rotation. These crops consume most of the energy used on Punjab farms. The area under these crops has constantly increased since the introduction of high yielding varieties in the mid-1960s. A multistage stratified technique was applied in conducting the farmers' survey to study the energy consumption for paddy-wheat rotation. Irrigation consumed the maximum energy in all the farm operations for both paddy (81.9%) and wheat (38.1%). The output-input ratio for paddy-wheat rotation was 4.59. The specific energy consumption for paddy was 5.87 MJ/kg, and that of wheat was 4.46 MJ/kg. Paddy consumed 90.9% and wheat 94.3% of the total energy input from commercial sources and the rest of the energy need was met through non-commercial sources. Keeping in view the fast depleting commercial energy sources, an alternative crop rotation may be thought of which requires less energy in the form of fertilizer, as well as as irrigation, and may give, if not more, equivalent output-input energy ratios. Introduction of oil crops and pulses on a large scale may be alternative crops which will reduce the load on commercial energy sources.

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65) Syp, A., Faber, A., Borzęcka-Walker, M., & Osuch, D. (2015). Assessment of Greenhouse Gas Emissions in Winter Wheat Farms Using Data Envelopment Analysis Approach. Polish Journal of Environmental Studies, 24(5).

Abstract: Data envelopment analysis (DEA) has been recognized as a suitable tool for efficiency assessment of the economic and environmental performance of multiple similar units in the agri-food sector. In the present study, DEA methodologies were applied to 55 winter wheat farms in three farm sizes in Poland to benchmark the level of operational efficiency for each producer. Next, the potential reduction in the consumption levels of inputs were defined, and the environmental profits linked to these reduction targets were calculating. Our results indicate that 55% of the analysed farms operated efficiently. The technical efficiency scores of inefficient farms were 0.72 for small farms and 0.84 for medium and large ones. The production of 1 kg winter wheat results with average greenhouse gas (GHG) emissions of 0.448, 0.481, and 0.411 kg CO2 eq. per kg of grain, for small, medium, and large farms, respectively. The performed analysis shows that GHG emissions per hectare depend

on farm size and ranged from 2,378 kg CO2 eq. for the small farms to 2,759 kg CO2 eq. for large farms. The reduction of material input in inefficient farms, converted into environmental gains, resulted in GHG emissions reduction of 25.7, 29.0, and 28.6% for small, medium, and large farms, respectively. The estimated potential reduction of global warming potential (GWP) according to the DEA for the whole sample ranged from 7 to 18%, and was dependent on farm size. The major contributor to GWP was nitrous oxide field emissions (49-52%), followed by nitrogen fertilizer (31-33%), and diesel (11-13%). Raising operational efficiency is recommended for potential environmental improvement in the surveyed region.
Keywords: environmental impact, global warming potential, nitrogen fertilizer, nitrous oxide field emissions, technical efficiency

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66) Toma, E., Dobre, C., Dona, I., & Cofas, E. (2015). DEA applicability in assessment of agriculture efficiency on areas with similar geographically patterns. Agriculture and Agricultural Science Procedia, 6, 704-711.

Abstract: Data envelopment analysis (DEA) is a non-parametric research technique based on a mathematical optimization method. Since was first developed in '78, the method is used in various sectors of economy and at different levels (companies, counties, regions, etc.). Our purpose is to apply DEA at regional level by using various inputs and outputs to analyse the performance of agriculture practiced in plain, hill and mountain areas. Thirty-six counties were classified into three categories based on their geographical main characteristics, respectively: group I – with 50-100% plain areas (20 counties); group II - with 50-80% hill areas (8 counties); group III - with 50-80% mountain areas (8 counties). For these groups were computed, under input-oriented option, CRS and VRS technical scores from which we calculated scale efficiencies. This empirical research shows that exists clear differences of performance between areas with similar geographical characteristics in terms of production factors (work, land and mechanization) allocation and outputs. Our results show that there are only 14 counties (5 in plain areas, 5 in hill areas and 4 in mountain areas) completely achieving DEA efficiency and operate at their optimal scale. In conclusion, in majority of areas the overall efficiency of agriculture is not reached, these regions needing to decrease the input levels (especially work hours that are too high compared with productivity) or to increase the output levels (production value) through a better use of fix capital and higher yields.
Keywords: agriculture; data envelopment analysis; technical efficiency; scale efficiency

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67) Travisi, C. M., & Nijkamp, P. (2008). Valuing environmental and health risk in agriculture: A choice experiment approach to pesticides in Italy. Ecological Economics, 67(4), 598-607.

Abstract: The widespread use of pesticides in agriculture shows a complex ramification of multiple negative externalities, ranging from food safety-related effects to the deterioration of farmland ecosystems. Recent research has demonstrated that the assessment of the economic implications of such negative

processes is fraught with many uncertainties. This paper presents the results of an empirical study recently conducted in Northern Italy aimed at estimating the economic value of reducing the wide-ranging impacts of pesticide use, by deploying a Choice Experiment approach. The experimental design provides a meaningful tool to assign monetary values to the negative environmental effects associated with agrochemicals use. In this connection, the paper addresses in particular the reduction of farmland biodiversity, groundwater contamination and harm to human health. The resulting estimates confirm that, on average, respondents demonstrate a substantial willingness-to-pay a premium for agricultural goods (in particular, foodstuffs) produced in environmentally-benign ways.
Keywords: Pesticide risks, Food safety, Willingness-to-pay, Choice experiment, Stated choice

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68) Vasiliev, N., Astover, A., & Mõtte, M. (2008). Efficiency of Estonian grain farms in 2000 2004. Agricultural and food science, 17(1), 31-40.

Abstract: The aim of this study is to analyse the efficiency of Estonian grain farms after Estonia's transition to a market economy and during the accession period to the European Union (EU). The non-parametric method Data Envelopment Analysis (DEA) was used to estimate the total technical, pure technical and scale efficiency of Estonian grain farms in 2000–2004. Mean total technical efficiency varied from 0.70 to 0.78. Of the grain farms 62% are operating under increasing returns to scale. Solely based on the DEA model it is not possible to determine optimum farm scale and the range of Estonian farm sizes operating efficiently is extensive. The most pure technically efficient farms were the smallest and the largest but the productivity of small farms is low compared to larger farms because of their small scale. Therefore, they are the least competitive. Since pre-accession period to the EU, large input slacks of capital have replaced the former excessive use of labour and land. This raises the question about the effects on efficiency of the EU's investment support schemes in new member states.
Keywords: Data Envelopment Analysis, scale efficiency, technical efficiency, farm size, grain farms, transition economies

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69) Vukelić, N., & Novković, N. (2013). Economic Efficiency Of Broiler Farms In Vojvodina Region (No. 1543-2016-132210, pp. 275-285).

Abstract: Measurement of the efficiency of agricultural production is very important issue especially in developing countries. The major problem of the broiler production in Vojvodina region is low level of productivity and inefficiency in resource allocation and utilization.

The objective of this study was to measure the economic efficiency of broiler farms using a nonparametric approach, Data Envelopment Analysis (DEA) which is used to quantify economic efficiencies of broiler farms in Vojvodina region by determining which farms are located on the production frontier and which are not. Data Envelopment Analysis method, one of new methods of operations research, is used very successfully in the last several years for assessing relative efficiency of organizational units having multiple inputs to produce multiple outputs. It was

originated by Charnes, Cooper and Rhodes in 1978. It is an efficiency estimation technique but it can be used for solving many problems of management such as ranking Decision Making Units (DMU). DEA develops a function whose form is determined by most efficient producers and indentifies a “frontier” on which the relative performance of all utilities in the sample can be compared: DEA benchmarks firms only against the best producers.
Furthermore, in order to fulfill the objective of the study, the authors were analyzing the performance of the broiler farms in Vojvodina region, their economic efficiencies. Data were collected from 30 broiler farms from which the input-output data were collected by using a structured questionnaire. The multiple-input, single-output production units (the broiler farms) were evaluated with the individual farms being referred to as individual Decision Making Unit (DMU). For the purpose of efficiency analysis, output (y) were aggregated into one category namely, gross margin of the broiler farms, and inputs were aggregated into five categories, namely, feed, day-old chickens, productivity, used energy and capital. Analyzed broiler farms were classified into three categories according to their production capacities. The first category included farms with production capacity between 5000 birds and 10000 birds per production cycle. The second category included farms with capacity of more than 10000 and less that 30000 birds per production cycle and the third category included farms with capacity of more than 30000 birds per production cycle.
Key words: Broiler production, economic efficiency, DEA method, Vojvodina

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70) Wadud, A., & White, B. (2000). Farm household efficiency in Bangladesh: a comparison of stochastic frontier and DEA methods. Applied economics, 32(13), 1665-1673.

Abstract: This study compares estimates of technical efficiency obtained from the stochastic frontier approach and the Data Envelopment Analysis (DEA) approach using farm-level survey data for rice farmers in Bangladesh. Technical inefficiency effects are modelled as a function of farm-specific socioeconomic factors, environmental factors and irrigation infrastructure. The results from both the approaches indicate that efficiency is significantly influenced by the factors measuring environmental degradation and irrigation infrastructure.

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71) Wei, Y. M., Liao, H., & Fan, Y. (2007). An empirical analysis of energy efficiency in China's iron and steel sector. Energy, 32(12), 2262-2270.

Abstract: Using Malmquist Index Decomposition, this paper investigates energy efficiency of China’s iron and steel sector during the period 1994–2003. Provincial panel data is employed, allowing various energy inputs and product outputs. The energy efficiency improvement is decomposed into two components: technical change (production frontier shifting effect) and technical efficiency change (catching up effect) over time. Our empirical results indicate that the energy efficiency in China’s iron and steel sector increased by 60% between 1994 and 2003, which is mainly attributable to technical progress rather than technical efficiency improvement. The energy efficiency gaps among provincial iron and steel sectors during this period have widened. However, energy efficiency of iron and steel plants

owned by the state has slowly improved in some regions, such as Shanghai, Liaoning, Beijing and Hubei. Nevertheless, technical efficiency in these four regions has decreased considerably. Energy efficiency in China's two largest private-own iron and steel bases (Heibei and Jiangsu) improved significantly.
Keywords: Iron and steel sector; Energy efficiency; Malmquist index; Technical change; Technical efficiency

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72) Yan, Q., Wan, Y., Yuan, J., Yin, J., Baležentis, T., & Streimikiene, D. (2017). Economic and technical efficiency of the biomass industry in China: a network data envelopment analysis model involving externalities. Energies, 10(9), 1418.

Abstract: This paper proposes the network data envelopment analysis (DEA) model accounting for negative externalities and applies it for decomposition of profit inefficiency in the biomass-agriculture circular system (Bio-AG system). A circular structure of the Bio-AG system which is different from the previously applied network structures is assumed. Since the negative externalities (i.e., pollutant emissions from the biomass industry) occur in the Bio-AG system, the property rights are taken into consideration to model the externalities-adjusted profits. Therefore, the changes in profits due to changes in the property rights (assuming no property rights, allocating property rights to agricultural sector, and allocating property rights to biomass power generation sector) are quantified. Further, the decomposition shows that the biomass power generation sector is less affected by technical inefficiency if contrasted to allocative inefficiency in terms of the profit loss. The findings suggest that the biomass power generation technology influences the profits of the biomass industry. What is more, the inefficient allocation of resources is now the key factor undermining performance of the biomass industry. Therefore, the government should adopt measures to improve the allocation of resources and prevent excessive investments or development of less efficient technologies.

Keywords: data envelopment analysis; biomass industry; negative externalities; efficiency decomposition

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73) Zhang, X. P., Cheng, X. M., Yuan, J. H., & Gao, X. J. (2011). Total-factor energy efficiency in developing countries. Energy Policy, 39(2), 644-650.

Abstract: This paper uses a total-factor framework to investigate energy efficiency in 23 developing countries during the period of 1980–2005. We explore the total-factor energy efficiency and change trends by applying data envelopment analysis (DEA) window, which is capable of measuring efficiency in cross-sectional and time-varying data. The empirical results indicate that Botswana, Mexico and Panama perform the best in terms of energy efficiency, whereas Kenya, Sri Lanka, Syria and the Philippines perform the worst during the entire research period. Seven countries show little change in energy efficiency over time. Eleven countries experienced continuous decreases in energy efficiency. Among five countries witnessing continuous increase in total-factor energy efficiency, China experienced the most rapid rise. Practice in China indicates that effective energy policies play a crucial role in improving energy efficiency. Tobit regression analysis indicates that a U-shaped relationship exists between total-factor energy efficiency and income per capita.
Keywords: DEA window analysis, Total-factor energy efficiency, Tobit model

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74) Zhou, P., Ang, B. W., & Zhou, D. Q. (2012). Measuring economy-wide energy efficiency performance: a parametric frontier approach. Applied Energy, 90(1), 196-200.

Abstract: This paper proposes a parametric frontier approach to estimating economy-wide energy efficiency performance from a production efficiency point of view. It uses the Shephard energy distance function to define an energy efficiency index and adopts the stochastic frontier analysis technique to estimate the index. A case study of measuring the economy-wide energy efficiency performance of a sample of OECD countries using the proposed approach is presented. It is found that the proposed parametric frontier approach has higher discriminating power in energy efficiency performance measurement compared to its nonparametric frontier counterparts.

Keywords: Energy efficiency, Distance function, Stochastic frontier analysis, Data envelopment analysis

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75) Zhu, J. (2001). Super-efficiency and DEA sensitivity analysis. European Journal of operational research, 129(2), 443-455.

Abstract: This paper discusses and reviews the use of super-efficiency approach in data envelopment analysis (DEA) sensitivity analyses. It is shown that super-efficiency score can be decomposed into two data perturbation components of a particular test frontier decision making unit (DMU) and the remaining DMUs. As a result, DEA sensitivity analysis can be done in (1) a general situation where data for a test DMU and data for the remaining DMUs are allowed to vary simultaneously and unequally and (2) the worst-case scenario where the efficiency of the test DMU is deteriorating while the efficiencies of the other DMUs are improving. The sensitivity analysis approach developed in this paper can be applied to DMUs on the entire frontier and to all basic DEA models. Necessary and sufficient conditions for preserving a DMU's efficiency classification are developed when various data changes are applied to all DMUs. Possible infeasibility of super-efficiency DEA models is only associated with extreme-efficient DMUs and indicates efficiency stability to data perturbations in all DMUs.

Keywords: Data envelopment analysis (DEA), Efficiency, Linear programming, Sensitivity analysis, Super-efficiency