Economic and Environmental Analysis of Energy Efficiency Measures in Agriculture

This project is funded by the European Union

The sole responsibility of this publication lies with the authors. The European Union is not responsible for any use that may be made of the information contained therein

Economic and environmental analysis of energy efficiency measures in agriculture

Case Studies and trade offs

This project was funded by the FP7 Program of the EC with the Grant Agreement Number 289139

Project Deliverable 3.1.

Andreas Meyer-Aurich, Hasan Jubaer, Lukas Scholz, Thomas Ziegler,	Leibniz-Institute for Agricultural Engineering Potsdam-Bornim
Tommy Dalgaard	Aarhus University
Hannu Yli-Kojola, Jussi Esala, Hannu Mikkola, Mari Rajaniemi, Tapani Jokiniemi, Jukka Ahokas	University of Helsinki
Janusz Gołaszewski, Mariusz Stolarski, Zbigniew Brodziński, Ryszard Myhan, Ewelina Olba-Zięty	University of Warmia and Mazury
Chris de Visser, Marcel van der Voort, Cecilia Stanghellini, Hilko Ellen, Arie Klop, Harm Wemmenhove	Wageningen UR
Fátima Baptista, Dina Murcho, Luis Leopoldo Silva, José Rafael Silva, José Oliveira Peça, Mário Louro, Carlos Marques	University of Evora
Antonis Mistriotis, Athanasios Balafoutis, Panagiotis Panagakis, Demetres Briassoulis	Agricultural University of Athens

Photo credits: left photo: Tommy Daalgard, Aarhus University / right photo: FNR/H. D. Habbe

Preface

This report is the result of the collaboration of the partners of the AGREE work-package "*Economic and environmental analysis*", which is based on case study analyses of the partners in seven countries of the EU. The case studies show economic and environmental trade-offs in the different regions in the EU, for which each partner is responsible. Nevertheless prior to the reporting of the case studies an intensive discussion on a common methodological approach has been accomplished and applied to the case studies. The case studies show a wide range of different perspectives of energy efficiency in agriculture, but they are all based on the common methodology presented in Chapter 3. In Chapter 4, the case studies are presented, with authors indicated at the beginning of each section. Each section of Chapter 4 ends with a synthesis analysis of the results from the different case studies. Chapter 5 summarizes and concludes the report by highlighting the major findings of the analyses.

The report builds upon the "State of the Art in Energy Efficiency in Europe" published separately by the AGREE consortium (Gołaszewski et al. 2012), which shows the status quo of energy use and possible energy efficiency measures in agriculture across different production systems and regions in Europe. This report presents an economic and environmental analysis based on in-depth case studies which show the potential for, and constraints on, energy efficiency measures in agriculture with respect to the specific environments in Europe.

List of Abbreviations

AGREE	AGRiculture & Energy Efficiency
AMS	Automatic Milking System
CAP	Common Agricultural Policy
CFD	Computational Fluid Dynamics
CHPP	Combined Heat and Power Plant
CTF	Controlled Traffic Farming
CVT	Continuously Variable Transmission
D	Germany
EE	Energy Efficiency
EL	Greece
EM	Effective Microorganisms
ENGAGE	European Network for Advanced Engineering in Agriculture and Environment
EU	European Union
EurAgEng	European Society of Agricultural Engineers
FI	Finland
GHG	Green House Gas
GPS	Global Positioning System
GNSS	Global Navigation Satellite System
HDPE	High-Density PolyEthylene
ICT	Information and Communication Technology
ISO	International Organization for Standardization
K	Potassium
KBBE	Knowledge-Based Bio-Economy
LDPE	Low-Density PolyEthylene
N	Nitrogen
NE	North-East
NL	The Netherlands
NPK	Nitrogen-Phosphorus-Potassium
NW	North-West
P	Phosphorus
PAR	Photosynthetically Active Radiation
PDO	Protected Designation of Origin
PEC	Primary Energy Consumption
PL	Poland
PP	Polypropylene
PRODER	Programa de Desenvolvimento Rural
PT	Portugal
PTO	Power-Take-Off
SCAR	Standing Committee on Agricultural Research

SE	South-East
SPEC	Specific Primary Energy Consumption
SW	South-West
TMR	Total Mixed Ration
UAA	Utilized Agricultural Area

Units:

°C	degree Celsius
% w/v	mass concentration (mass/volume ≈ mass in g in 100 ml solution)
CO_2e	equivalent carbon dioxide
EUR or €	Euro
h	hour
ha	hectare = 10,000 m^2
hp	horse power = 746 W
g	gram = 10^{-3} kg
GJ	gigajoule = 10^{9} J
J	Joule
K	Kelvin
kg	kilogram
kWh	kilowatt hour = 3.6 MJ
L	litre = 10^{-3} m^3
LU	livestock unit
m	meter
ml	milliliter = 10^{-3} L
MJ	megajoule = 10^{6} J
mg	milligram
PJ	petajoule = 10^{15} J
PLN	Polish Złoty
RPM	revolution per minute
t	metric ton = 1000 kg
W	Watt
y	year

Table of Content

List of Figures

List of Tables

1. Introduction

To date energy efficiency[1] in agriculture has received little attention, except for energy used in greenhouses. Nevertheless, energy use is considerable, especially when indirect energy use is taken into account. The project AGREE (AGRiculture & Energy Efficiency) has the objective of showing the potential of short term energy efficiency gains and the promise of the long term potential. Environmental effects of savings on direct and indirect energy use in agriculture are integrally considered, as energy use efficiency also implies reduction of greenhouse gas emissions per unit output. Because energy savings in agriculture depend greatly on the agri-environment, particularly climatic conditions. AGREE brought together south-eastern, south-western, north-eastern and north-western agricultural production systems. Evidence from the energy saving potential and corresponding environmental and economic effects at country level are brought to the transnational level to identify an agenda for transnational collaboration to increase the learning curve on energy use efficiency. To this end, AGREE sets up a stakeholder participation process for two reasons. Firstly by doing so, stakeholders will be involved in the development of the agenda and this will facilitate the implementation of the results. Secondly, AGREE needs the opinions and views of stakeholders to produce an agenda that reflects the needs and opportunities by the various agricultural practices.

To enhance implementation, AGREE has created a link with a European network of researchers committed to adopting the issue. This network (ENGAGE) is closely associated with the European Society of Agricultural Engineers (EurAgEng). This link will facilitate the adoption process. AGREE has established a close link with and involvement of the SCAR/KBBE Collaborative Working Group on agriculture and energy. This group is embedded in the Standing Committee on agriculture and the KBBE-net and is thus perfectly positioned to translate the agenda, produced by AGREE, into commitment for effective R&D on energy efficiency. To this end, it is important that AGREE provides evidence of the added value of such research.

This report uses case studies with an in-depth analysis of the interactions of energy efficiency measures, farm economics and the environmental impact of the measures across Europe. It builds upon the “State of the Art in Energy Efficiency in Europe” previously published by the AGREE consortium (Gołaszewski et al. 2012). It shows trade-offs and win-win situations associated with energy efficiency measures, farm economics and greenhouse gas emissions in agriculture across Europe. These cases studies are virtual farms of average size in which energy efficiency measures are implemented. The impact of these measures on

---

[1] Technically, 'energy efficiency' means using less energy inputs while maintaining an equivalent level of economic activity or service; 'energy saving' is a broader concept that also includes consumption reduction through behaviour change or decreased economic activity. In practice the two are difficult to disentangle and the terms are often used interchangeably (Energy Efficiency Plan 2011. Brussels, 8.3.2011, COM(2011) 109 final)

farm economics, energy use, energy efficiency and greenhouse gas emissions were calculated and discussed. This methodological procedure allowed the project to provide insight in the complexity of energy efficiency.

2. Energy Efficiency Measures in Agriculture

A reduction in energy use can be achieved by reducing energy input. Improved energy efficiency, however, is only achieved, if energy input per unit produce from the agricultural system is reduced. Therefore, improved energy efficiency can be realized with either increased or decreased energy inputs depending on the input-output relationship. Generally energy efficiency can be realized by the use of improved technologies, but also straightforward adjustments to the level of energy input into agricultural systems can contribute to better energy efficiency. Energy efficiency measures in agriculture can be grouped in seven clusters, according to the technology addressed with the energy efficiency measure.

2.1. Reduced tillage and controlled traffic farming

Reduced tillage in plant production systems has been identified as an efficient measure to reduce energy input. Agricultural systems with reduced tillage need less fuel and thus result in lower GHG emissions and lower costs for the farmer. Furthermore, an associated carbon sequestration effect in the soil may further mitigate the net greenhouse gas emissions from agriculture. However, with respect to soil and climate conditions, reduced tillage may also affect crop yields, which could counteract the positive effects. The individual situation needs to be evaluated in each regional setting, which will be provided in the case studies. Using Precision Farming techniques, especially GNSS-Real Time Kinematics to provide autosteer of tractors, can provide permanent trackways for Controlled Traffic Farming (CTF). CTF, very common in Australia and increasingly common in Europe, is primarily a technique to improve soil conditions but can show a fuel reduction of about 20% and additional yield increase as soil compacted by equipment is reduced. This greatly reduces energy used to break-up compacted soil and, over time, allows plant roots to penetrate deeper for nutrients and moisture (Tullberg et al. 2007; Tinker et al. 2010).

2.2. Waste/side stream valorization

The utilization of waste/side streams from agricultural production systems for energy, chemical or other material use can contribute to a more efficient use of energy in the whole agricultural process. The waste streams can be quite different; for instance straw can be used for bioenergy, or used to produce manure from animal husbandry systems, which then can be used to produce biogas. Another option is to use straw directly to produce materials for non-food purposes. Common to all valorization streams is that the production of additional goods, such as energy, chemicals or materials can avoid energy use in other production chains, which can be accounted for as credits according to life cycle assessment accounting methods. However it is necessary that accounting credits for waste stream valorization do not consider the waste in the reference system, otherwise, the value of the waste in the reference system needs to be accounted for. For example the use of animal manure as fertilizer *per se* is not regarded as an energy saving measure since animal manure is generally used as plant fertilizer. In Europe several regulations, for instance the Nitrogen

Directive, ensures that manure use is controlled when applied to agricultural fields especially maximum fertilizer rates per ha. Therefore, manure use per se cannot be treated as energy saving measure. Instead a more efficent use of manure can contribute substantially to energy efficiency since in this case less energy is needed for fertilizer production. Furthermore benefits for the environment can be expected because of reduced emissions of plant nutrients to the environment.

2.3. Efficiency measures in storage, drying, ventilation and cooling processes

Post-harvest processes such as storage, drying, ventilation and cooling often have a great impact on energy use in agriculture. Drying is a typical method of preserving the quality of different agricultural products like wheat, sunflower, fodder grass etc.. However, it is the most energy intensive unit operation in postharvest technology since typically large quantities of water must be evaporated due to the high moisture content of the harvested products. Gentle treatment of the crops and low drying temperatures are often essential. Some dryers or storage facilities e.g. for onions or potatoes require simple ventilation without significant additional thermal energy input, in order to keep the product free from moisture for avoiding microorganisms. This however requires as well considerable amount of electrical energy for the blowers.

Recognizing and applying efficiency measures in agricultural drying and cooling require a process-oriented approach. Increased uniformity of drying by optimizing the dryer apparatus, minimum heat losses, maximum heat recovery including by the use of heat pumps, and optimized process control are the measures that can be taken for an enhanced energy efficiency in drying. The effect of the measures can be expressed in terms of specific primary energy consumption (SPEC) per unit of evaporated moisture. The SPEC varies considerably depending on the type of the drying process (e.g. continuous or batch-type), the scale of the dryer, the product to be dried, the initial moisture content, the meteorological conditions, and the age of the equipment. In Europe an important difference that must be mentioned in this context, is observed among the countries. The post harvest process steps are not always carried out within the farm boundary. For instance in countries like Germany and Poland drying is often performed by the farmers on the farm in order to acquire a higher price in the market, whereas in the Netherlands usually contract drying is preferred. If storage, drying and other post harvest treatments are not done inside the farm, the corresponding energy efficiency measures are not relevant for the balance around the farm. Nevertheless the measures are still effective for the companies fulfilling the contracts and can contribute substantially to resulting in lower energy consumption in the overall balance for the agricultural products.

2.4. Irrigation systems

Pumping of irrigation water can contribute to substantial energy use. Innovative irrigation technologies use water more efficiently and thus use less energy per crop. The innovative systems have to be adjusted to the production systems in the specific farming contexts and cannot be applied to all systems in the same way. In the case study analyses views will be given for various systems. Reduced GHG emissions can be expected to be associated with the fuel savings. Furthermore different irrigation systems may provide interactive effects for N_2O emissions.

2.5. Fertilizer management (reduced inputs, precision agriculture)

Indirect energy associated with fertilizer use, contributes to the total energy use in agriculture by 30 to 50%. Therefore, all measures to improve the efficiency of fertilizer use contribute to the overall energy efficiency to a great extent. As an example Precision Farming technologies can contribute to improved fertilizer use efficiency. Different technologies, however, have different potentials, which have to be addressed specifically.

A reduction in fertilizer use reduces energy use, but at the same time yield may be reduced as well, which could thus even lead to a decrease in energy efficiency. This potential trade-off effect requires attention. A negative effect should be avoided and therefore a well balanced reduction of fertilizer to realize an optimum level of energy use needs to be found.

2.6. Housing (light construction, insulation)

The material and construction of housing in agriculture contributes to energy use efficiency indirectly by the energy cost of the materials including the insulation (leading to less direct energy demand). Even though significant indirect emission savings can be achieved with lightweight construction these gains need to be depreciated over the duration of use of the housing. In contrast, insulation provides yearly direct energy savings especially in northern Europe. In Mediterranean climate zones, housing can be lightweight, as the direct heating needs are low and only occur for a short period of the year.

2.7. Improving the energy efficiency in animal husbandry systems

In animal husbandry systems, energy efficiency can be improved to a certain extent by increased performance of the system in terms of milk yield per cow or meat per animal or eggs per layer. For example Kraatz (2012) showed that energy use per kg of produced milk can be reduced from 2.1 to 1.7 MJ/kg milk by changing the diet of the cows so that milk yield increased from 4000 to 8000 kg milk per year. The increased energy efficiency is primarily a result of reduced energy cost for rearing the offspring necessary to maintain the herd. However a further increase in milk yield per cow did not result in lower energy use per kg milk as the high energy cost of the concentrated feed eventually is not compensated by the reduced energy cost for rearing the offspring.

3. Methodological Framework for the analysis of measures for improved energy use efficiency in agriculture and their impact on economics and the environment

Increased efficiency in energy use implies using less energy for the same amount of agricultural product produced. The analysis of the environmental and economic trade-offs includes the analysis of energy efficiency measures on the use of direct and indirect energy, GHG emissions and farm economics. The energy use, environmental and economic analysis are based on a cradle-to-farm-gate analysis, taking all costs and emissions into account needed to produce the agricultural products following ISO 14040**.** This is a procedure followed throughout the AGREE project. The economic cost calculations were based on the economic settings in the considered countries, while for the energy use and GHG estimates, whenever possible, common methodologies were used.

3.1. Modeling of agricultural systems to explore trade-offs in the case studies

In order to model potential trade-offs between energy savings, GHG-emissions and farm economics the relevant energy efficiency measures were modeled in simple spreadsheet based models. Four model frameworks were constructed to estimate the effects of energy saving measures on farm level in cropping systems, animal production systems, greenhouses and permanent crop systems. The farms were defined as typical and thus virtual farms in the countries considered expressing a general and common or average situation. This procedure allowed to yield results of average and indicative value. The calculations are not based on real farming situations but prices, inputs and yield express average levels within a country.

For each farm system, models were constructed based on typical farm situations in the countries for the selected case studies. Instead of modeling just the production systems, we have put the studied production systems within a farm framework and included the related costs and savings on energy, economic costs and GHG emissions to the total costs at farm level.

In order to provide consistent results across Europe the same system boundaries for all economic and environmental assessments were chosen. The farm gate was considered as the ultimate boundary of the analysis of the trade-offs of energy efficiency measures (Figure 1). This means that in some countries processes are within farm boundaries whereas in other countries they lie outside the boundaries. For instance in wheat production, drying is not included in Dutch farms but is included in German arable farms. The target is not to compare different countries but to get an idea of the effects of energy efficiency measures on farm level.

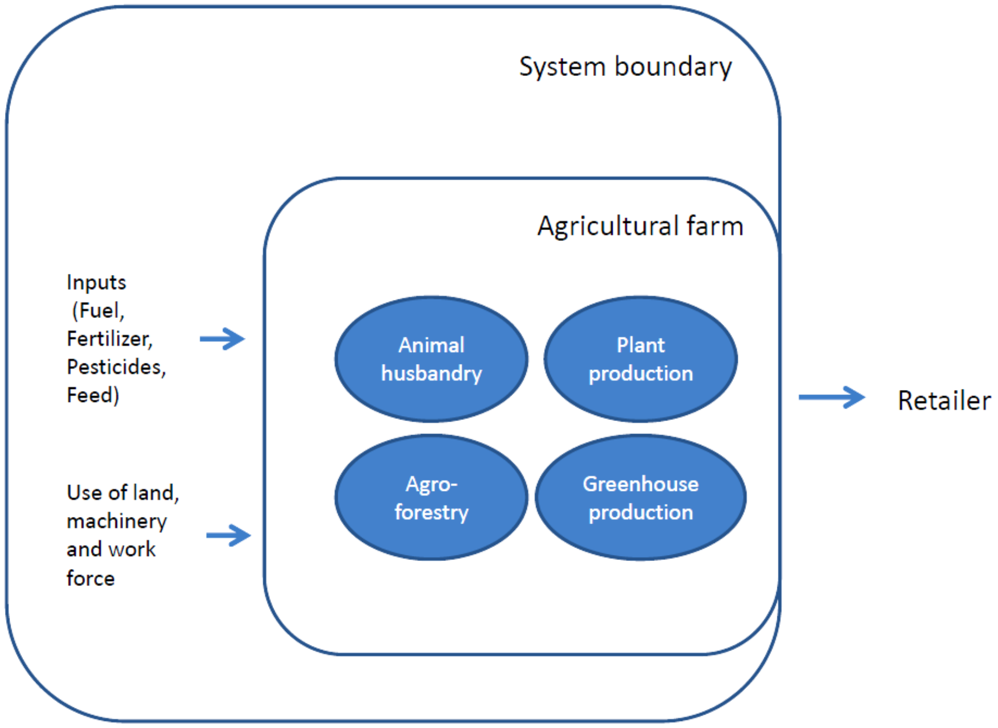

Figure 1: System boundary of economic and environmental assessments

3.2. Estimates for energy savings and GHG emission savings associated with the energy efficiency measure

The calculations of the energy savings and GHG emissions with the energy efficiency measures were based on the report "State of the Art on Energy Efficiency in Agriculture" published on the AGREE website[2] (Gołaszewski et al. 2012) and extended with regard to GHG emissions. Data on assumptions were, if not stated otherwise, drawn from published data from the Biograce database (www.biograce.net).

3.3. Estimates for cost savings associated with the energy efficiency measure

The economic assessments were based on the use of inputs calculated for the farm models. Furthermore, fixed costs were allocated according to the expected lifetime of the equipment used. Prices for inputs and machinery (variable costs) were taken from country specific data, as described in the case study analyses.

---

[2] www.agree.aua.gr

4. Analysis of Case Studies

In case studies across Europe energy efficiency measures were analyzed for their interactions with farm economics and environmental impacts. This is done in order to understand potential opportunities as well as drawbacks and pitfalls associated with energy efficiency measures across Europe. The production systems for the in-depth analysis are shown in Table 1.

Table 1: Production systems for in-depth analyses of case studies in the four regions

	Regions			
Production systems	SW (PT)	SE (EL)	NW (DE, NL)	NE (PL, FI)
Arable crops	Wheat	Cotton, wheat	Wheat (D, NL), sugar beet (NL),	Wheat
Dairy / beef	Dairy		Dairy (NL)	Dairy
Pork/ poultry	Pork, poultry		Pork, poultry (NL)	Pork (FI), poultry (FI, PL)
Greenhouse production	Tomato	Greenhouse production systems	Tomato, cucumber, sweet pepper (NL)	
Permanent crops	Olive trees, vineyards	Olive trees, vineyards	Vineyards (D)	

4.1. Case studies–arable crops

4.1.1. Energy efficiency measures in German wheat production

Andreas Meyer-Aurich, Thomas Ziegler, Hasan Jubaer, Lukas Scholz, Tommy Dalgaard

The statistical data regarding energy input in German wheat production was shown with three different scenarios (low, average, high) in the report “State of the Art on Energy Efficiency in Agriculture” published on the AGREE website (Gołaszewski et al. 2012). The highest energy inputs in typical German wheat production stem from fertilizer inputs and grain drying, followed by fuel use (Figure 2).

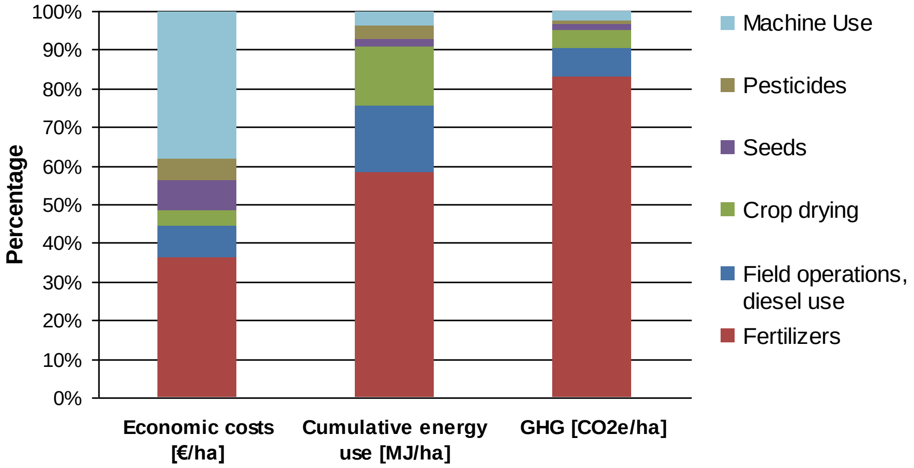

Figure 2: Relative contribution of different processing units and inputs in wheat production to economics, energy use and GHG emissions

The direct energy use is about one third of the total energy use in wheat production, two thirds of the energy use stems from indirect energy use, which statistically is typically accounted for outside the agricultural sector but is caused by agricultural activities and should be taken into consideration for energy saving potentials in agriculture. The implications of energy efficiency measures in different processing units are very different though. While typically for improved grain drying systems significant investments are necessary, reduced fertilizer input has no investment requirements unless technological solutions, like precision farming are applied. Anyhow, a reduction in fertilizer input compared to optimal fertilizer rates results in opportunity costs such as reduced yields, while precision farming, especially site-specific fertilizer application may increase energy efficiency without reductions in yield.

Investments in grain drying

In order to implement the proper efficiency measure in grain drying systems, it is very important to recognize the main causes of poor efficiency. The leading reasons causing variation in the specific energy consumption of wheat-drying include the type of the drying process (e.g. continuous or batch-type), the size as well as age of the equipment, the initial moisture content of the product and the weather conditions.

Several types of dryer are used in drying of wheat. Most of them are also well-established and well known. However, they are not always energy efficient in their design or operation. For instance a dryer with poor design causes heterogeneous drying of the crop, which ultimately leads to significantly high energy consumption. Therefore, one of the most important measures towards energy efficiency is to implement dryers with optimal design.

Another measure at farm level, which does not require as large investment as for new equipment, is to improve the operation of the existing dryer by implementing energy optimization. For instance, an optimized process control system can decrease the specific energy consumption considerably.

A substantial amount of energy gets wasted in drying of wheat only because the energy in the system is not utilized properly. Apart from the heat losses due to poor or missing thermal insulation, in most cases heat recovery from the waste air is lacking, which results in a considerable additional amount of energy to be consumed. Therefore, maximizing heat recovery for instance by using heat pumps as well as minimizing heat losses by better insulation are essential, in order to achieve a better energy efficiency.

Precision Farming

Precision farming is a measure to apply inputs more precisely and minimize inefficient nutrient losses. For this study we draw from a case study in Germany, where major investments were implemented in a farm, which resulted in increased yields and reduced fertilizer inputs (Meyer-Aurich et al. 2008).

Reduced nitrogen fertilizer input

Reduced nitrogen fertilizer input may be an effective measure to reduce the energy input per ha in cropping systems. However, since yield is affected by fertilizer levels, a reduction in fertilizer use may result in reduced yield. The impact of reduced fertilizer applications have been investigated by Meyer-Aurich et al. (2011) and is used to illustrate the trade-offs of reduced fertilizer inputs in cropping systems.

Relative Contribution of different inputs and process steps to energy use, total costs of production and greenhouse gas emissions

The different inputs and processing units contribute in different proportions to the total costs, primary energy consumption (PEC) and greenhouse gas emissions (GHG). This implies that some small changes may cause only a little change in costs, but have a high impact on energy use and GHG emissions. For example crop drying has a small contribution to the total economic costs of wheat production, but the relative impact on the energy use is much higher. In contrast, the relative economic cost of machinery use is much higher than its impact on energy use and GHG emissions.

Impact of different energy efficiency measures on economics and the environment

The analysis showed that all suggested energy efficiency measures contributed to energy savings and reduced GHG emissions, which were in the range of 2.3 to 4.4% of the total energy use and 1.3 to 5.9% for the GHG emissions (Table 2). Cost savings were in the range of 1.3% to 3.2% for all energy efficiency measures with the exception of reduced nitrogen fertilizer measure. In this case negligible costs apply because the fertilizer application rate was below the economically optimal rate.

Table 2: Annualized costs, PEC and GHG emissions with energy efficiency measures in wheat production

	Annualized Cost		PEC		GHG	
	€/ha	%	MJ/ha	%	CO_2e/ha	%
Reference	952	100.0	19260	100.0	1722	100.0
Dryer I (New dryer with optimal design)	932	97.9	18459	95.8	1679	97.5
Dryer II (Optimization of existing dryer)	939	98.7	18820	97.7	1699	98.7
Precision Farming	921	96.8	18620	96.7	1661	96.4
Reduced N	952	100.1	18414	95.6	1621	94.1

While the measures which affect the fertilizer application rate have a strong effect on GHG emissions, improved drying has a major effect on the energy use but a smaller effect on GHG emissions (Figure 3). Comparing other energy efficiency measures with “Precision Farming”, the economic and environmental effects were higher when the effects were related to the crop yield (per ton) (Figure 4). This is due to the assumed yield increasing effect of Precision Farming. Since “Reduced N” results in reduced crop yield, the environmental effects are less pronounced per ton of product, while the economic effects were more pronounced. However, the 10% reduced fertilizer application does not result in negative energy savings per ton of crop, although this is the case with more drastic fertilizer reductions.

All energy saving measures, which were associated with investments showed positive annualized cash flows, indicating economic profitability. These need to be analysed further with sensitivity analyses to provide a holistic investment analysis.

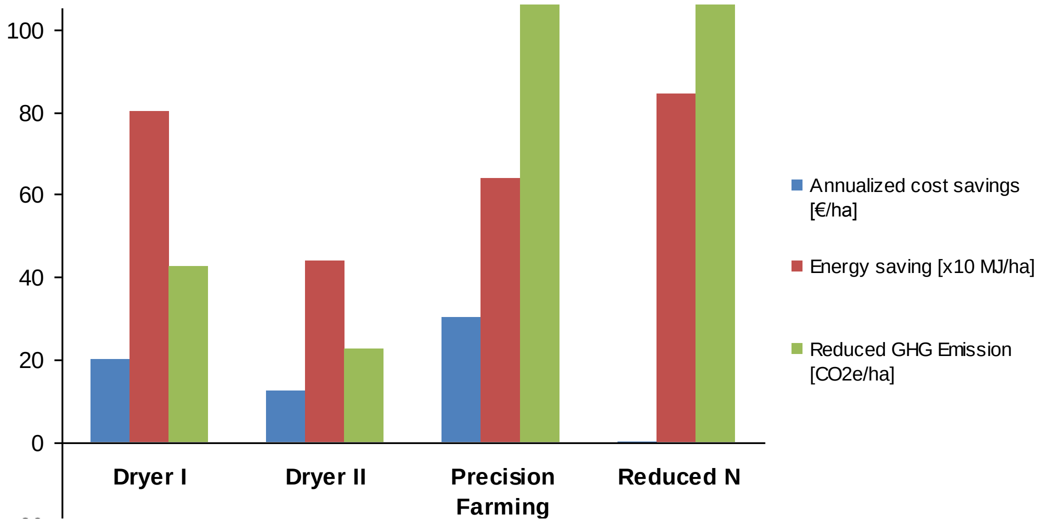

Figure 3: Impact of different energy saving measures on cost savings, energy use and GHG emissions per ha.

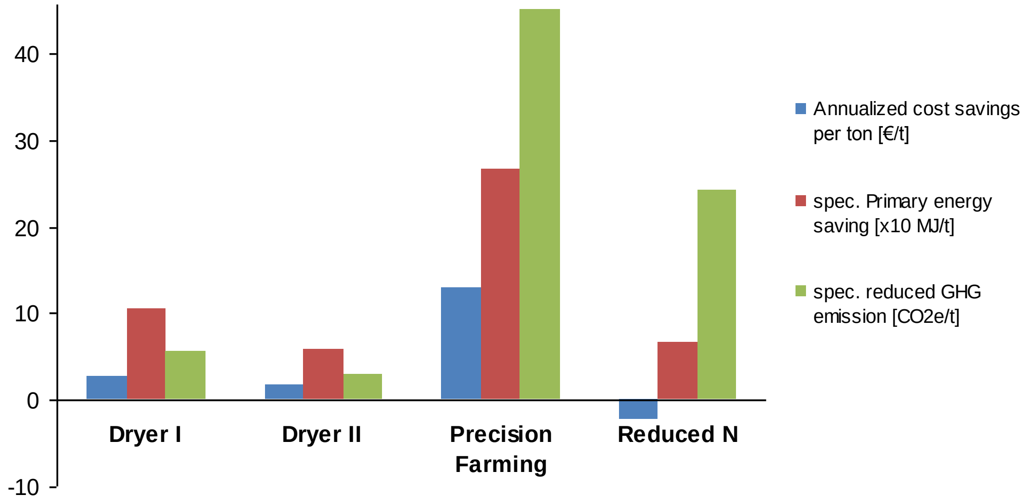

Figure 4: Impact of different energy saving measures on cost savings, energy use and GHG emissions per ton.

Conclusions

The introduction of Precision Farming, some reduced nitrogen fertilizer application and improved crop drying technologies proved to be efficient measures for enhancing energy efficiency in wheat production. While the Precision Farming and improved crop drying measures require investment, reduced fertilizer input can be realized without investments (although farmers will need to monitor carefully fertilizer use and impact on yield to ensure that it is still economically near optimum). While policies targeting reduced pollution with reactive nitrogen have been set in place, current policies do not consider energy and GHG aspects of different fertilizer strategies in the same way (Häussermann & Döhler 2010). The environmental effects of all measures are comparable and do not show a clear advantage of one measure against others. However, reduced fertilizer input implies an economic loss which is unlikely to be realized by farmers unless they are forced to do so, and currently given the interest in global food sustainability and CAP negotiations, may not be politically attractive. The measures of this case studies are rather process based and do not take into account complex interactions relevant for whole crop rotations, which can have a great effect on energy use efficiency, especially when integrating legumes in the crop rotation.

4.1.2. Energy efficiency measures in Finnish wheat production

Hannu Yli-Kojola, Jussi Esala, Hannu Mikkola, Mari Rajaniemi, Tapani Jokiniemi, Jukka Ahokas

Wheat is a grain crop cultivated all over Europe which is why it was chosen as a reference crop analyzed in all six AgrEE countries. However, barley and oats are more important cereal crops in Finland and they are cultivated on larger area (in 2010: barley 448 000 ha, oats 296 000 ha, wheat 214 000 ha (Information Centre of the Ministry of Agriculture and Forestry 2011)). Barley and oats are better adapted to the short Finnish growing season than wheat. Wheat has been traditionally cultivated in southern and south-western parts of Finland. Due to its longer growing season and higher temperature requirement, the risk of unfavorable growing seasons in the northern parts of the country are higher than those for barley and oats. A traditional cultivation chain of wheat starts with ploughing as a primary tillage method. It is followed by secondary tillage, combined seeding and fertilizer placement, plant protection, harvesting, and grain drying.

Combined seeding and fertilizer placement (to every other row spacing to a depth of 6–8 cm) is a Scandinavian specialty which has many positive impacts on the growth of cereals and oil seed crops. It improves exploitation of nitrogen, reduces pressure of weeds, lowers the moisture content of grains at harvesting time and increases the yield (Kara & Räisänen 1976; Esala & Larpes 1986a; Esala & Larpes 1986b; Rasmussen et al. 1996; Rees et al. 1997). This method is already widely used and it can’t be regarded as a novel EE measure. Farmers also favour stubble cultivation and direct drilling instead of ploughing in cereal cultivation. Both of the measures decrease diesel fuel consumption (Danfors 1988) and if the yield is the same as it is after ploughing, EE will be improved.

Grain drying is necessary in Scandinavian conditions. The moisture content of cereals at harvesting in Finland are, as long-term averages, for barley 18.8%, oats 18.5%, spring wheat 20.5%, winter wheat 21.0%, and rye 23.1% (Sieviläinen 2008). In practice, grain has to be dried every year. Grain can be stored by methods other than drying e.g. by silage method, with propionic acid addition, or by means of airproof preservation. However, drying has been used mainly (90% of the grain yield according to Suomi et al. 2003), because drying is an appropriate method for that part of the cereal yield which is used for human nutrition, seed, or for industrial purposes or exported. The rest of the yield (> 60% according to Suomi et al. 2003) is used for animal feed and it could be stored fresh without drying (Siljander-Rasi et al. 2000). The impact of fresh storage methods on EE and economy are discussed in the chapters of milk, pork and broiler production.

Energy consumption and saving in wheat production

The distribution of energy use in Finnish wheat cultivation is presented in Figure 5. Fertilizers are the major input and would be an attractive target for energy saving measures. There are potential measures to cut nitrogen input by implementing crop rotations which include legumes. There is also potential to reduce the need of P and K by means of better nutrient recycling. However, changes in crop rotations would also require changes in the market of agricultural products. There should be sufficient demand for products other than cereals at reasonable prices. One possibility could be to include green manure crops in the crop rotation or to grow catch crops after the cash crops. These measures should be economically competitive with synthetic fertilizers. Changes in crop rotations and their impacts on the market of agricultural products are difficult to forecast and therefore interest in this analysis was focused on grain drying and on diesel fuel consumption in field operations. They are the second and third most significant energy inputs in wheat cultivation.

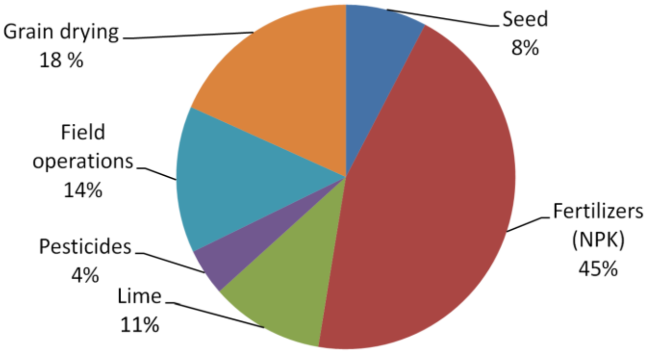

Figure 5: Distribution of energy input in Finnish wheat cropping with average intensity. Total energy input = 12.3 GJ/ha.

Grain drying was the second highest energy input in wheat production. 10-20% of energy could be saved in grain drying by thermal insulation of the hot metal surfaces of the grain dryer (Ahokas and Koivisto 1983). Thermal insulation does not interfere with the use of the grain dryer in any way and is an inexpensive investment which a farmer can do himself making it an attractive energy saving investment. Energy could be saved also by avoiding drying at night time. The impact of the temperature on the water holding capacity of air can be found from the Mollier diagram. Heating increases the absolute water holding capacity more in higher than in low temperatures. So, from the point of view of energy saving it is advisable to use as hot air for drying as possible but, of course, taking into consideration fire safety and the impact of high temperatures on the quality of grains. The ambient air temperature is at night time 5–10˚C lower than at daytime. This would save energy 5–20%. Heat recovery from the outlet air of a grain dryer is technically possible but it is so far uneconomical due to high investment costs.

One suggestion to reduce diesel oil consumption in agricultural is to teach economic tractor operating to farmers. Teaching is expected to have similar impacts on fuel consumption as courses on economic driving for car drivers. It is also assumed that online feedback on fuel consumption (l/ha) would help tractor operators to adopt economic driving .

These measures were seen as practical and relatively easy to be implemented quickly. They are expected to lower the direct energy demand of wheat production and if realized together they could cut 10% off the direct energy consumption and 3% off the total energy consumption for wheat production.

Thermal insulation of a grain drier

A hot air grain dryer of silo type is typical in Finland. The grain is dried in batches from 10 to 70 m^3. The grain circulates in the dryer during the drying process and normally it passes through a pre-cleaner several times as well to remove dust, trash, weed seeds and light, poor quality grain and improves the quality of the grain. Continuous operation grain dryers are not popular due to the lack of continuous grain input because of the uncertain harvesting conditions and difficulty in drying very moist grain. The temperature of the ingoing air is 60–80°C depending on the moisture content of the grain. It is lower the higher the moisture content because a high temperature destroys the germination ability of seeds. However, grain which is used for animal feed can be dried with air up to 100°C or even more (Suomi et al. 2003).

Due to the high temperature of the ingoing air metal surfaces of the grain dryer are hot. Significant energy can be lost from uninsulated surfaces (Ahokas and Koivisto 1983). Thermal insulation can be made simply by fixing insulation sheets on the hot surfaces of the grain dryer and round the air duct leading from the furnace to the grain dryer. Only the air input part of the dryer needs to be insulated. The outlet section can be left without insulation.

For thermal insulation of a 30 m^3 grain drier 40 m^2 polyurethane sheets is needed. The cost is 800 € (40 m^2 x 20 €/m^2 = 800 €). Labor cost for installation is 200 € (10 hours x 20 €/hour). The write-off period of the investment was supposed to be 15 years. Estimated savings were 10% of the fuel consumption for drying.

Figure 6 shows the energy savings MJ/t and cost savings €/t, reduction of GHG emissions kg CO_2e/t, and the pay-back time in years on a 120 ha farm. Cropping intensity had just no impact on these indicators. The pay-back time of the investment was 1.3-1.5 years. Calculation made with smaller cultivation areas indicated that the pay-back time was less than 10 years even though the farm size was only 30 ha. The annual profit of the investment was higher than the annual costs and for this reason the cost of GHG emission reduction was negative (from -172 € to -634 €/kg CO_2e).

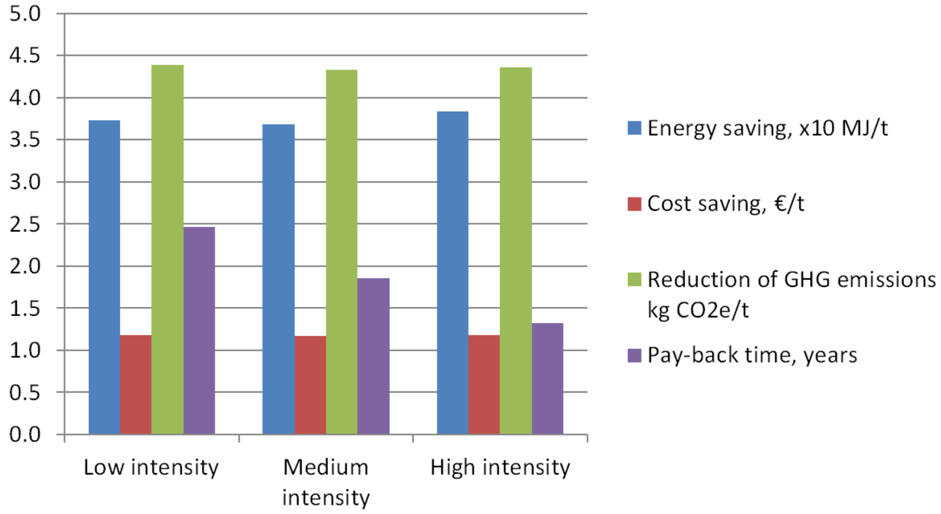

Figure 6: The impact of thermal insulation on the energy and cost savings of grain drying, reduction of GHG emissions and the pay-back time on a 120 ha farm. Low, average and high cultivation intensities were studied.

The temperature of the drying air should be kept constant during the drying period. If the ambient air temperature falls then more energy is needed to heat air. For example if 70˚C drying temperature is used, at daytime the ambient temperature can be 15˚C and a temperature rise of 55˚C is needed. At night time the ambient temperature can be 5˚C and a temperature rise of 65˚C is needed and some 18% more energy is needed to heat air. During intensive harvesting season it is not always possible to dry only at daytime because the dryer capacity in many cases restricts the harvest capacity and the dryer must be operated day and night.

Operating tractors for fuel economy

Diesel oil can be saved in tractor operations by using the tractor in the optimal loading range of the engine (Renius 1999; Handler and Nadlinger 2009). The most energy efficient loading range is engine specific but can be found from test reports. At the most fuel economic loading rate the torque is generally 70-90% of the maximum and the speed of the engine is 60–80% of the maximum. The tractor can be operated at the optimal load if the power of the tractor is correctly matched to the capacity of the implement and that power transmission by suitable sized and ballasted tyres or Power-Take-Off (PTO)use that allows the optimal engine load to be achieved. This is the technical basis of economic tractor operating (Green driving). This kind of short introduction to the theory of fuel economy could be included to the lessons of green driving. Gear Up, Throttle Back advice and engine efficiency indicators have been available for very many years in certain countries as described in Tinker 1992.

Courses on driving for fuel economy (Green driving) for car drivers have proved that after the course fuel consumption is 6–13% less than before the course (SenterNovem 2005). Studies have also shown that immediate feedback of fuel consumption by a gauge or monitor helps to save fuel and to adopt energy saving driving. A study of tractor fuel consumption in field work has shown that fuel efficient driving can be realized also in tractor operations (Ahokas & Mikkola 1986).

A driving course could be a one day event including 2–3 hours lessons and another 2–3 hours practical training. A group of 10–15 tractor operators at a time would be an ideal number of people for one course. The group is small enough to stimulate spontaneous discussion among course participants and practical training is easy to arrange. Lessons should contain information about fuel consumption meters to give real-time fuel consumption feedback in older tractors. If GNSS devices are incorporated then fuel use per distance or per area can be shown as well. In modern tractors these devices are mostly available as standard or as options.

Practical training is important because it demonstrates the impact of driving style on fuel consumption. Playful competitions are a good way to raise interest and to motivate participants. Existence of a GNSS device in a tractor can motivate farmers to use GNSS for field navigation. This can reduce overlapping by ca. 5-10% which improves the efficiency of fuel use, operator’s time, seed use and plant protection chemicals and fertilizer application. Better application, apart from reducing inputs, improves yield and quality and reduces emissions. Savings in plant protection chemicals and fertilizer are savings of indirect energy.

Investments needed to realize this energy saving measure are a course on operating for fuel economy (300 €) and devices to enable the online feedback of fuel consumption to be seen in the tractor cab (650 €). The write-off period for the devices was estimated to be 10 years and the estimated saving was 10% of fuel consumption.

Economic analysis was made for a 120 ha farm but costs were studied on smaller farms too. Figure 7 shows the energy and cost savings MJ/t, reduction of GHG emissions kg CO_2e/t, and the pay-back time on a 120 ha farm. The magnitude of this energy saving measure was much the same as that for thermal insulation of the grain dryer. Energy saving from green driving increased when cropping intensity increased while thermal insulation was not sensitive for cropping intensity. The pay-back time was 3.3–1.3 years and it was less than 10 years even for a 40 ha farm. Costs of GHG emission reduction were negative for this measure because the annual profit of the investment was higher than the annual costs.

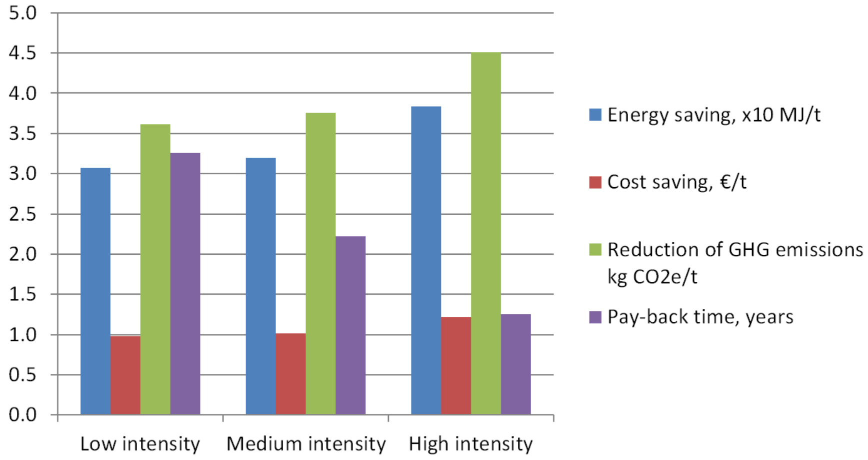

Figure 7: The impact of operating for fuel economy on the energy and cost savings, reduction of GHG emissions, and the pay-back time on a 120 ha farm. Low, average and high cropping intensities were studied.

Modern tractors equipped with an automatic powershift or a continuously variable transmission (CVT) help the operator to save energy because they enable the tractor engine to run at the most fuel efficient speed and torque for a range of vehicle speeds and loads. Integrated electronic engine control units, ECU, can adjust the engine speed and transmission ratio in a way that is beyond the driver's capabilities. Though the efficiency of the powershift and CVT transmissions is lower than that for a simple manual operated mechanical transmission the engine of the tractor operates so much more efficiently that it improves fuel economy.(Tinker 1992).

4.1.3. Poland–Case study on Energy Saving Measures in Wheat Production

Janusz Gołaszewski, Mariusz Stolarski, Zbigniew Brodziński, Ryszard Myhan, Ewelina Olba-Zięty

Poland's share is 1.4% of the global and 6.9% of the EU-27 wheat production. Despite a recent downward trend in the wheat use, with some replaced by maize and triticale, wheat remains the most important cereal and is cultivated across the whole country (Figure 8).

Our evaluation of the energy efficiency of winter wheat production and potential energy savings has been performed on a cash crop farm in Łężany (Province of Warmia and Mazury;

53.9667 °N, 21.1333 °E) taken as a case study, and with the 2011 data. The farm does not have any livestock production. The arable area is 1058 ha. The soils vary from sandy through sandy clay and clay loamy ones; in terms of agricultural usability, they are classified from complex 3 (defective wheat complex) to complex 6 (defective rye complex). The crops and proportions on the farm are winter wheat (59.4%), winter oilseed rape (18.1%), oat (14.2%), spring oilseed rape (8.1%) and winter rye (0.2%). The straw is used for energy generation.

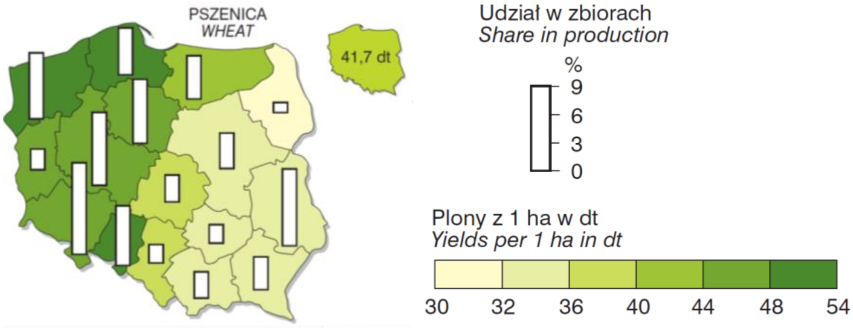

Figure 8: The regional distribution of wheat production in Poland by percentage share in production and yield per hectare. (Source: Concise Statistical Yearbook of Poland 2011)

Our analysis of the energy efficiency attained on the above farm contains three energy saving measures:

1) change in plant rotation by reduction of oilseed crops (winter rapeseed) and inclusion of leguminous crop–horse bean;
2) ploughing of straw and application of multi-compound inorganic fertilizer, and
3) application of effective microorganisms.

The energy saving measures considered here represent the three aspects of integrated production in a farming system, which takes into account the economics of production as well as protection of the environment.

Plant rotation and replacement of oilseed crops with leguminous crop–horse bean

By introducing leguminous crops into a crop rotation system including cereal and industrial crops, it is possible to reduce amounts of applied nitrogen fertilizers and to improve productivity of crops owing to increased organic matter resources, improved soil fertility, enhanced soil biological activity and more effective use of nutrients and moisture by plants (Korbas 2011). Consequently, the inputs for plant fertilizer use are lower as the nutrients are used by the plants more effectively. This means there is better effectiveness of chemicals used to protect plants from diseases and pests. Likewise, the biological activity in the soil is improved, e.g. it contains higher counts of beneficial organisms. As a result, fewer plant protection treatments and less pesticide, are needed.

Ploughing in of straw and application of liquid multi-compound fertilizers with macro and microcompounds

There is a high demand in Poland for energy biomass, which makes straw such a valuable fuel that many cash crop farms increase their income by selling straw. With such a demand and with a generally low level of humus in Polish soils, intensive cash crop production, together with the lack of organic matter input to soil, causes gradual degradation of soils from loss of nutrients, poor structure and drainage, low humus levels and poor moisture retention. On the analysed farm, it is recommended to plough in straw in order to retain humus in soil, which, accompanied by application of multi-compound NPK fertilizers with micronutrients (under the commercial name PRP SOL), can ensure a positive production balance in the context of energy, economy and the natural environment. Multi-compound fertilizers contain components which stimulate the uptake of nutrients by plants. When multi-compound fertilizers are applied, there is no need to use phosphorus and potassium fertilizers while nitrogen application is reduced by 10%. For winter wheat cultivation, multi-compound fertilizer is applied at a rate of 200-300 kg/ha. Besides, application of such fertilizers improves the plants' resistance to disease and pests and contributes to better yields.

Application of agricultural additives

The Effective Microorganisms (EM) biopreparation has been used increasingly often in sustainable winter wheat production (Higa & Parr 1994). Depending on current needs, it can be used together with the seed material, sprayed over leaves and/or introduced to the soil. EM is characterized by a broad spectrum of action and produces complex effects on the plants' habitat. This is associated with a multi-directional effect on various groups of antagonistic microorganisms, which belong to separate taxonomic classes. EM contains lactic bacteria (*Lactobacillus casei*, *Streptococcus lactis*), photosynthesizing bacteria (*Rhodopseudomonas palustris*, *Rhodobacter sphaeroides*), yeasts (*Saccharomyces albus*, *Candida utilis*), actinobacteria (*Streptomyces albus*, *Streptomyces griseus*) and moulds (*Aspergillus oryzae*, *Mucor hiemalis*) (Higa 1998; Valarini et al. 2003). Among positive effects of the biopreparation on the growth and development of plants, the following are suggested: induction of plants' resistance, protection of yields and stimulation of yields. Moreover, biopreparations demonstrate stimulating influence on the formation of humus and regulation of biotic relations in soils. By introducing EM into soil, we improve its physical and chemical properties, but the actual effect depends on the type of soil and dose of the preparation (Kaczmarek et al. 2007; Kaczmarek et al. 2008). Application of the biopreparation has a beneficial effect on the biological activity of soil and reduces putrefaction, improves the humus content, detoxifies soil contaminated with pesticides, improves availability of compounds not easily accessible to plants, enhances the effect of photosynthesis, inhibits the development of phytopathogens and improves the quality and yields of the crop (Higa 1998; Stielow 2003; Yamada & Xu 2000).

Relative Contribution of Different Inputs and Process Steps to Total Costs of Production, Energy Use, and Greenhouse Gas Emission

Winter wheat was one of the five crops grown in a cereal cash crop rotation system on the analysed farm. The structure of inputs for wheat production was dominated by the cost of purchase of synthetic fertilizers €317/ha (see Figure 9). The inputs for purchase of seed material, pesticides and diesel were similar, i.e. €74, €79 and €89, respectively. The highest energy inputs for winter wheat production were due to fertilizers (68%) and diesel (25%). However, the most serious environmental consequences were brought about by emission of carbon dioxide due to production of the applied synthetic fertilizers (1187 kg CO_2e) and emission of nitrous oxide directly from the fertilizers, either by leaching or volatilization (1601 kg CO_2e). In total, the above sources were responsible for 88% of the CO_2e emission per hectare. On average, around 1.4 kg N_2O is emitted per 1 ha annually, of which 50% of the emission is attributed to nitrogen fertilizers (Golka 2011).

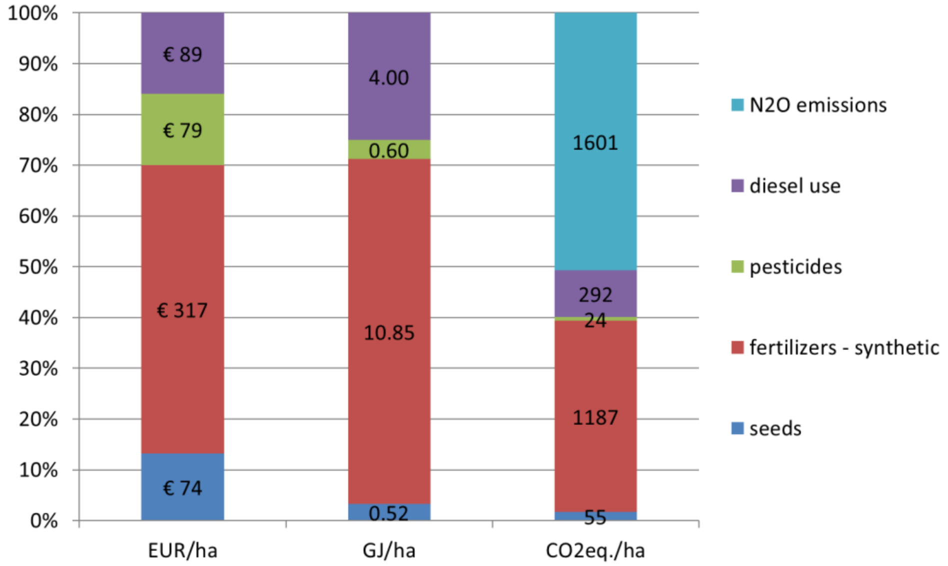

Figure 9: Contribution of different processing inputs in wheat production to economics, energy use (PEC) and greenhouse gas emissions (GHG)

The percentages of costs, energy inputs and carbon dioxide emission due to the seed material, diesel consumption and emission of nitrous oxide in winter wheat production in the total balance worked out for Łężany Farm are presented in Table 3. Costs of wheat production, regardless of the inputs, were within 17.9% to 19.6% of the total production costs. The energy inputs and volumes of emission of the pesticides used in wheat production reached 78.8% of the total inputs for the production means in the farm, whereas the remaining inputs as well as the emission of nitrous oxide were less than 20%.

Table 3: Percentage share of wheat in the total production costs, energy use and carbon dioxide emission for five crops cultivated in the farm.

Items	Cost	Energy use	Emission of CO_2e
Seeds	19.6	24.9	13.9
Fertilizers-synthetic	18.3	19.1	19.3
Pesticides	18.3	78.8	78.8
Diesel use	17.9	17.9	14.8
N_2O emissions			19.2

Impact of different energy efficiency measures on economics and the environment

Average production costs per ha of cropped area on the farm in Łężany were 1140 EUR/ha, with the energy inputs around 15.21 GJ/ha and emission volume of 1563 kg CO_2e/ha (Table 4). Among the three energy saving measures, two led to reductions in the energy inputs, i.e.

inclusion of leguminous crop into the rotation (by 4.5%) and use of effective microorganisms (by 1.4%). At the same time the third measure, ploughing in straw and application of liquid multi-compound fertilizers, did not cause any considerable change in the energy inputs or volume of gas emissions, but significantly reduced costs of production (by 13.8%). Application of liquid multi-compound fertilizers on several dates is becoming more and more popular on large farms. This is a way to lower production costs while maintaining the same energy inputs and volume of emitted greenhouse gases.

Table 4: Annualized costs, PEC and GHG emissions per one hectare in Łężany farm with energy efficiency measures in wheat production

Scenario	Income	Costs		Energy Use		CO_2e	
	€/ha	€/ha	%	MJ/ha	%	kg/ha	%
Current practice	1232	1140	100	15213	100	1563	100
Change in plant rotation		1120	98.2	14377	94.5	1514	96.8
Straw is plowed plus multi-fertilizer		983	86.2	15213	100	1563	100
Effective microorganisms		1129	99.0	14995	98.6	1519	97.1

The highest cost reduction at €157/ha was associated with ploughing in of straw and multi-fertilizer application, while significantly less cost effective were the change in plant rotation (€20/ha) and application of effective microorganisms (€11/ha) (Figure 10). Among the three ES measures, the highest reduction of energy input 836 MJ/ha was caused by the change in crop rotation and this figure was four-fold higher that in the case of effective microorganisms application. For these two ES measures, the impact on reduction of emissions was in the range from 44 CO_2e/ha to 49 CO_2e/ha.

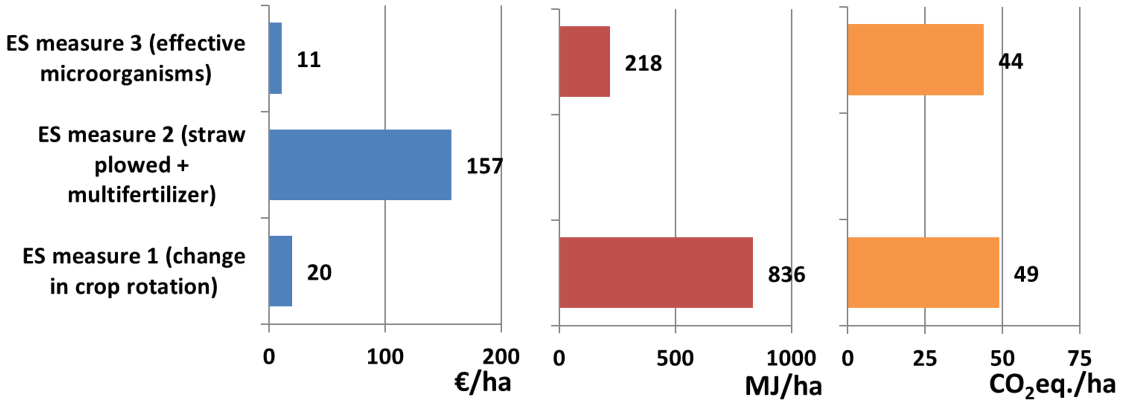

Figure 10: Impact of Different Energy Saving Measures on Cost Savings, Energy Savings and Greenhouse Gas Emission savings (GHG) per ha

4.1.4. Energy efficiency measures in Dutch wheat, sugar beet and potato production

Chris de Visser, Marcel van der Voort

Wheat, potatoes and sugar beet are the main three crops in Dutch arable farming. Measured by area wheat is the largest arable crop with 155 000 hectares, followed by sugar beet (72 000 ha) and potatoes for eating (ware potatoes) (69 000 ha) (Kamp et al. 2010). The energy consumption per hectare is in the reverse order (highest for potatoes, then sugar beet and lowest for wheat). However, when looking at total energy consumption on a national level, wheat is the largest energy consumer followed by potatoes for eating and sugar beet (Kamp et al. 2010). The highest energy inputs in typical Dutch wheat production are associated with fertilizer inputs and diesel fuel use (Figure 11, Figure 12, Figure 13). In the major part of the Netherlands, wheat is not stored on the farm. Therefore the energy for drying is not included as it takes place beyond the farm gate. For typical Dutch potato production the highest energy inputs are related to fertilizer input, diesel fuel use and drying/storage of potatoes which is typically done on the farm.

In order to indicate the possibilities for improved energy efficiency, three different energy-saving measures were applied to a typical representative Dutch farm of 120 ha. This standard farm-model produces wheat (25% of the area), sugar beet (25%), ware potatoes (25%), onions (12.5%) and peas (12.5%). Based on 2011 price levels, the farm income and cost can be summarized as follows.

The total costs of € 768,000 are calculated with norms based on recent information from suppliers and buyers, current agricultural practices and expert opinion (KWIN-AGV 2009). The costs for land and buildings are based on the current market value of arable land and the replacement value of the machinery. Land costs in the Netherlands are relatively high compared to the most other European countries. The farm model includes some contract work, but most work is carried out with the farm’s own machinery and labour. The costs for labour are based on task times and collective labour agreements. Mechanisation costs are based on percentages of the replacement value for interest, depreciation, insurance and maintenance. The variable costs include costs like energy, fertilizer, pesticides and seed. The storage costs are for the building and installations based on the storage needs of the product and are an annual percentage of the replacement value.

Table 5: Income and costs of a standardized Flevoland farm of 120 ha.

Income/cost	Amount
Income products	€ 418,000
Cost	
Variable cost	€ 174,000
Land and building	€ 260,000
Labour and mechanisation	€ 273,000
Storage cost	€ 61,000
Total cost	€ 768,000

In practice the cost- and income situation differs quite significantly by farm. Often farmers accept lower recompense for their owned land, own labour and capital.

The three energy saving measures under study were precision farming, improved air flow in storage and use of compost.

Precision farming

Precision farming is a farm management technique that further optimises crop and farm inputs by using satellite positioning systems to determine yield variation and corresponding variable spatial requirements of seed and nutrients. The precision farming relies on new techniques in ICT and GNSS. In a study by Van der Schans et al. (2008) the potential possibilities and effects in Dutch agriculture were addressed. For our standard farm, we have estimated the effect of implementing this technique on yield and savings on inputs and costs. The potential of this technique is not fully realised as much knowledge is still lacking regarding monitoring and sensors and the relation between sensor readings and operational activities. Nevertheless, we have made use of the study by van der Schans (2008) who estimated a 750 kg per ha increase in potato yield and a decrease in pesticide use and fuel use by using precision farming techniques at the current status of development in the Netherlands. Table 6 represents the used key figures.

Table 6: Used key figures for study.

Description	Amount	Source
Investment	€ 10,000.-	Van der Schans et al. 2008
Amortization period	5 years	
Interest rate	5.3%	
Annual costs	€ 1,250.	Van der Schans et al. 2008
Yield effect	750 kg/ha extra potatoes	Van der Schans et al. 2008
Pesticide reduction	5%	Van der Schans et al. 2008
Diesel fuel reduction	10%	Applied Plant Research

The investment is mainly the hardware for GNSS positioning and guidance. The annual costs are mainly the costs for subscriptions and licenses. The yield increase of potatoes is due to the better positioning of the planting of tubers with the ridging cultivation, also the placement of the tubers during planting is more optimal. The reduction in pesticide use is primarily due to less overlapping during application of pesticides. The diesel fuel reduction is based on experiences and verbal comments of the business unit manager of the experimental farm of Applied Plant Research (Wageningen UR). The costs and reductions are consistent with, what is referred to in the study (van der Schans et al. 2008), as “a light regime” of precision farming.

The impact of precision farming hasn’t been researched for energy and GHG savings in Dutch agriculture. The study that was used to calculate the effects mainly focused on the economic effects of precision farming. This means potentially there are more savings to gain by extending precision farming into other related techniques such as Controlled Traffic Farming.

Improved air flow in crate storage for potatoes

In a study of Kamp et al. (2010) the energy use of Dutch arable farming was studied. The study showed that storage is an especially big energy consumer. There are a number of different storage techniques used in the Netherlands, but bulk storage is the most popular. One of the storage techniques, which is increasing in popularity, is to store potatoes in wooden boxes in front of a letter box. This technique is especially suitable for smaller quantities. The same storage technique is also used for flower bulbs where research has shown that with minimal effort (costs) the air flow in these box storage systems can be improved significantly. The research showed that simple adjustments to the wooden pressure chamber, will significantly improve the energy efficiency. In Table 7 the key figures are used in the model are shown.

Table 7: Used key figures for study.

Description	Amount	Source
Investment	€ 4,200.-	Kamp et al. 2010
Amortization period	14 years	
Interest rate	5.3%	
Energy reduction	25%	Kamp et al. 2010

The investment is mainly rounding the edges of the timber beams of the letter box and additional timber skids. The energy saving is mainly due to the improved air flow in the pressure chamber. The product is better ventilated and has less back-pressure. The ventilation can therefore be less intensive, to maintain the same product quality.

Use of compost and less inorganic fertilizer

The attention to soil fertility and the concern over soil degradation is growing in the Netherlands. This concern is fed by a negative organic matter balance at the farm level. One of the ways to stimulate the organic matter content is to supply compost to soils. Together with this compost, minerals are introduced that can replace a part of the mineral fertiliser that we assumed for the reference farm. To estimate the effects of this measure, data has been used from a farmers' network. The main focus of the farmers in this network is to improve nutrient uptake by the plants through improving soil life and soil quality. For these farmers it results in a reduction in mineral fertilizer use, especially at the start of the growing season. But at the same time, the replacement of mineral fertilizer by compost minerals leads to more nitrogen emissions as the mineralization of compost nitrogen does not fully match the crop needs at a given time. In this case the supply of nitrogen is lower. This could lead to a yield loss, but this is not calculated in the model. The farmers' network indicates that they experience no loss in yield. Table 8 shows the key figures that are used in the model.

Table 8: Used key figures in the model.

Description	Amount	Source
Annual costs	€ 15,000.-	Vitalebodem.nl
Inorganic fertilizer	15%	Vitalebodem.nl
Organic fertilizer	100%	Vitalebodem.nl
Energy production compost	820 MJ/ton	Dekker et al., 2009
GHG-emission production compost	133 MJ/ton	Dekker et al., 2009

The reference farm is applying 12.5 ton of compost per hectare per year. The price of compost is EUR 10.00 per ton. The organic fertilizer is no longer applied and the use of inorganic fertilizer is reduced by 15%. The effect on N_2O field emissions is calculated as well. The N_2O field emission are calculated using the IPCC guideline and the relevant Dutch default values.

Relative Contribution of different inputs and process steps to energy use, total costs of production and greenhouse gas emissions

The different inputs contribute in different proportions to the total costs, primary energy consumption (PEC) and greenhouse gas emissions (GHG). For the three crops of the standard farm-model the relative contribution of the different inputs are given in Figure 11, Figure 12 and Figure 13. This gives an insight to the most important input for costs, energy consumption and greenhouse gas emissions. There is a significant difference in relative importance between costs, energy consumption and greenhouse gas emission. For example, the cost of crop protection is important, but crop protection does not represent substantial indirect energy consumption nor associated greenhouse gas emissions.

The negative costs for organic fertilizer in the Netherlands should be noted. Due to a surplus of organic manure arable farmers are paid to take organic manure from livestock farmers; so in fact, organic manure is an income. The energy and greenhouse gas emissions regarding production of organic manure are ascribed to the animal husbandry. This is in line with emission calculation schemes, like the Dutch NTA8080. Only transport and energy and emission of the application of organic manure are taken into account. As mentioned above the N_2O field emissions are calculated for the complete farm and thus included per crop. The other costs mentioned in Figure 11, Figure 12 and Figure 13 are costs of drying (wheat), transport (sugar beet) and drying/storage (potatoes).

The bars, with the cost-effects in Figure 11, Figure 12 and Figure 13, show that the crop protection, seed/planting material and inorganic fertilizers are the most significant input costs for these three crops. For energy input and GHG emissions the inorganic fertilizers and diesel are the two inputs with the main contribution to the total energy use and greenhouse gas emission. Especially for potatoes the storage/drying, and planting material for GHG, are also significant. This shows that the overlap in the three aspects is inorganic fertilizers. Also the figures show that energy efficiency and greenhouse gas are correlated to some extent.

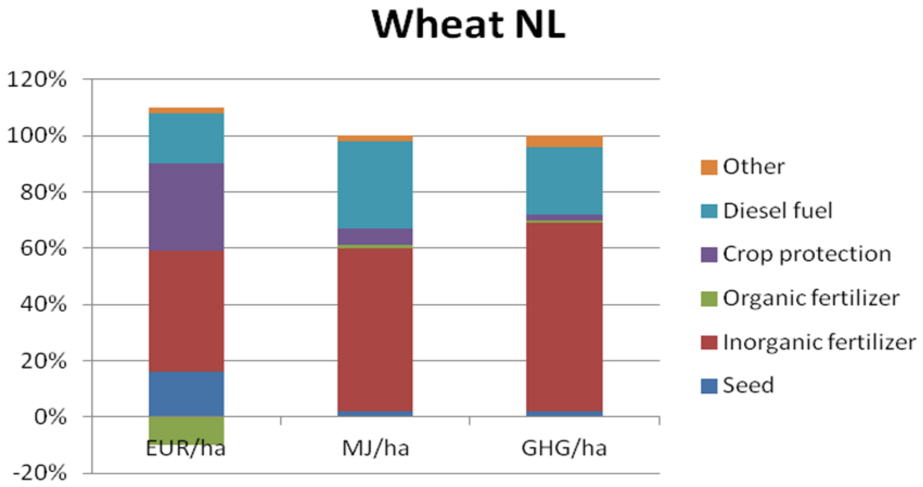

Figure 11: Relative contribution of different inputs in wheat production in The Netherlands to economics, energy use and greenhouse gas emissions (GHG).

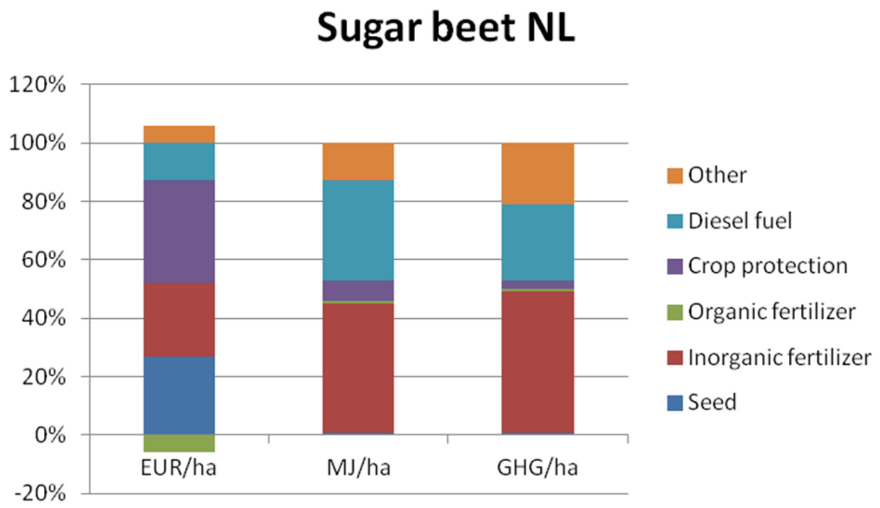

Figure 12: Relative contribution of different inputs in sugar beet production in The Netherlands to economics, energy use and greenhouse gas emissions (GHG).

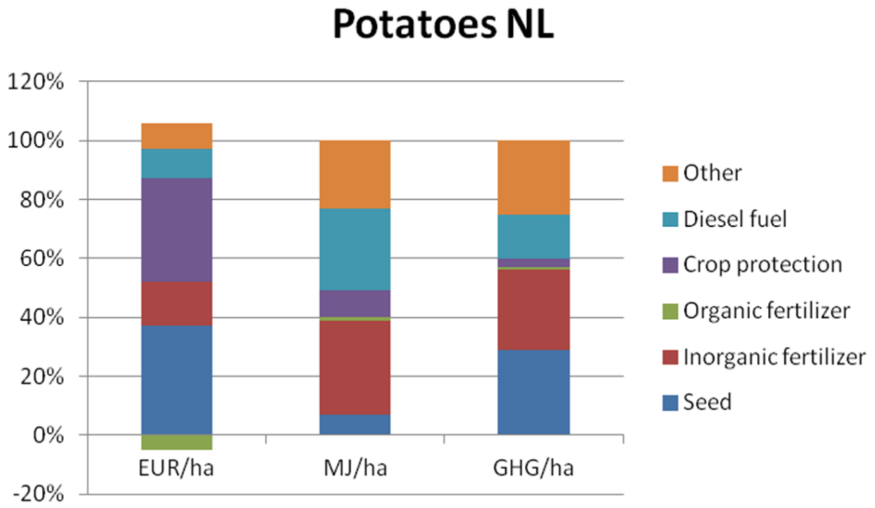

Figure 13: Relative contribution of different inputs in potato production in The Netherlands to economics, energy use and greenhouse gas emissions (GHG).

Additionally, the yields of wheat, sugar beet and potatoes, the energy consumptions (PEC) and the GHG emissions per hectare are stated in Table 9.

Table 9: Yield, energy consumption and GHG emission per crop of a standardized Flevoland farm of 120 ha.

	Wheat	Sugar beet	Potatoes
Yield (t/ha)	9	74	57
Energy (MJ/t)	2.094	235	786
GHG (CO_2e/t)	449	52	129

Impact of different energy efficiency measures on economics and the environment

All three measures were "implemented" at our standard farm and the effect was calculated on energy use, GHG emissions and emissions of minerals and pesticides. The analysis and results (Table 10) show that compared to the reference situation all suggested energy efficiency measures contribute to energy savings and reduced GHG emissions. These contributions were in the range of 3 to 7% of the total energy use and 1 to 6% for the GHG emissions. The cost remained, relatively, equal for all energy efficiency measures. The income improved 1% in the precision farming scenario. The minimal effect on the income is mainly due to the additional costs that counteract the savings.

Table 10: Annualized costs, PEC and GHG emissions with energy efficiency measures, based on a model farm of 120 ha in the Netherlands.

	Annualized Cost		PEC		GHG	
	€/ha	%	MJ/ha	%	CO_2e/ha	%
Reference situation farm	6,403	100	27,759	100	3,022	100
Precision Farming	6,379	100	26,949	97	2,992	99
Potato storage	6,392	100	26,256	95	2,829	94
Compost	6,415	100	35,295	132	4,924	157

The precision farming and potato storagemeasures reduce energy and GHG emissions. Precision farming and Potato storage improvements show a reduction in annualized cost, but less than 1%. The energy use and GHG emission increase significantly for the compost measure. The compost measure shows a small increase in annualized cost, but less than 1%. The addition of income is not included in the table. The precision farming measure shows an increase in income of just 1%.

Table 11: Environmental effects of additional compost.

	Reference	Additional compost
Effective Organic matter supply (kg/ha)	1,110	2,891
NH3-emission (kg/ha)	0	6
N-soil surplus (kg/ha)	54	141
Nitrate content soil (mg/L)	26	67

The reduction in pesticide use also has positive environmental effects. The weight of active substance is lowered from 29.2 to 27.9 kg for the total business (six crops). The effect of the lower active substance is positive on Dutch environmental parameters for terrestrial and water life and for emission to air, ground water and surface water.

Conclusions

The relative contribution of inputs to costs, energy consumption and greenhouse gas emission showed that inorganic fertilizer is the most important input for all three criteria. To lower the costs, energy consumption and greenhouse gas emissions measures to reduce the use of inorganic fertilizer are needed. Precision farming is focussed on pesticide and diesel fuel savings, but potentially savings in inorganic fertilizer use can play a bigger role. This has not been calculated in the model as there is still a lack of data. Potentially more interactive feedback of management systems for site-specific application of fertilizer and crop protection could be interesting in practice. Further research could contribute to more energy savings. The energy savings on storage show that limited adaptions can result in significant effects. Potatoes and onions are mainly stored in bulk, but due to the absence of data on energy use there is a limited knowledge on potential energy savings. At a national level potatoes and onions are, due to the large area grown, significant contributors to the overall energy consumption of agriculture. Further research could potentially save significantly on energy consumption. The application of compost to improve soil fertility is a less common measure. The primary goal of the measure is not to save on energy consumption but a side effect is a significant increase in energy consumption and greenhouse gas emission. The use of compost is especially beneficial for sandy soils and could have more beneficiary side effects such as improving water retention, the uptake of nutrients by the plants and soil cultivation and soil carbon sequestration. These beneficiary side effects all have potential to save energy and GHG. However, data and estimates of these effects are lacking so that these effects are not taken into account. Also, the yield stability in wet or dry conditions could be increased, which is also positive for the income of farmers and for energy efficiency of products. The measure should be researched to fully highlight its potential.

4.1.5. Energy efficiency measures in Portuguese wheat production

Fátima Baptista, Dina Murcho, Carlos Marques, Luis Leopoldo Silva, José Rafael Silva

Introduction

Diesel used for the machinery is one of the most important production factors contributing to direct energy use and greenhouse gas (GHG) emissions. Reduced tillage and no tillage systems have been identified as efficient measures to reduce energy input use in agricultural systems. These systems need less fuel and are associated with lower mechanization and thus reduce production costs and greenhouse gas emissions.

Indirect energy input through fertilizers contributes 30%-50% of the total energy use in agriculture. Therefore, it is expected that all measures that improve the efficiency of fertiliser use contribute to a great extent to energy efficiency. Differential or site-specific application, according to soil fertility and plant response, is a precision farming technique that could contribute to this improvement.

The use of irrigation for wheat production can lead to a great increase in productivity. However, investment in equipment is necessary and some inputs such as fertilizers, electricity and water will also increase.

The main objective is to analyse the effect in farm economic results, energy consumption and environmental impacts of three options: 1. no tillage cropping systems, 2. reduction of phosphorous application in wheat, and 3. introduction of irrigation.

Methodology

Alentejo is the largest agricultural region of Portugal, with a Mediterranean climate characterized by mild winters and dry and hot summers. Rainfall is between 400 to 600 mm, concentrated in autumn and winter. Average temperature is between 21 and 25 ºC, but maximum temperature can be higher than 40 ºC while minimum is frequently below zero during winter nights (Marques, 1988).

A typical farm of 250 hectares, with clay soils and a traditional crop farming system of dryland agriculture in the Alentejo was chosen as the basic scenario. In this work the effect of no tillage, reducing fertilisers and irrigation are evaluated considering economic, energy use and environmental adjustments and their effects. Crop farming systems are described and inputs and outputs are quantified for each analysed option.

Basic scenario–Traditional Crop system

The farm production system is based on a four year crop rotation (**sunflower–*durum* wheat 1–green peas–*durum* wheat 2**) established to achieve high production levels of cereals. Usually the cereal, namely *durum* wheat, because of specific subsidy policies, or other cash cereal crop, alternates with sunflower and peas.

Durum wheat 1 and 2-Conventional soil preparation is based on deep ploughing followed by two chisel tine passes. The first durum wheat in the rotation, 1, is then prepared with chisel tine and disc harrowing followed by sowing (200 kg seeds/ha) and fertilizer application (300 kg/ha of N_20:P_20:K0). Usually a in-crop chemical weed control operation takes place (0.02 kg/ha of Tribenuron-Methyl and 0.5 L/ha of Clodinafop + Cloquintocete) followed by a fertilizer application of 150 kg/ha (N 27%). Harvest is in July, with average yield of 3 t/ha of grain and 1.5 t/ha of straw.

Sunflower-Conventional soil preparation is similar to the one performed for wheat, consisting of deep ploughing, followed by two chisel tine passes during winter, and one before sowing sunflower in March. Sowing density is 4 kg/ha of seeds (75 000 plants). Sunflower does not receive fertilizer or herbicide treatments and it is harvested in August. Productivity is 850 kg/ha.

Peas- Sowing of green peas occurs in January, with 150 kg/ha, after harrowing and two chisel tine passes for soil preparation. As for sunflower, green peas require neither herbicides nor fertilizer treatments. Harvest is in July, with productivity of 1100 kg/ha.

Farm machinery

To perform the field operations described above the farm machinery consists of one 105 hp tractor, one 9 ton trailer, one disc harrow, one chisel tine, one drill with 25 coulters, a fertiliser distributor, a straw baler, a rake and a precision seeder. All the machinery is stored in a 75 m^2 building. The farmer also rents an 85 hp tractor with a plough implement, a 1000 L sprayer, and a combine harvester.

EU financial aid – Common Agricultural Policy

All farms receive, each year, an EC subsidy, the RPU (“*Single Payment Scheme”*). The value received is different for each farm and it is calculated based on the farm history of producing the specific crop, and it also takes into account the existence of any animals. The national average value attributed for the year of the study was 174 €/ha.

Methods used for cost calculations

For mechanisation the rate and value were calculated based on the replacement value and life span of each machine. The life span considers the durability of the item, the time between its first and last use. In the case of the tractors a life span of 12 years was considered, for the seeders 13 years and for the disc harrow, the chisel tine and the trailer a life span of 20 years.

For determining storage use, from harvest to the day that the products leave the farm, the proportion of the warehouse area occupied by the crops, according to their yields, was used in the calculations.

Alternative option 1–No tillage

As an alternative option to the traditional farming system a no tillage system was considered for all the crops, maintaining the same rotation. No tillage or direct seeding has been applied in wheat for several years in Portugal, by an increasing number of farmers, and it's a practice that has been increasing over the years as a sustainable and environmental friendly agricultural practice for wheat production.

Durum wheat 1-In the third week of October a weed control operation is performed using glyphosate (3 L/ha). Sowing is in November, using a direct drill seeder, with seed density of 200 kg/ha and fertilizer level of 250 kg/ha (N 15: P 15: K 15). In late January there is a fertilizer application with 140 kg/ha (27% N). During February there is a crop weeding operation (0.02 kg/ha of Tribenuron-Methyl and 0.5 L/ha of Clodinafop+Cloquintocete). Harvest is in July, with the same average yield attained in the traditional farming system.

Sunflower-In late February a herbicide (glyphosate) is applied. The sunflower sowing is in March, also with a direct precision seeder and a plant density of about 75,000 plants/ha. Harvest is performed in August.

Durum wheat 2-*Durum* wheat 2 ends the crop farming rotation and the same annual calendar and operations of *durum* wheat 1 apply. Productivities are also similar to those of *durum* wheat 1.

Farm machinery

To perform the above described field operations the farm machinery used consists of one 105 HP tractor, one 9 ton trailer, a fertiliser distributor, a straw baler. All machines and agricultural machines are stored in a 75 m^2 building. As before the farmer still needs to rent a direct drill seeder, a 1000 L sprayer and a combine harvester.

Financial aid

In this option, besides EU subsidies, there is a national aid from PRODER program. This aid is granted to farmers that do organic farming, integrated pest management, produce indigenous breeds, and use no tillage systems. The program has specific rules and maximum amounts for the different crops and animal breeds.

Alternative option 2–Reduced P_2O_5

Based on data obtained by experimental research (Marques da Silva, 2012) a reduction of 30% on the application of phosphorous on wheat crops was analysed as a further option.

This is considered as an energy efficiency measure with the reduction of indirect energy input, since it reduces the quantity of the fertilizer element used. Since in this rotation system the application of fertilisers is only in the wheat crops, 1 and 2, this option only applies to the wheat crops in the rotation.

Alternative option 3–Irrigation

As mentioned above the use of irrigation for wheat production can lead to a great increase in productivity. However, extra investment is needed, namely in irrigation equipment and there will be an increase in some inputs such as fertilizers, electricity and water.

Relative Contribution of different inputs and process steps to energy use, total costs of production and greenhouse gas emissions

Figure 14 shows the relative contribution of the different inputs in total costs, GHG emissions (CO_2eq) and energy consumption for the crops considered in the conventional production system of this farm, assumed as the base scenario.

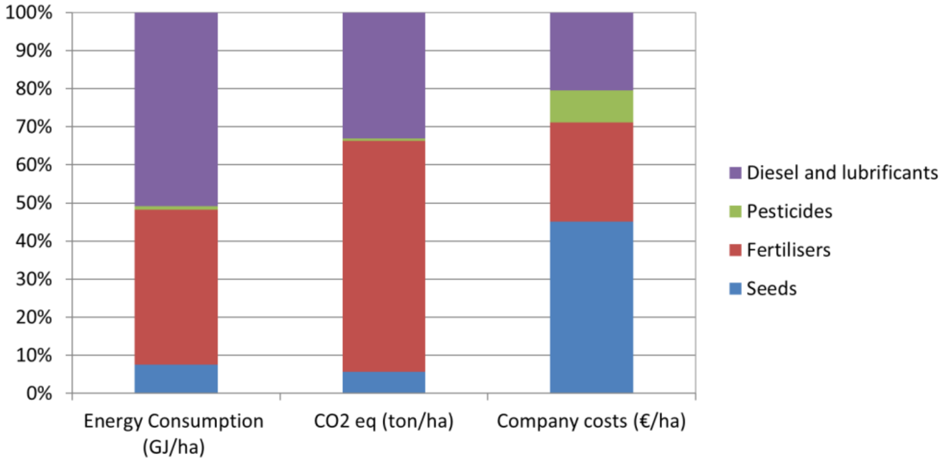

Figure 14: Relative contribution of different factors used on farm energy, greenhouse gas emissions (GHG) and costs under base scenario.

It is clear that different inputs contribute in different proportions to total costs, primary energy consumption and GHG emissions. Fertilizers and diesel are the most important factors concerning GHG emissions and energy consumption. Seeds are particularly important for farm costs. The relative high contribution of seeds for the total costs is explained by the fact that two of the crops do not require fertilizer or pesticides. This implies that small changes may induce only low costs but high impacts on energy use and GHG emissions.

Impact of different energy efficiency measures on economics and the environment for all the rotation system

Table 12 and Figure 15 present costs, energy consumption and GHG emissions per hectare for conventional and alternative systems described before. Options 1 (no tillage) and 2 (fertilizer reduction) decrease costs, energy consumption and GHG emissions and the opposite occurs with option 3 (irrigation). In fact, production costs decrease about 10% with no tillage, 1% with lower use of P_2O_5 and increase around 50% with the introduction of irrigation. The same is observed in energy consumption and GHG emissions. No tillage allows for 40% lower energy consumption, reduced fertiliser reduces energy consumption by 2% and irrigation increases energy consumption to almost double that of the conventional system. For CO_2eq emissions a decrease of 20% is obtained with no tillage, 2% with reduced fertiliser application and irrigation increases emissions by 70%. The decrease in the two first options is explained by less use of machinery/diesel and fertilisers and the increase in the last one is due to the increased inputs of fertiliser and electricity for irrigation.

Table 12: Annual costs, PEC and GHG emission for energy efficiency measures in the farm rotation.

	Annual Costs		PEC		GHG	
	€/ha	%	MJ/ha	%	CO_2e/ha	%
Conventional	528.43	100.0	7171.26	100.0	535.97	100.0
No Tillage	482.90	91.4	4109.36	57.3	431.70	80.5
Reduction P_2O_5	522.63	98.9	7045.01	98.2	527.06	98.3
Irrigation	770.25	145.8	13979.11	194.9	900.23	168.0

Figure 15 also includes farm profit for different options. It is possible to see that all three options allow an increase of farm profit (43% with no tillage mainly due to an agro-environmental subsidy given specifically for this type of production technology, 2% with less P_2O_5 and more than the double with the irrigation option). In the first two the increase is due to a decrease in the production costs and in the last one due to the increased yield.

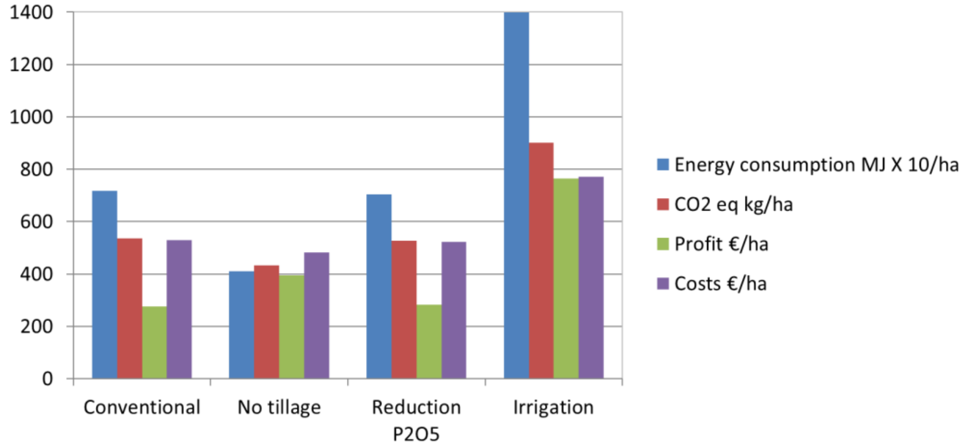

Figure 15: Impact of different energy saving measures on costs, profit, energy use and GHG emissions per ha.

Impact of different energy efficiency measures on economics and environment for the wheat crop

Figure 16 and Figure 17 allow a more detailed analysis only for the wheat crop (produced in 125 ha of the case study crop rotation), taking into account the wheat productivity in the different options. These figures show the costs, profits, energy consumption and CO_2e emissions per hectare and per ton of wheat produced on the farm.

Figure 16 shows the same tendency mentioned before considering all the rotation crops. Options 1 and 2 decrease costs, energy consumption and GHG emissions and the opposite occurs with option 3. In fact, production costs decrease by about 8% with no tillage, 2% with less use of P_2O_5 and increase around 66% with the introduction of irrigation. The same is observed in energy consumption and GHG emissions. No tillage allows reduced energy consumption of about 45%, less fertiliser use reduces by around 3% the energy consumption and irrigation increases energy consumption to almost double that compared to the conventional system. For the CO_2e emissions a decrease of 30% is obtained with no tillage, 2% with reduced fertiliser application and an increase of around 70% with irrigation. Finally, the profit per hectare increases with no tillage (24%) and with irrigation it approximately doubles.

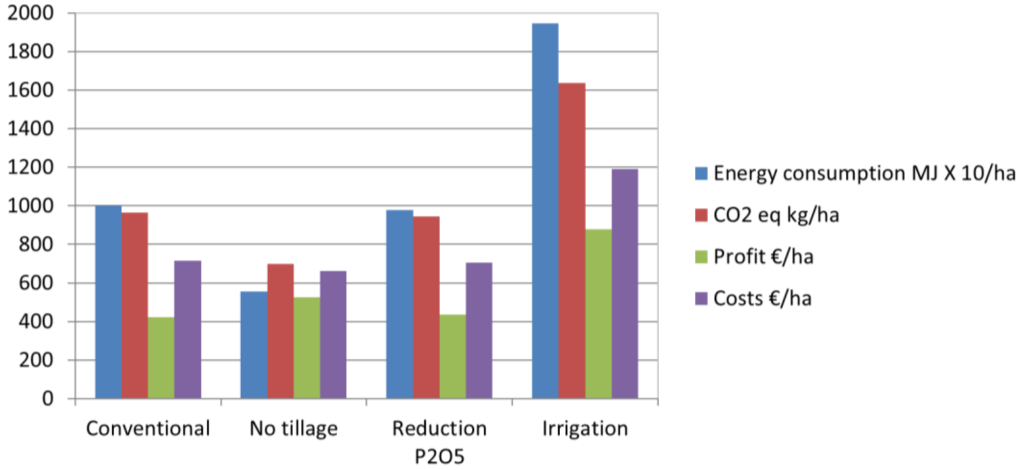

Figure 16: Impact of different energy saving measures on costs, profit, energy use and GHG emissions per ha of wheat.

Figure 17 presents the impact on costs, profit, energy use and greenhouse gas emissions (GHG) per ton of wheat produced. The picture is slightly different with the analysis performed by hectare. In fact, when considering the production obtained with those costs, energy consumption and GHG emissions it is possible to say that the three options can contribute to an increase of the resource efficiency (in different scale). Less energy is consumed, less GHG are emitted, and a higher farm profit is obtained either due to a reduction of the production costs or to the increased productivity.

Analysing the variation of the costs per ton of wheat produced a reduction of around 8%, 2% and 7% was attained for options 1, 2 and 3 respectively. Concerning the energy consumption a reduction of 45%, 3% and 3% was found for option 1, 2 and 3 respectively. For the CO_2e a reduction of 30%, 2% and 15% was attained. Profit increased for all the options, around 24% for no tillage, 3% for reduced P_2O_5 and 4% for irrigation.

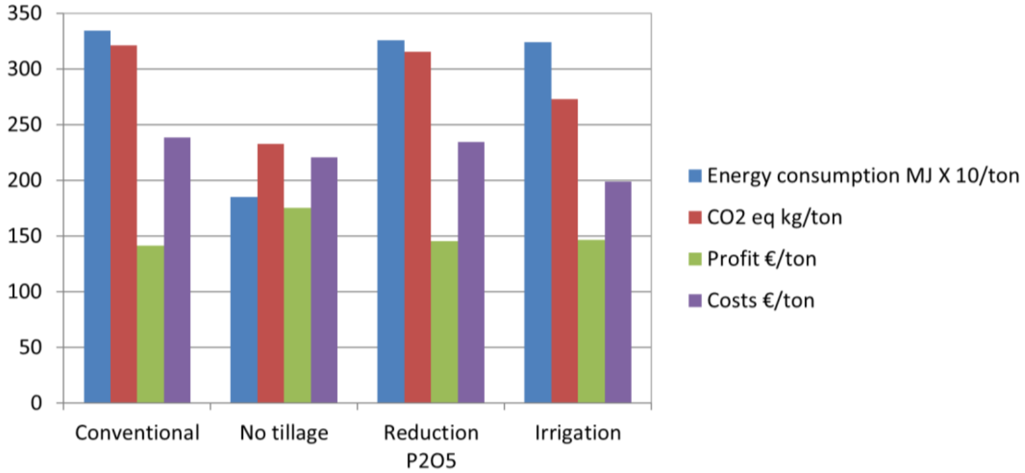

Figure 17: Impact of different energy saving measures on costs, profit, energy use and GHG emissions per ton wheat.

Figure 18 shows the differences between the conventional system and the analysed options, on energy, GHG emissions, costs and farm profit per ton of attained wheat yield. It is possible to see that the introduction of irrigation can contribute to the highest savings in the production costs. No tillage allows the highest savings in energy consumption and GHG emissions and the highest increase in farm profit.

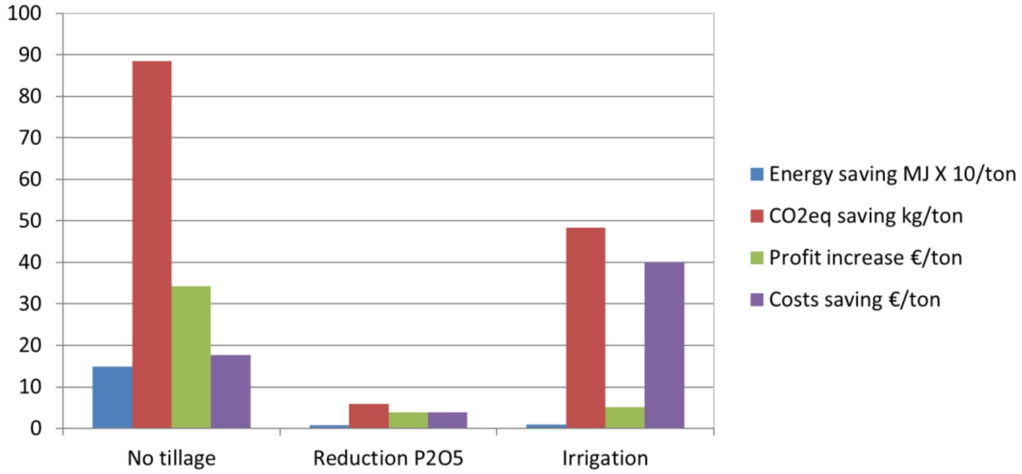

Figure 18: Differences of costs, profit, energy-use and greenhouse gas emissions (GHG) per ton of wheat between the basic scenario and the different energy saving measures.

Conclusions

The three analysed options showed a good potential to reduce input use on this farm, increasing the resource use efficiency thus contributing to the increase in farm profit. However, several factors interact in the production system and more research is needed in order to obtain experimental data that allows a more detailed analysis.

4.1.6. Energy efficiency measures in a Greek wheat-cotton rotation farming system

Athanasios Balafoutis, Panagiotis Panagakis, Demetres Briassoulis

Introduction

Agricultural production in Greece is divided into arable, perennial, orchards, vineyards and covered crops. Regarding arable farming, agricultural tractor fuel consumption accounts for 90-95% of total direct field energy consumption (Panagakis et al, 1996). Measures to reduce fossil fuel consumption should be adopted in arable farming in Greece. To achieve such a goal, several methods were investigated, including reduced or no tillage since soil tillage is the most fuel consuming agricultural practice, followed by mechanical harvesting.

Fossil fuel for the agricultural tractor also contributes a lot to GHG emissions. Reduced tillage or no tillage has been identified as efficient measures for both energy and GHG reduction in agricultural systems, with benefits on cost of production as well.

Fertilizers also contribute to a high extent of the total indirect energy use in arable agriculture. Therefore, measures improving fertilizers use efficiency will contribute significantly to energy use efficiency. Precision farming methodology on selective fertilizer application based on yield mapping could reduce fertilizers in arable farms to a great extent provided it is applicable (farm size, investment etc).

The rotational agricultural systems between intensive and extensive crops (e.g. cotton with durum wheat) can lead to an increase in soil fertility needing lower fertilizer application and perhaps increased productivity. Rotational farming has the advantage of no new investment need; however, it reduces the total income of the agricultural business, as extensive crops yield a lower income (this however depends on the fluctuations of market prices).

In this report, the main objective was to analyse the effect of 3 energy efficiency measures for wheat and cotton cultivations in Greece. Focus was primarily placed on the reduction of energy consumption and secondly on the economic results and the environmental impacts. The selected alternative energy efficiency measures were:

1) reduced tillage in both cropping systems (wheat and cotton)
2) reduced tillage in wheat
3) reduced fertilizer application through precision farming

Methodology

Thessaly is the largest agricultural region of Greece, with a continental climate characterized by average to cold winters and dry, hot summers. Annual rainfall is between 265 to 765 mm in the total region of Thessaly (Proias et al. 2010) and 423 mm in average for Larissa area, reported during the period 1955-1997 (EMY 2012). Average temperature is 15.7°C, but the maximum temperature can be higher than 45°C, while the minimum can reach a temperature close to or below zero during winter nights (EMY 2012).

The basic scenario that was chosen for this report is a typical farm of 15 hectares, with irrigation potential and sandy-clay soils that runs a 4 year rotation farming system between cotton and durum wheat in Larisa area of Thessaly region.

Basic scenario–Traditional Crop system

The farm production system is based on a four year crop rotation (**cotton–cotton–cotton–*durum* wheat).** Both crops are annual and durum wheat is used as an extensive crop that is used as a break crop after 3 years of intensive cotton production.

Conventional durum wheat:

The cultivation procedure in the farm under investigation follows the steps below:

- Soil treatment

Preparation of the seedbed by using the following machinery:

1) Plough for deep ploughing (35 cm)
2) Heavy cultivator (2 passes)
3) Disk harrow
4) Light cultivator

- Sowing

Sowing is executed in November with a drill type sowing machine (row spacing of 12 cm) that carries two containers, one for the seeds and one for the fertilizers. Sowing requires 170 kg seeds/ha combined with light fertilizer application (80 kg N/ha and 50 kg P/ha).

- Chemical application

Usually 1-2 crop weed control operation take place (10 g/ha triasulfuron 20% w/w, 0.5 L/ha clodinafop 24%-propargyl 24% w/v, 1.5 L/ha tralkoxidim 21.55%).

- Fertilizer application

Two post-emergence applications of fertilizer (total fertilizer application of 70 kg N/ha, 25 kg P/ha, 30 kg K/ha).

- Harvesting

Harvest is executed by the end of June using a contractor's combine harvester (yield of 5 t/ha of grain and 3 t/ha of straw).

Conventional cotton:

The cultivation procedure in the farm under investigation follows the steps below:

- Soil treatment

Preparation of the seedbed by using the following machinery:
1) Plough for deep ploughing (35 cm)
2) Sub-soiling ripper (every 3 years)
3) Heavy cultivator (2 times)
4) Disk harrow
5) Light cultivator

- Sowing

Sowing is executed in April with a four-line pneumatic linear sowing machine (row spacing of 1 m) that carries 4 containers for the seeds on each seeding unit and one container for the granular soil insecticide to protect the seed. Sowing requires 25 kg seeds/ha combined with fertilizer application (50 kg N/ha and 25 kg P/ha).

- Inter-row cultivations

Three inter-row mechanical cultivations for weed control are done without chemical applications. After the cotton plants become tall enough for the tractor to pass through the plantation without damaging the plants, weeds are controlled with herbicides. Another reason for these applications is the avoidance of root rot of healthy cotton plants.

- Chemical application

Usually 2 crop weed control operation takes place (2 L/ha trifluralin 48% w/v, 4 L/ha ethalfluralin 33% w/v).

Growth inhibitors are used to avoid late maturing (0.1 kg/ha trimethylammonium chloride (C.C.C.) or 1.5 L/ha Mepiquat chloride).

When the crop is ready to be harvested defolliating chemicals are used, in order to make harvesting easier for the cotton harvesters (2.5 L/ha ethephon 48% w/v - cyclanilid 6% w/v).

- <u>Fertilizer applications</u>

Two post-emergence applications of fertilizer (total fertilizer application of 50 kg N/ha, 25 kg P/ha, 30 kg K/ha)

- <u>Irrigation</u>

After sowing, light irrigation is applied to help the seeds to germinate but not heavy irrigation as it creates a crust that does not allow the new plants to emerge. Then, according to the needs of the plants, 6 irrigations of 300–350 m^3/ha are applied.

- <u>Harvesting</u>

Harvest is executed by the end of October using a cotton harvester under contract (yield of 4.5 t/ha of seed cotton).

Farm machinery

The farm owns the following machinery:

- Agricultural tractor 80 kW
- Reversible plough (3 furrow)
- Rigid-tine cultivator (3 m)
- Disk harrow (3 m)
- Light cultivator (3 m)
- Crop sprayer (mounted, 500 L, boom 12 m)
- Trailer (7 t)
- Pneumatic seed drill for row spring crops (4 m)
- Mechanical seed drill for winter cereals (4 m)
- Centrifugal fertilizer spreader (12–36 m, 500 L)
- Irrigation machinery (pump, auxiliary parts, 33 m^3/h)
- Dripping pipes

The farm contracts:

- Sub-soil ripper machine every 3 years
- Wheat - combine harvesting service
- Cotton - harvesting service

EU financial aids

The selected farm receives, each year, EU subsidies for both wheat and cotton. The value received is different for each farm and it is calculated based on the farm history of producing the specific crop. In particular, the subsidy for wheat is scalar, meaning that it reduces as the size of the farm is increased. The average value for wheat production in the selected farm is 110 €/ha. As for cotton, the subsidy is divided into two types. The permanent subsidy of 900 €/ha for any cotton plantation and the variable subsidy that depends on the size of the farm. In the selected farm the amount is 650 €/ha. Therefore, the average value attributed to cotton crop for the year of the study was 1550 €/ha.

Methods used for cost calculations

The average value per kg of compound fertilizer (N, P, K) was calculated based on the prices of compound fertilizers that are used for this farm. The same approach was used for chemicals (herbicides, fungicides and insecticides). Irrigation costs were calculated based on electricity consumption, as water was considered as a free resource.

Considering machinery, the rate and value were calculated based on the replacement value and life span of each machine or agricultural equipment in Greece (see Table 13). The life span considers the durability of the item for the time between its first and last use.

Table 13: Agricultural equipment of the selected farm and their useful life span

Agricultural Equipment	Years of useful life
Tractor	
4wd tractor, 70-80 kW	15
Tillage machinery	
plough, 3 furrow	12
rigid-tine cultivator, 3.00 m	15
diskharrow, 3.00 m	20
light cultivator, 3.00 m	20
Other machinery	
crop sprayer, mounted, 500 L, 12.00 m	15
Tipping trailer, 7 ton	20
pneumatic seed drill, 4.00 m	15
mechanical seed drill, 3.00 m	15
centrifugal fertilizer spreader, 12-36 m, 500 L	15
Irrigation machinery, 33 m^3/h	15
drip pipes	5

Alternative option 1–minimum tillage in both crops

One of the energy efficiency measures to be applied in the traditional farming system was a reduced tillage system for both crops (wheat and cotton), maintaining the same rotation. In general, reduced tillage systems are not widely applied as farmers still believe that high soil cultivation improves the final yield of both crops. However, there are several research results reported during the last few years that have shown positive results from reduced tillage with only a small to zero yield reduction for both wheat and cotton cultivations.

Durum wheat–Reduced tillage in wheat means that the ploughing and 2 out of the 3 cultivator passes are not applied resulting in 58% reduction of diesel fuel consumption from the agricultural tractor (Cavalaris et al, 2003) and a respective 16.7% labour reduction. All the rest of the agricultural practices are the same as the conventional tillage system. Harvesting is scheduled for June, with the same average yield attained as in the traditional farming system.

Cotton-Reduced tillage in cotton means that 2 out of the 3 cultivator passages are not applied resulting in a 27% reduction of diesel fuel consumption from the agricultural tractor (Gemtos et al, 1998; Cavalaris et al, 2003) and a respective 9.5% labour reduction. All the rest of the agricultural practices are the same as the conventional tillage system. Harvesting is scheduled for late September to early October, with a slight reduction in average yield (4.7%) as compared to that attained with the traditional farming system.

Farm machinery

One of the positive effects of minimum tillage systems is that the farmer does not have to invest in new machinery of agricultural equipment. Also the useful life time of some of the equipment increases because of reduced use.

Alternative option 2–Minimum tillage in wheat

The second scenario under investigation was the application of minimum tillage only in wheat as it does not affect the final yield of the crop. Therefore, minimum tillage for wheat was examined as shown (in Alternative option 1) above.

Alternative option 3–Reduced fertilizers and pesticides in cotton through precision farming

The third option to reduce the energy input in a wheat-cotton rotation agricultural system is the application of a precision farming system to minimize the use of fertilizers and herbicides in cotton, which is the most energy intensive crop in this system.

In Greece, there is a delay in the implementation of innovative systems like precision agriculture. The delay is attributed to several reasons, of which the most important are given by Papageorgiou & Spathis (2000) as:

1) The structural problems of the Greek agriculture with many small and fragmented holdings, which prevent the dissemination and application of technological advances that would improve farm incomes.
2) The geographic dispersion of production units and the resulting difficulty in providing knowledge and information from relevant organizations and agencies, which prevents the spread of new technologies.
3) The human factor, namely the low level of education of a large proportion (usually older) of people involved in agriculture, which contributes to the delay in assessment and adoption of innovative technologies.
4) The high average age of farmers has resulted in reduced interest in long-term perspective, lack of availability for application of new technology and a sense of professional competence consistently rejecting efforts to introduce high tech applications.
5) Producers are stuck in traditional production techniques with which they have been linked for a large part of their lives, especially the elderly,
6) Subsidies contribute significantly to their income, especially after the country's accession to the EU that led to complacency and unwillingness to seek innovative ideas.
7) The slow implementation of technology in Greece in general, compared to the northern EU countries.

Nevertheless, precision agriculture has already started its first applications in the last 10 years. Currently, the investigation of the applicability of precision agriculture in growing cotton and wheat by various agencies is in progress. The University of Thessaly, in collaboration with the National Agricultural Research Foundation (Annex Larissa), started in 2001 an attempt to apply precision agriculture in cotton cultivation in the prefecture of Karditsa by producing yield maps in conjunction with soil testing results (Markinos et al, 2002; Gemtos et al, 2002). A second attempt for precision agriculture application in wheat was executed by the American Farm School in collaboration with the University of Georgia in the U.S. (Gertsis et al. 2003).

Therefore, using the existing data it was considered that precision farming techniques in cotton could lead to 46% reduction of fertilizer use and 81% herbicide reduction (Mygdakos et al, 2005). The yield is not affected negatively by this and sometimes it can be increased.

Farm machinery

One of the negative effects of precision farming systems is that important investment by the farmer has to be undertaken and it is necessary that the machinery is operated and maintained by trained personnel. In this case, the sensors, the computer, the printer and most importantly the software to produce the yield maps have to be purchased with a cost of about 13000€. However, this equipment could be used for a farm of at least 100 ha, which could be an extra income in case of hiring out these services to other, neighbouring, farms. Alternatively, the specific farm could use an available precision farming system service through subcontracting. However, the cost of such a service is not yet known as it is not an common in Greek agriculture.

Relative Contribution of different inputs and process steps to energy use, total costs of production and greenhouse gas emissions

Figure 19 shows the relative contribution of the different inputs to energy consumption, GHG emissions (CO_2e) and to the total costs for both crops (wheat and cotton for a four year rotation system) considered in the conventional production system of this farm, which was assumed as the basic scenario.

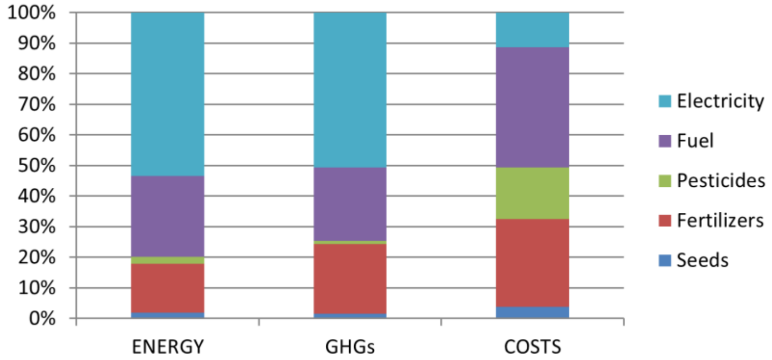

Figure 19: Relative contribution of different processing inputs in the farm production to energy use, GHG and economics.

This figure can give several results about the two crops. First of all, it is obvious that electricity through irrigation (3 years for cotton) is the biggest energy consumer (54%) in this farm with the very similar effect on GHG production (51%). Also, it can be observed that diesel and fertilizer (3 years for cotton and 1 year for wheat) follows in importance concerning energy consumption (26% and 16% respectively) and GHG emissions (24% and 22% respectively). From the figure above, it can be seen that in general the energy and GHG emissions more or less follow the same trend for each component.

However, it is very interesting to analyse the difference between the energy and environmental impact of this farm in comparison to the costs. The most significant example would be the electricity consumption that even if it requires high primary energy to be produced, with respective high GHG emissions, (mainly due to lignite used for electricity production that is of very low efficiency and of very high GHG emissions), it has a very low cost (natural resource) especially for agricultural production systems (11%). This helps the Greek farmer, but in some cases it is the reason for irrational use of water when the only target is maximum yield and no consideration of sustainability, especially in a Mediterranean country where water is a limited resource.

Another remarkable result is that diesel is very expensive (imported) and contributes considerably to the farm costs. As for the consumables (seeds, fertilizers and pesticides), they are also expensive influencing significantly the final income of the farm.

Environmental and economic impact of different energy efficiency measures for the wheat-cotton rotation system

The three alternative scenarios had a significant reduction of energy consumption, achieving the target set for applying them. As was expected, the reduced energy consumption was also translated into GHG emission reduction. As for the final economics of the farm (profit), there were two cases considered in this report. There is a presentation of the same farm using owned land and using rented land. The reason of such a presentation is that the mortgage cost is significantly higher than the rent for the same land size, reflecting on the final farm income reduction.

Figure 20 shows the farm results concerning energy savings. It can be observed that reduced tillage in both crops reduced energy consumption by 76531 MJ (8.45% of the total energy consumption), reduced tillage in wheat reduced energy by 21861 MJ (2.41% of the total energy consumption) and precision farming reduced energy consumption by 59377 MJ (6.55% of the total energy consumption).

Figure 21 shows the farm results concerning avoided GHGs. It can be observed that reduced tillage in both crops reduced GHGs by 5581 MJ (7.66% of the total GHG emissions), reduced tillage in wheat reduced GHGs by 1594 MJ (2.19% of the total GHG emissions) and precision farming reduced GHGs by 6191 MJ (8.5% of the total GHG emissions).

Regarding the costs of production, there was a reduction in all three cases. However, in the first scenario of minimum tillage application, cotton yield was also reduced, but was overcome from the cost reduction (less diesel use). Figure 22 shows that the highest mean annual profit increase was obtained by the first scenario (due to important fuel use reduction) and the least by the precision farming application (due to equipment purchase).

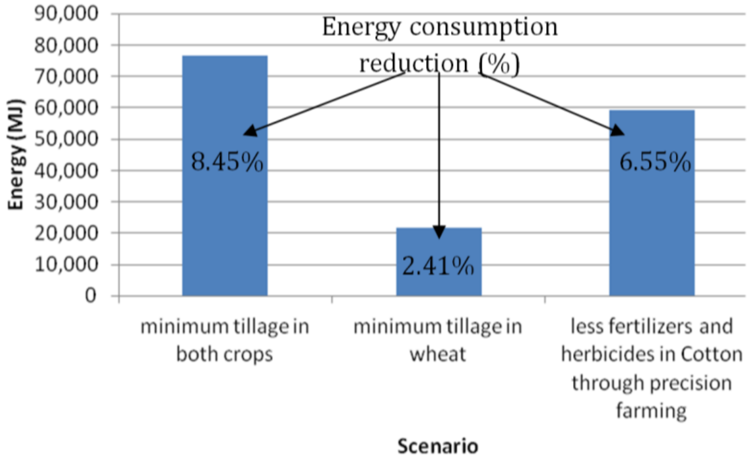

Figure 20: Energy consumption reduction using the three alternative scenario

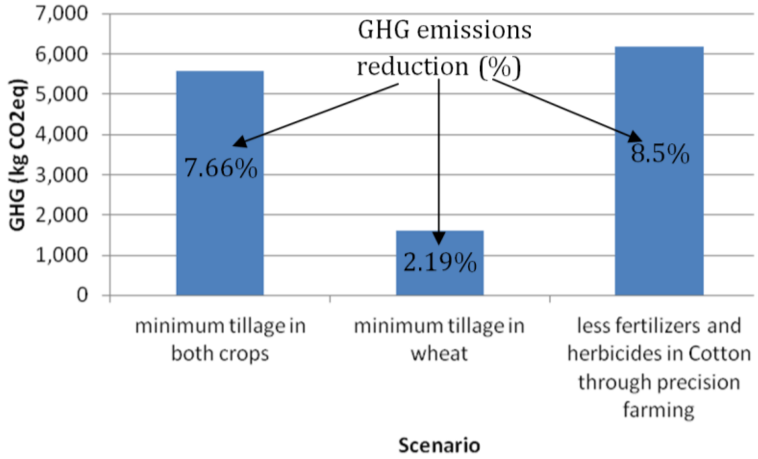

Figure 21: GHG emissions reduction using the three alternative scenarios

In the case of an owned farm the mortgage accounts for 16200 €/a (≈36% of the total annual costs), when in the case of the rented farm the rent accounts for 4500 €/annum (≈13% of the total annual costs). Therefore, the mean annual profit shown in Figure 22 is a lot more significant for an owned farm as it accounts for a higher percentage of the total profit (see Figure 23, Figure 24). In particular, the owned land farm gains 23.4%, 14.7%, 0.2%, when the three alternative scenarios substitute the basic one (Figure 23).

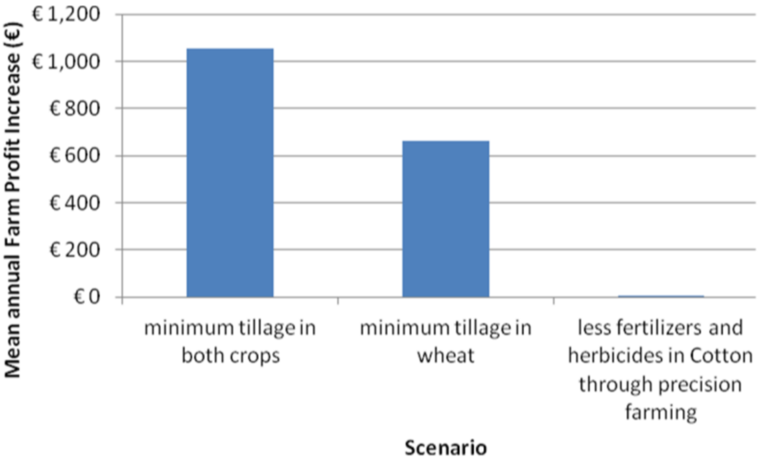

Figure 22: Profit increase using the three alternative scenarios

On the other hand, the rented farm gains 6.5%, 4%, 0.05%, when the three alternative scenarios substitute the basic one (Figure 24). However, for the rented farm the total income is higher. This is a result of overvalued land in comparison to land rent that indicates land purchase is not a profitable investment. It should also be pointed out that 1/3 (17850 €) of the total gross income of the 15 ha farm is derived by subsidies that still sustain the agricultural economy. If subsidies are eliminated, then this rotational system will be completely uneconomical.

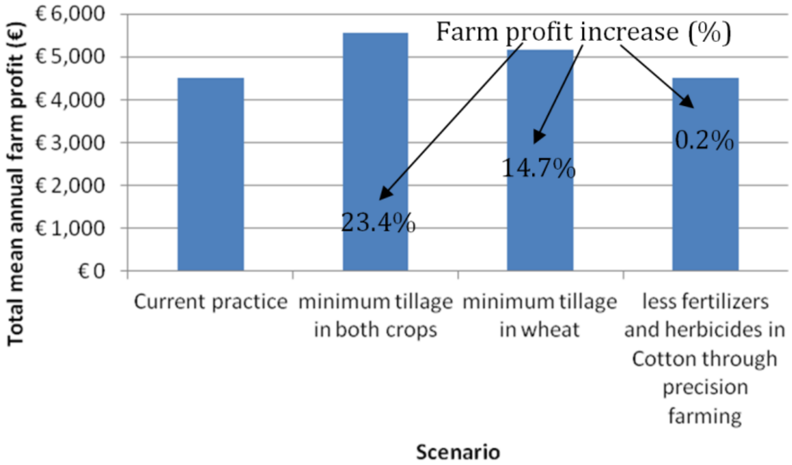

Figure 23: Total profit using the basic scenario and the three alternative scenarios (owned land)

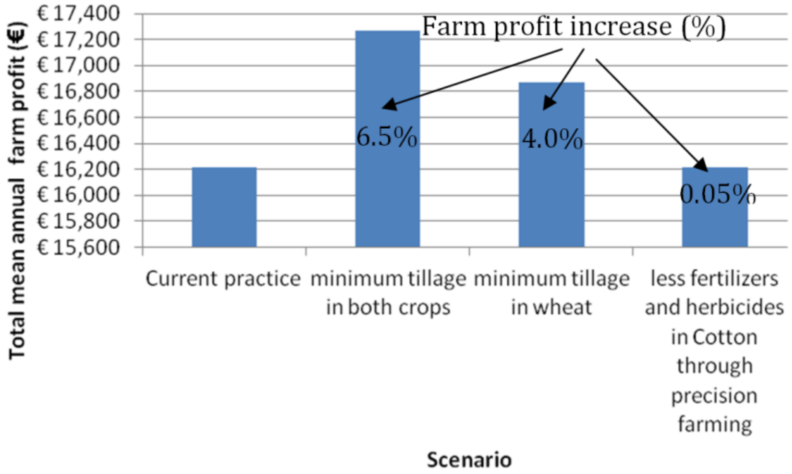

Figure 24: Total profit increase using the basic scenario and the three alternative scenarios (rent land).

Conclusions

In this report, there was an attempt to apply three of the energy efficiency measures that were proposed in the WP2 list for arable crops in Greece and in particular to wheat and cotton. The three scenarios analysed gave good results in terms of energy use reduction (which was the driver of this report), with positive side effects on environmental impact (GHG emissions decline) and on economics of the farm (higher final profit). However, it is believed that more energy efficiency measures should be evaluated by field experiments, in order to convince the Greek farmers to apply them in the near future.

4.1.7. Synthesis trade-off analysis of case studies in arable production systems

The case studies show different promising options for energy efficiency measures in crop production across Europe. Many of the presented energy efficiency measures target nitrogen fertilizer management since nitrogen fertilizer causes a very high share of total energy use in all cropping systems across Europe except organic farming, where synthetic nitrogen fertilizer is not allowed. Most of the measures targeting more efficient use of nitrogen fertilizer, like precision farming approaches, promise to be win-win solutions, with economic as well as environmental gains (Case studies from Germany (Ch. 4.1.1) and Greece (Ch. 4.1.6). The case study from the Netherlands (Ch. 4.1.4) reports energy savings but negligible economic effect for precision farming and the substitution of synthetic nitrogen fertilizer by compost. All energy efficiency measures targeting a more efficient nitrogen management also showed positive environmental effect in terms of GHG emission savings. Typically the impact of nitrogen fertilizer saving measures was the highest on reducing GHG emissions, slightly lower on energy saving and the lowest on economic indicators. It should be investigated as to what extent the economic benefit of these measures can be a sufficient incentive for farmers to adopt the energy efficiency measure.

Direct energy use in arable cropping systems is mainly caused by diesel use and on farm storage of the crops with the associated drying (in northern EU countries) and ventilation efforts. Reduced tillage is a known measure to reduce energy use in arable cropping systems, which is very successful, if it is feasible without negative impact on crop yields.

Investments in drying technologies, insulation or improved ventilation showed to contribute to economic and environmental gains in Finland, Germany and the Netherlands. The profitability of such investments of course depends on the current status of the farms and opportunity costs for capital, which varies substantially across Europe.

4.2. Case studies–dairy and beef production systems

4.2.1. Poland–Case study on Energy Saving Measures in Dairy Milk Production

Janusz Gołaszewski, Mariusz Stolarski, Zbigniew Brodziński, Ryszard Myhan, Ewelina Olba-Zięty

In Poland, about 60% of cash production on farms expressed in current prices, comes from livestock production, including over 6% generated by milk production. On average, the highest share in direct costs generated by milk production is attributed to animal feeding (63%), while 7% of the costs are due to veterinary services. This means that one of the principal means for increasing production efficiency is optimization of feeding and improved veterinary prophylaxis (feeding, breeding, insemination, culling, etc.). The above issues gain in importance when high-yielding cows are maintained (8-10 thousand kg of milk annually), because at such high milk yields, cows are extremely sensitive to any changes in production technology and require particularly rational and stable feed rations as well as frequent renewal of animals in the herd.

The energy saving measure tested in this analysis is an increase in dairy cow production intensity from moderate (6000 L of milk per year) to intensive one (8000 L milk per year). The analysis concerns a herd of dairy cows maintained in an indoor farming system fed all year on wilted grass silage containing 34% of dry matter. All our analyses are supported by numerical data included in a typical calculation sheet of farm income from production of 1 litre of milk, determined by experts from the Pomorski Agricultural Advisory Centre in Gdańsk.

In the following option we are presenting differences in costs, energy inputs and emission of greenhouse gases. The basic difference between the compared systems consists in the composition of feed, with a higher share of grinding grain (+41%) and high protein feed mixes (+5%) as well as supplementation of the feed with nutrient-rich preparation (Premix). Other differences are the quality of herds and veterinary services, including insemination treatments.

Relative Contribution of Different Inputs and Process Steps to Total Costs of Production, Energy Use, and Greenhouse Gas Emission

The energy saving measure in the following analysis is a change in milk production intensity from 6000L/LU to 8000 L/LU. At higher milk production yields, the total costs increased by 21.6%, total energy inputs by 14.1% and total CO_2e emission by 14.3% (Table 14).

Table 14: Annualized costs, PEC and GHG emissions per one LU for efficiency measure associated with the intensity of milk production (scenarios 6000 L/LU and 8000 L/LU).

Specification	Costs		Energy Use		CO_2e	
	€/LU	%	MJ/LU	%	kg/LU	%
6000 L variant						
Feed	1383	69.6	26392	73.8	3235	38.3
incl. concentrated feed	804	40.5	12116	33.9	1792	21.2
Veterinary services	75	3.8				
Herd replacement	119	6.0	3047	8.5	1355	16.0
Electricity	38	1.9	2910	8.1	150	1.8
Fuels	89	4.5	3400	9.5	197	2.3
Indirect costs	282	14.2				
Methane emission					3505	41.5
In total	1986	100.0	35748	100.0	8442	100.0
8000 L variant						
Feed	1766	69.7	31531	75.8	4135	42.0
incl. concentrated feed	1184	46.7	17216	41.4	2689	27.3
Veterinary services	99	3.9				
Herd replacement	159	6.3	3047	7.3	1355	13.7
Electricity	44	1.8	3395	8.2	175	1.8
Fuels	95	3.8	3630	8.7	211	2.1
Indirect costs	371	14.6				
Methane emission					3980	40.4
In total	2535	100.0	41602	100.0	9855	100.0
Percentage increase in total / LU	21.6		14.1		14.3	

Regardless of the production option, the structure of costs was dominated by feed €1383 (69.6%), followed by veterinary services and herd replacement €75+€119 (9.8%) as well as direct energy inputs €38+€89 (6.4%). At 8000 L/LU yield, the share of costs due to concentrated feed was 6.2% higher and those incurred by veterinary services and herd replacement increased by 0.4%. In turn, despite higher costs the energy inputs at 8000 L/LU milk yield contributed a smaller share to the structure of costs: electric energy consumption decreased by 0.1% and fuel consumption fell by 0.8%. The difference in the structure of energy inputs between the two production options was mainly due to 7.5% higher energy input for the concentrated feed. Analogously, the CO_2 emission for concentrated feed in this option ensuring higher yields (8000 L/LU) was 6.1% higher than in the other option (6000 L/LU).

Impact of energy efficiency measure on economics, energy use and the environment

By raising milk production intensity from 6000 L/LU to 8000 L/LU, it was possible to improve the economic, energy and environmental effects per litre of milk (Figure 25).

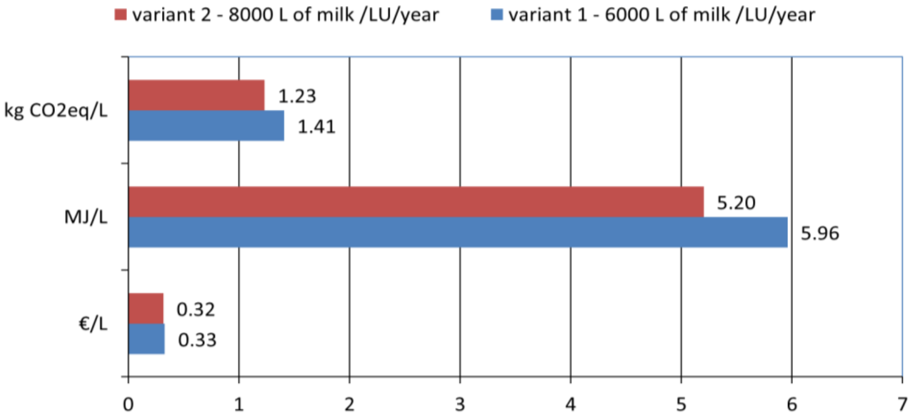

Figure 25: Impact of Energy Saving Measure on Cost Savings, Energy Use and GHG Emissions per L of milk.

Compared with the lower milk yielding (6000 L/LU), raising production to 8000 L/LU depreciated average costs of production of one liter of milk by 4.3% (from €0.33/L at less intensive production to €0.32/L in the more intensive production regime). At the same time, at higher milk yields, the energy inputs fell by 0.76 MJ/L (12.7%) from 5.96 MJ/L to 5.20 MJ/L, whereas emission of carbon dioxide decreased by 0.18 kg CO_2e/L (12.1%) from 1.41 kg CO_2e/L to 1.23 kg CO_2e/L.

4.2.2. Energy efficiency measures in Dutch milk production

Arie Klop, Harm Wemmenhove, Hilko Ellen

Dutch dairy farms are mainly based on a traditional family business. On average there are about 80 cows on the farm with a milk production of 8500 kg milk per cow per year, with 4.4% fat and 3.5% protein. A typical farm selected as a case study for this analysis has 16.19 ha of ground, divided in 11.33 ha grass and 4.86 ha of maize for silage (whole plant). For replacement there are about 28 heifers and 35 calves kept on the farm on a yearly basis. The cows have a liveweight of 600 kg on average and have an average age of 4 years and 3 months. During the summer months the cows graze in pastures near the farm. In wintertime the feed contains 20 kg grass silage, 14 kg maize silage and 7 kg concentrated feed (all kg product/cow/day). Milking is done in a herringbone milking parlour with 16 stands. At the farm level most of the energy is used for milking and cooling the milk during storage. Most of the work is carried out with own mechanization and labour. For silaging the farm partly uses contract work. The total investment in the housing is € 7000-€ 8000 per cow, not including land and mechanization.

Table 15 shows the income and costs of a typical Dutch farm (2011 level). Investment in housing and land should be paid from the difference between income and costs.

Table 15: Income and costs from a Dutch dairy farm with 80 cows.

Income/cost	Amount
Income products	€ 269200
Costs	
Feed cost	€ 40960
Pasture (fertilizer, fences, pesticides)	€ 23760
Housing (water, sawdust, etc)	€ 6320
Electricity	€ 6880
Healthcare cows	€ 15920
Contract work	€ 30400
Total costs (per 100 liter milk)	€ 124240 (€ 18.27)

For higher energy efficiency three measures were studied: 1) better fodder efficiency and less energy for producing young animals; 2) heat recovery from milk; 3) less total energy input but more energy / kg milk, comparing conventional to organic farming.

Better fodder efficiency

In this case a better fodder efficiency is the goal. Therefore replacement of dairy cows by heifers is changed from 30% to 20% per year. That means that less fodder is used for growing cattle, and that feedstuffs are used more efficiently for milk production. Conclusion: Longer lifetime for cows results in a lower yearly replacement from cows by heifers. Energy efficiency raises about 8%. The difference in energy efficiency is shown in Figure 26.

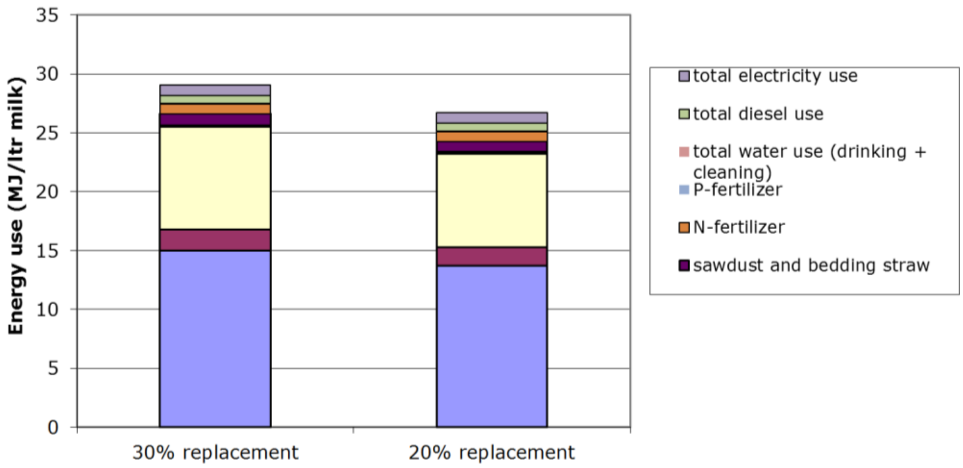

Figure 26: Difference in energy efficiency (in MJ/L milk) between 30% & 20% replacement of cows by heifers.

Heat recovery from milk

We used pre-cooling; directly after milking the milk is cooled with water down to 15 °C. The energy from the cooling machine is used to prepare water of 50 °C. This water is used for cleaning, and in some cases it can be used for domestic purposes. Besides that a frequency regulator for vacuum pump was added: total investment is about € 7,000. These measures give a reduction of energy input for milk cooling and storage of 740 MJ/LU per year for a farm of 80 cows. That corresponds to a reduction of 30%. In Figure 27 the difference in direct electricity use is shown.

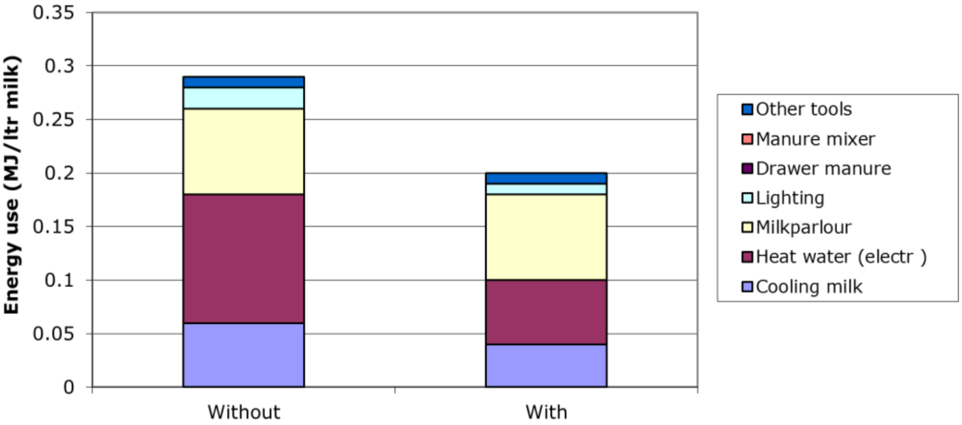

Figure 27: Difference in direct electricity use (MJ/L milk) for 80 cows with or without milk heat recovery.

Comparing conventional with organic farming

In literature a difference for energy input has been calculated between conventional and organic farming (Bos et al. 2007). The energy input was calculated for all feeds which were bought from outside the farm + the energy input in fertilizers + diesel and gas use and electricity needs for equipment. Conclusion: large differences were found in energy use and costs of fertilizers and concentrates. Organic farming leads to an energy use reduction of 25% with respect to conventional farming. In the study of Bos et al. (2007) the energy input for home grown roughage and concentrates were not taken into account. Figure 28 shows the difference in energy use based on this study.

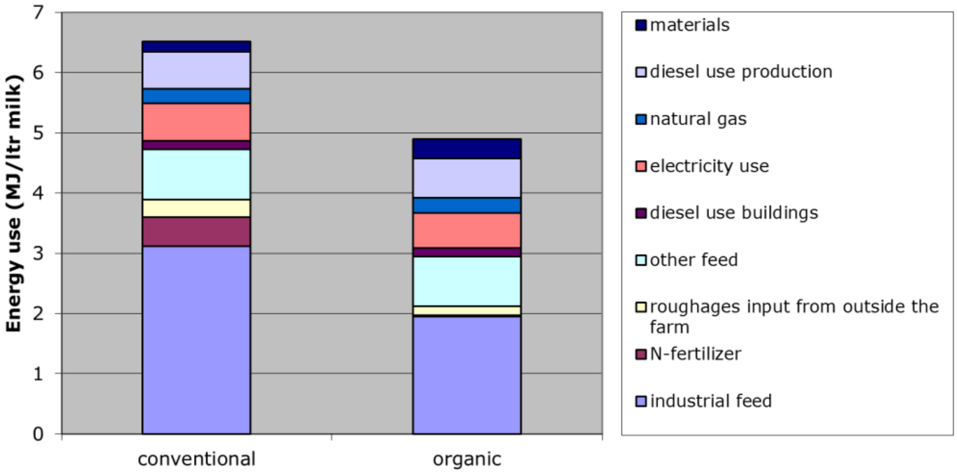

Figure 28: Difference in energy use between conventional and organic farming in MJ/L milk (Bos et al. 2007).

When we place the difference in energy use in the calculations for this project, we find a reduction in energy use of 13% per liter milk. The production of milk per cow per year on an organic farm is estimated at about 7950 kg.

Relative Contribution of different inputs and process steps to energy use, total costs of production and greenhouse gas emissions

In Table 16 the effects of the different measures on the energy use, the costs and the emission of greenhouse gases are shown. The effects are calculated for a 'standard' Dutch dairy farm with 80 cows and are presented per liter milk. Organic farming had the biggest impact on reducing energy use per liter milk and GHG emissions per liter milk. This is mainly because of the use of less industrial feed and fertilizers.

Table 16: Annualized costs, PEC and GHG emissions with energy efficiency measures, based on a Dutch model dairy farm.

	Annualized Cost		PEC		GHG	
	€/100 kg milk	%	MJ/L milk	%	CO_2e/L milk	%
Reference	18.27	100	29.1	100	280.3	100
Better fodder efficiency	18.27	100	26.7	92	280.2	100
Heat recovery from milk	17.96	98	28.8	99	245.3	90
Organic farming	n.a.		25.2	87	166.3	59

4.2.3. Energy efficiency measures in Portuguese Dairy Cows production

Fátima Baptista, Dina Murcho, Luis Leopoldo Silva, Carlos Marques

Introduction

According to Ministry of Agriculture, Rural Development and Planning (MADRP 2009) the dairy sector represented in 2009 around 12% of the agriculture national product. For the same year, in accordance with the National Statistics Institute (INE 2011), Portugal had 278,416 dairy cows, the Azores and Douro–Minho being the regions with the highest number of cows, each representing 33%. The North-coast had 12% and Alentejo 8%, with the biggest dairy farms located in this last region (average of 138.4 cows per farm).

Dairying is one of the agricultural subsectors that experienced a considerable development after the integration into the European Community due to the specialization of production and industrial structures. At the farm level there was an increase in farm size with a significant loss of small producers combined with a territorial concentration of farms. In spite of the decrease in the number of dairy cows in the last 10 years, national production has been almost constant due to the productivity increase resulting from the high investment in technology and genetic improvement.

Economic sustainability of dairy farms is mainly dependent on the quantity and quality of produced milk, feeding costs and reproductive performance (Rodrigues et al. 2012). According to these authors, average milk production was, in 2007, around 8500 kg of milk per cow per year with 3.61% fat and 3.21% of protein.

The main objective of this case study is to analyze the effect that changing to high milk production, through changes in feeding diet (quantity and quality), can have in the economic results, energy consumption and environmental impacts (GHG). The basic scenario is a farm with a production of 7,500 kg milk per cow and per year and the alternative is a farm with 11,000 kg milk/cow/year. It must be stated that cows producing at this level of intensification are much more sensitive to all changes and a huge attention is required to all production factors, such as buildings, environmental conditions, animal welfare, water quality, animal husbandry, skilled labour and feeding.

Basic scenario

A typical farm of 140 dairy cows in the Alentejo region was chosen to represent the basic scenario. The production is 7,500 kg of milk, per cow for 305 days of lactation. The farm has the necessary buildings, such as a dairy and milking parlor. Animals remain indoors day and night. The farm is equipped with all the necessary equipment, such as tractors, mixer-feeders to prepare and distribute the feed and a cooling tank to store and conserve the milk. Direct energy consumption is mainly for milking and cooling.

The feed mix, in total 39.5 kg per cow and per day, is composed of 24 kg of maize silage, 4kg of ryegrass silage, 3.6 kg of soybeans, 1.8 kg of maize gluten, 2.8 kg of maize flour, 2.8 kg of citrus pulp and 0.5 kg of proteins and minerals. Average dry matter is 40%. Feed is distributed twice a day. Cows go to the milking parlor twice per day. The dairy cows' production cycle was assumed to be 8 years which means that annual replacement rate is 12.5%. All animals born on the farm are sold and replacement is with cows bought in from specialized farms. Dairy farms receive a milk subsidy of 0.018 € per kg of milk.

High Production system

As mentioned above the alternative considered is milk production increased to 11,000 kg per cow per lactation. This is achieved with a different diet and assuming that all other important factors are under control. The data source is a real farm that produces under these conditions.

Feed, a total of 45.7 kg per animal per day, is distributed twice in order to be always available and fresh. The feed consists of 0.2 kg of hay, 6.5 kg of brewery waste grain, 2 kg of sugar beet pulp, 3.6 kg of millet, 1.33 kg of minerals, 2.55 kg of rapeseed, 2.5 kg of alfalfa, 23 kg of maize silage and 4 kg of ryegrass silage. Average dry matter is 48%. Cows go to the milking parlor for milking three times a day. The cows' productive life cycle is 5 years, therefore the annual replacement rate is 20%. As in the basic production system all animals born on the farm are sold and cow replacement is done with animal bought in from specialized farms. Milk subsidy is 0.018 € per kg of milk.

Impact of different energy efficiency measures on economics & environment

Figure 29 shows the relative contribution of the different inputs in the total costs, GHG emissions (CO_2eq) and energy consumption for the dairy farm in the basic scenario. It is clear that different inputs contribute in different proportion to the total costs, primary energy consumption and GHG emissions. This implies that small changes may induce only a little change in costs but have a high impact on energy use and GHG emissions.

Concerning the cost structure feed represents the highest amount and is around 83% of total costs. For the energy consumption feed contributes 70% and diesel and electricity account for almost 30%. For the GHG emissions the highest factor is from the cows themselves, contributing almost 70% of the emissions, followed by the feed with approximately 25%. This is due to the emission of methane by enteric fermentation and also due to animal manure fermentation. These impacts are well documented in literature (Schils et al. 2006; Van der Hoek & Van Schijndel 2006).

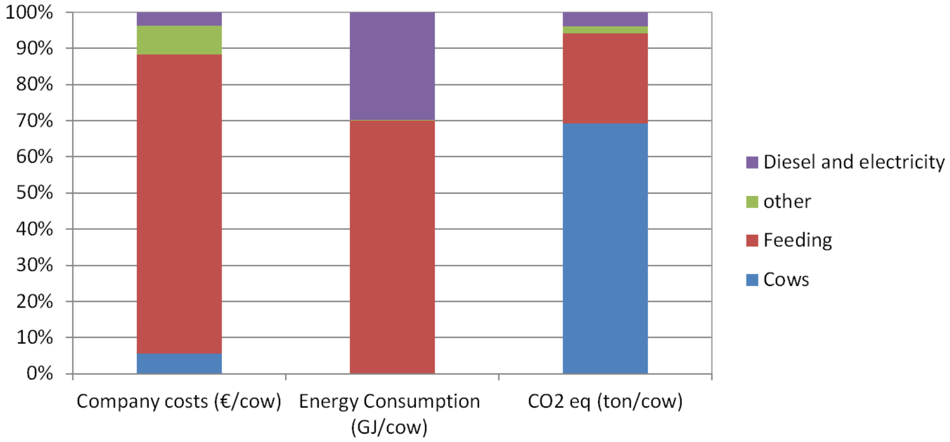

Figure 29: Relative contribution of different inputs in the farm production to farm costs economics, energy use and greenhouse gas emissions (GHG) per cow. (Other include bedding straw, veterinary and water).

Table 17 presents the costs and income for the basic scenario and the alternative option. Again, it can be seen the high contribution of feed costs in the total production costs, representing approximately 83% and 77% of the variable costs, for the basic scenario and the alternative, respectively. Fixed costs include labour and depreciation of machines, equipment, buildings and animals. Income results from selling milk, calves, cows at the end of their life cycle and the milk subsidy. The milk price considered is 0.33€ per kg.

The basic scenario presents a total costs per kg of milk of 0.354 €, which shows weak economic sustainability, expressed by the low margin (89.09 €/cow and without the CAP milk subsidy the net margin is negative). In the case of intensive production, the total costs is 0,297 €/kg and the net margin is approximately 765 €/cow, showing economic sustainability.

Table 18 and Figure 30 present costs, energy consumption and GHG emissions per cow. In an overall analysis it can be stated that increasing milk production by changing feed increases production costs, energy consumption and GHG emissions (23%, 47% and 14% respectively). This could be compensated for by the production increase. In fact it is possible to improve resource efficiency by increasing production and decreasing energy and GHG emission per product unit. In Figure 30 it is also showed the impact of the different options on farm profit. It is possible to see that intensive production increases the farm profit in more than 700%.

Figure 31 shows the impact on costs, profit, energy use and greenhouse gas emissions (GHG) per ton of milk produced. We can observe a different picture compared with the analysis performed by cow. Intensive production leads to a decrease of costs (16%), energy consumption is similar and GHG emissions decrease (22%). Profit increases due to the higher income and lower production costs (from 11.88 €/t to 69.55 €/t). The intensive production results in a substantial increase in profit, which seems to be a way to make the activity economically sustainable.

Table 17: Costs and income for a Portuguese dairy farm with 140 cows.

	Basic scenario		11000 kg	
	(€/year)	%	(€/year)	%
Variable costs				
Dairy cows replacement	15 750.00 €	6%	28 000.00 €	8%
Mixer feeder	236 235.30 €	83%	258 893.04 €	77%
bedding straw	9 345.00 €	3%	13 706.00 €	4%
veterinary drugs	12 915.00 €	5%	18 942.00 €	6%
water use	252.43 €	0%	252. 43 €	0%
buildings-electricity	8 190.00 €	3%	12 012.00 €	4%
diesel use	2 415.00 €	1%	3 542.00 €	1%
Total variable costs	285 102.73 €	100%	335 347.47 €	100%
Fixed costs	86 220.00 €		121 500.00 €	
Total costs	371 322.73 €		456 847.47 €	
Income	383 796.00 €		563 962.00 €	
Net private margin	12 473.27 €		107 114.53 €	
Net social margin	-6 741.73 €		78 932.53 €	

Table 18: Annual costs, PEC and GHG emissions with energy efficiency measures.

	Annual Cost		PEC		GHG	
	€/cow	%	MJ/cow	%	CO_2e/cow	%
basic scenario	2652.31	100.00	27257.47	100.00	4656.11	100.00
11000 kg	3263.20	123.03	40138.59	147.26	5308.65	114.01

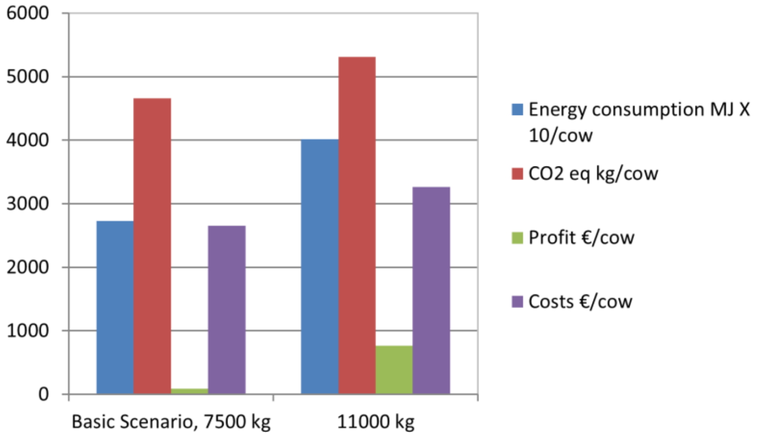

Figure 30: Impact of intensive production on costs, profit, energy use and GHG per cow.

Figure 32 shows the differences between the basic scenario and the intensive production, on energy, GHG emissions, costs and farm profit per ton of produced milk. Again, it is possible to see that intensive production can contribute to lower GHG emissions and to increased farm profit per unit of production.

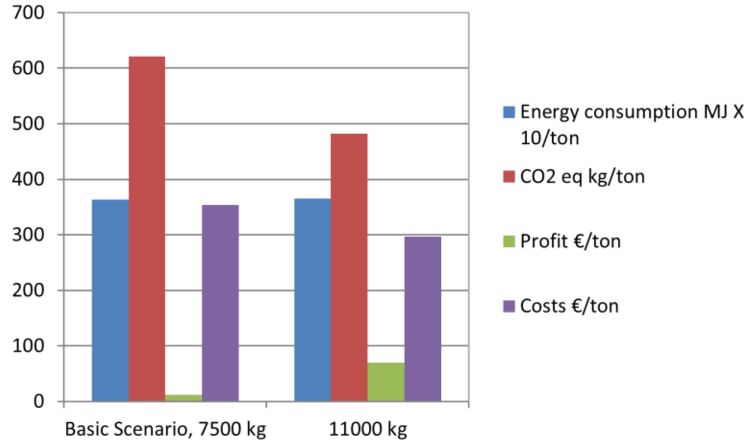

Figure 31: Impact of intensive production on costs, profit, energy use and GHG per ton of milk.

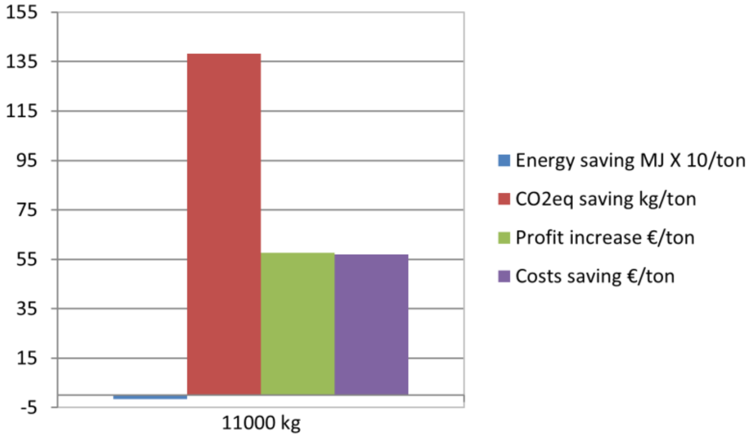

Figure 32: Differences of costs, profit, energy use and greenhouse gas emissions (GHG) per ton of milk between the basic scenario and the intensive production.

4.2.4. Energy efficiency measures in Finnish milk production

Hannu Yli-Kojola, Jussi Esala, Hannu Mikkola, Mari Rajaniemi, Tapani Jokiniemi, Jukka Ahokas

Milk is the most important sales product of Finnish farms. It totaled 37% of the selling incomes in 2009 (Niemi and Ahlstedt 2009). The number of milk producing farms was 19% of all farms in 2008 but the number of farms is decreasing by some 7% per year. Pyykkönen et al. (2010) have estimated that in 2020 there will be 4 800 milk producing farms, 11% of all farms (45 000). Though the number of the milk farms has decreased significantly the volume of milk produced has decreased by only 7% in the period of 2000-2010 (from $2{,}450\times10^6$ L to $2{,}270\times10^6$ L (Maa- ja metsätalousministeriön tietopalvelukeskus – TIKE 2011). The average number of cows per farm has increased in the same time from 19 to 30 and the average milk production per cow from 7 700 L to 8 700 L (cows in milk recording).

A change in cow housing goes parallel with the structural change. Tie-stalls for 15–30 cows are being replaced with free-stall cowsheds for 60 or 120 cows (1 or 2 milking robots). Almost half of Finnish cows live in free-stall housing today. Free-stalls enable exercise for cows and cows can decide themselves when they eat, rest, or go for milking (if an Automatic Milking System–AMS is used). Straw, saw dust, wood shavings or peat is used for bedding. Tied cows are milked in stalls and cows in free stalls at milking stations or increasingly by means of the automatic milking system (AMS). At the end of 2008 there were 385 AMSs in use and some 100 new AMSs are installed every year (Manninen 2009). In half of the new cow houses manure is handled as slurry and in one third as solid manure. In old cow houses the share of solid manure and slurry is 50/50. Natural ventilation is used in new cow houses with curtain side walls. Laminated wood or steel is the construction material of the frame of the new cow houses with the floor of concrete.

Silage made of grass is the most important feed for cows. In addition, protein concentrate, cereal, hay, and other feed components are used for feeding depending on the price and availability of the feed components and also on the intensity of production. Energy input for producing the feed (transport of feed components, mixing, and delivery) depends on the location of feed stores and on the feeding system (Total Mixed Ration–TMR or concentrate portioned individually and silage freely available).

Energy consumption in milk production

Direct energy is needed in milk production for heating water, lighting, ventilation, milking, milk cooling, manure removal, feed preparation and feed delivery. In cow houses less energy is needed for heating the building itself than in piggeries and poultry houses because full grown cows generate heat at 600–700 W (Mannfors and Hautala 2011). Moreover, cows thrive well in lower temperatures than pigs and poultry. The optimal temperature range for cows is 5–15°C and the critical lower temperature is -15°C (Maa- ja metsätalousministeriö 2012). In older cow houses there is in general no heating because buildings are heat insulated and the heat from the animals keeps the building warm enough. A semi-insulated free-stall cow house with curtain walls is a popular construction today and heating is needed at the milking station, at the rest room, and for heating water. Cubicles for sick and calving cows are also heated. The indoor air temperature stays above zero except for coldest days at winter time. Kivinen et al. (2007) found that the indoor temperature sank below zero when the outdoor temperature was -23°C but the limit depends *inter alia* on the number of animals per square metre, wind speed, wind direction and the location of the cow house.

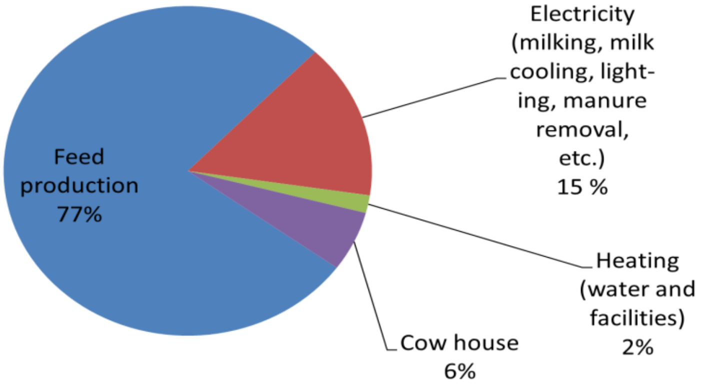

Figure 33: Distribution of energy input in milk production.

Figure 33 shows the distribution of energy input in milk production and also the dominating role of feed production. In the feed menu the main energy input originates from silage, pasture, cereal, protein concentrate and half concentrate. Silage, pasture and cereal are on-farm produced feed and farmers can have an impact on their energy inputs.

Energy saving measures in milk production

In the energy analysis of milk production it was assumed that the case farm had 30 or 50 cows and milk outputs were 6 831 l/year (low), 8 655 l/year (average) and 10 113 l/year (high). Feed mixes were the same as in the AGREE-WP2 report (Gołaszewski et al. 2012). Heat recovery from milk and replacement of grasses with nitrogen fixing plants (clovers) in silage cropping were the energy saving measures chosen for closer inspection.

Heat recovery from milk

A plate heat exchanger is a popular solution for recovering heat from milk and it was assumed to be used in this case. Furthermore, it was assumed that recovered heat was used to heat water. Wood chips were the reference fuel used for water heating. In the case study the investment in the heat exchanger was 3 500 € and the write-off period was 15 years.

Because wood chips are a cheap (16 €/MWh) renewable biomass energy source no GHG reduction was gained and the annual costs of heat recovery were higher than the annual profit. Thus, this was an uneconomical investment achieving no reduction in GHG emission. If electricity had been used as reference energy heat recovery from milk would have been economical and GHG emission reductions would have been gained in the case of 50 cows.

Replacement of grasses with nitrogen fixing plants (clovers) in silage leys

Replacement of grasses with nitrogen fixing plants (clovers) in silage leys would make it possible to produce silage without synthetic nitrogen. This is how farmers producing organic milk produce silage for their cows. So, this measure is tested in practice and it has proven to work. The analysis made for clover leys took into account the economic advantage and the reduction of GHG emissions. On the other hand, it did not take into account the probable additional costs caused by lower yield, higher annual yield variations and 1–2 years shorter time for a clover ley than for a grass ley. The shorter time of the clover leys is perhaps no problem because there are today seed drills which are capable for adding (drilling) clover seeds to existing leys. The time of clover leys can be extended in this way.

Clover leys have also other advantages than low costs for synthetic nitrogen and lower GHG emissions. Clover leys reduce the need to apply synthetic nitrogen for the next crop because the degrading root mass of clover supplies nitrogen for the next crop. Leys of 2–3 years diversify the crop rotation and improve soil structure. Clover leys can also reduce pressure of plant diseases. It is difficult to give a monetary value for these advantages and disadvantages but they certainly compensate each other partly. Perhaps more field area is needed to ensure adequate feed for the animals.

Cropping clover leys instead of grass leys is an energy saving measure which has an energy saving potential of 0.6–0.8 MJ/l milk. It saves costs 1.3–1.6 eurocents/l milk and reduces GHG emissions 52–65 g CO_2e/l milk. Cropping clover is not an investment but rather an operational measure. Therefore no payback time was counted. Reduction of GHG emissions of clover cropping is free of charge (Figure 34).

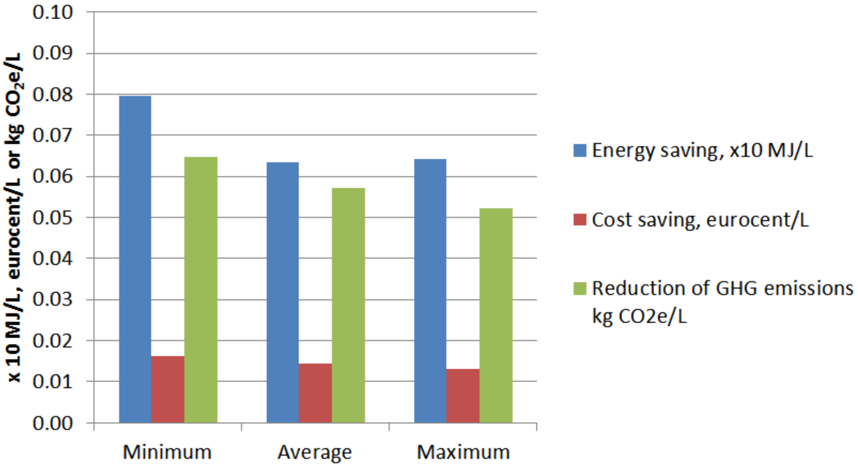

Figure 34: The impact of replacing grasses with nitrogen fixing clovers in silage lays on the energy and cost savings and reduction of GHG emissions. Minimum, average and maximum are production intensities.

4.2.5. Synthesis trade-off analysis of case studies in dairy production systems

The case studies suggested different auspicious as well as economically viable options for energy efficiency measures in dairy production across Europe. Poland and Portugal studied the option with a higher production by modifying the fodder composition and quantity. It has been proven to be effective in both regions. Although the total cost, energy consumption as well as GHG emissions increase with higher production rates, the efficiency increases as well. Per unit of milk production the costs, energy consumption and GHG emissions decrease up to 16% (Portugal), 12.7% (Poland) and 22% (Portugal) respectively. Moreover the case studies in Portugal showed a profit increase by almost 700%. As disadvantages of this method a higher proportion of replacement cows and a higher sensitivity of the cows to changes are expected. However Netherlands reported a lower replacement rate as well as a higher energy efficiency (8%) can be achieved by increasing the fodder efficiency. As an idea regarding the animal feed, Finland pointed out not only lower costs as well as lower GHG emissions but also other attractive advantages by replacing the grass with nitrogen fixing plants (clovers) in silage leys.

The concept of reducing fodder inputs per kg milk to dairy systems by increasing milk yield per cow is effective and convincing. Anyhow, as has been shown by the Dutch case study an increase in milk production has its limits and may not necessarily result in lower energy use per kg milk. The case study illustrates that the financial effects may create an incentive to develop milk production systems at very high milk yields, which do not contribute to energy savings anymore. Even though in this case study the increased milk yield resulted in CO_2 savings, it has been shown, that increasing milk production may also increase greenhouse gas emissions (Zehetmeier et al. 2011). Therefore, a balanced level of milk yield and the associated diet needs to be determined from economic as well as environmental perspectives, which probably differs strongly across Europe.

Another interesting energy saving measure is the heat recovery from milk. The study in Netherlands reported a reduction in energy consumption by 30%. The Finnish case study also pointed out the potential of saving energy by this method; however wood chips being used as the reference energy source dilute the advantages. In other words in the countries where no such cheap energy source is available, it can further be treated as a feasible option.

The Netherland' s case study suggested organic farming as an energy saving measures which proved to be very effective considering the 13% reduction in energy consumption per unit of milk production as compared to the conventional farming. However, this method involved compromising the milk production up to 6.5% (from 8500 L/LU/year to 7950 L/LU/year).

For future analysis and research ideas it should be noted that in the dairy and beef production the highest share in the total production cost as well as in total energy consumption is caused by the feed (see section 4.2.1 and section 4.2.3), whereas the source of highest GHG emission is the cow itself due to enteric and manure fermentation, which is one of the reasons why GHG emissions are lower on a product basis for high input systems (see section 4.2.3).

4.3. Case studies–pork and poultry production systems

4.3.1. Poland – Case study on Energy Saving Measures in Broiler Production

Janusz Gołaszewski, Mariusz Stolarski, Zbigniew Brodziński, Ryszard Myhan, Ewelina Olba-Zięty

In Poland, commercial production of poultry expressed in current prices reaches about 20% of livestock production. On highly intensive poultry farms with large flocks, the biggest problem is waste management. The legally permissible nitrogen rate is 170 kg ha^{-1} of agricultural land and limits considerably the use of poultry manure as fertilizer. For example, about 350-600 ha of arable land would be needed for a farm with a flock of 100 thousand laying hens to use the waste as fertilizer, but many poultry farms do not have the arable land area required by law. The problem of waste management is compounded by the question of transport, because the waste must be stored or transported away from the farm. The current animal husbandry systems have a strong influence not only on productivity and quality of produce or animal welfare but may also be a threat to the environment.

There are about 124.3 million poultry birds on Polish farms. Converted per 100 ha of arable land, this is 771 individuals. The number of large commercial poultry farms in Poland is 606, and so the number of large commercial poultry farms per 1 ha of arable land is 0.04. Estimates of amounts and physical properties of waste depend on a bird species and age. For broilers, the estimated amount of waste per bird is 65g/indiv./day, and the weight of 1 m^3 of waste is 622 kg, containing 68% of water.

Removing of manure after each cycle and application of rye straw by external contractor

Poultry manure, a by-product of poultry farms, is valuable material for production of organic fertilizers or as a potential source of energy, but on the other hand it is a possible threat to the poultry farm itself and to the natural environment.

Table 19: Input parameters for analysis of energy efficiency in broiler production.

Specification	Value
No of animals per cycle	19000
Duration of cycle	45 days
No of cycles	7
Age of animals at beginning of cycle	1 day
Planned losses of chicks	4%
Feed consumption per 1 kg body gain	1.9 kg
Final weight of broiler	2.5 kg
EUR:PLN	1:4.405
Veterinary services	
Vaccinations	0.06 PLN/indiv.
Check-up visits	150 PLN/visit
Veterinary examination (dead animals)	250 PLN/examination
Antibiotic	0.03 PLN/indiv.
Salmonella presence test (5th week of cycle)	55 PLN/flock
Specialist costs	
Detergenst and disinfectants	600 PLN/house
Bedding 2.5 t (rye straw)	250 PLN/t
Electric energy	2920 PLN/cycle
Heating oil	12800 PLN/cycle
Hired labour	017 PLN/indiv.
Weight of waste bedding	65 g/indiv./day
Value of manure	1675.56 PLN/cycle

Among alternative uses of poultry manure is energy generation. Due to a large content of nitrogen and mineral substances, use of poultry manure is subjected to many limitations. Straw bedding waste can undergo methane digestion or thermal conversion in combustion, co-combustion, gasification or pyrolysis processes.

In this analysis, it was assumed that the energy saving measure would be manure management by a contracted firm, which most often is an owner or someone cooperating with a local biogas plant or a thermal gasification plant. At the same time, a contracted company supplies the poultry farm with rye straw to use for bedding. The analysis was performed for a grow out house containing 19000 broilers per cycle. Seven cycles are run per year, and the mean weight of a broiler is 2.5 kg. Other assumptions are listed in Table 19.

Relative Contribution of Different Inputs and Process Steps to Total Costs of Production, Energy Use, and Greenhouse Gas Emission

In the following analysis, the energy saving measure consisted in chicken waste management for energy purposes by a contracted company after each of the 7 cycles of broiler rearing.

Table 20: Costs, Primary Energy Consumption (PEC) and GHG emissions per cycle of broiler production for efficiency measure associated with the utilization of poultry manure by external company for energy purposes.

Specification	Costs		Energy Use		CO_2e	
	€/cycle	%	MJ/cycle	%	kg/cycle	%
Original variant						
Feed	29625	63.9	356419	66.2	33766	64.6
Veterinary services/ disinfection	1165	2.5				
Other costs	7310	15.8				
Electric energy	894	1.9	68191	12.7	3515	6.7
Fuel	2985	6.4	113941	21.2	6609	12.6
General maintenance costs	4387	9.5				
Sale of manure						
Methane emission					8402	16.1
In total	46367	100.0	538551	100.0	52292	100.0
Variant including use of manure for energy generation purposes						
Feed	29483	64.4	356419	66.6	33766	64.8
Veterinary services/ disinfection	1165	2.5				
Other costs	7310	16.0				
Electric energy	894	2.0	68191	12.8	3515	6.7
Fuel	2887	6.3	110191	20.6	6392	12.3
General maintenance costs	4387	9.6				
Sale of manure	-380					
Methane emission					8402	16.1
In total	45747	100.8	534801	100.0	52075	100.0
Percentage decrease in total / cycle	1.34		0.70		0.42	

The reduction in the total costs, energy inputs and emission of carbon dioxide equals 1.34%, 0.70% and 0.42%, respectively (see Table 20). Better economic efficiency of the broiler farm is mainly attributed to the income from selling manure and reduced consumption of fuel needed to remove and store manure. At the same time, lower fuel consumption led to a higher energy efficiency and lower GHG emission.

Noteworthy is the fact that in a broader energy and environmental balance, beyond the farm to gate analysis, the positive effect of the analyzed energy saving measure is much more prominent as it conditions trade-off costs in the microeconomic context. Manure is a substrate in the process of energy generation, which means it will be utilized and serve as a substitute for fossil fuels, thus contributing to less emission of greenhouse gasses. Besides, it is a source of income for the companies cooperating with the poultry farm–collecting the manure and/or generating energy from renewable resources in own installations.

4.3.2. Case studies – pork and poultry production systems in the Netherlands

Energy efficiency measures in Dutch fattening pigs production

Fridtjof de Buisonje, Hilko Ellen

An average house for fattening pigs in The Netherlands has 14 climate separated units for 290 pigs each, for 4200 fattening pigs in total. The units can also be divided into pens in order to accommodate smaller groups of e.g. 12 pigs per pen. Fattening pigs are taken from a weaner or store pig of 25 kg to 118 kg of pig ready for slaughter. The average number of production cycles is 3.1 per year; resulting in a total production of around 13000 pigs per year, equivalent to 1500 tons of live pig weight per year.

The floor surface area per pig is 0.8 m^2, resulting in a total surface area for a pig house of around 4000 m^2 (including corridors, office space, hygienic sluice, storage and sick-bay).

The houses are insulated (Rc-value of walls and roofs of 2.5 (m^2.K/W)) and the convex concrete floors (except for the 60% surface share of the concrete slatted floors) are heated by underfloor warm water from a central heating unit. No bedding material is used. The feed conversion ratio (kg feed per kg live weight gain) is 2.65 kg/kg. Liquid manure is stored in deep manure pits under the slatted floors (7 month storage capacity is required).

Table 21: Income and costs from a Dutch pig farm with 4200 fattening pigs

Income/cost	Amount
Income products	€ 488040
Costs:	
Feed cost	€ 212940
Piglets	€ 161700
Water	€ 3780
Electricity	€ 4620
Heating (gas)	€ 3780
Healthcare	€ 5460
Others	€ 12180
Total costs (per 100 kg meat)	€ 404460 (€ 104.45)

The investment for the building is estimated at € 285 per pig place and € 140 for the inventory and amenities (or € 450 per m^2 or a total investment of € 1800000 for a pig house with 4200 places). In Table 21 the income and costs of a farm with 4200 fattening pigs are presented (2011 level). Costs for investment in housing should be paid from the difference between income and costs.

Three measures were studied for a higher energy efficiency: 1) the Canadian Bedding System; 2) mixed natural and forced ventilation and natural lighting; 3) replacement of 50 %

compound pelleted feed by agro-industrial wet byproducts.

The Canadian Bedding System

The Canadian Bedding System (‘wroetstal’ in Dutch) is an alternative housing system without slatted floors and with regular provision of bedding material (sawdust or chopped straw) with the aim to provide extra comfort and distraction to the pigs and to reduce the emissions from the manure storage. The objective is to get a higher price for the meat from this certified animal friendly production method, since the costs for bedding material are higher than the savings on gas consumption for heating. Because of the insulating properties of the bedding material, no heating of the pig house is required. The final mixture of manure and bedding material is more or less solid and the pens have a gently sloping floor, which slopes down towards a slatted manure channel. The pigs play and root in the bedding material and gradually move the mixture of bedding material and manure towards the manure channel where a scraper moves to an outside store, thus avoid around 65 % of the methane emission from a traditional pig house with manure storage under a slatted floor.

Mixed natural and forced ventilation and natural lighting

Mixed natural and forced ventilation and natural lighting aims at reducing the electricity consumption for ventilation and lighting. Natural ventilation e.g. with an open ridge in the roof using free airflow during periods when the pigs are smaller and outside climatic conditions are suitable, reduces the need for forced ventilation to periods only when the pigs are bigger and ambient temperatures are higher. Shuttered windows in the sidewalls, an open ridge and light shafts in the roof can provide natural lighting and replace artificial lighting almost completely.

Replacement of 50 % compound pelleted feed by agro-industrial wet byproducts

Replacement of 50 % compound pelleted feed by agro-industrial wet byproducts can reduce the carbon footprint of the mixture (in kg CO_2e) by almost 50 % since the direct and indirect energy contents of wet byproducts is more than 90 % lower compared with compound pelleted feed[3]. This is due to the calculation method for Greenhouse gas emissions where most energy inputs are attributed to the primary product from an agro-industrial process and not to the byproducts. Feeding byproducts requires facilities for storage, mixing, distribution and feeding of the liquid diet, causing a longer pay-back period, since the price difference between compound feed and wet byproducts on a nutritional base is decreasing due to competition from biogas installations.

Relative Contribution of different inputs and process steps to energy use, total costs of production and greenhouse gas emissions

In Table 22 the effects of the different measurements on the energy use, the costs and the emission of greenhouse gases are shown. The effects are calculated for a ‘standard’ Dutch

---

[3] for more information http://webapplicaties.wur.nl/software/feedprint/

pig farm with 4200 fattening pigs and presented per 100 kg meat produced.

Table 22: Annualized costs, PEC & GHG emissions with energy efficiency measures, based on a Dutch fattening pig farm.

	Annualized Cost		PEC[*)]		GHG[*)]	
	€/100 kg meat	%	MJ/100 kg meat	%	CO_2e/100 kg meat	%
Reference	104.45	100	3650	100	8624	100
Canadian Bedding System	118.00	113	4232	116	8526	99
Mixed natural and forced ventilation and natural lighting	102.35	98	3597	99	1877	22
Replacement of 50 % compound pelleted feed	143.10	137	2109	58	8586	99

*) The PEC or CO_2e emission is not known for all the input variables.

Energy efficiency measures in Dutch broiler production

Fridtjof de Buisonje, Hilko Ellen

An average broiler farm in The Netherlands consists of three poultry houses of around 1400 m^2 for 30000 broilers each, for 90000 broilers in total. A production cycle lasts 42 days, followed by a 9 days vacancy period for manure removal, cleaning and disinfection. This corresponds to 7 production cycles per year. The stocking density at the start of a cycle is 22 broiler chicks per m^2. At a live delivery weight of 2.15 kg per broiler, this farm produces 90000×7×2.15 = 1355 tons of live broiler weight per year (equivalent to 2709 Livestock Units (LU's) of 500 kg each).

The houses are insulated (Rc-value of walls and roofs of 2.5 (m^2.K/W)) and heated with direct gas heaters (hot air guns). The feed conversion ratio (kg feed per kg live weight gain) is 1.7 kg/kg. The concrete floors are littered with wood shavings or chopped straw at a quantity of 1 kg/m^2 at the start of each round. No litter material is added afterwards. Manure is evacuated from the house after every production round and stored in a shed.

Table 23: Income and costs from a Dutch broiler farm with 90000 broilers

Income/cost	Amount
Income products	€ 987522
Costs:	
Feed cost	€ 574749
Chickens	€ 186361
Water	€ 5054
Electricity	€ 14214
Heating (gas)	€ 28428
Healthcare	€ 30702
Others	€ 35314
Total costs (per 100 kg birds)	€ 874821 (€ 66.90)

The investments for buildings are estimated at € 200/m^2 and for the complete inventory € 87/m^2, so the total investment for a broiler farm with three houses is estimated at € 1,200,000.

In Table 23 the income and costs of a farm with 90,000 broilers are presented (level 2011). Costs for investment in housing should be paid from the difference between income and costs.

Three measures were studied for a higher energy efficiency: 1) integrated climate control; 2) heat exchanger with air mixing system; 3) central warm water heater with local heaters.

Integrated climate control

Integrated climate control 'Terra Sea' is a combination of different air treatment technologies (cooling, mixing, heating, scrubbing) with maximal energy saving and recovery. The aim is to control the climate in the house independently from the outside conditions and reduce emissions of ammonia, odor and particulate matter. It is a very complex and expensive system. The payback time is highly dependent on a predicted improvement of technical results of the broiler production. At the moment, this is the technology with the highest potential for reducing gas consumption for heating while increasing the electricity consumption by 25 %.

Heat exchanger with air mixing system

Heat exchanger with air mixing system is a combination of a heat exchanger that recuperates heat from the outgoing warm ventilation air, with an improved ventilation system that allows for a very efficient and even distribution of fresh warm air at animal level. The aim is to create favorable conditions for drying of the litter and therefore reduction of ammonia emission. The payback time is influenced by a predicted improvement of technical results of the broiler production. This system has a potential of 50 % savings on gas consumption for heating while increasing the electricity consumption by 10 %.

Central warm water heater with local heaters and ventilators

Central warm water heater with local heaters and ventilators is a combination of a high efficiency boiler, connected to a number of heat exchangers equipped with ventilators to ensure an energy efficient heating and an even distribution of warm air at animal level. The payback time is considered to be short because the yearly costs of this system are limited, compared to the yearly saving on gas consumption.

Relative Contribution of different inputs and process steps to energy use, total costs of production and greenhouse gas emissions

In Table 24 the effects of the different measurements on the energy use, the costs and the emission of greenhouse gases are shown. The effects are calculated for a 'standard' Dutch broiler farm with 90000 broilers and presented per 100 kg birds produced.

Table 24: Annualized costs, PEC and GHG emissions with energy efficiency measures, based on a Dutch broiler farm.

	Annualized Cost		PEC*)		GHG*)	
	€/100 kg meat	%	MJ/100 kg meat	%	CO_2e/100 kg meat	%
Reference	66.90	100	4220	100	49640	100
Integrated climate control	65.22	98	4240	101	60626	122
Heat exchanger	65.62	98	4224	100	53722	89
Central warm water heater	66.23	99	4215	100	49356	92

*) The PEC or CO_2e emission is not known Not from for all the input variables.

4.3.3. Case studies – pig and poultry production systems in Portugal

Energy efficiency measures in Portuguese Broiler production

Fátima Baptista, Dina Murcho, Luis Leopoldo Silva, Carlos Marques

Introduction

According to the ministry of agriculture, rural development and planning (MADRP 2009), in 2009 the poultry sector accounted for around 6.7% of the national agricultural output. Also in 2009, in accordance with the national statistics institute (INE 2011), Portugal had 20,254 million broilers, approximately 60% of all poultry. Production is concentrated in the regions of Beira Litoral, Ribatejo and Oeste. Portugal is self-sufficient in poultry-meat production.

In Portugal, broiler production is one of the sectors organized as a vertical integrated business. Companies provide production factors to farmers including chicks, feed, technical assistance and ensure the market supply. Most companies have their own feed production factories, slaughterhouses and distribution systems. The poultry industry uses various types of facilities, but typically only laying hens are kept in cages. Broilers are produced on the ground with a litter (rice husk, wood shavings etc.) or in less intensive outdoor production systems.

The main objective of this case study is to analyse the effect in economic results, energy consumption and environmental impacts (GHG) of 1) changing the heating system and 2) introducing a heat exchanger integrated in the ventilation system. The basic scenario is a farm with a production of 110,000 broilers per year equipped with air heaters.

Basic scenario

The basic scenario is an aviary located in the Ribatejo and Oeste region with a production of 20 000 broilers per flock, 5.5 flocks per year, producing a total of 110 000 broilers per year. The production cycle lasts in average 38 days reaching 1.8 kg of live weight. The feed conversion rate is 1.7 kg feed/kg broiler. One Livestock unity (LU) corresponds to 278 broilers. After each cycle, manure is removed and cleaning and disinfection are performed.

The poultry house area is 1200 m^2, with 17 broilers per m^2. Walls and roof are insulated (thermal resistance 2 m^2K/W) and the floor is littered with rice husk. Environmental control is achieved with mechanical ventilation, pad-and-fan cooling system and air heaters. Feed and water is automatically distributed. Electricity is the energy source for all the systems (0.03 € per broiler for ventilation, light, feed and water distribution and 0.04€ for the heating system). The total investment for housing and equipment is approximately 220 €/m^2.

Floor Heating/Underfloor Heating)

The aviary has the same characteristics in all alternatives except for the heating system. For the floor heating system it is necessary to invest in the floor radiator and a boiler using biomass as fuel. The investment is approximately 25 000 € more than before and the heating costs 0.015 € per broiler, which is significantly lower than before. The total investment for housing and equipment is in this case approximately 245 €/m^2.

Heat recovery

For this option a heat exchanger is integrated in ventilators, which allows recovery of the heat in the warm air that goes out through the ventilation system. The fresh air coming inside passes through the hot surfaces, without mixing with the outgoing air, and becomes warm and fresh. It is expected to decrease electricity consumption for heating in the order of 50% and the investment in this equipment is approximately 10 000 €. The total investment for housing and equipment is, in this case, approximately 230 €/m^2.

Impact of different energy efficiency measures on economics and the environment

Figure 35 shows the relative contribution of the different inputs in the total costs, GHG emissions (CO_2e) and energy consumption for the broiler farm assumed as the basic scenario. It is clear that different inputs contribute in different proportion to the total costs, primary energy consumption and GHG emissions. This implies that small changes may induce only a small change in costs but may have high impacts on energy use and GHG emissions. CO_2 equivalent emission was calculated using data presented in van der Sluis (2007).

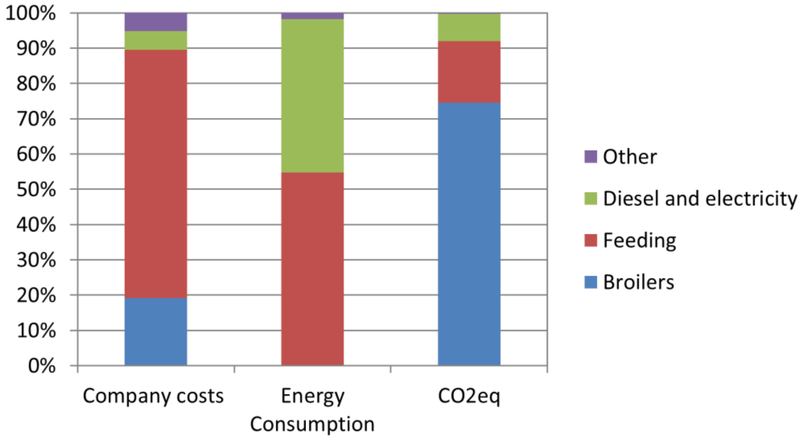

Figure 35: Relative contribution of different inputs in the farm production to economics, energy use and greenhouse gas emissions (GHG). Other include bedding straw, veterinary and water.

Concerning the costs structure it can be seen that feeding represents the highest value, around 70%. For the energy consumption it contributes for approximately 55% and diesel and electricity 43%. For the GHG emissions the major responsible are the broilers, due to the manure fermentation, contributing with almost 75% of the emissions, followed by the feeding with approximately 20% and diesel and electricity with less than 10%. Feed is a very important input concerning economy, energy and environment, in spite of the feed conversion rate being already a good value. More research about diet composition and industrial processes less energy consumer could be important to reduce this.

Table 26 presents the costs, energy consumption and GHG emissions per ton. Again, it can be seen that using the floor heating and the heat recovery will not cause high change in costs (2% and 1% respectively). However, the results concerning the energy consumption and GHG emissions are promising. Changing to floor heating allows reducing the energy consumption around 17% and 11% with the heat recover. Concerning the GHG emissions the reduction is not so high, 4% and 2%, for floor heating and heat recover, respectively, which is explained by the reduced amount of diesel and electricity and high contribution of animals to GHG emissions.

Table 25 presents the costs and income for the basic scenario and the studied options. Again, it can be seen the high contribution of feed in the production costs, representing more than 70% of the variable costs, for all scenarios. In the fixed costs were considered the labour, amortization of machines, equipment and buildings. Income results from selling the broilers. The market price for the broiler was assumed 1.6 € per kg. The basic scenario presents a total costs per 100 kg of broilers around 100.6 €, using the floor heating it is reduced to 98.8 € and with the heat recover 99.8 €, which are not significantly different. In all the cases farms are economically sustainable.

Table 25: Costs and income for a Portuguese broiler farm.

	Basic scenario		Floor Heating		Heat recover	
	(€/year)	%	(€/year)	%	(€/year)	%
Variable Costs						
Poultry	33,000	19	33,000	20	33,000	19
industrial feed	121,429	70	121,429	72	121,429	71
bedding straw	2,112	1	2,112	1	2,112	1
veterinary drugs	5,500	3	5,500	3	5,500	3
water use	1,291	1	1,291	1	1,291	1
buildings - electricity	7,700	4	1,414	1	5,504	3
biomass for heating		0	1,651	1		0
diesel use	1,538	1	1,538	1	1,538	1
	172,570	100	167,934	100	170,374	100
Fixed costs	26,586		27,752		27,252	
Total costs	199,156		195,687		197,627	
Income	316,800		316,800		316,800	
Net margin	117,644		121,113		119,173	

Figure 36 shows the differences between the basic scenario and the options studied, on energy consumption, GHG emissions and farm profit per ton of broilers produced. Again, it is possible to see that using floor heating or the heat exchanger can contribute to lower energy consumption and GHG emissions and consequently to increased farm profit per unit of production.

Table 26: Annual costs, PEC and GHG emissions with energy efficiency measures.

	Annual Cost		PEC		GHG	
	€/t	%	MJ/t	%	CO_2e/t	%
Basic Scenario	1006.64	100.00	13461.72	100.00	4028.54	100.00
Floor Heating	989.11	98.26	11230.33	83.42	3869.64	96.06
Heat recover	998.91	99.23	11923.89	88.58	3949.27	98.03

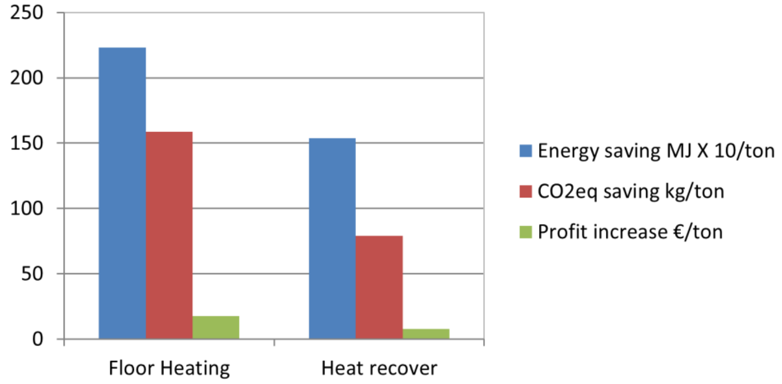

Figure 36: Differences of costs, profit increase, energy use and greenhouse gas emissions (GHG) savings per ton of broilers between the basic scenario, the floor heating and the heat exchanger.

Energy efficiency measures in Portuguese Pig production

Fátima Baptista, Dina Murcho, Luis Leopoldo Silva, Carlos Marques

Introduction

According to the Ministry of Agriculture, Rural Development and Planning (MADRP, 2009), pork is the meat with the highest consumption in Portugal and the pig production sector represented in 2009 around 8.5% of the national agricultural production. For the same year and, in accordance with the National Statistics Institute (INE, 2011), Portugal had a total number of 1,913 million pigs. Production is concentrated in the regions of Ribatejo and Oeste (45% of livestock), Alentejo (25%) and Beira Litoral (21%). In Ribatejo and Oeste are located the biggest pig production farms with an average of 264 pigs per farm.

It is a sector based mainly on the intensive livestock production, with a high degree of industrialization. Pigs are kept in buildings in order to control production conditions allowing reduced mortality and increased animal productivity. Buildings are adapted to the production phase, with separate areas for sows, maternity and fattening. Around 70% of the pig housing has partial slatted floor, with a solid area for animal resting. The slatted floor has the advantage of direct manure collection to pits located below the floor, which creates a barrier between the gas emissions (CH_4 and NH_3 that results from manure fermentation) and the air inside the housing. It implies frequent cleaning of the pits to avoid contamination and odour emissions. Heating is used only in the maternity and rearing of the piglets. Ventilation is natural or mechanical by extraction fans.

The main objective of this case study is to analyse the effect in the economic results, energy consumption and environmental impacts (GHG) of introducing new feeder equipment. The basic scenario is a farm dedicated to fattening with a production of 6,000 pigs per year.

Basic scenario

The studied farm, dedicated to fattening, has a building with 42 pens for 48 pigs each, fattening a total of approximately 2000 pigs. The average number of production cycles is 3 per year, which results in a total production of around 6000 pigs per year, with an average weight of 100 kg live weight. Assuming a mortality rate of 2% total production per year is 588 ton. Pigs are fattened from weaners of 20 kg to 100 kg pigs, ready for slaughter. During the fattening period pigs eat an average of 200 kg of industrial concentrate. The feed conversion ratio is 2.5 (kg feed per kg live weight gain).

The pig house area is 1545 m^2, including corridors, office and other areas. The floor surface area per pig is 0.75 m^2. Walls and roofs are insulated, with a thermal resistance of 1.7 m^2K/W. No heating is used and ventilation is achieved naturally, automatically controlled. The floor is partially slatted and no bedding material is used. Liquid manure is stored in deep manure pits under the slatted floors. Feed (ad libitum) and water are automatically distributed. Electricity is the energy source for all the systems (1 € per pig for ventilation, light, feed and water distribution). Total investment for housing and equipment is approximately 210 €/m^2.

Feeder equipment: Controlled access

The building has the same characteristics as the basic scenario except for feeding equipment. With the alternative feeder it is possible to reduce by approximately 100 g of concentrate per pig and per day (Aguiar, 2012). When the animal goes to eat, it touches a sensor and a small quantity of concentrate falls each time, helping to reduce food waste.

The investment in these feeders is 31,500 € (8000 € more than before). The total investment for housing and equipment, in this case, is approximately 215 €/m^2.

Impact of different energy efficiency measures on economics and the environment

Figure 37 shows the relative contribution of the different inputs in the total costs, GHG emissions (CO_2eq) and energy consumption for the pig farm assumed as the basic scenario. It is clear that different inputs contribute in different percentages to the total costs, primary energy consumption and GHG emissions. This implies that small changes in factors may have small effects in costs but different impacts on energy use and GHG emissions. Energy consumption for piglet production (feeding and heating) was assumed as 150 MJ/piglet.

CO_2eq emission was calculated using data presented in Amon et al. (2007) and Lesschen et al. (2011).

Concerning the cost structure it can be seen that feeding represents the highest share, around 59% followed by the piglets themselves with 36%. For the energy consumption feeding contributes for approximately 73% followed by the piglets and electricity with 14% and 13%, respectively. Regarding the GHG emissions, as expected, pigs account for the largest share, mainly due to enteric fermentation and also due to the manure fermentation, contributing to 83.5% of the emissions, followed by feeding to approximately 14.8% and electricity to 1.7%. Feed is a very important input concerning economy, energy and environment, in spite of the feed conversion rate being already a good value. Research into diet composition and industrial processes with less energy consumption could be important.

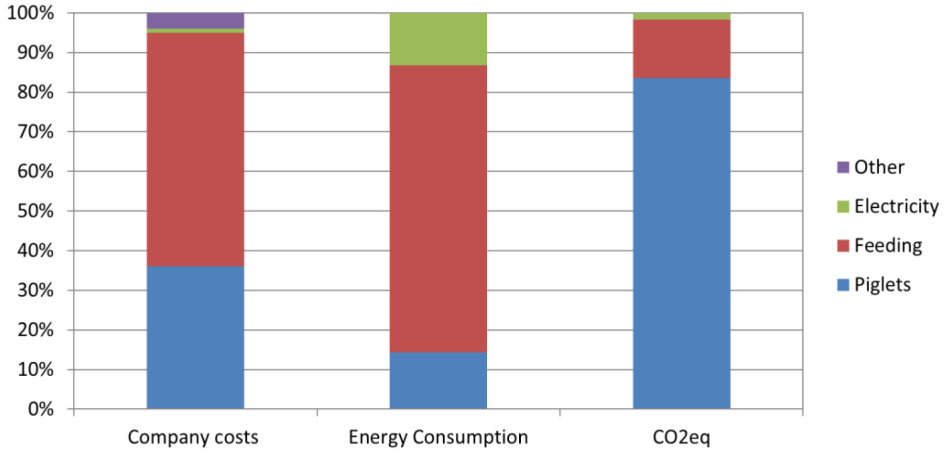

Figure 37: Relative contribution of different inputs in the farm production to economics, energy use and greenhouse gas emissions (GHG). Other includes veterinary and water for drinking and cleaning.

Table 27: Costs and income for a Portuguese pig fattening farm.

	Basic scenario		Feeders	
	(€/year)	%	(€/year)	%
Variable Costs				
piglets	205,800	36.0	205,800	37.3
Feeding	336,571	58.9	317,520	57.5
veterinary	8,820	1.5	8,820	1.6
water	14,300	2.5	14,300	2.6
buildings - electricity	5,880	1.0	5,880	1.1
	571,371	100	552,320	100
Fixed costs	27,827		28,617	
Total costs	599,198		580,937	
Income	789,684		789,684	
Net margin	190,485		208,747	

Table 27 presents the costs and income for the basic scenario and the alternative option. Again the high contribution of the feeding in the production costs can be seen, representing near 60% of the variable costs, for both scenarios. In the fixed costs are considered labour and amortization of equipment and buildings. Income results from selling the pigs. Weaners cost 35 € each and sale price for fattened pigs is 1.7 €/kg carcass (21% reduction). The basic scenario presents a total cost per pig around 100 € and using the feeder with controlled access costs are reduced to 97 €, which is not significantly different. In both cases farms are highly profitable and are economically viable under present product and input prices.

Table 28 presents the costs, energy consumption and GHG emissions per ton. Again, it can be seen that using the feeder alternative will not cause a high change in costs (3%). The same happens with the GHG emissions, with a reduction of less than 1% because of the high contribution of the pigs themselves. Concerning the energy consumption using the feeder option allows a reduction of almost 4% in energy consumption.

Table 28: Annual costs, PEC and GHG emissions with energy efficiency measures.

	Annual Cost		PEC		GHG	
	€/t	%	MJ/t	%	CO_2e/t	%
Basic Scenario	1019.04	100.00	10732.36	100.00	4376.96	100.00
Feeders	987.99	96.95	10291.55	95.89	4340.23	99.16

Figure 38 shows the differences between the basic scenario and the option analyzed, on energy consumption, GHG emissions and farm profit per ton of pigs produced. Again, it is possible to see that the use of the feeder with controlled access can contribute mainly to lower energy consumption per unit of production.

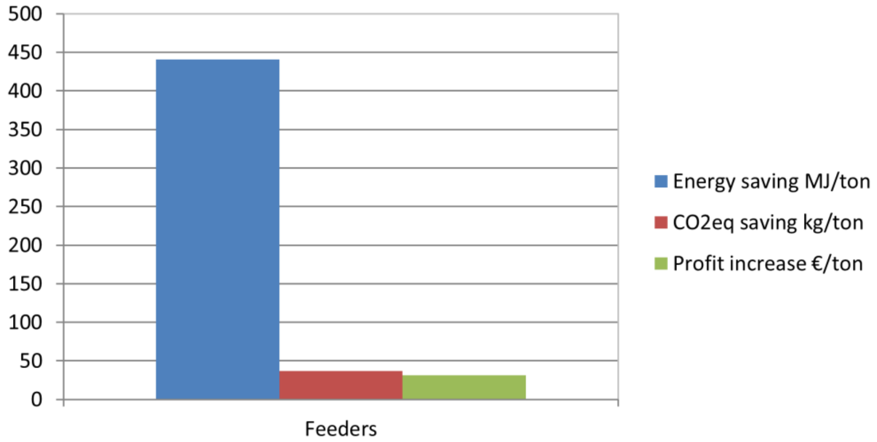

Figure 38: Differences of profit, energy use & GHG emissions (per ton) between the basic scenario and the studied option.

4.3.4. Energy efficiency measures in Finnish Poultry and Pork production

Hannu Yli-Kojola, Jussi Esala, Hannu Mikkola, Mari Rajaniemi, Tapani Jokiniemi, Jukka Ahokas

Pork production in Finland

Pork production is the second most important animal production sector in Finland, after milk production. In both sectors, a strong structural change is going on, and the number of pork producing farms is predicted to halve from 2010 to 2020 (Pyykkönen et al. 2010). The number of pig farms was 2,200 in 2009 and it is predicted to be less than 900 in 2020. The number of animals per farm will double from 275 fattening pigs per farm in 2010 (Maa- ja metsätalousministeriön tietopalvelukeskus – TIKE 2011) to over 500 in 2020. The volume of the Finnish pork production is supposed to stay at the present 200×10^6 kg level (Maa- ja metsätalousministeriön tietopalvelukeskus – TIKE 2011) if investment support for the structural development continues (Pyykkönen et al. 2010). Finnish pork farms are still small compared with e.g. Danish ones but they are developing from small family enterprises to bigger units using more paid employees. Pork production is concentrated in the southern and western part of Finland (Niemi & Ahlstedt 2012).

Feed for pigs is produced and prepared mainly on the farm but there are also farms which use industrially made compound feed. Farms produce on their own barley for pig feed. Milled barley flour is mixed with protein concentrate (soya) and other feed components.

The number of animals on a farm is limited by the requirements for a manure spreading area. This area requirement depends on the nutrient content of manure and soil. The higher the nutrient content in manure and soil the more area is needed for manure spreading because terms of the environmental support do not allow to exceed the regulated N and P application rates (kg/ha) (Maaseutuvirasto 2012). These regulations concern all animal farms not only pig farms. Pig manure is handled mainly as liquid slurry.

In a typical piggery layout for fattening pigs pens for 10 – 15 pigs each are located at both sides of the central passage which lies lengthwise in the building. Feeding troughs are located at the passage side of the pens and dung channels are at the opposite side of the pens at the outer walls. Ventilation is normally a forced negative pressure ventilation with outlet fans above the central passage and inlets at the upper edge of the walls or in the roof at the wall side. The piggery is subdivided into compartments of 250 – 300 pigs with partition walls. Feed is delivered to pigs dry or in bigger piggeries as liquid feed.

Energy consumption in pork production

An energy analysis made for Finnish pork production indicated that energy input for feed production (47%) and energy for piggery heating (34%) were the major energy inputs (Figure 39). They covered together over 80% the total energy input. The energy input for renewable animals (piglet production) was excluded from this analysis because very little data was available from piglet production.

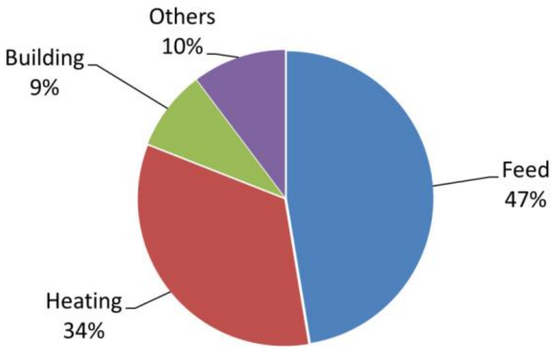

Figure 39: Distribution of the energy input in pork production in Finland.

However, a preliminary estimation was made for energy consumption for piglet production and it indicated that about 100 kg feed was needed to produce one piglet (from birth to the weight of 25 – 30 kg). The major part of the feed was consumed by the sow during the periods of gestation and lactation. In piglet production more energy is needed for heating than in pork production because piglets require higher inside temperature than fattening pigs and they generate less heat than fattening pigs. For these reasons it was concluded that energy input for replacing one fattening pig may be as high as half of the energy needed to raise one fattening pig.

Energy saving measures

A case study was made for a pork farm of 500 pig places. Three batches of 500 pigs were raised per year, totalling 1,500 pigs. Barley was the most important feed and it was cultivated on the farm. In average 221 – 225 kg barley was needed to raise one pig to 105–110 kg live weight and totally 340,000 kg barley was needed for feeding 1,500 pigs. Pig feed was mixed on the farm and delivered as liquid to the pigs.

In Finnish conditions it is necessary to heat pig houses because it ensures acceptable temperature and indoor air quality for pigs and people working in the pig house. In many cases farmers use wood chips as fuel because it is one of the cheapest fuels and it can be harvested from their own forests on the farm. It is common that there is a district heating system heating both the pig house and the domestic house. The same heating plant could be used also for grain drying because there is no demand for heating buildings at the time of grain harvesting. Peat sods are also used locally for heating piggeries and light fuel oil in some cases.

Two energy saving measures were chosen for a closer inspection. They were: 1) conserving fodder cereal in an airtight silo instead of drying and 2) a ventilation system with a heat exchanger in order to recover heat from the outlet air.

An airtight silo instead of drying

Drying is not necessary for barley which is used for pig feeding. Barley can be stored fresh in an airtight silo and the quality of the feed is as high as the quality of the feed made of dried grains (Siljander-Rasi et al. 2000). Energy input for drying is 10 – 11% of the total energy input of barley cultivation chain (Mikkola et al. 2010) and the expected energy saving was 10–11% respectively. The saving would decrease the total energy consumption in pork production 5% in maximum because the share of feed was 47% of the total energy consumption.

The costs of grain drying and airtight storage were compared in Table 29. In the column headed ‘An airproof silo’ there is a cost for grain drying also because some drying is needed anyway. A danger exists that grains spoil in the airtight silo at summer time when the air temperature is high.

Costs of these two conservation methods indicate that airproof storage is a more economical conservation method than drying. On the other hand, it is sensible to use any existing grain drier because operating costs for grain drying are lower than the total costs of airproof storage.

A Finnish grain drier is typically a building with integrated concrete foundation, steel made silos, and the drier itself. It is quite impossible to move the grain dryer economically to another place. It is more sensible to use the drier as long as it is usable and no major repairs are needed. An airproof silo is a good investment in cases where there is no grain drier on the farm at all, or the capacity of the old drier is inadequate, or the drier is in such bad condition that it should be replaced with a new one.

Table 29: Investment and operating costs of a grain dryer and an airproof grain silo. These are alternative methods for conserving cereal on a pork farm.

	A hot air grain dryer, batch volume 20 m^3	**An airproof grain silo, volume 400 m^3**
Basics of the investment		
Investment, €	130 000	40 000
Write-off period, years	20	20
Salvage value, 20% of the investment, €	26 000	8 000
Interest rate, %	5	5
Costs		
Annual amortization, €	8 345	2 568
Operating costs (grain dryer: 1.5 eurocent/kg), €	5 100	400
Drying, 30% of the grain yield, 6.0 eurocent/kg, €	-	6 000
Total, €	**13 445**	**8 968**

Heat recovery from outlet ventilation air

Heating of the pig house was the second highest energy input in pork production. An earlier study (Karhunen et al. 1983) indicated that recovering heat from the outlet ventilation air could substitute up to 90% of the heating energy. By means of a heat recovering system up to 30% of the total energy input could be saved in pork production. Suppliers of heat recovery systems emphasize that non-draughty conditions inside the piggery are even more important than energy saving. When inlet air is preheated the temperature differences in different places of the piggery are less and the animals thrive better. Though heat recovery improves welfare, it is difficult to calculate a monetary value for it.

Figure 40 and Figure 41 show that the heat recovery system would save more energy and costs than the airproof storage but the pay-back time for heat recovery is unacceptably long (66 years). Heat recovery caused additional costs to the case study farm but airtight storage as a substituting investment for the grain dryer resulted in a profit. Drying was the default method (business-as-usual) and airproof storage was found to be a cheaper choice. For this reason there is no pay-back time for the airproof storage and the cost for GHG emission saving is zero. As stated in the previous paragraph this assessment does not take into consideration welfare advantages of preheated ventilation air. These advantages can be considerable in the form of better health, faster growth, and lower feed consumption but more research would be needed to quantify the economic significance of these advantages.

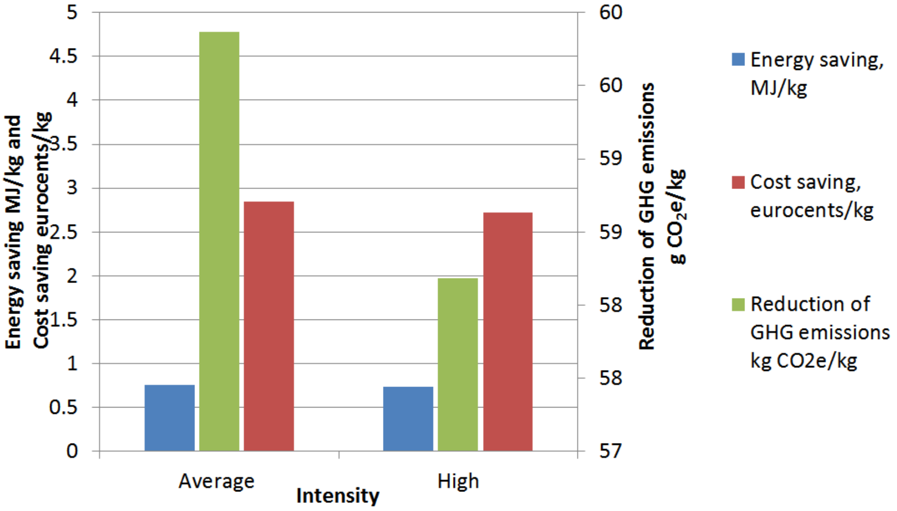

Figure 40: The impact of airproof storage on the energy and cost savings and the reduction of GHG emissions per 1 kg live weight in pork production. Average and high are production intensities.

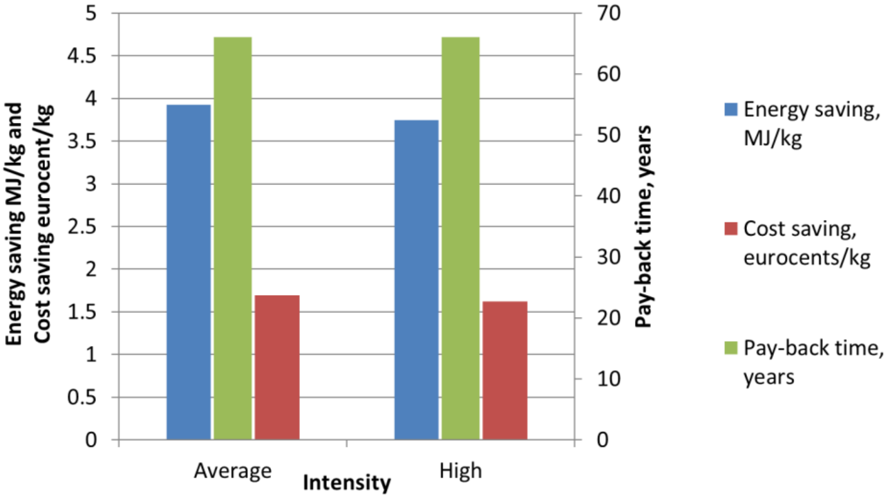

Figure 41: The impact of heat recovering from outlet ventilation air on the energy and cost savings per 1 kg live weight and the pay-back time of the investment. Average and high are production intensities.

Broiler production in Finland

Finnish broiler production is based on contracts between slaughter-houses and private farms. The production chain as a whole-from the import of broilers' grandparents to a meat package at a shop shelf-is carried out following a national quality system. Prevention of animal diseases (especially salmonella) and promotion of animal welfare are the vital goals of this system. The structure of the broiler production chain is presented in the Figure 42.

Scottish Ross is the genotype of broilers raised in Finland. Broilers are raised in batches of some 30 000 birds. The length of the raising period is 32 – 42 days. Population density in broiler houses is defined as the mass of living animals per square metre (Valtioneuvosto

2011). There is no exact upper limit for the population density but there are requirements for the air quality and temperature when the population density is over 33 kg/m^2. There must be a heating and cooling system which guarantees that the lowest and highest temperatures given in the decision of the Council of The Finnish State (Valtioneuvosto 2011) are not exceeded. The ventilation system has to keep the content of carbon dioxide, ammonia and air humidity under regulated limits. Additionally, if the population density is over 39 kg/m^2 (Valtioneuvosto 2011) the average mortality rate of seven preceding batches must be less than 1%.

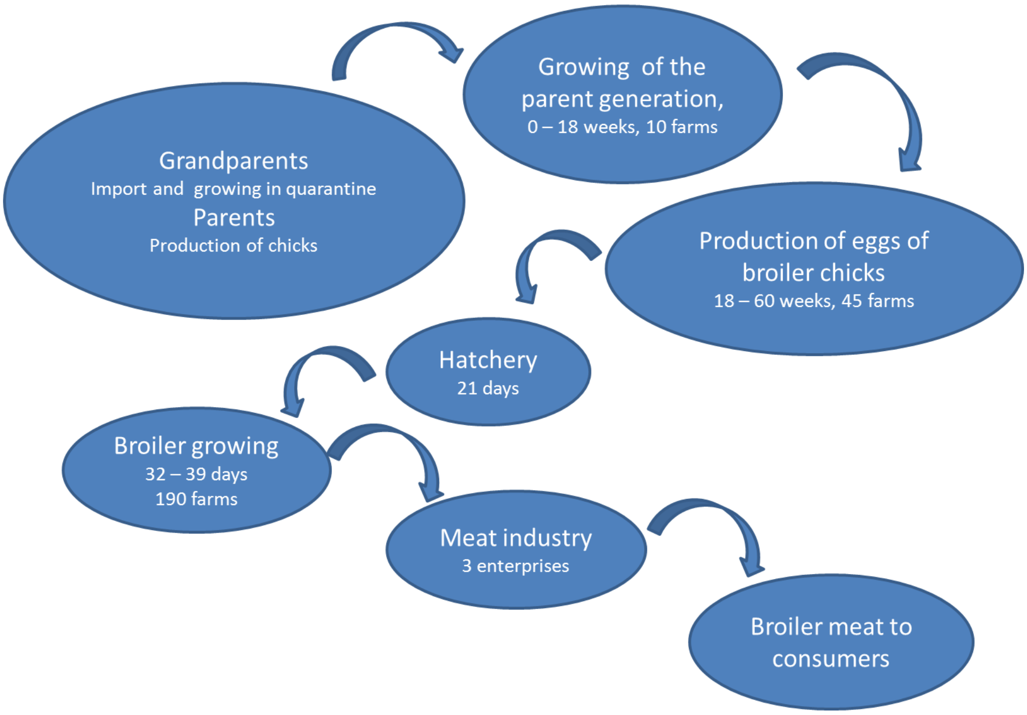

Figure 42: A scheme of the broiler production chain in Finland (Siipikarjaliitto 2012).

A typical broiler house is a heat insulated building with central heating, and forced ventilation. It is a windowless building. Light programs are used to optimize effective meat production. Broilers are free on the floor and a layer of 10 cm peat is used for littering. Birds get feed and water from feeding cups and drinking cups or nipples on the floor. In the beginning of the raising period the inside temperature is 32°C and it is lowered gradually to 22°C towards the end of the period. Ventilation is needed to keep the temperature, moisture, and the content of carbon dioxide and ammonia below recommended levels. Between batches there is a period when the broiler house is cleaned, disinfected, and littered for the next batch.

Broiler producing farms produce part of the feed (wheat) on their own fields but in general they buy a considerable part of the feed i.e. compound feed and protein. The feed mix is precisely tailored according to the raising phase of the birds.

The energy input for raising replacement chicks was excluded from this analysis accordingly as the energy input for raising piglets in pork production analysis because there is no data available. As the scheme in the Figure 42 shows there are many energy consuming steps before the actual raising period. A rough estimation based on the number of farms in the production chain before and during the raising period (55-60 farms producing chicks and 190 producing meat) indicated that the energy input for replacement could be up to 30% of the total energy input for raising broilers. This conclusion can be made if the energy input is on the same level on farms producing replacement animals and on farms producing broiler meat. This subject would need more research anyway, in the same way as energy input for replacement animals on all animal production sectors.

Energy consumption in poultry production

An energy analysis made for poultry production indicated similar distribution of energy inputs as in pork production (Figure 43). Feed was the major energy input (59%) and heating was the second (37%). Possibilities to save energy in feed production are more limited in broiler production than in pork production because a significant part (75%) of the feed is of industrially produced.

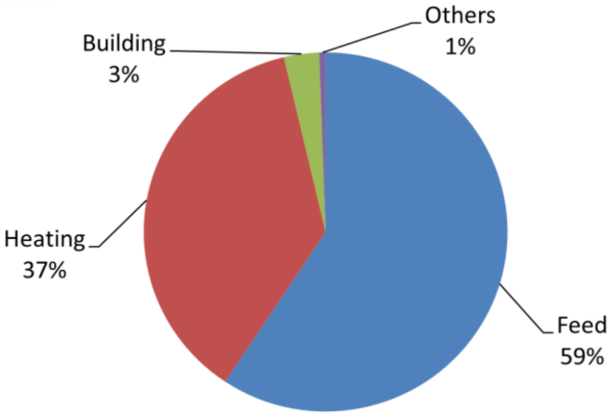

Figure 43: Distribution of the energy input in broiler production in Finland.

Energy saving measures

Suggested energy saving measures were the same as they were in pork production. Replacing grain drying with airproof conservation and heat recovery from the outlet ventilation air were seen as the most potential energy saving measures. In this case airtight conservation could save 1.5% from the total energy consumption maximum. Costs of drying and airproof storage are compared in Table 30. Figure 44 presents the impact of airproof storage on energy and cost saving and on reduction of GHG emissions.

Heat recovery was the second potential ES measure and the ES of heating energy was estimated to be 60% on the grounds of experiences in pig houses (Karhunen et al. 1983). In broiler houses there is demand for thermal energy especially in the beginning of the raising period when the temperature requirement is 32°C and small chicks generate little heat (less than 1 W, when their weight is below 150 g at the age of 1 – 7 days). The energy saving of the heat recovery system could be 19 – 22% of the total energy input of the broiler production chain at a maximum. Figure 45 represents the energy and cost saving as well as the pay-back time for heat recovering systems.

Table 30: Investment and operating costs of a grain dryer and an airproof grain silo on a poultry farm. Drying and airproof conserving are optional methods to conserve grain for broiler feed.

	A hot air grain dryer, batch volume 20 m^3	An airproof grain silo, volume 400 m^3
Basics of the investment		
Investment, €	140 000	40 000
Write-off period, years	20	20
Salvage value, 20% of the investment, €	28 000	8 000
Interest rate, %	5	5
Costs		
Annual amortization, €	8 987	2 568
Operating costs (grain dryer: 1.5 eurocent/kg), €	6 000	400
Drying, 30% of the grain yield, 6.0 eurocent/kg, €	-	6 000
Total, €	**14 987**	**8 968**

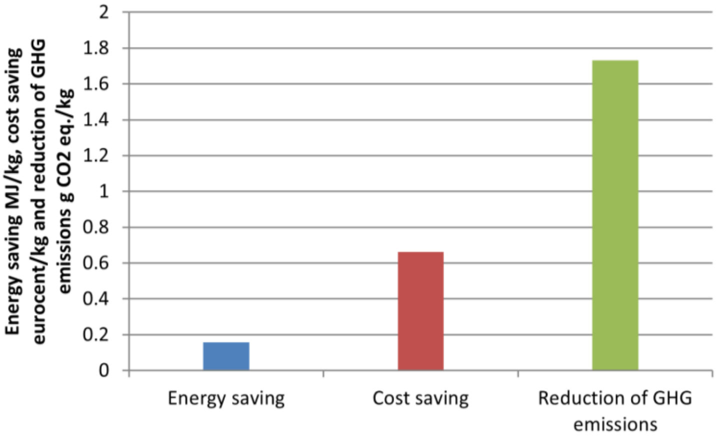

Figure 44: The impact of airproof storage on the energy and cost savings and the reduction of GHG emissions per 1 kg live weight in broiler production in Finland.

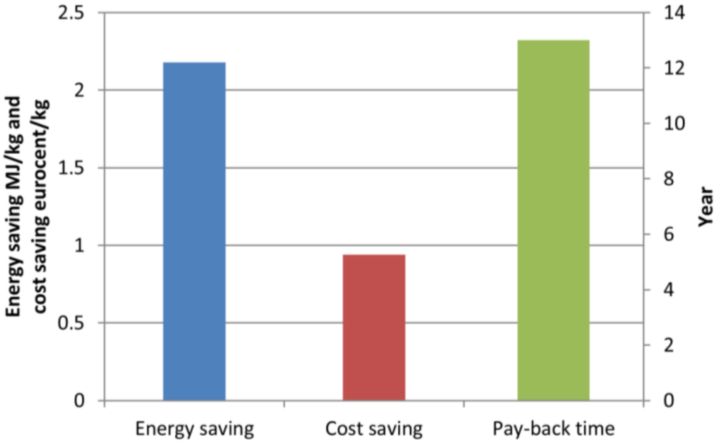

Figure 45: The impact of a heat recovering system on the energy and cost savings per 1 kg live weight and the pay-back time of the investment in broiler production in Finland.

4.3.5. Synthesis trade-off analysis and conclusions in pork and poultry production systems

Tommy Dalgaard

The case studies in pig and poultry production systems illustrate a number of interesting examples of trade-offs between the effects of measures to reduce energy consumption, GHG emissions, and their economic costs.

In general the systems for pig and poultry production are among the most industrialized and intensive agricultural systems of the countries studied, and cover a significant part of the total farm economy (for example about 20% in Poland, 15% in Portugal, and a similar or even higher proportion of the total farm economy in Finland, Denmark and The Netherlands). In total Gołaszewski et al. (2012) estimated a Primary Energy Consumption (PEC, in PJ) for broiler versus pig production of about 1 PJ vs. 6 PJ in Finland, 7 PJ vs. 43 PJ in Germany, 9 PJ vs. 33 PJ in The Netherlands, 12 PJ vs. 23 PJ in Poland, and 4 PJ vs. 3.89 PJ in Portugal. Consequently, in the countries studied, there is a significant potential for energy saving measures in these sectors. However, it must be noted that the total dairy production PEC in all countries was about 1.5 to 2 times higher than the summed PEC for pig and poultry production, except for Denmark, which has a high production of pig and poultry meat () compared to dairy and beef, and a similar total PEC in the dairy sector compared to the pig production sectors (Dalgaard et al. 2002).

As summarized in Table 31, the case studies of production system improvements show large differences between trade-offs between associated costs and the effect on energy consumption (PEC) and GHG emissions, emphasizing the importance of a case by case systems evaluation of such measures.

Table 31: Summary of estimated trade-offs between costs, primary energy consumption (PEC) and total CO_2 equivalent GHG Emissions (measured in % point difference compared to the reference) for the case studies selected in Poland (PL), The Netherlands (NL), Portugal (PT) and Finland (FI).

	Costs	PEC	GHG
Poultry:			
Energy generation from manure (PL)	-1.3%	-0.7%	-0.4%
Integrated climate control (NL)	-2%	+1%	+22%
Heat exchanger (NL)	-2%	0%	-11%
Central warm water heater (NL)	-1%	0%	-8%
Floor heating (PT)	-1.7%	-12.6%	0%
Heat recovery (PT)	-0.8%	-11.4%	-2.0%
Airtight feed storage (FI)		-1.6%	
Heat recovering system (FI)		-18%	
Fattening pigs:			
Canadian bedding system (NL)	+13%	+16%	-1%
Natural ventilation and lighting (NL)	-2%	-1%	-78%
Wet feed system (NL)	+37%	-42%	-1%
Controlled feed access (PT)	-3.0%	-4.1%	-0.8%
Airproof feed storage (FI)		-0.6%	
Heat recovery system (FI)		-21%	

Discussion and perspectives

In general, the mitigation measures included in the case studies have been selected for two different main reasons:

1) Either because of a desired reduction in the net energy use (for example via heat recovery systems, more efficient heating systems, more energy efficient feeding systems, natural ventilation or energy generation from manure), or
2) Because of other types of desired effects (for example better animal welfare in new bedding systems, or reduced costs and greenhouse gas emissions via more integrated climate control systems).

For the first category it is interesting to study possible synergy effects between reduced energy consumption, and reduced costs and GHG emissions. Consequently, the most interesting measures to promote are those energy saving measures which in addition reduce both costs and greenhouse gas emissions. In general this is the case for all the category one cases shown (except for the Dutch wet feeding system case, with a high implementation cost) , and we can thereby conclude that they are good examples of a potential big gain and that there is scope for further promotion of such measures in European farming. However the question is still whether there could be other measures with even higher potentials for reducing the energy consumption, but at substantial economic costs and undesirable effects on the emissions of other types of greenhouse gasses other than the energy linked CO_2-emissions (i.e. emissions of nitrous oxide or methane, in particular).

For the category two measures it is also interesting to see whether types of objectives other than reduced energy consumption, could also lead to energy savings or even reduced costs. However, in general monetary costs as well as energy costs and increased greenhouse gas emissions of such measures could be expected, and the agenda for the evaluation of category two measures is thereby how to reduce these derived disadvantages, and also in this respect the systems analyses illustrated gain useful results for decision making.

To compare the system level effect of measures like the cases studied here (Table 31) it is often not enough to calculate the partial effects of the single mitigation measures, but also to estimate the extent to which it may be expected that these measures can be implemented in the different livestock production sectors. Table 32 shows an example of such an estimation of plausible extents of three different measures to reduce GHG emissions from agriculture in Denmark. In this study it was furthermore discussed and concluded how far such measures could be combined to achieve a positive energy balance and a significant reduction of the GHG emissions (Dalgaard et al. 2011).

These results indicate the very different importance of various types of GHG-emissions effects from the exemplified measure options, and the importance of including fossil energy consumption related CO_2-emissions as well as emissions related to soil carbon pool changes in the accounts. To interpret the results and trade-off analyses it is consequently of vital importance to define and discuss the system boundary for the results synthesized and accounted, and especially for the energy related mitigation measure cases studied in this present report, the two categories of CO_2 emissions from respectively fossil energy combustion and negative soil carbon pool balances may be of special importance.

Table 32: Example on trade-offs between the net energy use and the effects on GHG emissions in the form of nitrous oxide (N_2O), methane (CH_4) or changes on the soil carbon pool (ΔC) in a Danish study (Dalgaard et al. 2011). The total effect of each mitigation option is derived from the partial effect per Livestock Unit (LU) and the expected extent to which the single measure can be implemented.

Mitigation option	Partial effect	Extent	(10^3 t CO_2e y^{-1})			
			N_2O	CH_4	ΔC	Energy
Cooling of pig slurry	230 kg CO_2e LU^{-1}	30 %	11	70	0.8	-10
Separation						
- Pig manure	330 kg CO_2e LU^{-1}	50 %	0	161	1.8	-5.8
- Cattle manure	285 kg CO_2e LU^{-1}	50 %	0	117	1.3	-5.3
Incineration, fibre fraction						
- Pig manure	290 kg CO_2e LU^{-1}	50 %	-1.6	9.0	-116	250
- Cattle manure	415 kg CO_2e LU^{-1}	50 %	-1.1	6.1	-144	313

The overall system and the various subsystems of pig farming and pig meat production are illustrated in Figure 46, and a similar overview could be made for poultry farming. The trade-off cases studied in this report all relate to different subsystems/sub-processes of either pig or poultry farming (for example the manure system, the heating system, or the feeding system). It is clear that these systems are interlinked, and that affecting one sub-system may also have influence on energy consumption and GHG emissions in other subsystems, and eventually the overall cost of the product. Consequently, a chain perspective is often useful in the evaluation of pork and poultry production systems, as well as for other type of products, and explicitly discussed in the synthesis and conclusion of results.

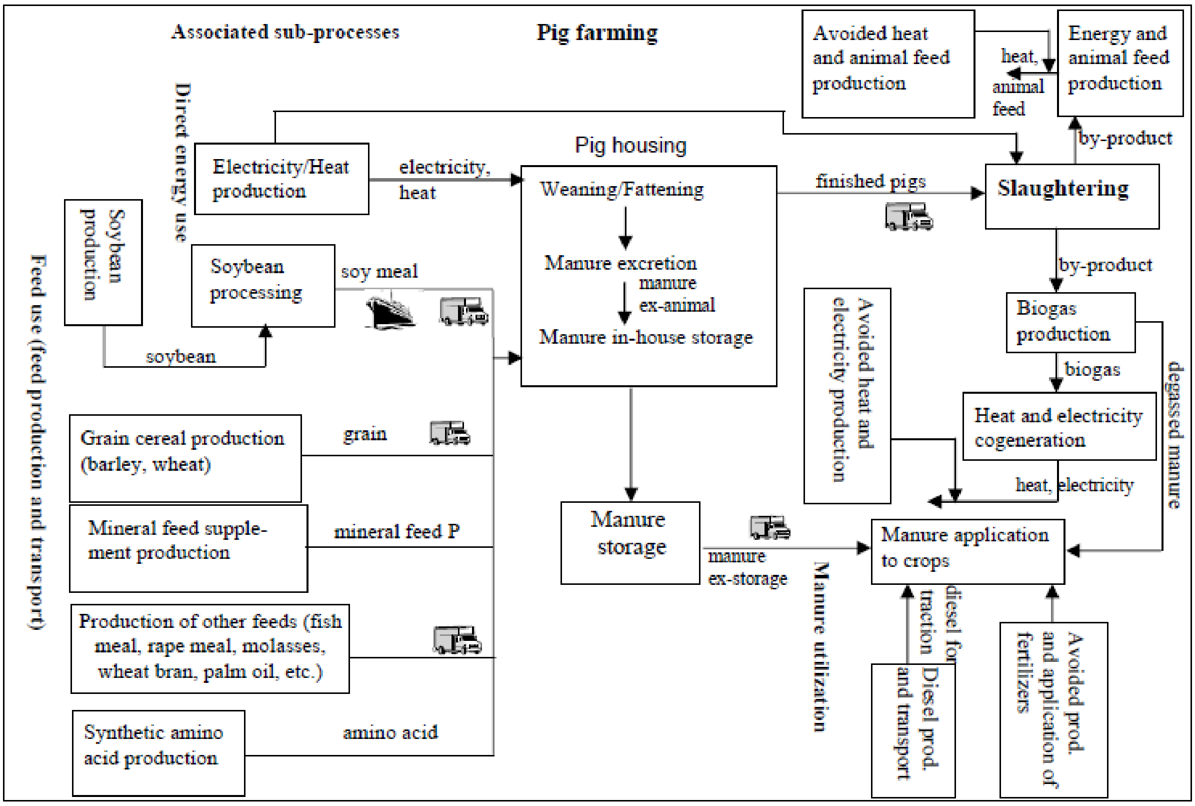

Figure 46: Overview of the product chain of pork (adapted from Nguyen et al. 2010).

In conclusion, the pig and poultry system cases studies of measures to reduce the net energy consumption showed remarkable potentials for reduced energy consumption and potentials for positive trade-offs to both lower costs and lower greenhouse gas emissions. However, some cases also revealed negative trade-offs, and costs both in term of economy, energy and greenhouse gas emissions. This was especially the case when the primary goal of the measure was not energy consumption mitigation but for instance animal welfare or production cost reductions. However, in all cases the system analyses yielded important information for the further development of environmentally sound and economically efficient production systems.

4.4. Case studies–greenhouse production systems

4.4.1. Case studies–greenhouse production systems (The Netherlands)

Cecilia Stanghellini

Relative contribution of processes to environmental impact

Of the various processes in a heated glasshouse in the Netherlands, the one that contributes most (by far) to the environmental impact is burning gas for heating. That was shown in the simple analysis of WP2, and has been analyzed through Life Cycle Analysis of all processes, including structure and transport of all production means, by Torrellas et al. 2012 (FP7-EUPHOROS), see Figure 47.

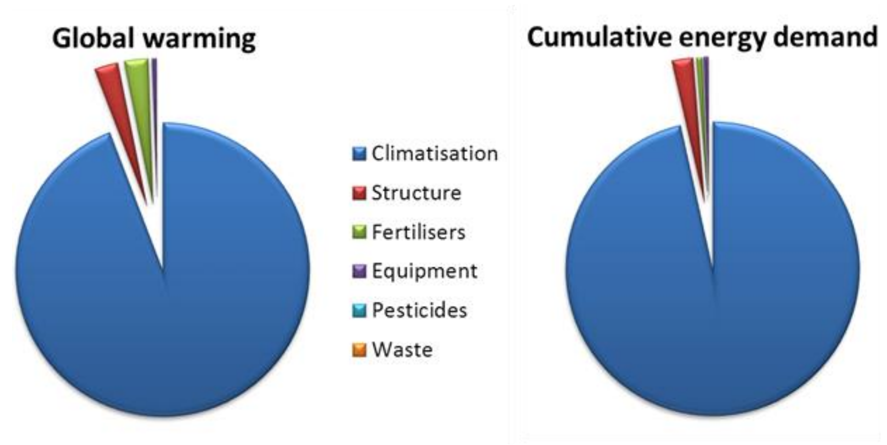

Figure 47: Relative contribution of the production processes (direct and indirect) in a standard Dutch glasshouse to global warming (measured by kg CO_2 equivalent, left) and total energy use (PEC, right). (Torrellas et al. 2012)

Therefore, the only significant way to save energy, and in general to decrease environmental impact in Dutch glasshouse production is to decrease heating requirement.

Description of the options considered

As gas for heating is also one of the largest cost components in glasshouse production, the fact that we are still so dependent on it is not for lack of trying to reduce its use. Indeed, the main topic of research about Dutch glasshouse production in the past 20 years or more, has been on energy saving.

Our reference case was a 1.5 ha multispan Venlo glasshouse producing either tomato or sweet pepper or cucumber. The glasshouse is fitted with the climate control that is standard in The Netherlands, that is: fully automated ventilation; heating, CO_2 enrichment and one energy screen. As the purpose of this exercise is to analyze possible energy saving measures for the primary production processes, our reference case is not fitted with combined heat and electricity production, although most Dutch growers are presently electricity producers as well. Three possible energy-saving measures are considered, with respect to this reference:

1. The use of an innovative, double layer cover, coupled to forced dehumidification
2. The new cultivation management system
3. The use of a diffusive glass cover

The first option analysed for this report is the most advanced energy-saving greenhouse design, the "Venlow" greenhouse, a prototype of which was built and tested at the facilities of Wageningen UR Greenhouse Horticulture in Bleiswijk, The Netherlands. The name "Venlow" combines Venlo (the most common glasshouse in The Netherlands) with "low" (energy requirement). That prototype realizes a reduction of more than 50% in heating requirement by coupling an innovative cover to innovative dehumidification. The cover is double-glazed, coated with an anti-reflection layer to attain a total light transmissivity comparable to the transmissivity of standard single glass. This is necessary as a loss of light would result in loss of production, because light is the limiting factor for production in Dutch greenhouses. One of the four glass-surfaces, however, is coated with a low-emissivity (rather than anti-reflection) layer, which limits energy losses at night. In addition, the chamber between the layers is filled with Argon, for further lowering heat transmission.

Besides light (and then production) loss, the reason that double glazing is rarely used in Holland is that most of the expected energy saving does not occur, as more ventilation is needed to remove the vapor that would condense on the cold inner surface of a standard glass cover. Dehumidification in the Venlow greenhouse is done by aspiring dryer external air through a cross-flow heat exchanger, whereby the humid air extracted from the greenhouse heats-up the air entering it. An additional advantage is that this kind of de-humidification is possible also while the energy screens are closed. Of course the fans entail an increase in electricity consumption but this is negligible with respect to the huge reduction in gas use (from 39.8 to 14 m^3 m-2/year for tomato).

The second scenario analyzed is known as "the new cultivation" in Dutch, which entails more flexible climate set-points which is something that does not require additional investment, and is coupled to the dehumidification method described above. More flexibility in climate is attained by allowing higher temperatures in sunny days (ventilating less) compensated for by less heating on cold nights. Indeed, it has been shown in extensive experiments that, in so far as the mean temperature as is usually desired, is maintained, some flexibility in climate does not reduce yields but does save on gas use for heating.

The third scenario is the application of a diffusive glass cover, which has been shown to increase productivity of most crops by some 10%, which of course only reduces energy consumption per unit yield, but not per unit surface.

As the energy requirement of all non-heating processes is negligible (see Figure 47), we did not consider the energy costs of coating, nor the possible increase in fertilizer use in the scenario that increases yield, that is scenario 3.

Results

The results for tomato are summarized in Table 33. It may be surprising that none of the options, including current practice, yields a positive financial result. This is known and, indeed, it is generally acknowledged that Dutch greenhouse production is profitable only through combined generation of heat and power, whereby excess electricity is sold.

Table 33: Annualized costs, PEC and GHG emissions per ha, with EE measures in greenhouse tomato production.

Scenario	Total company income		Total company costs		Total energy use (PEC)		Total GHG-emission	
	€/ha	%	€/ha	%	MJ/ha	%	kg CO_2e/ha	%
Current practice	437,100	100	550,900	100	13,070,581	100	750,855	100
Double glazed & innovative dehumidification	437,100	100	531,214	96	4,671,514	36	272,801	36
Additional screen & innovative dehumidification	437,100	100	541,327	98	8,903,602	68	557,399	74
Light diffusive cover	478,720	110	565,900	103	13,070,581	100	750,855	100

Table 34: Annualized costs, PEC and GHG emissions per ha, with EE measures in greenhouse sweet pepper production.

Scenario	Total company income		Total company costs		Total energy use (PEC)		Total GHG-emission	
	€/ha	%	€/ha	%	MJ/ha	%	kg CO_2e/ha	%
Current practice	414,375	100	470,000	100	10,406,651	100	598,410	100
Double glazed & innovative de-humidification	414,375	95	456,278	97	3,681,162	35	215,386	36
Additional screen & innovative dehumidification	414,375	95	463,386	99	6,989,303	67	403,967	68
Light diffusive cover	455,812.5	104	485,000	103	10,246,549	98	588,571	98

Table 35: Annualized costs, PEC and GHG emissions per ha, with EE measures in greenhouse cucumber production.

Scenario	Total company income		Total company costs		Total energy use (PEC)		Total GHG-emission	
	€/ha	%	€/ha	%	MJ/ha	%	kg CO_2e/ha	%
Current practice	469,600	100	573,500	100	12,192,915	100	700,687	100
Double glazed & innovative de-humidification	469,600	107	560,019	98	4,944,657	41	288,337	41
Additional screen & innovative dehumidification	469,600	107	565,053	99	8,521,795	70	492,134	70
Light diffusive cover	514,800	118	588,500	103	12,505,554	103	717,921	102

A light diffusive cover does not reduce energy consumption but does increase production; therefore the effect on energy does not show in Table 33, which refers to hectares. The results per ton produced, Table 36, are slightly more promising in this respect.

The results for all greenhouse crops considered are very similar. That is: there is a significant potential for energy saving and reduction of greenhouse gas emissions, but the gains are too marginal for the presently cash-strapped growers to consider. As Figure 48 shows, all options add to the fixed costs (capital) of the enterprise, which represent the largest fraction also in the reference case, whereas the gain is in the variable costs.

Table 36: Annualized costs, PEC and GHG emissions per ton product, with EE measures in greenhouse tomato production

Scenario	Total company income		Total company costs		Total energy use (PEC)		Total GHG-emission	
	€/t	%	€/t	%	MJ/t	%	kg CO_2e/t	%
Current practice	683	100	861	100	20,423	100	1,173	100
Double glazed & innovative dehumidification	683	100	830	96	7,299	36	426	36
Additional screen & innovative de-humidification	683	100	846	98	13,912	68	871	74
Light diffusive cover	680	100	804	93	18,566	91	1,067	91

Table 37: Annualized costs, PEC and GHG emissions (per ton), with EE measures in greenhouse sweet pepper production.

Scenario	Total company income		Total company costs		Total energy use (PEC)		Total GHG-emission	
	€/t	%	€/t	%	MJ/t	%	kg CO_2e/t	%
Current practice	1,275	100	1,446	100	32,020	100	1,841	100
Double glazed & innovative dehumidification	1,275	100	1,404	97	11,327	35	663	36
Additional screen & innovative dehumidification	1,275	100	1,426	99	21,506	67	1,243	68
Light diffusive cover	1,275	100	1,357	94	28,662	90	1,646	89

Table 38: Annualized costs, PEC and GHG emissions (per ton), with EE measures in greenhouse cucumber production.

Scenario	Total company income		Total company costs		Total energy use (PEC)		Total GHG-emission	
	€/t	%	€/t	%	MJ/t	%	kg CO_2e/t	%
Current practice	241	100	294	100	6,253	100	359	100
Double glazed & innovative dehumidification	241	100	287	98	2,536	41	148	41
Additional screen & innovative dehumidification	241	100	290	99	4,370	70	252	70
Light diffusive cover	240	100	274	93	5,830	93	335	93

Figure 49 shows the environmental impact (total energy use and global warming) of the production of 1 kg sweet pepper, in current practice and in the three energy saving options considered. The figures for the other crops would be very similar.

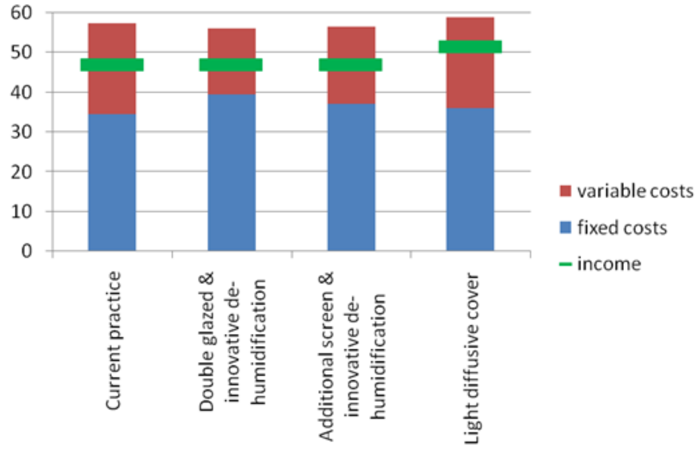

Figure 48: Cost distribution (fixed and variable) and income (€/m^2.year) for a greenhouse cucumber operation.

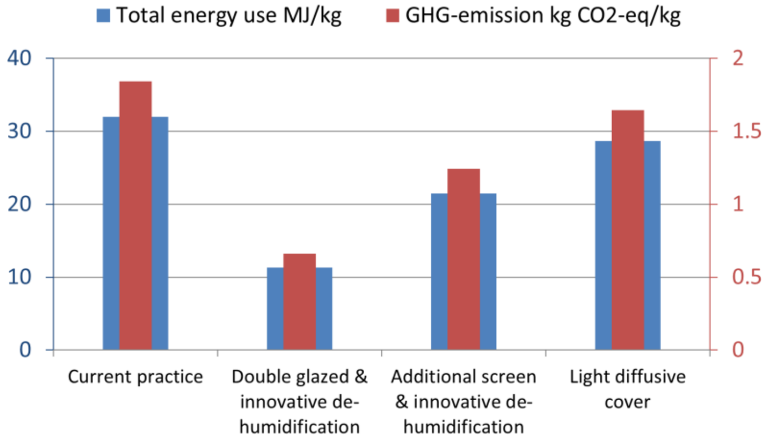

Figure 49: Environmental impact of the production of 1 kg sweet pepper for all options. The energy use (MJ/kg) is on the left axis and the emission of greenhouse gases (kg CO_2e/kg) is on the left.

Discussion

Given the overwhelming contribution of heating to the energy requirement of glasshouse production in The Netherlands we have only considered energy efficiency measures related to the issue of heating requirements. We have established that present technology allows for a reduction of more than 50% of gas use. However, that would require an investment that is presently out of the scope of most Dutch growers, even though it may deliver gains in the long term. As mentioned above, the primary production would be at a loss, were it not for the sale of electricity. Unfortunately, that income is also under pressure given the downward trend of electricity prices on the world's/national market. The whole sector (including the Dutch greenhouse builders association) does not expect investment in greenhouse construction in the Netherland to pick-up anytime soon. Unfortunately, the same bleak outlook applies also to intermediate options, since the smaller capital requirement would be coupled to a smaller reduction in running costs.

Although unheated greenhouse production is out of the scope of this project, it is worth observing that the energy requirement of un-heated greenhouses is about evenly split among production of structure; of equipment; and of fertilizers (Torrellas et al. 2012). Savings of some 40% of fertilizers (and 25% of irrigation water) have been attained by applying closed-loop irrigation in greenhouse tomato on substrate (García-Victoria et al. 2012) and by improving irrigation of soil-grown cucumber (Tuzel et al. 2012). This means that a better management of fertigation could bring about a significant reduction in energy requirement in the Mediterranean greenhouse production, but not in The Netherlands where, re-circulation of drain water is already commonly applied.

4.4.2. Energy efficiency measures in a Greek greenhouse production system

Antonis Mistriotis, Athanasios Balafoutis, Demetres Briassoulis

Introduction

Greenhouses in Greece cover a total agricultural area of 4900 ha approximately, out of which 4000 ha concern vegetables production (EL.STAT 2006). The majority is concentrated in Crete, where more than 40% of greenhouses are located (EL.STAT 2006; Ministry of Rural Development 2006), with emphasis in vegetables (tomato, cucumber, sweet pepper, eggplant etc) and flower production (recent data for greenhouses area in Crete: 2,332 ha).

The vast majority, more than 90%, are plastic covered (94% according to Ministry of Rural Development 2006). About half of the Greek greenhouses are unheated and 26% are lightly heated (Ministry of Rural Development 2006). However, in the case of heated greenhouses, heating is the most important energy consumption (Figure 50). On the contrary, unheated greenhouses consume much less energy, but provide low productivity. A typical productivity of an unheated greenhouse for tomatoes is 150 tons/year/ha, while for heated ones it can reach 230-380 tons/year/ha.

Considering the above data, two general strategies may be proposed aiming at reducing energy consumption in greenhouses. If fully heated greenhouses are considered (only 25% in Greece), measures aiming at improving heating efficiency and reducing heat losses have to be proposed.

On the other hand, in the most important for the Greek case of unheated greenhouses attention should be given towards the improvement of the indoor microclimate. In this way their productivity can improve. Since low temperature during the winter nights is the most important problem of unheated and lightly heated greenhouses, heat storage or other passive systems have to be added. Despite the fact that heat storage in greenhouses has been extensively studied in the last twenty years (Sethi & Sarma, 2008), the technology is rarely used due to higher installation cost and the more sophisticated operational skills required by the farmer. Further research is required on this topic for adding heat storage equipment as a standard component of unheated greenhouses in S. Europe.

Methodology

The current report focuses on energy saving measures for two cases: a) an average input heated greenhouse in S. Greece (Attica) and b) a typical unheated greenhouse in Crete.

There are several types of energy efficiency measures that could be applied in a greenhouse system (see Energy efficiency measures report for Greece in WP2, Gołaszewski et al. 2012a), but in this report it was selected to analyse the case of insulation of the side towards the main wind, the case of wind brake installation in front of the side towards the main wind and change of heating system from electricity to biomass as possible energy efficiency measures. The impact of these measures on greenhouse gas (GHG) emissions and on the economics of the farm are also examined.

The basic scenario that was chosen for this report is a typical greenhouse of 1 hectare, where tomato or cucumber is cultivated.

Basic scenario–Heated greenhouse in Attica

The greenhouse surface is in total 1 ha (50 m x 200 m). It is constructed in year 1 and in this report we consider a lifetime of 20 years.

The cultivation procedure in the greenhouse under investigation follows the steps below:

Greenhouse installation

1. Preparation

The land parcel selected for the greenhouse installation is prepared (earth moving if necessary) and the foundations are installed (cement basis for the frame).

2. Frame and plastic cover installation

The frame is assembled and installed in the foundations. The roof windows, together with the automated mechanisms, are also adjusted on the frame. Then, specialised workers install the plastic cover.

3. Mechanisms installation

After the frame is ready, then all mechanisms are installed. In particular:

- Electric circuit for all the greenhouse requirements (accompanied by an electric generator for electricity cuts)
- Thermal screen
- Aeration (fans) and cooling (panels) equipment
- Automatic drip irrigation system is installed (pumps + drip pipes + automatic control).
- Plant suspension system

Annual work

- *Soil treatment*

Preparation of the soil by using the following machinery:

1. Light cultivator
2. Rotary cultivator

- Solarisation

Solarisation film is installed every year for 4–8 weeks during the summer period (July–

August). Before installing the film the soil is cleared of plant residues and the irrigation drip pipes are put in the future plant lines. Then, the soil is irrigated heavily and is covered with the film. The solarisation film is kept in the greenhouse for the whole cultivation period, aimed at weakening or eliminating disease, weeds and nematodes harmful to plants in the soil. At the end of the period, it is sent for recycling and new solarisation film is installed. There are solarisation films available that last for several cultivation seasons. (Cascone et al 2012).

- Planting

Planting is executed manually. When the period of solarisation is finished, then small holes are opened in the film for the new plants to be planted (in-line distance: 0.3 m, between lines distance: 0.6 m). Planting requires 53300 plants/ha combined with irrigation. Chemical fertilizers are also diluted in the irrigation water (light fertilizer application with 50 kg N/ha, 20 kg P/ha and 40 kg K/ha).

- Chemical application

There are many enemies of tomato and a lot of chemical substances to control them. In this report the fungicide and insecticide applications that were given by the farmer were recorded. The main fungicides used were Bacillus thuringiensis, sulphur and copper. It should be mentioned that sulphur evaporators are installed in the greenhouse. As for insects, the most important enemies of tomato are Nematodes (*Meloidogynae spp, Heterodera rostochiensis),* Aphids, *Liriomyza solani, Tetranychus urticae, Thrips tabaci, Traleurodes vaporariorum.* Sticky paper traps are widely used for small insects and insecticides are used only when the population is extensive. For *Tuta Absoluta* (which is a new insect for the Mediterranean affecting tomato plantations) there are several insecticides that are used (active ingredient: *emamectin benzoate, metaflumizone, clorantranipole, flubendiamide, spinosad, indoxacarb*).

- Weed control

Weed control is covered by the solarisation film.

- Fertilizer application

Fertilizers are applied throughout the year following the irrigation plan. Total post-planting application of fertilizer is 1660 kg N/ha, 330 kg P/ha, 1220 kg K/ha)

- Irrigation

Irrigation is executed using a drip irrigation system. Total water quantity 18330 m^3/ha.

- Heating

Heating in this case study is conducted with electric fan heaters spread evenly in the greenhouse. The total installed heating capacity is 800 kW. The energy consumption to keep the greenhouse temperature above 14 ^{o}C during the night and above 20 ^{o}C during the day time is about 3.6 GJ.

- Ventilation and cooling

Basic ventilation is conducted using automatic roof windows operated by electric motors controlled by a double thermostat. In Greece though, from April to October, this ventilation is not enough during day time and it is required to have mechanical ventilation. In the greenhouse of this case study, 46 fans of 1.1 kW power are installed on one of the wide sides (200 m) with total air supply of 1750000 m^3/h and have the ability of changing the air in the greenhouse 27 times/h. Cooling is also required during this period. It is conducted in collaboration with the fans, using panels sprayed with water on the opposite side of the fans.

- Harvesting

Harvest is executed manually throughout the year for about 8 months of the total 11.

Farm machinery

The farm owns the following machinery:

- Small scale agricultural tractor 30 kW
- Light cultivator (2 m)
- Rotary cultivator (1.5 m)
- Trailer (7 t)
- Irrigation machinery (pump, auxiliary parts, 33 m^3/h)
- Drip irrigation pipes

EU financial aid

There are no EU subsidies for tomato production.

Methods used for cost calculations

The average value per kg of fertilizer component (N, P, K) was calculated based on the prices of combined fertilizers that are used for the fertilizing on this farm. The same approach was used for chemicals (fungicides and insecticides). Irrigation cost was calculated based on electricity consumption, as water was considered as a free resource.

Considering greenhouse facilities, the annual cost was calculated based on the replacement value and life span of the construction and equipment for greenhouses in Greece (Table 39). The greenhouse of this case study is consisted of the items shown in Table 39 below.

Considering machinery, the rate and value were calculated based on the replacement value and life span of the agricultural machinery and equipment in Greece (see Table 40). The life span considers the durability of the item, the time between its first and last use.

Total energy consumption in the basic greenhouse reaches **18654 GJ ha^{-1} y^{-1}**. The GHG emissions produced in total are in the level of **2373 t CO_2e ha^{-1} y^{-1}**. As for the total cost of production for tomato, this is about **147000 € ha^{-1} y^{-1}**. The energy profile of the existing situation in the greenhouse is illustrated in Figure 50. In the same figure, GHGs and costs distribution for the main energy consuming activities in the greenhouse are also shown.

Table 39: Greenhouse construction and equipment

	Cost (€)	*Useful lifetime (years)*
	Construction	
Frame	100000	20
Land moving + foundations	20000	20
Roof windows	25000	20
Aeration + cooling	40000	20
Electric installation	30000	20
Irrigation system	15000	20
Electricity generator	20000	20
Fan heaters	50000	20
Plant suspension system	15000	20
TOTAL	315000	
	Periodic consumables	
Plastic cover (LDPE)	10000	4
Thermal screens	10000	5
Solarisation film	4900	1

Table 40: Agricultural equipment of the selected farm and their useful life span

Agricultural Equipment	Years of useful life
Tractor	
4wd tractor, 30 kW	15
Tillage machinery	
light cultivator, 3.00 m	20
Rotary cultivator, 1.50 m	12
Other machinery	
Tipping trailer, 7 ton	20
Irrigation machinery, 33 m³/h	15
drip pipes	5

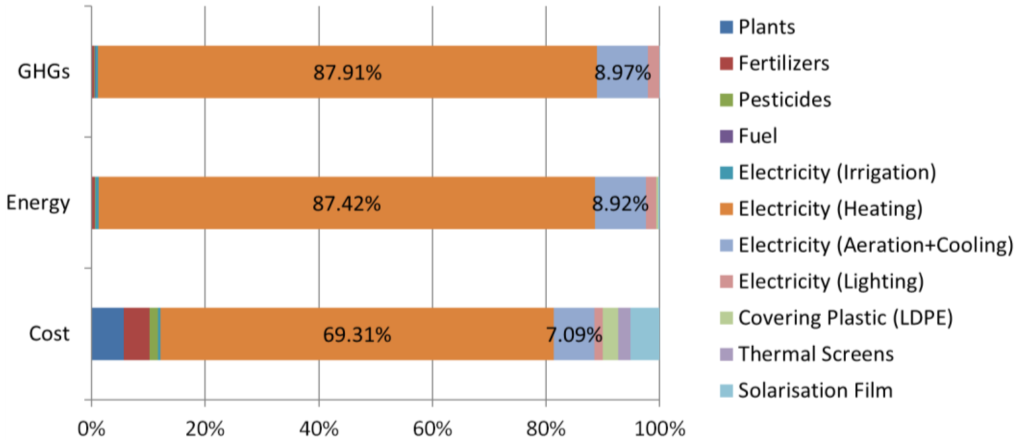

Figure 50: Energy, GHGs and Cost profile of the basic scenario.

It can be seen that Energy and GHGs follow the same trend. Electricity for heating covers about 88% of the total primary energy needs of the greenhouse. All electricity needs account for 99% of total energy requirements.

The cost analysis though is different. Electricity for heating accounts for 69.3% and in total electricity covers 78% of total costs. Other main cost sections are the plants (5.7%), the solarisation film (5.2%), the fertilizers (4.6%) and the pesticides (2.5%).

Alternative option 1–Insulated north greenhouse side

Energy Analysis

The improvement of the insulation of a plastic covered greenhouse can be easily implemented by using a double inflated LDPE film. The overall heat insulation of a wall is described by the overall heat transfer coefficient K (W m^{-2} K^{-1}), which is defined as following:

$$Q = K\,\Delta T$$

Where Q is the heat flux (Wm^{-2}) through the wall, and ΔT is the temperature difference across the wall. The heat transfer coefficient describes collectively all the mechanisms involved in heat transfer through a wall, namely conduction, convection, radiation, etc. The K-value for a LDPE-film made wall is 9 Wm^{-2}K^{-1}, while if a double layer LDPE film is considered, the K-value drops to 6.4 W m^{-2} K^{-1} (Papadakis et al, 2000).

For estimating the importance of such an energy saving technique, we consider the greenhouse of this case study (dimensions 50mx200m, with total area 1 ha) and height at the gutter 4 m as a typical example. Assuming a uniform heat loss from all covering area of the greenhouse, the energy saving which can be obtained if the north wall has dimensions 4mx200m (800 m^2), is roughly estimated to be 2.5% of the total heating cost. Therefore, the saving in terms of final energy consumption is **90 GJha^{-1}y^{-1}** (3600 GJha^{-1}y^{-1}×2.5% = 90 GJ). In primary energy basis the saving is **407.7 GJha^{-1}y^{-1}** (as we are referring to a greenhouse heated by electrical fan heaters, it is required to multiply with 4.53 MJ$_p$/MJ$_{el}$ that corresponds to the Greek electricity mix). The energy input corresponding to the use of the additional plastic is estimated to **13.6 GJha^{-1}** (800 m^2×17 MJ/m^2), but after considering the useful life of the plastic cover (4 years), the total energy added in the system is **3.4 GJha^{-1}y^{-1}**. Therefore, the expected net energy saving is estimated equal to **2.2%**. In this example, additional insulation was added only at a wall with minimal contribution in the overall light transmittance of the greenhouse, since increase of insulation performance always results in a decrease of transmitted PAR radiation.

GHG Analysis

On a GHG basis, the insulation of the north side of the greenhouse would result in a reduction of the electricity used for heating of 2.5%, which is reflected in GHG emissions with a reduction of about **52.155 t CO$_2$e ha^{-1} y^{-1}** (90 GJ ha^{-1} y^{-1} × 0.5795 t CO$_2$e/GJ electricity). On the other hand, the addition of 800 m^2 of cover plastic would increase the GHG emissions by only **29.7 kg CO$_2$e ha^{-1} y^{-1}** (800 m^2 × 0.1485 kg CO$_2$e/m^2 / 4 years). Therefore, the total avoided GHG emission reach **2.2%**.

Cost Analysis

The impact of such change in the cost of the greenhouse is also significant in annual costs. The investment for the extra plastic cover in the insulated side of the greenhouse is about **1200 €**. In order to repay the investment in a 5-year period, with interest rate of 5.2% (rate for agricultural loans in Greece), it is required to pay **340 € y^{-1}**. However, the 2.5% electricity reduction for the fan heaters translates to **1635 € y^{-1}** (90 GJ × 0.018164 €/MJ). Therefore, there is an annual profit of **1295 € y^{-1}**, which accounts for a cost reduction of **0.9%**.

Table 41: Reduction in cost, energy and GHG emissions due to Alternative 1

Scenario	Total company costs	Total energy use (PEC)	Total GHG-emission
	%	%	%
Insulated north side	1	2.4	2.2

Remark

The use of a double layer LDPE film cover may influence productivity by reducing the solar radiation reaching the canopy. However, if the analysis of the local climatic conditions shows that the solar radiation exceeds the required level, a double layer inflated roof cover can be considered. The energy savings could be much higher under specific conditions if the whole greenhouse is covered by a double layer LDPE film. The use of such insulation will result into final energy saving of about **1000 GJ ha^{-1} y^{-1}**. In primary energy basis, the energy saved is **4530 GJ ha^{-1} y^{-1}** (as we are referring to a greenhouse heated by electrical fan heaters and it is required to multiply with 4.53 MJ_p/MJ_{el} that corresponds to the Greek electricity mix). On the other hand, the energy consumption corresponding to the use of the additional film layer is **192.1 GJ ha^{-1}** and adding in the calculation the useful life of the plastic cover (4 years), the final annual energy contribution will be about **48 GJ ha^{-1} y^{-1}**. The energy for compensating leakages and maintaining a pressure of 50-80 Pa in the inflated cover is roughly estimated equal to **15 MJ ha^{-1} y^{-1}**, so it may be considered negligible. Therefore, the expected net energy saving is estimated to be equal to **24%**. This value roughly agrees with estimates given in the literature, where the heat loss reduction due to an inflated double film cover was measured equal to 30% (Weimann 1985). Further research is needed to confirm experimentally these results under Greek climatic conditions.

Alternative option 2–Windbreak against the dominant wind direction

Energy Analysis

The most important mechanism of heat transfer through the greenhouse cover is convection. The colder external wind takes away heat from the hotter greenhouse cover due to its speed. If the air velocity at the greenhouse cover is reduced, heat losses can be reduced. Therefore, the construction of a windbreak, natural (tree) or artificial (made of plastic netting) may contribute to important energy savings for greenhouses.

A recent numerical (CFD) study (Mistriotis et al, 2011) indicates that the construction of an artificial windbreak against the dominant wind direction with height equal to the sidewall of the greenhouse at a distance of one height of the sidewall upstream, may result in an important reduction of the wind speed along the greenhouse cover. More specifically, the wind speed is reduced by **50%** at the wall facing the wind, and about **12%** along the roof as an average. This air velocity reduction can be transformed into energy savings by a rough approximate calculation.

The convection energy transfer along a flat plat is proportional to $Re^{0.8}$ (Mills 1992), where *Re* is the Reynolds number defined as:

$$\mathrm{Re} = \frac{\rho v L}{\mu}$$

where ρ is the density of air, L is the dimension of the wall parallel to the air velocity, v is the air velocity, and μ is the dynamic viscosity of air.

Therefore, the heat losses through a wall are proportional to $v^{0.8}$ where v is the wind speed along this wall. Assuming that roughly all walls and the roof contribute to the heat losses of a greenhouse proportionally to their area, we may estimate that a **12%** reduction of heat loss along the roof may result in an important energy saving. The energy savings due to reduced convection at the roof can be as high as **10%** of the overall heating cost. Moreover, the reduction of heat losses at the sidewall which is exposed to the wind can contribute by **2%** more to the overall energy savings.

Therefore, a windbreak with optimal height and position can provide final heat savings as high as **432 GJ ha^{-1} y^{-1}**. In primary energy basis, the energy saved is **1957 GJ ha^{-1} y^{-1}** (as we are referring to a greenhouse heated by electrical fan heaters and it is required to multiply with 4.53 MJ_p/MJ_{el} that corresponds to the Greek electricity mix). The energy needed for the construction of such a windbreak is **6.24 GJ ha^{-1}** (800 m^2 × 7.8 MJ/m^2). Therefore, annual energy consumption is **624 MJ ha^{-1} y^{-1}**, assuming that the life time of the plastic net is approximately 10 years. Consequently, the expected net energy saving is estimated equal to about **10.5%**. If the artificial windbreak is replaced by a natural one (trees) there is no energy consumption. In this case, an artificial wind break can be constructed for protection during the initial period, when the protecting trees are short.

GHG Analysis

On a GHG basis, the addition of a windbreak against the dominant wind to the greenhouse would result in a reduction of the electricity used for heating of 12%, which is reflected in reduced GHG emissions of about **250.37 t CO_2e ha^{-1} y^{-1}** (432 GJ ha^{-1} y^{-1} × 0.5795 t CO_2e/GJ electricity). On the other hand, the addition of 800 m^2 of plastic net for the construction of the windbreak would increase the GHG emissions by only **12 kg CO_2e ha^{-1} y^{-1}** (800 m^2 × 0.1485 kg CO_2e/m^2/10 years). Therefore, the total avoided GHG emission reach **10.5%**.

Cost Analysis

The impact of such change in the cost of the greenhouse is also significant in annual costs. The investment for the windbreak is about **5000 €**. In order to repay the investment in a 5-year period, with interest rate of 5.2% (rate for agricultural loans in Greece), it is required to pay **654 € y^{-1}**. However, the 12% electricity reduction for the fan heaters is translated to **7847 € y^{-1}** (432 GJ × 0.018164 €/MJ). Therefore, there is an annual profit of **7193 € y^{-1}**, which accounts for a cost reduction of **5%**.

Table 42: Reduction in cost, energy and GHG emissions due to Alternative 2.

Scenario	Total company costs	Total energy use (PEC)	Total GHG-emission
	%	%	%
Windbreak against the dominant wind direction	5	10.5	10.5

Remark

The use of a windbreak could help in reducing the total cost of the greenhouse if the wind is the dominant load. In this case, the greenhouse structure may be designed with a lighter frame. Such an option would be preferable for areas where snow is rare, because the light frame can allow the greenhouse to collapse more easily.

Alternative option 3–Heating system replacement with biomass

Energy Analysis

The third alternative refers to the change of the heating system from electrical fan heaters to biomass boiler heating system. In this case, in order to cover the energy needs for heating (around **3600 GJ ha^{-1} y^{-1}** in final energy terms), it is required to combust 265 t of biomass (16 MJ/kg) annually in a boiler of 85% efficiency. Total biomass energy input would be **4240 GJ ha^{-1} y^{-1}** (265 t × 16 GJ/t), adding **18 GJ ha^{-1} y^{-1}** for the fuel consumed to transport the biomass from production (olive oil mills, nut and almond industry) to the greenhouse (0.36 t × 50 GJ/t). If we consider the fact that when electrical fan heaters are used, the total heating energy consumption was **16308 GJ ha^{-1} y^{-1}**, alteration to biomass heating would reduce total primary energy consumption by **64.8%**.

GHG Analysis

On a GHG basis, the result is even better, as it could be assumed that biomass do not emit GHG emissions based on the carbon cycle (there is a low GHG emission level that is not taken into account in this report). Therefore, biomass combustion will result only in the GHGs that transporting trucks emits, which is **1.312 t CO_2e ha^{-1} y^{-1}** (0.36 t of diesel × 3.646 t CO_2e/t diesel). In the basic scenario of electrical fan heaters, total GHG emissions due to heating system were in the level of **2086 t CO_2e ha^{-1} y^{-1}** (3600 GJ ha^{-1} y^{-1} × 0.5795 t CO_2e/GJ electricity). Having in mind that total GHG emissions of the basic scenario is **2384 t CO_2e ha^{-1} y^{-1}**, it can be seen that if biomass would replace electricity for the heating purposes of the greenhouse, then total GHG emission reduction would reach **87.5%**.

Cost Analysis

The impact of such change in the cost of the greenhouse is also significant in annual costs. However, as an important investment for the new heating system is required (about 80000

€), the final annual profit from this replacement is reduced considerably due to loan payments. In particular, in order to repay the investment in a 10-year period, with interest rate of 5.2% (rate for agricultural loans in Greece), it is required to pay **10460 € y^{-1}**. The annual cost of operation of the new biomass heating system is **39750 € y^{-1}** (265 t biomass ×150 €/t). However, the existing electricity heating system requires **65400 € y^{-1}** (3600 GJ × 0.018164 €/MJ). Therefore, there is an annual profit of **15190 € y^{-1}**, which accounts for a cost reduction of **11.2%**.

Table 43: Reduction in cost, energy and GHG emissions due to Alternative 3.

Scenario	Total company costs	Total energy use (PEC)	Total GHG-emission
	%	%	%
New biomass heating system	11.2	64.8	87.5

Relative Contribution of different energy efficiency measures to energy use, total costs of production and greenhouse gas emissions

All the above analysis for the three alternatives of the greenhouse of the basic scenario can be seen in total in Table 44.

Table 44: Annualized costs, PEC and GHG emissions per ha, with EE measures in greenhouse tomato production.

Scenario	Total company costs		Total energy use (PEC)		Total GHG-emission	
	€/ha	%	GJ/ha	%	t CO_2e/ha	%
Current practice	146850	100	18654	100	2373	100
Insulated north side	145555	99.1	18250	97.8	2321	97.8
Windbreak against dominant wind direction	139657	95.1	16697	89.5	2123	89.5
New biomass heating system	130376	88.8	6568	35.2	288	12.1

The case of unheated greenhouse in Crete

The main energy consumption in unheated greenhouses concerns fertilizers and agrochemicals. These two categories roughly correspond to 60% of the overall energy consumption in such a greenhouse. In contrast, the covering material represents only 20% of the total energy. The remaining 20% of the energy consumption represents other materials and operations, such as pumping of irrigation water, thermal screens, solarisation films, cooling by evaporation, etc.

Therefore, the introduction of organic or integrated production cultivation techniques may also contribute to important energy savings besides the increase of the value of the produce itself. However, the reduction rate of the energy consumption is difficult to quantify due to the limited information concerning the energy equivalence of organic fertilizers and pest management techniques. For example, the use of manure as organic fertilizer may correspond to zero energy consumption if it is naturally processed. Additional energy is needed if manure and /or compost are industrially processed to be transformed into fertilizer which is not easily calculated. Similarly, the use of predator insects for controlling pests is a measure with uncertain and difficult to estimate energy equivalence. The use of sulfur in the place of several agrochemicals is also estimated to result in energy savings.

Organic or IP cultivations cause a low energy consumption with respect to fertilizers and agrochemicals. However, an optimized internal microclimate, which requires using energy, is needed to support the health of the plants. For example, under certain conditions the reduction of internal relative humidity can only be achieved by energy consuming air drying systems. Therefore, energy savings can be obtained by advanced design techniques, which lead to structural and functional optimization of the greenhouse with minimal use of energy.

Conclusions

In this report, there was an attempt to apply three of the EE measures that were proposed in WP2 list for greenhouses in Greece. The two first analysed scenarios (insulation of the north side and windbreak installation in the side against the dominant wind) were based on simple adjustments on the existing greenhouse system. Therefore, the result in energy, GHG emissions and costs were not very significant. However, in comparison to the investment required, they provide a good result. The last alternative energy efficiency measure (replacement of the heating system with biomass boiler system) gave very good results in terms of energy use reduction (which was the driver for this report), with more positive side effects on environmental impact (GHG emissions decline). The reason was the fact that the greenhouse was heated with electrical fan heaters and the Greek electricity mix is based on fossil fuels of low efficiency (on lignite, and less on diesel and natural gas) that increase significantly the primary energy and GHG emissions derived by electricity production. As for the costs of the farm, the impact was also important, but not as much as in energy and GHG emissions, due to high investment cost for the new biomass heating system.

The above examples are very rough preliminary estimates of the efficiency of the proposed energy saving measures for greenhouses in Greece. The calculated energy savings are approximate since very simple models were used. The commercial success of any proposed energy saving measures requires detailed analysis of the characteristics (design, orientation, local climate etc.) of the specific greenhouse where they are to be applied. The application of energy saving innovations in greenhouses is not straightforward and generic in most cases. As a result, greenhouse builders have to invest in design methodologies and software for modeling the greenhouse performance, similar to building simulation tools used for the design of offices, houses and industrial buildings. The academic and research community may contribute to the development of such design methodologies and software tools.

4.4.3. Energy Efficiency Measures in Portuguese Greenhouse Tomato Production

Fátima Baptista, Dina Murcho, Luis Leopoldo Silva, Mário Louro, Carlos Marques

Introduction

Tomato is one of the most important greenhouse crops in Europe. The majority of fresh tomatoes marketed in the European Union are produced as protected crops. In 2005, the greenhouse area for vegetable and flower production reached 53 800 ha in Spain and 2 550 ha in Portugal (Meneses & Castilla 2009). According to the National Statistics Institute, in 2011, tomato greenhouse crop occupied approximately 1 400 ha (INE I.P., 2012). Most tomato greenhouse production use soil in unheated greenhouses, but hydroponics using substrate is increasing. The main production regions are Ribatejo and Oeste (approximately 50%), Algarve and Entre Douro e Minho.

Mediterranean greenhouses are very different from those used in Northern countries. In the North most greenhouses are heated and covered with glass. In the South, where the air temperature is warmer and solar radiation is considerably higher, greenhouses are usually not heated and covered with plastic film. Environmental control in such greenhouses is essentially achieved using various ventilation techniques to control temperature and humidity (Baptista et al. 2011).

According to Afonso (2012) the regular production consists in two crops per year, one in winter-spring (planting in December; harvesting by the end of April) and the other in summer-autumn (planting in June; harvesting after the end of August). Many producers are now prepared to better exploit market opportunities. Producers in the Oeste region know that the big export window opportunity is from June to September, when the production is difficult in other regions of south Europe due to high temperatures.

The main objective of this case study is to analyse the effect in economic results, energy consumption and environmental impacts of: 1) hydroponics with substrate; 2) hydroponics and fertilizer and water doses adjusted; 3) rationalised use of fertilizers, pesticides and water in soil production and 4) use of an integrated control system.

Basic scenario

The basic scenario is a real farm with 7 ha of unheated greenhouses producing tomato crops grown in soil. The structural material of the greenhouses is galvanized steel and the covering material consisted of low density polyethylene (LDPE). The climate is controlled by natural ventilation, using continuous vents located on the roof over the entire length of the greenhouses.

Before planting the soil is prepared and ridges for the young tomato plants are made. Tomato plants are planted in twin rows. The growing technique is usual for greenhouse tomatoes in Portugal, which means that the plants are trained to a single stem; pollination is made by bumblebees, fruit pruning and defoliation to allow better air circulation between plants, in accordance with normal horticultural practice, allowing adjacent fruits to be perfectly formed.

Plant density is 22 000 plants per ha. The crop is irrigated with a drip irrigation system, with an average amount of 7 500 m^3/ha of water. Fertigation is used to supply the necessary nutrients to the plants during the crop cycle with approximately 290 kg/ha N, 160 kg/ha P and 570 kg/ha K. Also a micronutrients solution (manganese, molybdenum, iron, boron, cobalt and zinc) is applied. These characteristics and data refer to one crop cycle. Since regular production consists of two crops per year, for computing energy, GHG emissions and economics values per year, all values are doubled.

Tomato cultivation techniques are mainly related to the crop training, defoliation and pruning on the trellis, weed control, fertigation, crop protection against pests and diseases and harvesting. This farm is equipped with all the necessary equipment, such as a tractor (70 hp), irrigation and fertigation systems and sprayers.

In the mechanisation item, the rate and value were calculated based on the replacement value and life span of each machine and the agricultural equipment. The life span considers the durability of the item, *i.e.*, the number of years of use. The greenhouse structure material is assumed to be an investment for 20 years and the cover material, since it is used only for 3 years, was considered as an input for each year (total value divided by three). The same split was considered for energy consumption and GHG emissions. Total annual production (for the two crops/year) is 180 ton per ha. Total investment (greenhouse structure, ventilation and irrigation/fertigation systems) is approximately 130,000 € per ha.

Alternative option 1–hydroponics with substrate (hydro)

In Portugal, the interest in hydroponic cultivation of tomato is increasing, mainly in regions with high concerns about pollution in subterranean aquifers, (*i.e., Vila do Conde and Entre Douro e Minho* regions) and also due to problems caused by soil fungi and insects or soil salinization (Mourão et al. 2010).

This option is also based on information of a real farm. The greenhouse structure and cover material are the same, the main difference being the production system, which was hydroponics with substrate, in this case rockwool. Total investment is approximately 142,000 € per hectare.

The crop is planted in the rockwool substrate with a density of 26,000 plants per ha. Water consumption is on average 4,000 m^3/ha. This technology allows great water efficiency, as mentioned in Rosa et al. (2006). All nutrients, approximately 635 kg/ha N, 200 kg/ha P and 625 kg/ha K, are supplied through the water. A micronutrients solution (manganese, molybdenum, iron, boron, cobalt and zinc) is also applied. As in the basic system these data refer to one crop cycle. Hence, for the energy, GHG emissions and economics calculations per year, everything was doubled.

Since the substrate is used for two years (four crops cycles) it was considered as an input for each year (total value divided by two). The same was considered for the energy consumption and GHG. Total annual production (for the two crops/year) is 200 ton per ha.

Alternative option 2–hydroponics with adjustment of fertilizers doses and water (hydro_FW)

As mentioned before option 1 considered is based on a real farm. However, studies conducted by Reis (2012) suggested that it is possible, using closed systems, to reduce the amount of fertilizers and water supplied to the crop. This author found consumption reductions of 35% in N, 20% in P, 17% in K and 20% in water. These were the adjustments considered for option 2. For this it is necessary to invest in a recirculation and disinfection system, at in approximately 30,000 €.

Alternative option 3–Adjustment of fertilizers, pesticides and water (FPW)

The basic scenario is the most representative of tomato greenhouse production in Portugal. However, several studies indicate that it is possible to improve the efficiency of the use of fertilizers, pesticides and water used for tomato greenhouse production. Concerning fertilizers a reduction of 30% was considered (Montero et al. 2012) and for water application 20% (Tüzel et al. 2009). For pesticides a reduction of 20% was also assumed, based on the experience of the research team.

Nocturnal ventilation offers a great potential for the control of humidity dependant diseases in greenhouse vegetables in Mediterranean regions. Furthermore, this does not imply great changes in cropping practices, which could facilitate their adoption by growers, as well as their integration with other control methods (Baptista et al. 2011). In unheated greenhouses Baptista et al. (2012) have shown that nocturnal ventilation was able to reduce *Botrytis cinerea* severity by 50% when compared with a traditional ventilation system.

Alternative option 4–Integrated Control System (ICS)

The last option analysed is the implementation of an integrated control system, which allows automatic control of irrigation and fertigation systems, pumps, ventilation and the energy consumption controls. This implies an investment in equipments, such as sensors, meteorological station and software, to a total value for this farm of approximately 15 000 €. Based on practical experience it is expected that a reduction in 20% of water and energy consumption is achievable.

Impact of different energy efficiency measures on economics and the environment

Figure 51 shows the relative contribution of the different inputs in the variable costs, GHG emissions (CO_2eq) and energy consumption for the farm assumed as the basic scenario. It is clear that different inputs contribute in different percentages to the total costs, primary energy consumption and GHG emissions. As in other crop and livestock systems this implies that small changes may have little effects on costs but high impacts on energy use and GHG emissions.

Concerning the business variable cost structure it can be seen that plants (42%), materials (20%), fertilizers (11%) and others (12%) are the most important. Other costs include the bumblebees (10%) and water. Direct energy (diesel and electricity for irrigation) and pesticides both contribute 8% to the variable costs. In terms of energy consumption direct energy (diesel and electricity) used for the field operations and the electricity used for the irrigation represents the most important factor, contributing approximately 68% and materials and fertilizers, with approximately 19% and 12%, respectively. The same order applies for the GHG emissions, with diesel and electricity responsible for 69%, fertilizers 20%

and materials 10%. Pesticides do not have a great contribution on energy consumption or GHG emission, which agrees with a previous study of Antón et al. (2012).

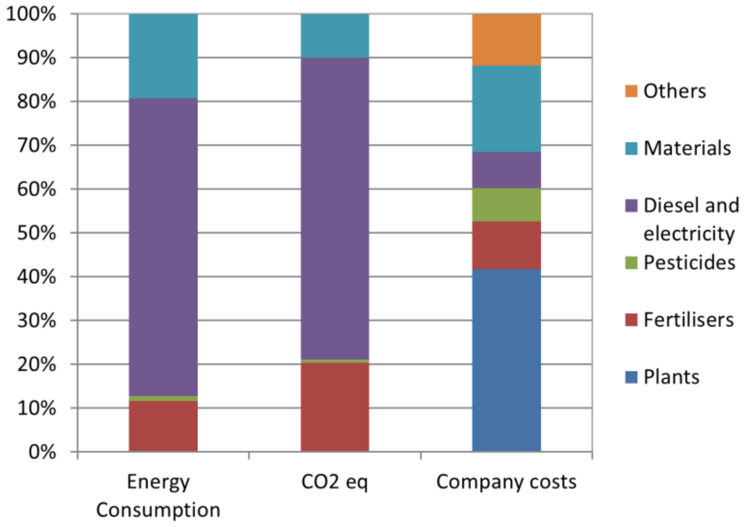

Figure 51: Relative contribution of different inputs in the farm production to economy, energy use and greenhouse gas emissions (GHG). (Materials are the LDPE and raffia for tutoring. Others include bumblebees and water).

Table 45 presents the costs and income for the basic scenario and the alternative options. Again, it can be seen the high contribution of plants, fertilizers and materials in the production costs, the sum representing from 73% to 78% of the variable costs. The higher variable costs are in the hydroponic options due to higher material costs, which include the substrate. The material costs in these options are higher than in the basic scenario, representing 28 to 29% of total variable costs, when in the basic scenario they represented around 20%. The fixed costs were considered as labour, amortization of machines and equipment, greenhouse structure and irrigation/fertigation systems. The hydroponics options present a decrease in labour cost to nearly half of the labour costs of the other options, which decreases significantly the fixed costs. Production in a soil system has higher labour costs due to crop maintenance operations, such as weed control and harvesting since these operations are less mechanised. Income comes from the sale of tomato at a price of 500 € per ton. In all cases farms are economically sustainable, presenting a positive net margin, with highest values for the hydroponic options. In fact, minimal tomato price for breakeven is approximately 330 €/t for the basic scenario and the integrated control system option and around 310 €/t in all the other options, hydroponics and rational use of fertilizers and water.

Table 46 presents total costs, energy consumption, GHG emissions and profit per ha and year. The basic scenario presents total costs per hectare around 58 500 € and the only option that allows reducing costs is option 3, with the reduction of fertilizers, pesticides and water, to approximately 56 600 €. All other alternatives have higher production costs that vary between 0.2 to 7.2%. Concerning energy consumption, options 1 and 2 (hydroponics) show an increase of 64 and 39%, while options 3 and 4 allow a decrease, from the basic scenario, of 15 and 9%, respectively. The same occurs with GHG emissions, expressed as CO_2eq. Options 1 and 2 increased emissions by 65 and 36%, respectively and options 3 and 4 decreased it around 17 and 8%, respectively. Concerning profit, the best results are attained with the hydroponic options. Option 2 presents the best results, with an increase of 23%. Option 4, using an integrated control system to improve greenhouses management, does not significantly change farm profit which is explained by the necessary investment in equipment, not translated into sufficient input savings. More research is necessary to improve the efficiency of this alternative.

Table 45: Costs and income for a Portuguese tomato greenhouse farm.

	Basic scenario		Hydro		Hydro_FW		FPW		ICS	
	(€/year)	%	(€/year)	%	(€/year)	%	(€/year)	%	(€/year)	%
Variable Costs										
Plants	92,400	42	109 200	36	109,200	38	92, 400	44	92,400	42
Fertilisers	24,236	11	41,554	14	31,389	11	17,550	8	24,236	11
Pesticides	16,774	8	18,874	6	18,874	7	13,419	7	16,774	8
Diesel and electricity	18,039	8	22,750	8	19,390	7	15,395	8	16,359	8
Materials	43,885	20	83,384	28	83,384	29	43,885	21	43,886	20
Others	26,015	11	24,304	8	23,923	8	25,292	12	25,292	11
Total	221,349	100	300,066	100	286,160	100	207,942	100	218,946	100
Fixed costs	188,345		139,063		142,063		188,345		191,345	
Total costs	409,694		439,129		428, 223		396,286		410,290	
Income	630,000		700,000		700,000		630,000		630,000	
Net margin	220,307		260,871		271,777		233,714		219,710	

Figure 52 shows the impact on costs, profit, energy use and greenhouse gas emission (GHG) per ton of tomatoes produced. We can observe the same trend as mentioned before. The major difference is related to costs/t, which decreased in the two hydroponics options, due to higher crop yields.

Table 46: Total annual costs, PEC, GHG emissions and Profit with energy efficiency measures.

	Annual Cost		PEC		GHG		Profit	
	€/ha	%	MJ/ha	%	CO$_2$e/ha	%	€/ha	%
Basic Scenario	58528	100	364165	100	21037	100	31472	100
1 -1Hydro	62733	107	597312	164	34785	165	37267	118
2 -Hydro_FW	61175	105	505915	139	28559	136	38825	123
3-FPW	56612	97	309611	85	17418	83	33388	106
4-ICS	58613	100	330908	91	19322	92	31387	100

Figure 53 shows the differences between the basic scenario and the other options on energy, GHG emissions and farm profit per ton of yield. It is possible to conclude that a more rational use of input factors can contribute to save energy, to lower GHG emissions and to increase farm profit. It is also possible to increase productivity and consequently to improve the efficiency of resources use. However, several factors interact in the production system, and more research is needed in order to obtain experimental data that could allow a more detailed analysis.

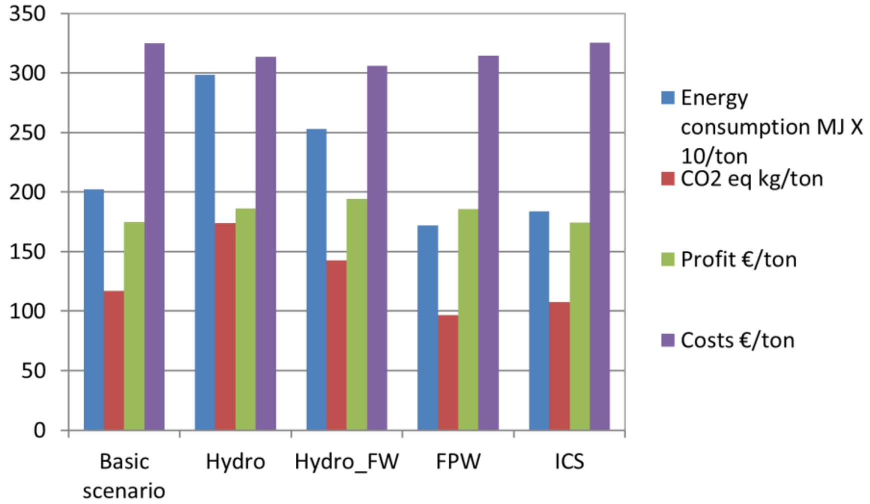

Figure 52: Impact of different energy saving measures on costs, profit, energy use and greenhouse gas emissions (GHG) per ton of tomato.

Figure 53: Differences of profit, energy use and greenhouse gas emissions (GHG) savings per ton of tomato between the basic scenario and the different options studied.

4.4.4. Synthesis trade-off analysis of case studies in greenhouse production systems

Greenhouse production possesses obvious basic differences across Europe depending on the production region. Most greenhouses in the relatively cold northern region are heated and covered with glass, whereas the Mediterranean or the southern regions mostly produce in non-heated plastic-film covered greenhouses. Greenhouse areas dedicated for tomato production amount to approximately 2,500 hectares in Greece and 1,440 in Portugal, where the majority of the tomato is soil-grown, in unheated greenhouses. In the Netherlands tomato is grown on 1,702 hectares, usually soilless and in heated glasshouses. Therefore, in the central and northern EU countries distribution of energy consumptions is dominated by the supply of heating unlike the production system in the southern EU countries. In Northern

Europe the direct energy input (heating and electricity) is predominant, accounting for over 99% of the total energy input, while in the southern countries it accounts for 10-40% of total energy consumption. In Portugal, the indirect energy input is mainly associated with application of fertilizers and greenhouse materials, while in Greece it is associated with auxiliary equipment (thermal screens, solarisation and LDPE films) and fertilizers.

In the case studies from different countries all the different production scenarios were covered. Netherlands dealt with heated greenhouses, Portugal focused on non-heated ones, whereas Greece showed a combination of both types. This broad analysis enabled an opportunity to bring all the scenarios across Europe under one roof.

In the heated greenhouses the energy consumption, as well as environmental impact of heating, is evidently dominant over other production steps/units. Therefore, the Netherlands concentrated their study in reducing the heating requirement. In their analysis of three different possibilities the most promising one was the double glazed & innovative dehumidification. It showed the most potential of saving energy (up to 50% reduction in fossil fuel consumption) as well as GHG emission at similar costs as the reference case. However, it should be noted that the reference state of the analysis excluded the use of combined heat and power plant (CHPP), which on the other hand is the only means of economic survival for the present production system of the Dutch greenhouse industry. Without selling the electricity the firms have little chance of economic sustainability not only in the present, but also in the foreseeable future. Although the investment for the analysed options in the case-studies is not feasible from the current Dutch perspective, it showed some environment friendly options for other circumstances.

The case studies in Greece involved both heated and non-heated systems. No quantitative analysis was performed for the non-heated systems due to limited information regarding energy equivalence. It was suggested that the non-heated systems may have a potential of improvement through organic or integrated production cultivation techniques and optimized internal microclimate by advanced design techniques. On the other hand for the heated systems, all three options were economically (although marginal), energetically and environmentally viable. The most promising option was to replace the conventional heating system with biomass heating. A 64.8% reduction in energy consumption along with 87.5% decrease in GHG emission was reported for this option at 11.2% reduced cost. Although high investment cost for the new biomass heating may be considered as a drawback, the energy and environmental prospects are well capable of overwhelming any second-guess. In the Greek case studies the need for further research and development in the field of design methodology and software for modeling was also pointed out. The support of the academic and research community in this was recommended.

In their analysis of non-heated greenhouse production systems Portugal focused on a more rational use of input factors (fertilizer, water etc.) in order to save energy. In the case-studies the increasing popularity of hydroponic cultivation of tomato was mentioned, although the alternatives involving hydroponics were, despite their water saving, more energy intensive.

The alternatives involved mainly saving water and decreasing fertilizer usage. The best results were derived by adjusting the fertilizers, pesticides and water for a conventional greenhouse production system. 15% saving in energy and 17% reduction in GHG emission was achieved with a 6% increase of profit. An integrated control system was also reported to be more energy efficient with good environmental aspects. Further requirement in research was mentioned to increase the productivity as an energy efficiency measure.

4.5. Case studies–Permanent crop production systems

4.5.1. Energy efficiency measures in German vineyard production

Andreas Meyer-Aurich, Manfred Stoll, Hans-Peter Schwarz[4]

Introduction

Energy input in viticulture systems which can be cultivated with tractors is dominated by fuel use and post-harvest processing. Since the vegetative growth of grape vines is greater than that needed for wine production, traditionally the grapes are pruned in winter time. The cut canes and grape wood often are mulched and left in the vineyard. The energy of the wood and canes, however, may reduce the energy use from fossil resources and thus contribute to higher energy efficiency of the whole system. While the gains in energy efficiency are obvious and easy to identify, it is more difficult to assess the impact of the use of the mulched prunings on humus and nutrient supply in the soil.

Technology for energy use of grape canes

Different technologies are available, which can be used to collect and transport the canes out of the vineyard. The canes can be either baled as large round bales or chopped and collected in a wagon for transport to an energy use facility. The technologies differ with regard to mass of the implement, operating speed and costs.

Economic assessment of energy use of grape canes

The lower heating value of grape canes with a water content of 15 % water can be estimated at 4.1 kWh/kg (Schwarz 2012). With cane yields of 1400 to 1800 t/ha total energy yields to 5700 to 7400 kWh/ha. This equals the energy of 570 to 740 L of heating oil, equaling 570 to 740 € per ha (assuming a fuel price of 1.00 € per l). In order to keep the humus level balanced, additional carbon should be added to the vineyard, if cane wood is removed. Schwarz (2012) suggests the application of straw or animal manure to the fields as a substitute for the grape canes.

The total costs for substituting humus and nitrogen losses due to the energetic use of the canes were estimated at 100 €/ha, costs for collecting the canes were estimated at 51 €/ha, including variable costs. Including costs for storage and transport the costs sum up to 186 €/ha. Compared to the energy costs for heating oil with the same energy content, the energy use of the canes results in additional revenues of 384 to 554 €/ha.

---

[4] Fachgebiet Technik der Forschungsanstalt Geisenheim, Von-Lade-Straße 1, D-65366 Geisenheim

Table 47: Cost analysis energetic use of grape canes (Schwarz, 2012).

	Total cost	Annualized cost
Costs for substitution of humus and nutrients		100.- €/ha
Cane collecting implement	1550.- €	31.- €/ha
Variable costs for collecting the canes		25.- €/ha
Transport and storage		30.- €/ha
Sum of costs		**186.- €/ha**

Environmental - economic trade-off analysis

Based on the energy saving potentials due to the use of the grape canes the economic and environmental trade-offs can be calculated. We assumed additional fuel efforts (40 L/ha) for collecting, transport, storage of the canes and broadcasting of substitute mulch material. The net effect of the use of the canes sums up to 530 to 700 L. The GHG mitigation potential is based on the net fuel saving effect as 2.9 kg per L fuel use. The results are shown in Figure 54 for low and high cane yields.

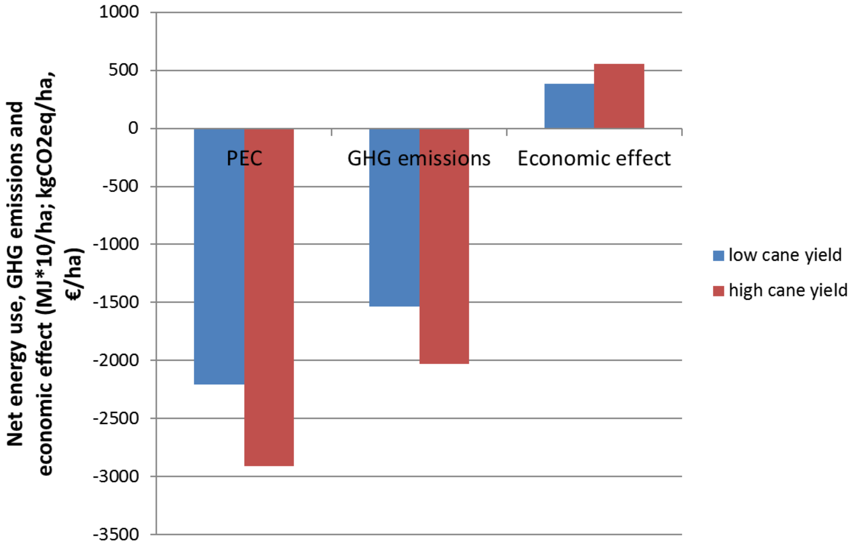

Figure 54: Net effects of energetic cane use on environmental and economic indicators.

Conclusions energy efficiency measures in vine-production

The proposed energy use of the vine canes proves to be a win-win solution for the farmer and the environment also when taking efforts for maintaining the soil fertility with additional supply of organic material into account.

4.5.2. Energy efficiency measures in a Greek vineyard production farming system

Athanasios Balafoutis, Panagiotis Panagakis, Demetres Briassoulis

Introduction

This section presents the analysis of scenarios of different energy efficiency measures regarding vineyard farming systems in Greece. Vineyards are considered as one of the most important permanent crops in Greece, with olive groves being the most significant one. Vineyards are found in most parts of the country in many different terrain types.

Due to its importance and its specific crop production system, it is one of the selected crops to be investigated in the framework of the AGREE project. There are several types of energy efficiency measures that could be applied in a vineyard (see Energy efficiency measures report for Greece in WP2). In this report two case studies were selected to be analysed as possible energy efficiency measures for vineyards: organic farming and precision farming. The impact of these measures on greenhouse gas (GHG) emissions and on the economics of the farm are also examined.

Organic farming was selected based on the fact that this agricultural practice is strongly supported by EU through the subsidised environmental friendly agricultural practices, even if the final yield of all organic crops is being reduced significantly due to significant restrictions in the types and quantities of chemical pesticides and fertilizers allowed. However, organic farming provides consumers with high quality agricultural products that can receive higher prices in the market while it contributes to the protection of natural resources.

Precision farming is also one of the agricultural practices that focus on reduction of chemical pesticides and fertilizer inputs. It also attempts to reduce consumption of irrigation water based on improved technologies. In comparison to organic farming the final yield of the grown crop is not affected and sometimes it is even increased due to spatial and time application precision of chemicals and water. Therefore, the target of this practice is to utilize the least quantities of agricultural inputs to achieve the same or even higher yields than with conventional farming.

A new agricultural practice that has been applied in vineyards recently, but is still at an early stage of development, is the use of biodegradable mulching film to cover the soil along each line of vines. Although this practice is not very common and it does not provide an apparent energy efficiency improvement (see below), it is a practice that is under consideration as it provides the farm with positive economic results and labour savings. Research on energy consumption reduction and the associated environmental and financial benefits resulting from the application of biodegradable mulching films in vineyards production is needed to analyse systematically all aspects of this new agricultural practice and promote its application by EU farmers. Research is also needed in the direction of energy efficiency of biodegradable films processing and bio-based raw material production.

In this report, the main objective was to analyse the effect of 3 alternative agricultural practices for vineyards in Greece. The focus was primarily placed on how much energy consumption is reduced and secondly on the economic results and the environmental impacts. The selected alternative energy efficiency measures were:

1. Organic farming
2. Precision farming
3. Biodegradable mulching film along the vine rows

Methodology

The Central Macedonian plain is the second largest agricultural region of Greece after Thessaly. The crops that are mainly cultivated in the area are wheat, cotton, tobacco, peaches, apples, olives and wine grapes. Mean annual precipitation, temperature and relative humidity are 610±124.2 mm, 19.2±2.0 ^{o}C, 57.0±8.3% respectively (EMY, 2012).

The basic scenario that was chosen for this report is a typical farm of 15 hectares, with irrigation potential and sandy-clay soils where a "Roditis" native grape variety is cultivated in Katerini area of Central Macedonia region.

Basic scenario–Traditional Crop system

The traditional vineyard production system is shown below.

Conventional wine grapes "Roditis":

The cultivation procedure in the farm under investigation follows the steps below:

1. *Vineyard installation*

The land area selected to be the vineyard is prepared for the new wine grape vines to be planted.

- Soil treatment

Preparation of the soil by using the following machinery:

1. Plough for deep ploughing (35 cm)
2. Heavy cultivator
3. Light cultivator

- Planting

Planting is executed manually. The land plot is measured and holes are opened along parallel lines in equal distances of 1.2 m. The distance between rows is 2.7 m. Metal poles are set along every line of vines to support the new plantation. Planting requires 3000 plants/ha combined with light fertilizer application (30 kg N/ha, 40 kg P/ha and 40 kg K/ha).

- Chemical applications

Usually, the vineyards are sprayed with Bacillus turingiensis, sulphur, copper, Topsin M (thiophanate methyl 97% w/w), dithane M-45 (mancozep 72% w/w), thiodan (endosulfan 47% w/w).

- Weed control

For weed control, the soil is cultivated with light cultivator and sprayed with Paraquat (20% v/v) and Glyphosate (36% v/v).

- Fertilizer applications

Two post-planting applications of fertilizers (total fertilizer application of 25 kg N/ha, 35 kg P/ha, 35 kg K/ha)

- Irrigation

1-2 irrigations using drip irrigation systems. Total water quantity 1600 m^3/ha.

- Harvesting

Harvest is executed by the end of September manually (in this period of vine development the mean yield for a period of 4 years is 4 t/ha of grapes).

2. *Vineyard operation*

The cultivation procedure of the vineyard follows the steps below:

- Inter-row cultivations

Three inter-row cultivations per year for weed control without chemical applications using the light cultivator.

- Chemical application

The same as above.

- Fertilizer application

Three applications of fertilizer per year (total fertilizer application of 55 kg N/ha/y, 75 kg P/ha/y, 75 kg K/ha/y)

- Irrigation

1-2 irrigations using drip irrigation systems. Total water quantity 800 m^3/ha/y.

- Harvesting

Harvest is executed by the end of September manually (this is the period of high yield for the grown vines with an annual mean yield 14 t/ha of grapes).

Farm machinery

The farm owns the following machinery:

- Agricultural tractor 50 kW
- Rigid-tine cultivator (2 m)
- Light cultivator (2 m)
- Crop sprayer (mounted, 500 L, turbo-air assisted)
- Trailer (7 t)
- Centrifugal fertilizer spreader (12–36 m, 500 L)
- Irrigation machinery (pump, auxiliary parts, water supply of 33 m^3/h)
- Drip irrigation pipes

The farm contracts:

- Plough for preparing land for new plantings

EU financial aid

The selected farm receives, each year, EU subsidies for wine grape production. The value received is different for each farm and it is calculated based on the farm history of producing the specific crop. The average value of subsidies in the selected farm is 330 €/ha.

Methods used for cost calculations

The average value per kg of fertilizer component (N, P, K) was calculated based on the prices of combined fertilizers that are used for this farm. The same approach was used for chemicals (herbicides, fungicides and insecticides). The irrigation cost was calculated based on electricity consumption, as water was considered as a free resource.

Considering machinery, the rate and value were calculated based on the replacement value and life span of each machine or agricultural equipment in Greece, based on personal communication with farmers (see Table 48). The life span considers the durability of the item, the time between its first and last use.

Table 48: Agricultural equipment of the selected farm and their useful life span

Agricultural Equipment	Years of useful life
Tractor	
4wd tractor, 50 kW	15
Tillage machinery	
rigid-tine cultivator, 2.00 m	15
light cultivator, 3.00 m	20
Other machinery	
crop sprayer, suspended, 500 L, turbo	15
Tipping trailer, 7 ton	20
certrifugal fertilizer spreader, 12-36 m, 500 L	15
Irrigation machinery, 33 m^3/h	15
drip pipes	5

Alternative energy efficiency option 1: organic farming

One of the energy efficiency measures to be applied in the traditional farming system was organic farming. In general, organic farming is not widely applied in vineyards as farmers still believe that the “green revolution” standard of high chemical input should continue to be followed to ensure high yields and profits. However, organic farming could help to conserve water in arid and semiarid areas (Altieri, 1992) and reduce GHG emissions (Dalgaard et al, 2001) while the price of the product is higher to counterbalance the lower yields.

Organic farming in the vineyard reduces fuel consumption by 20%, because several agricultural practices of the conventional farming are not applied in organic farming. In particular, chemical pesticides are zero and fungicides (copper and sulfur) are applied but 34% less than in the conventional farming system. In addition, fertilizer application is reduced by 45.7%. Therefore, labour is also reduced by 4 h/ha/y (tractor operator). All the rest of the agricultural practices are the same as in the conventional system. Harvesting is scheduled for September, but the average yield is reduced by 31% due to lower inputs and higher disease and pest impact on the crop. These data are based on the work of Kavargiris et al, 2009.

Regarding the economics of this alternative, it should be noted that the Greek government provides the organic vineyards with a 5-year higher subsidy of 900 €/ha and then it drops to 330 €/ha as regular.

Farm machinery

One of the positive effects of organic farming systems is that the farmer does not have to invest in new machinery of agricultural equipment. Also the useful life time of some of the equipment increases because of reduced use.

Alternative energy efficiency option 2: precision farming

The second option to reduce the energy input is the application of a precision farming system to minimize the use of fertilizers, pesticides and water.

Unfortunately, precision farming in vineyards is not widely used in Greece. At the moment, there is activity in this subject, but data are not yet published. Thus, the expected input reduction was estimated based on personal communications with specialists in the field in Greece and using the published data from the University of Evora, Portugal (AGREE project partner).

According to the data provided, it was estimated that by applying precision farming techniques it is possible to obtain 20% fertilizer reduction, 10% pesticide reduction and 10% of irrigation water consumption reduction. It has to be mentioned that the yield is not affected and sometimes it can increase.

Farm machinery

One of the negative effects of precision farming systems is that important investment has to be made by the farmer and the machinery needs to be operated and maintained by trained personnel. In this case, the sensors, the computer, the printer and most importantly the software to produce the yield maps have to be purchased with a cost of about 15000€. However, as this equipment could be used for a farm of at least 100 ha, such an investment could bring an extra income in this particular case-study by hiring the precision farming services to neighbouring farms. Alternatively, the specific farm could use available precision farming systems service through subcontracting. However, the cost of such service is not yet known as it is not an extensive service in Greek agriculture.

Alternative energy efficiency option 3: biodegradable mulching film covering soil under vines

The third option is the use of biodegradable mulching film for soil coverage along the vine rows. This alternative production system has shown very positive results in terms of yields and labour cost savings, but not enough to reduce the energy input in comparison to the conventional production system. However, it was selected to be examined to show the needs of further research on the potential of using biodegradable mulching film in vineyard production. The target of such research could be twofold: a) to optimise the use of biodegradable mulching films in vineyards and b) minimize energy use in biodegradable mulching film processing and raw material production.

It is expected that irrigation water consumption will be reduced by 30% due to better water utilization by the plants (reduced soil evaporation in combination with elimination of weeds under the vines). In addition, fuel use is expected to be lowered by 10% due to less soil cultivation. Labor is reduced significantly, as weed control under the vines in the traditional system is executed manually (with mulching film application this practice is stopped and translates into 44 h/ha/y of work reduction). Furthermore, an increase in average yield is expected due to in the vines reaching full production one year earlier.

However, in this alternative case it is necessary to install the biodegradable mulching film that costs about 0.1 €/m^2 and needs 13 h/ha of labor to be installed. The biodegradable mulching film also represents an indirect energy input of 44 MJ/kg and GHG emissions of 1.35 kg CO_2e/kg. The use of thicker conventional fossil-oil based mulching films of at least two years duration may change these data accordingly.

Relative Contribution of different inputs and process steps to energy use, total costs of production and greenhouse gas emissions

Figure 55 shows the relative contribution of the different inputs in the energy consumption, the GHG emissions (CO_2e) and the total costs for the vineyard considered in the conventional production system of this farm, assumed as the basic scenario.

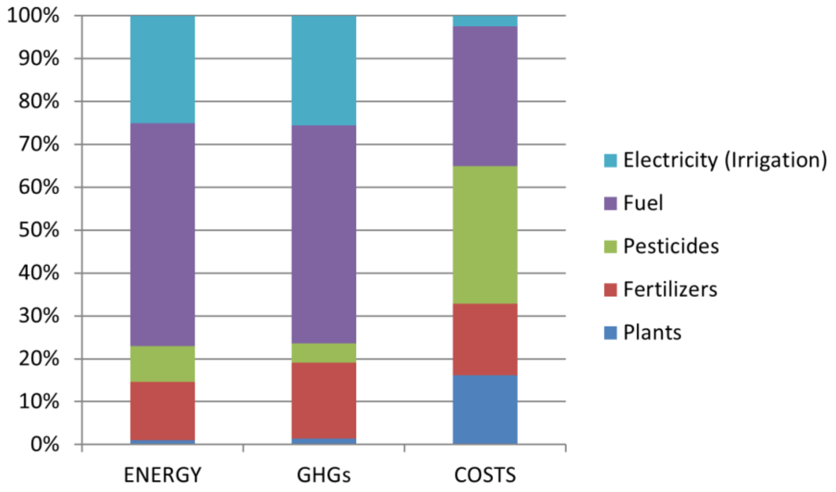

Figure 55: Relative contribution of different processing units and inputs in the farm production to energy use, GHG and economics

This figure can give several results about the vineyard. First of all, it is obvious that diesel fuel is the biggest energy consumer (52%) on this farm with the very similar effect on GHG production (51%). Also, it can be observed that electricity for irrigation follows in importance concerning energy consumption (25%) and GHG emissions (25.5%). Fertilizers and pesticides follow with energy contribution of 13.6% and 8.3% respectively and GHG emissions contribution of 17.7% and 4.5%. From the Figure 55, it can be seen that in general energy and GHG emissions follow more or less the same trend on the effect of each component.

However, it is very interesting to analyse the difference between the energy and environmental impact of this farm in comparison to the costs. The most significant example would be the electricity consumption that even if it requires high primary energy to be produced with respective high GHG emissions (mainly due to lignite use for electricity production that is of very low efficiency and of very high GHG emissions), it has a very low cost (natural resource) especially for agricultural production systems (2.5%). This favours the Greek farmer, but in some cases it is the reason for irrational use of water with the only target being the expected maximizing of yield (which in most cases is not achieved and the water is wasted) and no consideration of sustainability, especially in a Mediterranean country where water is a limited resource.

Another notable result is that diesel is very expensive (imported) and contributes to the farm costs considerably. As for the consumables (seeds, fertilizers and pesticides), they are also expensive influencing significantly the final income of the farm. Finally, it should be noted that the vines installed on the land are very important economically, whereas their impact on the energy use of the system is insignificant.

Environmental and economic impact of different energy efficiency measures for vineyards

The two first alternative scenarios had a significant reduction in energy consumption, achieving the target set for them. As was expected, the reduction of energy consumption was also translated into GHG emission reduction. In the third alternative scenario (mulching film), energy use was increased by 7.6%.

Figure 56 shows the farm results concerning energy consumption per tonne of produced grapes. It can be observed that organic farming reduced energy consumption by 2.46%, precision farming reduced energy by 4.83% and mulching film application increased energy consumption by 7.59%.

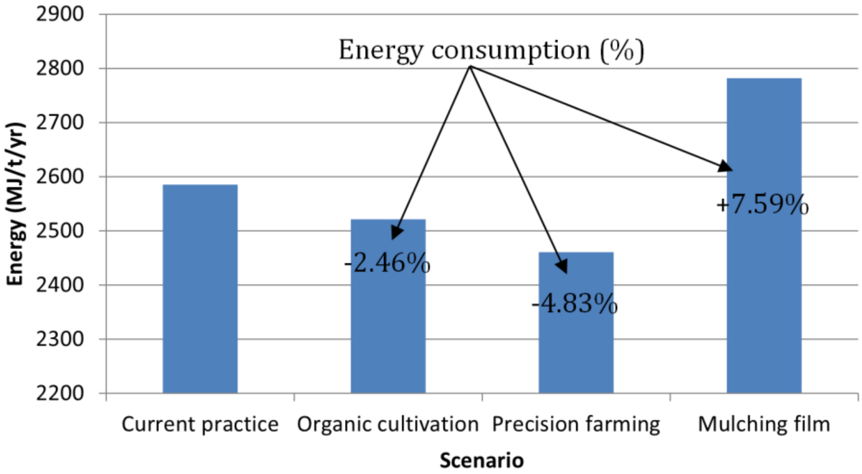

Figure 56: Energy consumption reduction using the three alternative scenarios

Figure 57 shows the farm results concerning GHG emissions. It can be observed that organic farming reduced GHGs by 2.18%, precision farming reduced GHGs by 5.2% and biodegradable mulching film application reduced GHGs by 4.87%. In this case, GHG emissions are reduced in the case of biodegradable mulching film application in contrast with energy use. This is because the energy to produce biodegradable films is high, but on the other hand the fact that the materials used to produce them are not fossil-oil based raw materials as in conventional films, this makes GHG production much lower.

Regarding the profit of the farm, there was a change in comparison to the results of energy and GHG emissions. In particular, in the first scenario of organic farming, profit was reduced by 25.51% due to the fact that the yield reduction produced an income 12% less than the conventional farming system, but the vineyard production costs were only reduced by 9%. In precision farming, the reduction in profit is due to the combination of maintaining yield, but increasing costs due to new equipment.

In Figure 58, it can also be seen that the highest mean annual profit increase was obtained by the biodegradable mulching film application scenario due to higher production, caused by achieving a regular yield one year earlier, and keeping the costs at almost the same level.

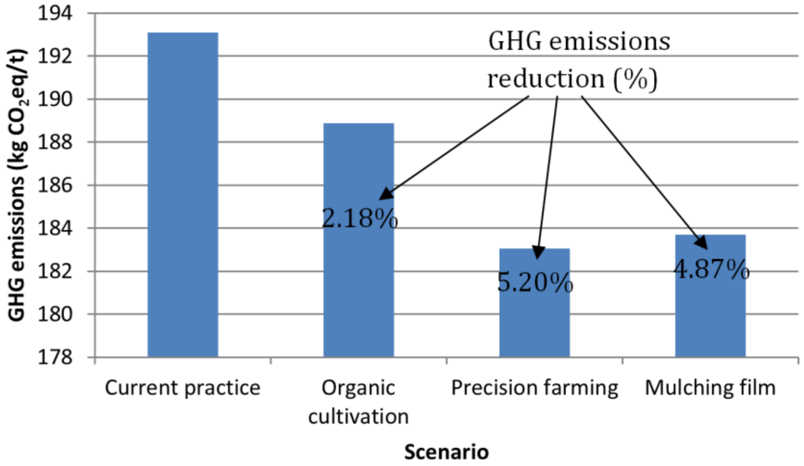

Figure 57: GHG emissions reduction using the three alternative scenarios

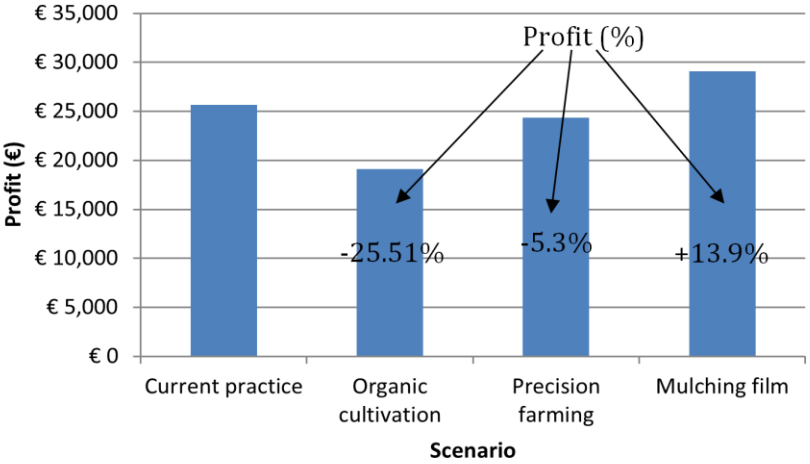

Figure 58: Profit increase using the three alternative scenarios

Conclusions

Three alternative EE measures, selected from those proposed in the WP2 for vineyards in Greece, are analysed for a vineyard in northern Greece. The first two analysed scenarios (organic farming and precision farming) gave good results in terms of energy use reduction, with positive side effects on environmental impact (GHG emissions decreased). However, the economics of the farm was affected negatively in both cases (lower final profit). The third scenario (biodegradable mulching film application) did not give good results on energy basis. However, it resulted in lower GHG emissions than conventional farming and in a higher profit for the farmer. Therefore, it is believed that more EE measures should be evaluated by field experiments and the biodegradable mulching film technology should be examined more carefully in both aspects: its application in vineyards, which is still at an early stage of development, and in reducing the energy required to produce it.

4.5.3. Energy efficiency measures in Portuguese vineyards production

Fátima Baptista, Dina Murcho, Carlos Marques, Luis Leopoldo Silva, José Rafael Silva

Introduction

Vineyards are a very important crop in Portuguese agriculture. The estimated area of vineyards was 177 831 ha (4.8%) in 2009 of the Portuguese utilized agricultural area (INE, 2011), and was the second most important permanent crop. Due to its importance and its specific crop production system, it has been one of the crops in which several precision agriculture studies have being developed in Portugal (Marques da Silva et al. 2009). The objectives of these studies have been to identify possibilities to improve efficient application of production factors, such as fertilizers and irrigation water.

Another agricultural practice that has been applied in vineyards is organic farming. Although not very common, it's a practice encouraged by European policies and it should be studied, particularly with respect to aspects involving energy consumption, greenhouse gas emissions (GHG) and costs. It is expected that a reduction in productivity will occur but income could be compensated for by higher expected market prices for these products.

The main objective of this case study is to analyse the effect in economic results, energy consumption and environmental impacts of two options: 1.Organic farming, and 2. Precision agriculture.

Methodology

Alentejo is the largest agricultural region of Portugal, with a Mediterranean climate characterized by mild winters and dry and hot summers. Mean annual precipitation is 550 to 650 mm concentrated in autumn and winter. Average maximum temperature is around 21 ºC with an absolute value of 42 ºC. Average minimum temperature is 12 ºC and minimum absolute -5 ºC. Insolation is approximately 3000 h per year (Marques da Silva et al. 2010).

A typical farm of 300 hectares and a traditional vineyard cropping system in the Alentejo region was chosen as the basic scenario. The two alternatives studied were the effect of using precision agriculture techniques for differential, spatial, application of fertilizers and pesticides and an organic cropping system which uses alternative crop protection products.

Basic scenario–Traditional Crop system

The basic scenario is a vineyard in its full production stage, with a 7 t/ha grape yield for quality wine production. Mean plant density is 4000 plants/ha, planted on a grid of 2.5 x 1.0 m. The vineyard is irrigated by a drip irrigation system.

Vineyard installation is initiated with several operations for soil preparation, followed by a fertilizer application using 200kg/ha of P and K complemented with the application of 500

Kg/ha of an organic fertilizer. Soil is marked and holes are opened for the vines. The support system is installed. These operations take place only in the first year but they have been considered when taking into account the costs, energy consumption and GHG emissions. The vineyard life time is assumed to be 20 years.

Vineyard cultivation techniques are mainly related to soil maintenance and weed control, fertilizer application, irrigation, pruning, thinning fruits, crop protection against pests and diseases and harvesting. Fertilizer application is approximately 35 kg/ha N, 80 kg/ha P and 15 kg/ha K. In early spring there is an application of herbicide along the row (glyphosate) and usually in April there start several pesticide treatments that continue until August, according to weather or climatic conditions. In May there is a green harvesting operation in order to control excess vegetation and to define the final grape production target according to the farmer's goals for quantity and quality of the grapes.

Vines are irrigated from May to July with an average annual amount of 2000 m^3/ha of water, and with the application of a liquid fertilizer. The amounts of applied water depend of the meteorological conditions each year, but are mostly supplemental irrigation practices. Grape harvest is from August to September.

Farm machinery

This farm is equipped with tractors (between 145cv and 70cv), a harvesting machine, sprayers, grass cutters, vine breaks or cutting mulchers and all the necessary equipment.

EU financial aid – Common Agricultural Policy

All farms receive, each year, an EU subsidy, the RPU ("*Single Payment Scheme*"). The value received is different for each farm and it is calculated based on the average farm planting historical area of specific crop and on the number and type of livestock. In 2011, the national average RPU value was 174 €/ha. Additionally, farmers receive a PRODER subsidy, with an average value of 59.58 €/ha (for the 300 ha), for vineyards.

Methods used for cost calculations

Since we have the installation of the vineyard and then the system operation, the calculations include *vineyard operation* and *vineyard installation financial and energy* estimates for the different inputs. Variable Costs, PEC and CO_2 final values are the sum of the values of vineyard operation per ha and vineyard installation also per ha and per year.

In the mechanisation item, the depreciation rate and value were calculated based on the replacement value and life span of each machine. The life span considers the durability of the item, *i.e.*, the expected length of time that it lasts in use.

Alternative option 1–Organic farming

Organic farming relies on a number of practices designed to minimise the impact on the environment, while ensuring that the agricultural system operates as naturally as possible. Typical organic farming practices in vineyards include the limitation in the use of synthetic chemical pesticides and fertilisers and takes advantage of on-site resources, such as livestock manure for fertiliser. However, usually this system leads to lower production. In this option it is assumed a 5 t/ha grape yield for quality wine. Farm machinery is the same as in the basic scenario. The PRODER subsidy has an average value of 116.78 €/ha (for the 300 ha).

Alternative option 2–Precision agriculture

As an alternative option to the traditional farming system the introduction of precision agriculture techniques such as the differential application of fertilisers, pesticides and water were also studied. Based on data obtained by experimental research (Marques da Silva, 2012), a reduction of 20% in fertilisers, 10% in pesticides and 10% in water was used. Additional investment in specific equipment is required as well as costs related to soil analysis and elaboration of maps to study field variability. These are estimated to need an investment of 18 000€ and a variable cost per ha of 7.5 €. Yield is assumed to be the same as in the basic scenario.

Relative Contribution of different inputs and process steps to energy use, total costs of production and greenhouse gas emissions

Figure 59 shows the relative contribution of the different inputs in costs, GHG emissions (CO_2e) and energy consumption for the vineyard farm production system assumed as the basic scenario. It is clear that different inputs contribute in different proportions to the total costs, primary energy consumption and GHG emissions. Hence, factor levels may have different impacts on costs, energy use and GHG emissions. Pesticides, diesel and fertilizers are the most important factors concerning GHG emissions and energy consumption. Materials are also a relevant component of costs. These materials refer to the support system and plants used in the crop installation. These investment costs were divided over the 20 years in order to have an annual value.

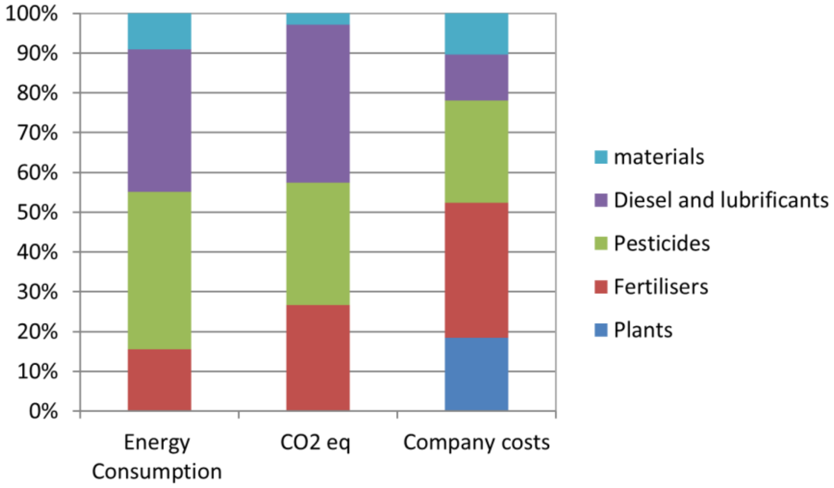

Figure 59: Relative contribution of different processing units and inputs in the farm production to economics, energy use and greenhouse gas emissions (GHG).

Impact of different energy efficiency measures on economics and the environment

Table 49 and Figure 60 present the total costs, energy consumption and GHG emissions per hectare. In an overall analysis it can be stated that options 1 (organic production) and 2 (precision agriculture) decrease costs, energy consumption and GHG emissions relative to basic system. In fact, production costs decrease about 12% with organic production and 5% with the precision agriculture technologies. The same is observed in energy consumption and GHG emissions. Organic production allows a reduction in energy consumption of about 22% and precision agriculture around 7%. For the CO_2eq emissions a decrease of 25% is obtained with organic production and approximately 8% with precision agriculture. These reductions are explained in the first case with the use of products with organic origin, with reduced or none contribution for the GHG emissions and in the second case with the reduction of the quantity of inputs due to the differential rate application.

Table 49: Annual costs, PEC and GHG emissions with energy efficiency measures.

	Annual Costs		PEC		GHG	
	€/ha	%	MJ/ha	%	CO_2e/ha	%
Reference	2874.86	100.0	20391.68	100.0	1109.20	100.0
Organic	2539.20	88.3	15873.06	77.8	831.65	75.0
Precision Agriculture	2738.10	95.2	18875.88	92.6	1019.12	91.9

Figure 60 also shows the impact of the different options on farm profit. It is possible to see that organic production results in a decrease of the farm profit (approximately 17%) but with precision agriculture profit increases around 12%. The decrease in organic production is explained by lower yield levels of this production system. In fact, higher market prices do not compensate for the negative effects of reduced production on profits. This question must be addressed for this kind of productions because farmers will not invest to adopt these systems. In the case of precision agriculture, the yield is the same but with lower costs, so profit obviously increases.

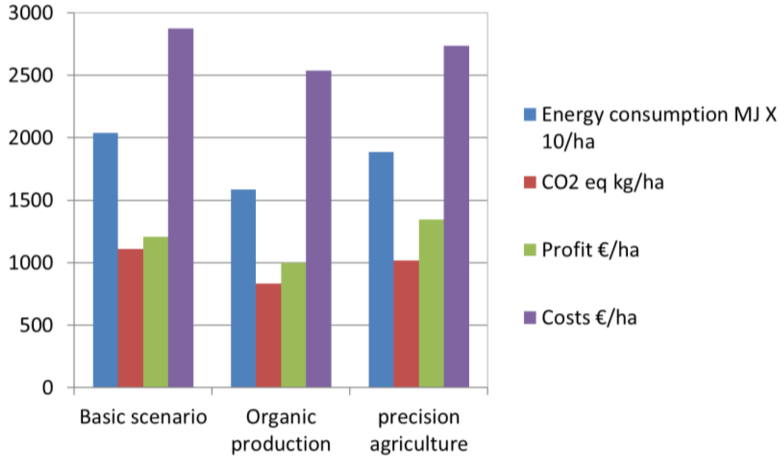

Figure 60: Impact of different energy saving measures on costs, profit, energy use and GHG emissions per ha.

Figure 61 presents the impact on costs, profit, energy use and greenhouse gas emissions (GHG) per ton of grapes produced. Alternative systems analysis, per hectare, lead to different conclusions. In fact, when considering the production obtained with those costs, energy consumption and GHG emissions we obtained a completely different picture for each of the studied options.

Organic production leads to an increase of costs (24%), energy consumption (9%) and GHG emissions (5%) due to the lower productivity per ha (5t instead of 7t). An increase of profits (16%) indicated in the figure are due to the higher price paid for the grapes. The use of precision agriculture technologies allows reduced production costs (5%), energy consumption (7%) and GHG emissions (8%) and, therefore, increases farm profit (11%).

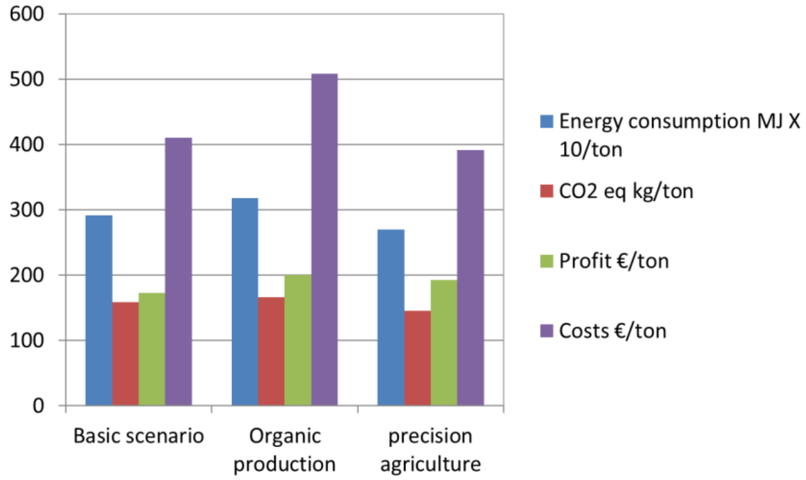

Figure 61: Impact of different energy saving measures on costs, profit, energy use and GHG emissions per ton of grapes.

Figure 62 shows the differences between the basic scenario and the analysed options, on energy, GHG emissions, costs and farm profit per ton of yield. It is possible to see that the introduction of precision agriculture can contribute to save energy, to lower GHG emissions and to increase farm profit. Organic production system does not have similar effects, due to the reduction of productivity. However, this production system may have advantages, and it should be considered as an option. For instances, some studies are being developed in order to find adapted varieties with higher productivity. Improved technologies could also help to obtain better results.

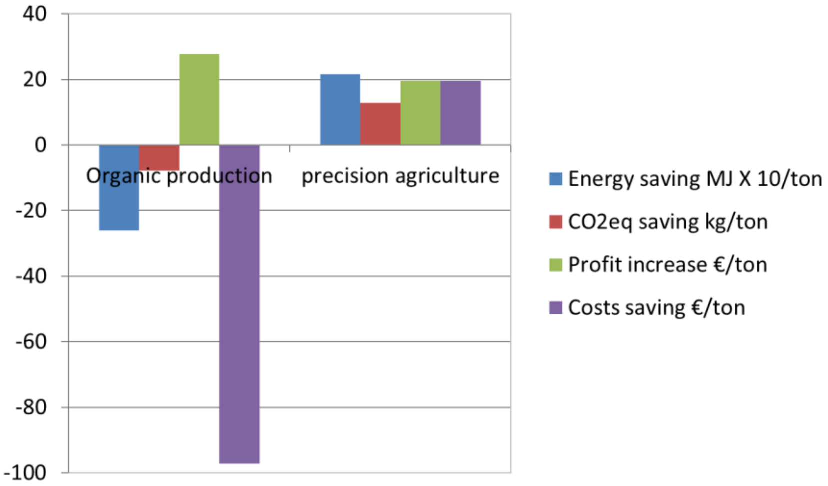

Figure 62: Differences of costs, profit, energy use and greenhouse gas emissions (GHG) savings per ton of grapes between the basic scenario and the different options studied.

Conclusions

The analysed options show a good potential to reduce costs, energy consumption and GHG emissions per hectare contributing to increase the efficient use of resources, thus contributing to increase farm profits. However, in the case of organic production, the productivity is lower and the results, per ton of production are not favourable. However, as we all know, several factors interact in the production system, and more research is needed in order to obtain experimental data that allows a more detailed analysis, turning this system into a real alternative for farmers.

4.5.4. Energy efficiency measures in Greek olive groves

Athanasios Balafoutis, Panagiotis Panagakis, Demetres Briassoulis

Introduction

This section presents the analysis of various energy efficiency scenarios regarding olive farming systems in Greece. Olive groves represent the most significant permanent crop in the country and they are found in most parts of the country under different terrain types. The indigenous olive tree (wild olive tree) first appeared in the eastern Mediterranean but it was in Greece that it was first cultivated. Since then, the presence of the olive tree in the Greek region has been uninterrupted and closely connected with the traditions and the culture of the Greek people.

Over 100 different types of olive trees are cultivated in Greece and that thrive in the Greek climate of long hot summers and mild winters with very little frost. The majority of trees yield ‘oil olives’ from which olive oil is extracted. Also, there are a great number of types which are cultivated for eating. Some particularly important cultivars of *Olea europaea* in Greece include[5]:

- **Amfissa** is a Greek table olive grown in Amfissa, Central Greece near the oracle of Delphi. Amfissa olives enjoy protected designation of origin (PDO) status, and are equally good for olive oil extraction. The olive grove of Amfissa, which consists of 1,200,000 olive trees is a part of a protected natural landscape.
- **Hondroelia Halkidikis** ('hondro=thick' olive from Halkidiki or 'donkey-olive', due to its size), a large green olive with a strong bitter taste, originated in the Halkidiki peninsula in North Greece.
- **Kalamata**, a large, black olive with a smooth and meatlike taste, is named after the city of Kalamata, Greece, and is used as a table olive. These olives are usually preserved in wine, vinegar or olive oil. Kalamata olives enjoy PDO status.
- **Koroneiki** originated from the southern Peloponese, around Kalamata and Mani in Greece and in Crete. This small olive, though difficult to cultivate, has a high yield of olive oil of exceptional quality.
- **Patrinia olive**, is a Greek variety of olive tree grown primarily in Aigialeia, Greece.

Olive production in Greece is reported at 1809800 tonnes and the area cultivated at 834200 ha, with an average production of 2.17 t/ha (FAO 2010).

Due to its importance and its specific crop production system, it was selected to be

---

[5] http://en.wikipedia.org/wiki/Olive - cite_note-46

investigated in the framework of AGREE. There are several types of energy efficiency measures that could be applied in an olive grove (see Energy efficiency measures report for Greece in WP2), however in this report two case studies were selected and analysed so as to investigate possible energy efficiency measures, namely organic farming and non-irrigated organic farming. The impact of these measures on greenhouse gas (GHG) emissions and on the economics of the farm are also examined.

Organic farming was selected based on the fact that this agricultural practice is strongly supported by EU through the subsidised environmental friendly agricultural practices, even if the final yield of all organic crops is significantly reduced due to substantial restrictions in types and quantities of chemical pesticides and fertilizers used. However, organic farming provides consumers with high value agricultural products that can receive better prices in the market, while it contributes to the protection of natural resources.

Methodology

Sterea Ellada region is a traditional agricultural region of Greece. The crops mainly cultivated in the area are wheat, cotton, tobacco, olives and wine grapes. The basic scenario chosen for this report is a typical farm of 10 ha at the *Lamia* area, with irrigation potential and sandy-clay soils wherein a *Koroneiki* native olive variety is cultivated.

Basic scenario–Traditional Crop system

The traditional olive grove production system is shown below.

Conventional olive trees of Koroneiki variety:

The cultivation procedure in the farm under investigation follows the steps below:

1. *Olive grove installation*

The land area selected to install the olive grove is prepared for the new olive trees to be planted.

Soil treatment

Preparation of the soil is by using the following machinery:

1. Plough for deep ploughing (35 cm)
2. Heavy cultivator
3. Light cultivator

Planting

Planting is executed manually. The plot is measured and holes are opened along parallel rows in equal distances of 6 m. The distance of the rows is also 6 m. Planting requires ≈250 plants/ha combined with light fertilizer application (5.5 kg N/ha, 7.5 kg P/ha & 7.5 kg K/ha).

Chemical application

Usually, the conventional olive groves are sprayed 2–4 times from August to October with insecticides (dimethoate or fenthiol with 0.3%).

Weed control

For weed control, the soil is cultivated with light cultivator 4 times every year.

Fertilizer application

Every second year, an 11-15-15 fertilizer is applied. The quantity required is 0.2 kg/tree for every year of the tree growth. The total quantity of fertilizers for the first 15 years of the olive grove is estimated to be 352 kg N/ha, 480 kg P/ha, 480 kg K/ha.

Irrigation

3-5 irrigations using drip irrigation systems. Total water quantity 120 m^3/ha/y.

Harvesting

Harvest is executed manually from mid November to late December (in this period of olive trees development the mean yield for a period of 15 years is about 2.25 t/ha of olives). Plastic olive nets or olive mats (textile or cloth) are used for olives harvesting. The olive nets' fabric technology is high density polyethylene (HDPE) monofilament (100 g/m^2) and the olive mats' fabric is woven PP cloth (100 g/m^2) with a minimum life of 5 years. They are moved from tree to tree in order to collect the olives harvested from the tree. The average olive mat and net surface is 50 m^2, in order to cover a surface larger than the canopy area of the tree harvested.

2. *Olive grove operation*

The cultivation procedure of the olive trees after the first 15 years follows the steps below:

Weed control

Three inter-row cultivations per year for weed control, without chemical applications, with a light cultivator.

Chemical application

Same as in the installation of olive grove section.

Fertilizer application

Three applications of fertilizer are executed every second year (3 kg/tree). Indicatively, the total quantity of fertilizers for the next 95 years (for a 100 years old grove, although olive groves can have productive life of 500 years) is 3465 kg N/ha, 4725 kg P/ha, 4725 kg K/ha.

Irrigation

1-2 irrigations using drip irrigation systems. Total water quantity 180 m^3/ha/y.

Harvesting

Harvest is executed manually from mid November to late December (this is the period of high yield for the grown olive trees with annual mean yield 6.5 t/ha of olives). Olive mats are used as in the installation of olive grove section.

Farm machinery

The farm owns the machinery below:

- Agricultural tractor 40 kW
- Light cultivator (2 m)
- Crop sprayer (mounted, 500 L, turbo)
- Trailer (7 t)
- Irrigation machinery (pump, auxiliary parts, water supply of 33 m^3/h)
- Drip irrigation piping

The farm contracts:

- Plough for plant installation
- Rigid tine cultivator (3 m)

EU financial aid

The selected farm receives, each year, EU subsidies for olives production. The value received is different for each farm and it is calculated based on the farm history of producing the specific crop during the period 2001–2003. Note that during that period many areas of the country suffered heavy winters with frost resulting in very low olive production when many trees were destroyed. Therefore, when subsidies were calculated from the *“Payment and Control Agency for Guidance and Guarantee Community Aid (OPEKEPE)”*, these areas were assigned with low subsidies, when other areas (e.g. Crete) received higher subsidies due to more or less unchanging production throughout this period. The average value of subsidies in the area where the selected farm is situated is 200 €/ha.

Methods used for cost calculations

The average value per kg of fertilizer component (N, P, K) was calculated based on the prices of combined fertilizers that are used for fertilizing this farm. The same approach was used for chemicals (herbicides, fungicides and insecticides). Irrigation cost was calculated based on electricity consumption, as water was considered a free resource.

Table 50: Agricultural equipment of the selected farm and their useful life span.

Agricultural Equipment	Years of useful life
Tractor	
4wd tractor, 50 kW	15
Tillage machinery	
light cultivator, 3.00 m	20
Other machinery	
crop sprayer, suspended, 500 L, turbo	15
Tipping trailer, 7 t	20
Irrigation machinery, 33 m^3/h	15
drip pipes	5
Manure spreader	15

With regards to machinery, the rate and value were calculated based on the replacement value and life span of each machine or agricultural equipment in Greece, based on personal communication with farmers (see Table 50). The life span concerns the durability of the item, namely the time between its first and last use.

Alternative energy efficiency option 1: organic farming

One of the energy efficiency measures to be applied in the traditional farming system was organic farming. In general, organic farming is not widely applied in olive groves in Greece, but there is a tendency to increase due to higher product prices, especially for high quality exported certified olive-oil, and environmental awareness of the farmers. Organic cultivations are mostly concentrated in some specific regions of the country.

Organic farming impact on olive yield is negative, but the percentage of this reduction is within a wide range (1.6–35%), according to Guzman and Alonso (2008) and Kaltsas et al. (2007). However, the reduction for mature olive trees that are properly treated (i.e. pruned correctly and fertilized with animal and green manure) can be limited down to 5%.

Organic farming will result in 29% fuel consumption increase. In the primary system there were three cultivation applications. In the alternative system, manure is spread using a trailed manure spreader (20 t/ha every second year). Then, one cultivation application is applied, followed by the sowing process for the installation of legumes (green manure of *trifolium sp*., *vicia sativa*). Sowing requires 135 kg seed/ha/y. Finally, one more cultivation is applied to incorporate the legumes at the end of their cycle; therefore labour is also increased by 2 h/ha/y (tractor operator).

In addition, chemical pesticides are zeroed and bait [Elcophon (plastic bottle)] or bait-pheromone [BIORYL (paper envelope)] and traps for olive fruit fly are applied. Therefore, labour is also reduced by 1 h/ha/y [(no tractor operator (4 h/ha/y), but manual work to install the baits and traps (3 h/ha/y)] is added to the system. As for fertilizer application, the chemical fertilizers are substituted by sheep/goat manure that is spread using a manure spreader, as mentioned above. All the rest of the agricultural practices are the same as in the conventional system. Harvesting is scheduled for November-December, but the average yield is reduced by 35% due to lower fertilizer inputs. These data are based on the work of Kaltsas et al. (2007); Guzman and Alonso (2008) and a report of the Ministry of Agriculture (see reference website in the reference section).

Regarding the economics of this alternative, it should be noted that the Greek government provides the organic olive groves with a higher subsidy for the first five years when the subsidy is 756 €/ha before reducing to 415 €/ha, the same as the regular subsidy.

Farm machinery

One of the positive effects of organic farming systems is that the farmer does not have to invest in new machinery or other equipment, except a manure spreader (possibly owned for other crops). However, in the calculations regarding this report, the manure spreader is imported into the system as a new investment. Also the useful life time of some of the equipment increases because of reduced use.

Alternative energy efficiency option 2: non-irrigated organic farming

The second option to reduce the energy input is to keep the same cultivation techniques as in organic farming and also convert this farm from irrigated into non-irrigated. The impact on the final olive yield is 29–37%, according to Guzman and Alonso (2008) and private interviews of olive growers in Greece. In this report it was assumed that the reduction in yield in comparison to organic farming would be 30%.

This energy efficiency measure zeroes the mechanization cost for the pumping facility and the plastic drip pipes. In addition, there is a reduction of the total variable cost of the olive grove due to less electricity consumption for pumping.

Farm machinery

One of the positive effects of conversion into non-irrigated farming systems is that there is no need for irrigation system.

Relative Contribution of different inputs and process steps to energy use, total costs of production and greenhouse gas emissions

Figure 63 shows the relative contribution of various energy consumption inputs, the GHG emissions (CO_2e) and the total costs for the olive grove considered in the conventional production system of this farm, assumed as the basic scenario.

This figure gives several results for the olive grove. It is obvious that the highest energy consumption in this farm is related to fertilizers (39%) with a slightly higher effect on GHG production (45%). It can also be observed that pesticides follow in importance concerning energy consumption (24%). This is not seen in the GHG production putting pesticides in the 4th place of importance (12%), because despite the high energy (268.4 MJ/kg a.i.) needed for pesticides to be produced, the relevant GHG emissions are low (10.97 kg CO_2e/kg a.i.). Electricity for irrigation accounts for 19% of the total energy consumption, but due to the high environmental impact of the Greek energy mix its GHG production effect is much higher (29%). On the other hand, fuel follows with 15% and 13% in terms of energy contribution and GHG emissions, respectively.

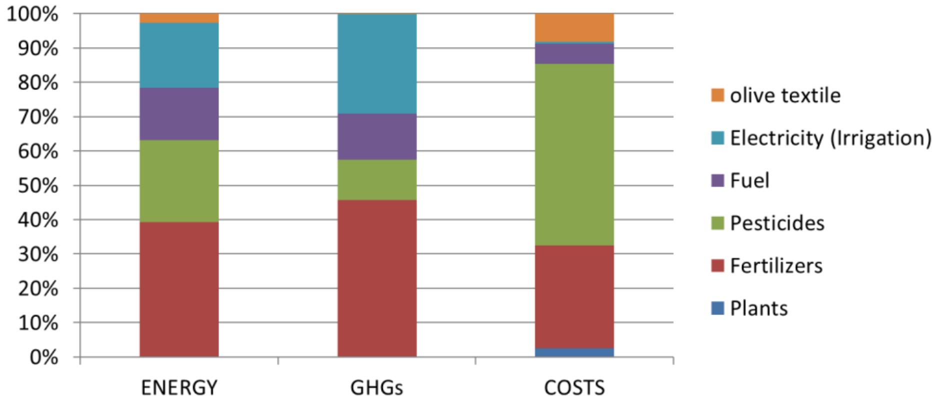

Figure 63: Relative contribution of different processing units and inputs in the farm production to energy use, GHG emissions and economics

It is very interesting to analyse the difference between the energy and environmental impact of this farm in comparison to the costs. The most significant example would be the electricity consumption that even if it requires high primary energy to be produced with respective high GHG emissions (mainly due to lignite use for electricity production that is of very low efficiency and of very high GHG emissions), it is of very low cost (natural resource) especially for agricultural production systems (0.5%). This is to the benefit of Greek farmers, but in some cases it is the reason for irrational use of water with the main target being the expected maximization of yield, which in most cases does not occur and the water is wasted, and is not sustainable, especially in a Mediterranean country where water is a limited resource.

Another notable result is that pesticides are very expensive and contribute considerably (53%) to the farm costs (it is noticed that in the last two years the use of agrochemicals in Greece has been reduced in general, due to the crisis; this fact has not been considered in the present analysis). It should also be noted that the plants installed are financially important (2.5%) but their impact on the energy system is insignificant.

Environmental and economic impact of different energy efficiency measures for the vineyard

The two alternative scenarios had a significant reduction on energy consumption, achieving the target set for applying them. As was expected, the reduction of energy consumption was also translated into a reduction of GHG emission.

Figure 64 shows the farm results concerning energy consumption per tonne of produced olives. It can be observed that organic farming reduced energy consumption by 13.2%. The main reason for this reduction was the fact that chemical fertilizers and pesticides are not applied as they are substituted by less energy consuming materials.

Non-irrigated organic farming application decreased energy consumption by 11%. The difference from the irrigated organic farming scenario is due to the fact that primary energy consumption for electricity production is reduced significantly (8407 MJ/ha for the whole period), but this does not compensate for the greater reduction in olive production.

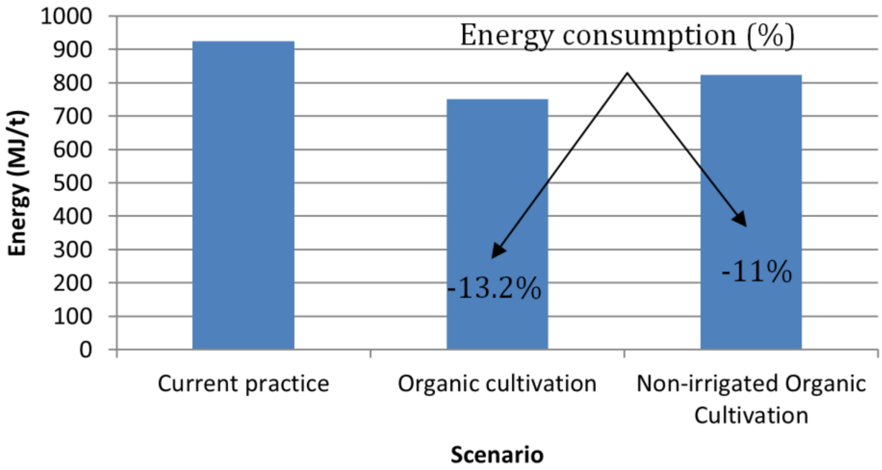

Figure 64: Energy consumption reduction using the three alternative scenarios

Figure 65 shows the farm results concerning GHG emissions. It can be observed that organic farming reduced GHGs by 37.8% and non-irrigated organic farming reduced GHGs by 56.8%. It can be seen that GHG reduction is significantly higher than energy reduction. The main reason for this result is the fact that the chemical fertilizers applied in the primary scenario are substituted by manure (zero GHG emissions as the sheep/goat farms manage the manure in piles and then deposit it nearby; this means that manure GHGs are emitted anyway, even if used in the farm or not). Another reason is that pesticides that are not applied in the organic system are substituted by paper traps that emit insignificant amount of GHGs.

The difference between the irrigated and non-irrigated system results in the very important amounts of GHGs that are avoided due to not using electricity for water pumping.

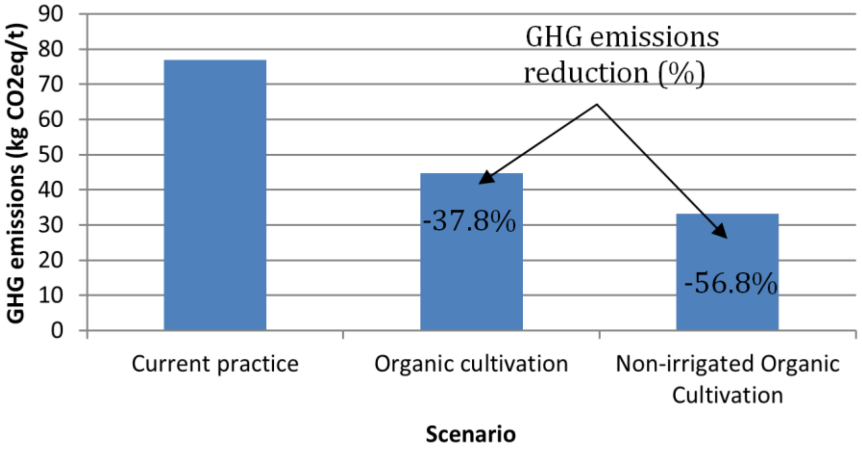

Figure 65: GHG emissions reduction using the three alternative scenarios

The farm profit was increased however in both organic scenarios but was higher in the irrigated organic cultivation one. The main reason was the higher subsidy for organic farming that contributes considerably to the final farm income, but also the higher price of the product.

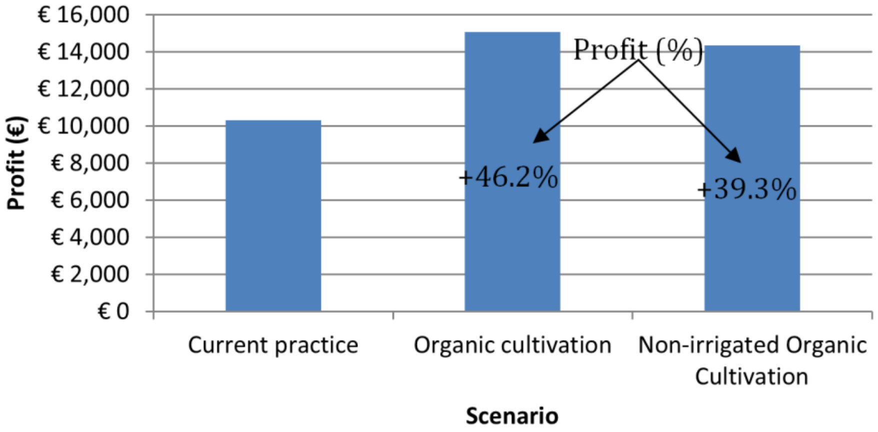

Figure 66: Profit increase using the three alternative scenarios.

In particular, the organic cultivation scenario was more profitable by 46.2%, due to the fact that yield reduction was very low and was combined not only with higher product price of

40%, but also with lower inputs. In non-irrigated organic farming, the increase in profit was 39.3%, due to the fact that the significant yield reduction was compensated for by the reduced inputs.

Conclusions

Two alternative energy efficiency measures for olive groves in Greece, selected from those proposed in WP2 list, are analysed for an olive grove in Southern continental Greece. The two analysed scenarios (organic farming and non-irrigated organic farming) gave good results in terms of energy use reduction (which was the driver for this report), with positive side effects on environmental impact (GHG emissions decline) and economics.

It should be pointed out that the profit gained from the selected farm of 10 ha is rather low and cannot support financially the farm business viability, even when converted into an organic farm. The main reason for the low income from olive groves (a situation concerning the majority of the conventional olives production and olive oil production in Greece, with several exceptions) is the intervention of a series of intermediates in the olive and olive oil market in Greece. In particular, farmers sell their product (olives and olive oil) in bulk quantities. For example, in the case of olive oil the average market price of 2.5 €/l and in the case of organic farming an average price of 3.5 €/l, when the product ends up in the retail shops at double or even triple prices. Packaging, distribution and marketing of certified olives and olive oil products benefit from much higher prices. Certification and marketing enhancement has been set as a major goal for the Ministry of Agriculture and the regional farmers' cooperatives, especially for young farmers.

4.5.5. Energy efficiency measures in Portuguese Olive Groves production

Fátima Baptista, Dina Murcho, Luis Leopoldo Silva, Carlos Marques, José Rafael Silva, José Oliveira Peça

Introduction

Olive groves are a typical crop of Mediterranean regions and acording to INE (2011), it is the permanent crop with more utilized agricultural area in Portugal, occupying 52% of the total area with permanent crops (excluding pines). This area was, in 2009, 335 841 ha, 99% for olive oil production, corresponding to 9.2% of the total Portuguese utilized agricultural area *(UAA)*. Alentejo is the region with the highest area (49%), followed by Trás-os-Montes (22%) and Beira Interior (14%). Intensive and super-intensive production systems, with tree densities higher than 300 trees per ha, are present in approximately 9% of the olive groves area, located mainly in Alentejo (79%). Almost 40% of the olive grove area is concentrated in 2000 farms, with an average area greater than 20 ha. In recent years this sub–sector has been particularly dynamic, with the introduction of new technologies and new irrigated plantations located near the dams built in the last decade and where irrigation is available.

Olive mills have presented also a positive evolution with modernization and technological adaptation to respond to the European Community rules concerning hygiene and environmental requirements. Mills are scattered and relatively well located in the production regions, which contributes to improving the olive oil quality (MADRP, 2009).

A typical farm located in the Alentejo region with 143 hectares was chosen to represent the basic scenario. It is an intensive plantation, with an average of 314 trees per ha. Alternatives considered were 1) a reduction of water for irrigation, fertilizers and pesticides through improved irrigation scheduling and fertilizer and pesticide application strategies and 2) the super intensive production. The main objective of this case study is to analyse the effect on the economic results, energy consumption and environmental impacts of the alternative systems based on more efficient application production factors and a super intensive production system.

Basic scenario

The basic scenario is an olive grove in its full production stage, with a production of 8.8 t/ha olives for olive oil production. Mean plant density is 314 trees/ha, with a tree spacing of 8 x 4 m. The crop is irrigated by a drip irrigation system.

The installation is initiated with several operations regarding soil preparation. Land is marked and holes are opened for planting. The plant supports and protectors are installed. These operations take place only in the first year and it is considered here to take into account crop installation costs, energy consumption and GHG emissions. The olive grove's life was assumed to be 30 years.

Olive grove cultivation techniques are mainly related to soil maintenance and weed control, fertilizer application, irrigation, pruning, crop protection against pests and diseases and harvesting. Fertilizer application is approximately 72 kg/ha N, 16 kg/ha P and 70 kg/ha K. In early spring there is an application of herbicide along the row (glyphosate) and usually in May there are several pesticide treatments that continue until September, depending on climate conditions.

Trees are irrigated from May to October with an average annual amount of 2000 m^3/ha of water, and with the application of a liquid fertilizer. The amounts of applied water depend on each year specific meteorological conditions, but are mostly supplemental irrigation practices. Olives harvest is from November to December.

This farm is equipped with all the necessary equipment, namely tractors (between 145cv and 70cv), a vibrator with a collecting umbrella, sprays, cut grass, and trailer. The materials used in the farm include harvesting canvas, protectors and tutors used during the installation.

All farms receive, each year, an EU subsidy, the RPU ("*Single Payment Scheme*"). The value received is different for each farm and it is based on the farm historical area of production of specific crops, and animal numbers. In 2011, the national average value attributed was 174 €/ha.

Since we have the installation of the olive groves for 30 years life time, calculations include olive operation and olive installation financial and energy estimates for the different inputs. Costs, PEC and CO_2 final values are the sum of the values of operation and installation per ha and per year.

In the mechanisation item, depreciation values and rates were calculated based on the replacement value and life span of each machine or agricultural equipment. The life span considers the durability in years of the item.

Alternative option 1

Alternative option 1 was to investigate the improvement of the irrigation scheduling and the use of differential application of fertilisers and pesticides by using simple technologies of precision agriculture, with the use of soil analysis, climatic information and risk of pest/disease occurrence. It was expected that a reduction of 10% in use of fertilizers, pesticides (Marques da Silva 2012) and water (Silva 2012). This system requires consideration of the costs related to the soil analysis and the investment in a meteorological station (4000€). A variable cost per ha of 7.5 € was considered. Yields are assumed to be the same as in the basic scenario.

Alternative option 2 – super intensive

The second option analysed is the super intensive system. This system was first initiated in Spain in the early 1990s and has been introduced into Portugal in the early 2000s. The super intensive olive groves have become more common in Portugal in the last few years, mostly in Alentejo region, where it occupies an area of over 10000 ha (Paço et al. 2012). It is characterized by an elevated planting density, higher than 1500 plants/ha, and seems to be promising since it guarantees high yield within a few years of planting and has full mechanization (De Gennaro et al. 2012).

We assumed an olive grove in its full production stage, with a production of 11 t/ha olives for olive oil production. Mean plant density is 1975 trees/ha (3.71 m x 1.35 m). The crop is irrigated with a drip irrigation system.

The operations for the crop installation are similar to those described before. The olive grove's life time was assumed to be 15 years. Fertilizer application is approximately 150 kg/ha N, 60 kg/ha P and 100 kg/ha K. Weed control takes place in spring by applying herbicide and pests and diseases are controlled with several pesticide treatments, depending on climate conditions. The trees are irrigated with an average annual amount of 2400 m^3/ha of water, and with the application of a liquid fertilizer. The olives are harvested by a fully mechanized system using a straddle harvester.

Impact of different energy efficiency measures on economics and the environment

Figure 67 shows the relative contribution of the different inputs in total costs, GHG emissions (CO_2e) and energy consumption for the farm assumed as the basic scenario. It is clear that different inputs contribute in different proportions to the total costs, primary energy consumption and GHG emissions. This implies that small changes may induce only small changes to costs but high impacts on energy use and GHG emissions.

Concerning the cost structure it can be seen that direct energy use (diesel and electricity) and fertilizers and are the most important, with 38 and 26%, respectively, followed by the costs for pesticides (21%) and water (7%). For energy consumption the most important inputs are diesel used for the field operations and electricity used for irrigation, contributing approximately 57% of total energy consumption, and then materials and fertilizers, both with approximately 16% and pesticides with 11%. The same picture can be seen for the GHG emissions, with diesel and electricity responsible for 56%, fertilizers 27%, materials 11% and pesticides 7%. Materials include harvesting canvas, tree protectors and supports used during the installation. Several studies have been realized to develop mechanical harvesting equipment (Peça et al. 2004) adapted to intensive and super-intensive plantations with the objective of improving the equipment in order to allow more efficient operations, by increasing harvesting capacity, decreasing diesel use, etc.

Table 51 presents the costs and income for the basic scenario and the studied options. Again, there is a high contribution of direct energy and fertilizers in the production costs, the sum representing more than 50% of the variable costs for the basic scenario and option 1 and about 50% for option 2. In this last option (super intensive olive grove production) there is a significant increase in the variable costs (from 76 – 80,000 € to almost 140,000 €). The high quantity of materials used in the super intensive olive grove farm, that have a significant value increase, include the protectors and supports used for olive planting. In the fixed costs are the labour, amortization of machines and installation are considered. The values are similar for all considered options. The income results from selling olives. The market price for the olives was assumed as 0.25 €/kg of olives sold for olive oil. Total costs are similar in the basic scenario and option 1, but increase around 12% in option 2. Since income also increases, this option presents the highest net margin of all. In all cases the farms are economically sustainable.

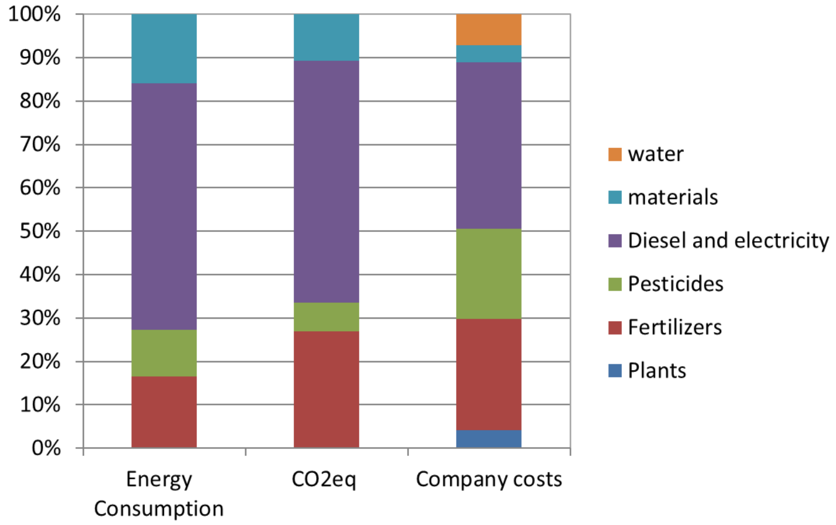

Figure 67: Relative contribution of different inputs in the farm production to economics, energy use and greenhouse gas emissions (GHG).

Table 51: Costs and income for a Portuguese olive groves farm.

	Basic scenario		Option 1		Option 2	
	(€/year)	%	(€/year)	%	(€/year)	%
Variable Costs						
Plants	3,292.81	4	3,292.81	4	16,571.52	12
Materials	3,127.72	4	3,127.72	4	19,858.20	14
Fertilisers	20,572.34	26	18,515.11	24	35,770.31	26
Pesticides	16,654.18	21	14,988.76	20	24,093.36	17
Diesel & electricity	30,728.93	38	30,059.69	39	36,149.00	26
Water	5,806.08	7	5,225.50	7	6,970.54	5
Other			1,072.50	1		
	80,182.06	100	76,282.09	100	139,412.92	100
Fixed costs	173,268.28		168,535.95		168,574.92	
Total costs	253,450.34		244,818.04		307,987.84	
Income	339,339.00		339,339.00		418,132.00	
Net margin	85,888.66		94,520.96		110,144.16	

Table 52 presents the costs, energy consumption, GHG emissions and profit per ha. The basic scenario presents total costs per hectare around 1,772 €, option 1 has a small reduction (3.4%) to 1,712 € (3.4%), while for the option 2 it increased to 2,154 € (21.5%). Concerning energy consumption and GHG emissions the results are more promising, with a reduction of approximately 5%. Regarding the super intensive system costs, energy consumption and GHG emissions increase between 15 and 26%, due to the incorporation of more inputs in the production factors (plants, fertilisers, pesticides, direct energy etc.).

Table 52: Annual costs, PEC and GHG emissions with energy efficiency measures.

	Annual Cost		PEC		GHG	
	€/ha	%	MJ/ha	%	CO_2e/ha	%
Basic Scenario	1772.38	100.0	28819.08	100.0	1898.08	100.0
Option 1	1712.01	96.6	27383.18	95.0	1800.87	94.9
Option 2	2153.76	121.5	33113.84	114.9	2399.90	126.4

Figure 68 shows the impact on costs, profit, energy use and GHG emissions per ton of olives produced. In this case we can observe a different picture. In fact, when we consider the values per unit of olives produced, both options allow a reduction of production costs and energy consumption, between 5% and 3% and 5% and 8%, respectively for options 1 and 2. Concerning the GHG emissions the first option allows a reduction of 5% and the second an increase of 1%. Profit increases in the two cases, 10% (option 1) and 3% (option2). This is explained by the decrease of inputs used (fertilisers, pesticides and water) in option 1 and with the higher productivity in option 2. However, we believe that some more research should be done in order to understand better the impacts of the super intensive olive grove production system, mainly in its effects on soil fertility, biodiversity, olive oil quality, etc. Also it must be stated that this analysis refers only to one year of full production and a deeper analysis should be done considering the full productive life cycle, which is completely different in intensive and super intensive systems.

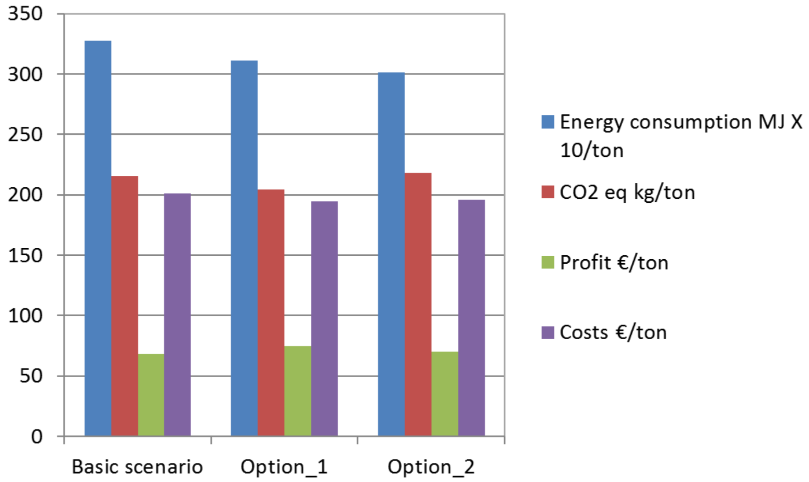

Figure 68: Impact of different energy saving measures on costs, profit, energy use and greenhouse gas emissions (GHG) per ton of olives.

Figure 69 shows the differences between the basic scenario and the analysed options on energy, GHG emissions and farm profit per ton of attained yield. Again it is possible to see that a more rational use of input factors can contribute to save energy, to lower GHG emissions and increase farm profit. It is also shown that increasing productivity is another way to increase energy efficiency per unit of product attained. However, several factors interact in these production systems, and more research is needed in order to obtain experimental data that could allow a more detailed analysis.

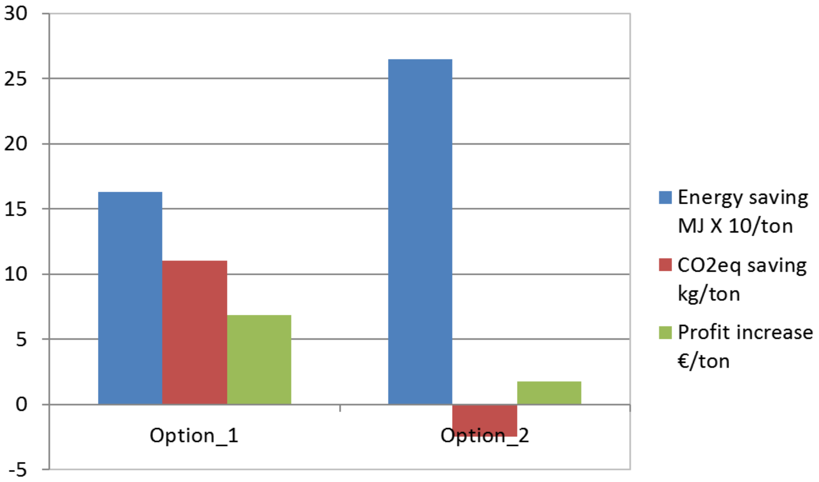

Figure 69: Differences of costs, profit, energy use and greenhouse gas emissions (GHG) per ton of olives between the basic scenario and the different options studied.

4.5.6. Synthesis trade-off analysis of case studies in permanent crop production systems

Fátima Baptista

Vineyards:

The case studies suggested different promising and economically viable options for energy efficiency measures in vineyard production. Greece and Portugal studied the options of organic cultivation and precision farming and Germany evaluated the energy use of grape vine trimmings from pruning. Greece also analyzed the use of biodegradable mulching film to cover the soil along the vine rows.

Organic cultivation, a practice stimulated by government subsidies, presents different results in each of the two countries. In Greece organic cultivation allowed a decrease of 2.5% in energy consumption, 2.2% GHG emissions and a 25.5% drop in profit, all per ton of produced grapes. In Portugal, this option showed an increase in energy consumption (9%) and GHG emissions (5%) explained mainly due to lower productivity per hectare obtained with this production system. An increase in profit (16%) was found due to the higher price paid for grapes.

Concerning precision farming, in Portugal this option showed an increase in farm profit (11%) and a decrease in energy consumption and GHG emissions, 7% and 8% respectively. In Greece, the same picture was found concerning energy consumption (less 4.8%) and GHG emissions (less 5.2%). However, in Greece profit decreased, due to the necessary investment in new equipment.

In fact, these results prove the importance of more research and studies in this subject since several factors interact in the production system and should be studied with more detail.

Another interesting energy saving measure proposed by Greece is the use of mulching biodegradable films, which did not give good results on an energy basis (increased by 7.6%). However, GHG emissions decreased (4.9%) and farm profit increased (13.9%). This Greek study also mentions that other energy efficiency measures should be evaluated by field experiments and that biodegradable mulching film technology should be examined more carefully in both aspects: its application in vineyards (still at an early stage of development) and in reducing the energy to produce it.

Germany suggested using vine trimmings as a biomass to produce energy and this proves to be a win-win solution for the farmer and the environment even accounting for the effort to maintain soil fertility with additional supply of organic material.

For future analysis and research it is important to mention that quality in wine production nowadays means producing fewer grapes, which implies an increase in energy use per kg of output. It is the case of the vineyard production in Portugal, since the wine technology begins in the field. Grape production is reduced in the field with the pruning of fruits in the early growth stages to decrease yields in order to attain better fruit quality required for producing quality wines. The challenge for the future will be to produce more grapes but maintaining a high quality standard. Another important statement is that post-harvest energy use, used for example for cooling juice during fermentation, in southern Europe is very important, but it was not considered here, since it was assumed that this study would only consider grape production and not wine processing.

Olive Groves:

Olive groves were considered in Portugal and Greece as the most important perennial crop. In Portugal, simple precision agriculture methods were selected to be analysed for energy consumption mitigation and it was shown that energy consumption and GHG emissions was reduced by approximately 9%, while the farm profit increased around 11%. In Greece, the impact of organic farming (irrigated or non-irrigated) was investigated in a typical farm in the central part of the country. It was found that organic farming has positive effects in energy (13.2 and 11% reduction respectively) and greenhouse gas emissions (37.8 and 56.8% reduction respectively) with a significant profit increase of 46.2% and 39.3% respectively. The result in energy and greenhouse gases was based on the fact that the inputs were highly reduced (especially in terms of chemical fertilizers that were substituted by animal manure) in combination with a lower yield (but not as much as the inputs decrease). Profit was increased significantly, mainly due to higher olive prices gained from organic farming.

5. Summary and Conclusions

This report illustrates case studies with an in-depth analysis of the interactions of energy efficiency measures with farm economics and the environmental impact (GHG) of the measures across Europe. The analyses followed a common methodology considering the farm gate as the system boundary. Therefore, considerable energy use in the post-processing of agricultural products were only taken into account, when they can be assumed to be realized on the farm. The analyses of the energy use, economic and environmental effects follow an LCA approach taking into account all costs of the production, including those for machines according to the concept of "useful life" of the machines used. The environmental effects of energy saving were illustrated with the greenhouse gas emission effect of the energy efficiency measures. The case studies are only a selection of specific energy saving measures across Europe and therefore cannot be regarded as representative for all Europe. Nevertheless, they will help to understand constraints and opportunities for increased energy efficiency in agriculture, which can be used to translate to an agenda of practical action or applied research. The findings are valid sometimes only in the specific regional settings, sometimes they are of general validity.

The analyzed case studies are grouped by production systems, which are arable cropping systems, dairy and beef production systems, pork and poultry production systems, greenhouse production systems and permanent crops systems. Each of the production systems uses different energy sources which results in different potentials for energy savings or energy efficiency potential. In arable systems the focus of energy efficiency measures is put on diesel fuel and nitrogen fertilizer saving technologies. Precision Farming is one of the technologies, which may contribute to improved energy efficiency. The analyses showed, however, that the limited economic effect of the technologies may be a major constraint for the adoption of these technologies. Therefore, a research need for identifying economically viable Precision Farming solutions, which furthermore contribute to energy efficiency and other environmental benefits can be seen. Rather simpler measures, which target the fertilizer supplied to arable production systems have shown a strong effect on both energy saving and greenhouse gas emissions but are difficult to implement because of often negative economic effects at the farm level. In dairy and beef production systems a focus of energy efficiency measures was laid on efficient feeding strategies. These contribute to farm economic gains, energy saving and greenhouse gas mitigation effects. However, the limits of energy efficient feeding strategies in ruminant production systems should be investigated. There is evidence that the economically most efficient feeding strategy may be not effective from an energy efficiency and greenhouse gas emission point of view. These trade-offs need to be analyzed in more detail in the specific regional settings to derive strategies for energy efficient dairy and beef systems across Europe. In pig and poultry production systems most attention has been given to the heat management. While in northern Europe insulation and heat recovery is of biggest importance in southern Europe ventilation techniques and cooling is most important. Since pork and poultry production systems are the most industrialized agricultural production systems all measures on energy efficiency should be checked for compliance with the consumers' demand for animal welfare. Greenhouse production systems use a huge amount of energy especially in northern Europe, which indicates great energy saving potentials. Most of the saving measures target added insulation and heat recovery systems, which mostly are beneficial from economic and environmental perspectives. However, typically, significant investments are necessary for most efficient greenhouse systems. The Dutch case shows that the combination of electricity generation in combination with greenhouse production may create a win-win situation for the environment and farm economic. This, however, requires regulation from the government. The permanent crop production systems showed a variety of different promising energy efficiency measures including precision agriculture, improved irrigation and energy generation from the biomass of the vine trimmings.

In general indirect energy use has been identified as an important driver for energy use at the farm level in many cases. Especially the use of nitrogen fertilizer has been shown as a key factor in improved energy efficiency across different production systems and countries. Nitrogen is not only important in crop production systems, but also in animal production systems, since indirect energy use in animal production systems is often related to nitrogen use in feed production. In addition to the energy related effect nitrogen management has an even more important role for greenhouse gas emissions. Therefore, even though studied for long, nitrogen in agricultural systems still requires most attention when targeting a more energy efficient agriculture.

Even though it is true that efficiency measures concerning the use of indirect energy should be targeted at the industry level, which is responsible for the primary energy use, the impact of management systems on the use of indirect energy should not be left out of focus. It may be more effective to adapt the management of the use of indirect energy than to reduce direct energy use in agriculture. This is true for many situations where the effect of efficiency measures targeted at fuel use are compared with efficiency measures targeted at mineral fertilizer use.

Energy efficiency measures targeting direct energy are most effective in post-harvest operations like drying and storage in northern, cooler and wetter countries, while cooling and irrigation are more relevant in southern countries. Since the system boundary of this report is set to the farm gate relevant energy efficiency measures beyond the farm gate should be addressed in further investigations to identify the most efficient energy saving measures across the whole production chain.

The report illustrates that it is important to identify trade-offs of specific energy saving measures, to identify bottlenecks of an energy efficient development. For example as can be seen from the Greek case study apparently the economic cost structure of irrigation in many situations may cause inefficient irrigation patterns with very high energy input. A further task is to elaborate solutions for more efficient energy use taking into account cost and environmental issues.

References

Afonso C. 2012. Tomato. Investment in quality. Frutas, Legumes e Flores 131: 78-79.

Aguiar C. 2012. Personal communication.

Ahokas, J. and Koivisto, K. 1983. Energiansäästö viljankuivauksessa. Vakolan tutkimusselostus 31. Valtion maatalouskoneiden tutkimuslaitos. 89 p.

Ahokas, J. and Mikkola, H. 1986. Traktorin polttoainekulutukseen vaikuttavia seikkoja. Valtion maatalousteknologian tutkimuslaitos, VAKOLAn tutkimusselostus no 4. 107p.

Alcamo, J., J.M. Moreno, B. Nováky, M. Bindi, R. Corobov, R.J.N. Devoy, C. Giannakopoulos, E. Martin, J.E. Olesen, A. Shvidenko, 2007: Europe. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 541-580.

Altieri M.A., (1992). Agroecological foundations of alternative agriculture in California, Agriculture Ecosystems and Environment, 39, 23-53.

Amon B., Kryvoruchko V., Fröhlich M., Amon T., Pöllinger A., Mösenbacher I. and Hausleitner A. 2007. Ammonia and greenhouse gas emissions from a straw flow system for fattening pigs: Housing and manure storage. Livestock Science 112:199–207.

Antón A., Torrellas M., Montero J.I., Ruijs M., Vermeulen P.and Stanghellini C. 2012. Environmental Impact Assessment of Dutch Tomato Crop Production in a Venlo Glasshouse. Acta Horticulturae 927:781-791.

Artyszuk H. 2012. Exemplary calculation of agricultural profit from production of 1 liter of milk at various levels of production intensity. In Polish: Przykładowa kalkulacja dochodu rolniczego z produkcji 1 litra mleka przy różnych poziomach intensywności produkcji. PODR Gdańsk.

Auernhammer, H. (2001). Precision farming–the environmental challenge. Computers and Electronics in Agriculture 30, 31-43.

Baptista FJ, Bailey BJ and Meneses JF. 2011. Development of a warning system for controlling *Botrytis cinerea* in unheated tomato greenhouses. Acta Horticulturae 893:1263-1269.

Baptista F.J., Bailey B.J. and Meneses J.F. 2012. Effect of nocturnal ventilation on the occurrence of Botrytis cinerea in Mediterranean unheated tomato greenhouses. Crop Protection 32:144-149.

Bos, J.F.F.P., Haan, J.J. de, Sukker, W., Energieverbruik, broeikasgasemissies en koolstofopslag: de biologische en gangbare landbouw vergeleken, Plant Research International (Wageningen UR), rapport 140, maart 2007

Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz (BMELV) 2009. Modellvorhaben "Betriebsleiterqualifikation und Generationswechsel in der Landwirtschaft".

Cascone, G., D'Emilio, A. and Mazzarella, R. 2012. Polyamide-based film as greenhouse covering in soil solarization . Acta Hort. (ISHS) 927:659-666 http://www.actahort.org/books/927/927_81.htm

Cavalaris C., Karamoutis C., Papathanasiou I. and GemtosT., (2003). Prospects for energy savings in applying reduced soil treatment in wheat, Proceedings of the 3rd Hellenic Conference on Agricultural Engineering, Thessaloniki, pp 473-80.

Concise Statistical Yearbook of Poland 2011. Ed. Central Statistical Office, Warsaw, 2011.

Dalgaard T, Durand P, Dragosits U, Hutchings NJ, Kedziora A, Bienkowski J, Frumau A, Bleeker A, Magliulo E, Olesen JE, Theobald MR, Drouet JL, Cellier P (2012) Farm nitrogen balances in European Landscapes. Biogeosciences 9, 5303-5321.

Dalgaard T, Halberg N and Fenger J (2002) Can organic farming help to reduce national energy consumption and emissions of greenhouse gasses in Denmark? In: EC van Lerland and AO Lansink (eds.) Economics of sustainable energy in agriculture. Economy and Environment vol. 24. p. 191-204. Kluwer Academic Publishers, Dordrecht, The Netherlands. ISBN 1-4020-0785-X.

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 and Environment, 87, 51-65.

Dalgaard T, Olesen JE, Petersen SO, Petersen BM, Jørgensen U, Kristensen T, Hutchings NJ, Gyldenkærne S and Hermansen JE (2011) Developments in greenhouse gas emissions and net energy use in Danish agriculture – How to achieve substantial CO_2 reductions? Environmental Pollution 159 (2011) 3193-3203.

Danfors, B. 1988. Bränsleförbrukning och avverkning vid olika system för jordbearbetning och saådd. Jordbrukstekniska Institutet, meddelande 420. 84 p.

DBFZ (Deutsches Biomasse Forschungszentrum) (2011): Nachhaltige Biogaserzeugung in Deutschland–Bewertung der Wirkung des EEG. URL: http://www.fnr-server.de/ftp/pdf/berichte/22003410.pdf

De Gennaro B., Notarnicola B., Roselli L. and Tassielli G. 2012. Innovative olive-growing models: an environmental and economic assessment. Journal of Cleaner Production 28:70-80.

Dekker, Ir. P.H.M., Stilma, Dr. Ir. E.S.C., Geel, W.C.A. van, Ir. A. Kool, Levenscyclusanalyse van vaste rundermest, runderdrijfmest, digestaat, GFT-compost en kunstmest bij gebruik in biologische en gangbare landbouw, Praktijkonderzoek Plant & Omgeving (Wageningen UR), rapport 3250109708, mei 2009.

El.STAT. Hellenic Statistical Authority, Statistical Database, Agriculture 2006; http://www.statistics.gr/portal/page/portal/ESYE

EMY, 2012 http://www.emy.gr/hnms/greek/index_html, accessed 5 Nov 2012

Esala, M. and Larpes, G. 1986. Effect of the placement technique and amount of fertilizer on spring wheat and barley grown on clay soils. I. Effect on grain yield. Annales agriculturae Fenniae 25: 159 – 167.

Esala, M. and Larpes, G. 1986. Effect of the placement technique and amount of fertilizer on spring wheat and barley grown on clay soils. II. Effect on the quality and mineral contents of grain yield. Annales agriculturae Fenniae 25: 169 – 175.

European Commission 2007. Evaluation on the impact of Nordic aid schemes in northern Finland and Sweden. Final report. December 2007. 266 s. Available in the Internet: http://ec.europa.eu/agriculture/eval/reports/nordic/index_en.htm

Eurostat 2010. Agricultural Statistics. Main results–2008-2009. Available in Internet: http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-ED-10-001/EN/KS-ED-10-001-EN.PDF Read: 2012-09-23

EUROSTAT (2012). Data and Tables. URL: http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database/

FAOSTAT, FAO Statistics Division, Production data, Greece 2010, http://faostat.fao.org

Federal Ministry of Food, Agriculture and Consumer Protection (2011): 2011 Agricultural Policy Report. URL: http://www.bmelv.de/SharedDocs/Downloads/EN/Publications/German-Gov-Agriculture-Report-2010.pdf?__blob=publicationFile

Federal State Office 2009. Germany’s population by 2060-Results of the 12th coordinated population projection. Statistisches Bundesamt, Wiesbaden 2009.

Frielinghaus M., Müller L., Willms M. and Ulrich A. (2007). Conservation agriculture, organic farming and GM crops in Germany Main focus: Eastern Germany. Research Report of project “Knowledge Assessment and Sharing on Sustainable Agriculture” (KASSA). 10 August 2012. <http://z2.zalf.de/oa/D1.1%20A6%20Germany%202.pdf>

García-Victoria N., Kempkes, F.L.K., López-Hernández, J.C., Baeza-Romero, E.J., Incrocci, L., Pardossi, A. 2012. Evaluation trials of potential input reducing developments in 3 test locations. EUPHOROS, deliverable 19: 56-65. www.euphoros.wur.nl or (complete link) http://www.wageningenur.nl/upload_mm/5/6/5/da3a7397-2a6c-4290-8d8c-96f1ff1dd6eb_Evaluation%20trials%20of%20potential%20input%20reducing%20developments%20in%203%20test%20locations.pdf

Gemtos T., Fountas S., Blakcmore B. and Greipentrong H. (2002). Precision farming experience in Europe and the Greek potential. Paper presented at the Conference of the Greek Applied Informatics in Agriculture, Athens.

Gemtos, T.A., Galanopoulou, St., and Kavalaris, C. (1998). Wheat establish after cotton with minimal tillage. Europ. Journ. of Agronomy. 8, pp 137-47.

Genitsariotis M, Chlioumis G., Tsarouhas B, Tsatsarelis K., Sfakiotakis E. (2000). Energy and nutrient input and output of a typical olive orchard in northern Greece, Acta Horticulture, 525, 455-458.

Gertsis A., Vellidis G., and Rains G. (2003). Applications of precision agriculture in Ellas (Greece): wheat yield mapping.

Gołaszewski J., de Visser C, Brodziński Z, Myhan R, Olba-Zięty E, Stolarski M, de Buisonjé F, Ellen H, Stanghellini C, van der Voort M, Baptista F, Silva L, Murcho D, Meyer-Aurich A, Ziegler T, Ahokas J, Jokiniemi T, Mikkola H, Rajaniemi H, Balafoutis A, Briassoulis D, Mistriotis A, Panagakis P, Papadakis G (2012). State of the Art on Energy Efficiency in Agriculture. Report WP2 AGREE. Available on the internet: http://www.agree.aua.gr/Files/Agree_State.pdf.

Gołaszewski J., de Visser C, Brodziński Z, Myhan R, Olba-Zięty E, Stolarski M, de Buisonjé F, Ellen H, Stanghellini C, van der Voort M, Baptista F, Silva L, Murcho D, Meyer-Aurich A, Ziegler T, Ahokas J, Jokiniemi T, Mikkola H, Rajaniemi H, Balafoutis A, Briassoulis D, Mistriotis A, Panagakis P, Papadakis G (2012a). Energy Saving Measures in Agriculture-Overview on the Basis of National Reports. Project Deliverable 2.3 AGREE. Available on the internet: http://www.agree.aua.gr/Files/Publications/D2.3%20Energy%20Efficiency%20Measures%20in%20Agr.pdf.

Golka W. 2011. Soil tillage techniques reducing the emission of greenhouse gases (In Polish: Techniki uprawy gleby ograniczajęce emisję gazów cieplarnianych). Problems of Agricultural Engineering-Problemy Inżynierii Rolniczej, nr 4/2011.

Guzman G.I., Alonso A.M. (2008). A comparison of energy use in conventional and organic olive oil production in Spain, Agricultural Systems, 98, 167-176.

Handler, F. and Nadlinger, M. 2009. Strategies for saving fuel with tractors. Trainer Handbook. Intelligent energy. Efficient 20. IEE/09/764/SI2.558250. Available on the internet: http://efficient20.eu/files/2011/02/D3-8-Training-Handbook-Fuel-saving-measures.pdf

Häussermann U., Döhler H. (2010): Modellierung von Kohlenstoffdioxid-, Lachgas-, und Methanemissionen, Energieaufwand und Kosten verschiedener Düngestrategien. In: KTBL (ed.): Emissionen landwirtschaftlich genutzter Böden. KTBL-Schrift 483, Darmstadt, S. 221-228

Higa T. 1998. Effective Microorganisms, concept and recent advances in technology. Proceedings of the Conference on Effective Microorganisms for a sustainable agriculture and environment. 4th International Conference on Kyusei Nature Farming, Bellingham-Washington USA, s. 247-248 116

Higa T., Parr J.F. 1994. Beneficial and Effective Microorganisms for a Sustainable Agriculture and Environment. Publ. International Nature Farming Research Center Atami, Japan.

INE, I.P. 2011. Recenseamento Agrícola 2009. Análise dos principais resultados. Lisboa, Portugal. 185 pp.

INE I.P. 2012. Estatísticas Agrícolas 2011. Lisboa, Portugal. 171 pp.

Information Centre of the Ministry of Agriculture and Forestry 2011. Yearbook of farm statistics 2011. Available on the internet: http://www.maataloustilastot.fi/maatilatilastollinen-vuosikirja-2011_fi, 269 p.

Jürgens, C. (2006). Langsames, aber stetiges Wachstum. Beobachtungen zur Akzeptanz von Precision Farming in Deutschland. Neue Landwirtschaft 1/2006,45–47.

Kaczmarek Z., Jakubas M., Grzelak M., Mrugalska L. 2008. Impact of the addition of various doses of Effective Microorganisms to arable-humus horizons of mineral soils on their physical and water properties. J. Res. and Appl. in Agric. Eng., Nr 53(3), s.118-121

Kaczmarek Z., Owczarzak W., Mrugalska L., Grzelak M. 2007. The influence of effective microorganisms for some of physical and water properties on arable-humus horizons of mineral soils. J. of Res. and Appl. in Agric. Eng., Nr 52(3), s. 73-77

Kaltsas A.M., Mamolos A.P., Tsatsarelis C.A., Nanos G.D., Kalburtji K.L. (2007). Energy budget in organic and conventional olive groves, Agriculture Ecosystems and Environment, 122, 243-251.

Kamp, J., Reeuwijk, P. van, Schoorl, F., Montsma, M., Energiebesparing op het agrarisch bedrijf, Kansen voor verhoging van de energie-efficiency in de akkerbouw, vollegrondsgroenten en fruitteelt, Praktijkonderzoek Plant & Omgeving (Wageningen UR), Lelystad, Nederland, March 26, 2010.

Kara, O. and Räisänen. L. 1976. On the development and field experiments of fertilizer placement in Finland. The Journal of the Scientific Agricultural Society of Finland 46: 175-184

Karhunen, J., Mykkänen, U., Nieminen, L., Wikstén, R. and Saloniemi, H. 1983. Lämmönvaihtimet eläinsuojien ilmastoinnissa. Valtion maatalouskoneiden tutkimuslaitos, Vakolan tutkimusselostus nro 36. 79 p.

Katsoulas N., Kittas C., Bartzanas Th., (2011), Energy needs and energy savings in greenhouses, Agriculture–Animal Husbandry 10, p. 54-57, (in Greek)

Kavargiris S.E., Mamolos A.P, Tsatsarelis C.A., Nikolaidou A.E., Kalburtji K.I., (2009). Energy resources' utilization of organic and conventional vineyards: Energy flow, greenhouse gas emissions and biofuel production.

Khanna, M., Epouhe, O., F.and Hornbaker, R. (1999). Site-Specific Crop Management: Adoption Patterns and Incentives. Review of Agricultural Economics 21, 455–472.

Kivinen, T., Mattila, K. M., Teye, F., Heikkinen, J. and Heimonen, I. 2007. Air quality in cow houses with curtain wall ventilation in Finnish climate. In: Proceedings volume 2 : Animal health, animal welfare and biosecurity / Aland A.(ed.). Tartu: p. 947-951.

Korbas M., Mrówczyński M. (Ed.) 2011. Methodology of integrated production of winter and spring wheat. (In Polish: Metodyka integrowanej produkcji pszenicy ozimej i jarej.)

Kowalczyk-Juśko A., 2010. Degestate–source of income or trouble? (In Polish" Pozostałość po fermentacji beztlenowej–źródło przychodu czy kłopot). Aeroenergetyka, 3.

Kowalczyk-Juśko A., 2010. Waste bring up income (In Polish: Odchody przynoszą dochody). Agroenergetyka, 2.

Kraatz. S. (2012). Energy intensity in livestock operations-modeling of dairy farming systems in Germany. Agricultural Systems 110, 90-106.

Krawczyk W., Walczak J., 2010. Potential of manure as a source of ammonia emission and threat for environment. (In Polish: Potencjał biogenny obornika jako źródło emisji amoniaku i zagrożenia środowiska). Rocz. Nauk. Zoot., T. 37, z. 2, 187–193.

KWIN-AGV 2009, Schreuder, R., Leeuwen, M. van, Spruijt, J., Voort, M. van der, Asperen, P. van, Hendriks-Goossens, V., Kwantitatieve Informatie, Akkerbouw en Vollegrondgroenteteelt 2009, Praktijkonderzoek Plant & Omgeving, PPO 383, Lelystad, juli 2009

Lesschen J.P., van den Berg M., Westhoek H.J., Witzke H.P. and Oenema O. 2011. Greenhouse gas emission profiles of European livestock sectors. Animal Feed Science and Technology, 166:16-28.

Maa- ja metsätalousministeriö 2012. Maa- ja metsätalousministeriön rakentamismääräykset ja -ohjeet. Maatalouden tuotantorakennusten lämpöhuolto ja huoneilmasto. MMM-RMO C2.2. 9 p. Available on the internet: http://www.mmm.fi/attachments/maaseutujarakentaminen/5iiBVUyGW/L10-rmoC22-01.pdf

Maa- ja metsätalousministeriön tietopalvelukeskus–TIKE 2011. Yearbook of farm statistics2011. 269 s. Available on the internet: http://www.maataloustilastot.fi/node/1131

Maa- ja metsätalousministeriö 2012. Maa- ja metsätalousministeriön rakentamismääräykset ja -ohjeet. Maatalouden tuotantorakennusten lämpöhuolto ja huoneilmasto. MMM-RMO C2.2. 9 p. Available on the internet: http://www.mmm.fi/attachments/maaseutujarakentaminen/5iiBVUyGW/L10-rmoC22-01.pdf

Maaseutuvirasto 2012. Maatalouden ympäristötuen sitoumusehdot 2012. Available on the internet:

http://www.mavi.fi/attachments/mavi/ymparistotuki/66eIWeNri/Ymparistotuen_sitoumusehdot_2012.pdf

MADRP, 2009. Plano Estratégico Nacional. Desenvolvimento Rural 2007–2013. Portugal. Revisão Novembro 2009. 115 pp.

Mannfors, B. and Hautala, M. 2011. Eläinten hyvinvointiin perustuva tuotantoeläinrakennusten mikroilmasto. Ilmanvaihtoon ja lämpötilaan liittyvät suositukset. Helsingin yliopisto. Maataloustieteiden laitos, Julkaisuja 6. 106 p.

Manninen, E. 2009. Automaattilypsy yleistyy Pohjoismaissa. Maito ja me. Available on the internet: http://ammattilaiset.valio.fi/maitojame/laatu09/teema13.htm

Markinos A., Gemtos T., Toulios., Pateras D., and Zerva G. **(**2002). Yield mappingof cotton crop in Greece, *Proceedings of the 1st HAICTA Conference, Athens, 6-7 June 2002,* pp. 56-62.

Marques da Silva, J.R. 2012. Personal comunication.

Marques da Silva, J.R., P. Mesquita, A. Sousa, L.L. Silva, J.M.R. Serrano and F. Baptista. 2010. Influência da temperatura do ar na variabilidade espacial e temporal da maturação da uva para vinho–Variedades: Aragonês e Trincadeira, *in Resumos do 8º Simpósio de Vitivinicultura do Alentejo*. Évora.

Marques da Silva, J.R., Sousa, A., Mesquita, P., Silva, L.L., Serrano, J., Roma, J., Baptista, P., Torres, J., Torres, M., Simões, A., Terrón López, J.M., Becerra Traver, D., Moral Garcia, F.J., Alves, C., Condeças, J. 2009. Viticultura de precisão: um caso de estudo na Fundação Eugénio de Almeida, Évora, (Precision viticulture: a case study in the Eugénio de Almeida Foundatio, Évora) in Braga, R. (Ed). Viticultura de Precisão. Inovação e Tecnologia na Formação Agrícola, Associação dos Jovens Agricultores de Portugal (AJAP). Cap. 4, p. 49-64. ISBN: 978-989-8319-05-0. (in portuguese).

Marques, C.A.F. (1988), Portuguese Entrance into the European Community: Implications for Dryland Agriculture in the Alentejo Region, Ph.D. thesis, University of Purdue, USA.

Meneses, J.F. and Castilla, N. 2009. Protected cultivation in the Iberian horticulture. Cronica Horticulturae. 49 (4), 37-39.

Meyer-Aurich A; Ziegler Th; Jubaer H; Scholz L; Dalgaard T (2012): Implications of energy efficiency measures in wheat production. International Conference of Agricultural Engineering CIGR-Ageng 2012, Valencia, Spain, 8-12 July 2012.

Meyer-Aurich, A; Gandorfer, M; Heissenhuber, A (2008): Economic analysis of precision farming technologies at the farm level: Two german case studies. In Castalonge, O.W. (Eds.): Agricultural Systems: Economics, Technology, and Diversity. Nova Science Publishers, Hauppage NY, USA. S. 67-76.

Mikkola, H, Pahkala, K. and Ahokas, J. 2010. Energy consumption in barley and turnip rape cultivation for bioethanol and biodiesel (RME) production, Biomass and Bioenergy, Vol. 35, (2011): 505-515.

Mills, A.F. (1992), "Heat Transfer", publisher Irwin Inc., chapter 4, pages 289-290.

Ministry of Rural Development and Food, Statistical data, Plant Production, year 2006; http://wwww.minagric.gr/en/index.html

Mistriotis A., Giannoulis A., Briassoulis D., (2011), Numerical estimation of wind loads on a greenhouse protected by a net-covered windbreak analysed as an integrated system, Acta Horticulture 952, 169-176.

Montero J.I., Antón A., Torrellas M., Ruijs M. 2012. Report on Economic & Environmental Profile of new technology greenhouses at the three scenarios. Project EUPHOROS (Efficient Use of Inputs in Protected Horticulture), KBBE-2007-1-2-04 European Commission, 63 pp.

Mourão I., Silva J.A., Brito L.M. and Moura M.L. 2010. A qualidade e a produtividade de tomate produzido em cultura hidropónica e em solo. Vida Rural 1761:30-33.

Mygdakos E., Gemtos T. and Markinos A., (2005) Application of precision agriculture in cotton cultivation in Greece: Implementation costs and financial results, Internal report of University of Thessaly

Nasalski Z. 2011. Methods for cost reduction in milk and beaf production. In Polish: Metody obniżania kosztów produkcji mleka i mięsa wołowego. http://www.portalhodowcy.pl/hodowca-bydla/198-numer-122010/1848-metody-obnizania-kosztow-produkcji-mleka-i-miesa-wolowego.

Nguyen. T.L.T., Hermansen, J., Mogensen, L., 2010. Fossil energy and GHG saving potentials of pig farming in the EU, Energy Policy 38, 2561-2871.

Niemi, J. (Ed.) and Ahlstedt, J. (Ed.) 2009. Suomen maatalous ja maaseutuelinkeinot 2009. Maa- ja elintarviketalouden tutkimuskeskus–MTT, Taloustutkimus. Julkaisuja 109: 97 s. Available on the internet: https://portal.mtt.fi/portal/page/portal/mtt/mtt/julkaisut/suomenmaatalousjamaaseutuelinkeinot/7909C091BA206C99E040A8C0023C59B6

Niemi, J. (Ed.) and Ahlstedt, J. (Ed.) 2012. Suomen maatalous ja maaseutuelinkeinot 2012. Maa- ja elintarviketalouden tutkimuskeskus–MTT, Taloustutkimus. Julkaisuja 112: 97 s. Available on the internet: https://portal.mtt.fi/portal/page/portal/mtt/mtt/julkaisut/suomenmaatalousjamaaseutuelinkeinot/jul112.pdf

Organic cultivation of olive groves, Ministry of agriculture of Cyprus, http://www.moa.gov.cy/moa/da/da.nsf/All/40822EABC4963BBBC2256F58003EE7CF/$file/VIOLOGIKHKALLIERGIAELIAS.pdf?OpenElement, accessed on 25/12/2012.

Paço T.A., Nogueira A.M., Silvestre J.C., Gonzalez L.F., Santos F.L., Pereira L.S.. 2012. Water Requirements and Footprint of a Super-intensive Olive Grove under Mediterranean Climate. Submitted to *Acta Horticulturae* (In Press).

Panagakis P., Papadakis G., Natsis T., and Kyritsis S., (1996) Strategic R&D for better energy efficiency in the agricultural sector, EU Project Contact No. JOU2-CT-94-0461-GR (DG 12 CSMC)

Papadakis G., Briassoulis D., Scarascia-Mugnozza G., Vox G., Feuilloley P., Stoffers J.A., (2000), Radiometric and Thermal Properties of, and Testing Methods for, Greenhouse Covering Materials, J. agric. Engng Res., 77(1), 7-38.

Papageorgiou C. and Spathis P. (2000). Agricultural Policy. Stohastis Publishing-Agricultural University of Athens

Peça J., Almeida A., Pinheiro A., Dias A., Santos L., Lopes J., Gomes J. and Reynolds D. 2004. Mechanical Harvesting of 400 trees per hectare Olive Orchards based on a Rolling Canvas Prototype. *Acta Horticulturae* 791:363-367.

Portaria nº 229-B/2008, 6 de Março. Valorização de modos de produção. Do programa de desenvolvimento rural do continente, designado por PRODER. Portaria nº 427-A/2009, 23 de abril. Alteração à portaria nº 229-B/2008.

Proias G., Stathakis D., Paliatsos A., (2010) Spatial distribution of rainfall in Thessaly, 6th Panhellenic Conference of the Greek Geographical Geographical Society (HellasGIs), Athens, 2-3 December.

Pyykkönen, P., Lehtonen, H. and Koivisto, A. 2010. Structural change and investments in Finnish agriculture 2010-2020. Available on the internet: http://www.ptt.fi/site/?lan=1&mode=tiedotteet&tiedote_id=1291

Pyykkönen, P., Lehtonen, H. and Koivisto, A. 2010. Maatalouden rakennekehitys ja investointitarve vuoteen 2020. Pellervon taloustutkimus PTT. PTT Työpapereita 125. 24 p. Available on the internet: http://www.ptt.fi/dokumentit/tp125_1111100930

Rasmussen, K., Rasmussen, J. and Petersen, J. 1996. Effects of Fertilizer Placement on Weeds in Weed harrowed Spring Barley. Annales Agriculturae Scandinavica 46: 192 – 196.

Rees, R. M., Roelcke, M., Li, S. X., Wang, S. Q., Li, S. Q., Stockdale, E. A., McTaggart, I. P., Smith, K. A. and Richter, J. 1997. The effect of fertilizer placement on nitrogen uptake and yield of wheat and maize in Chinese loess soils. Nutrient Cycling in Agroecosystems 47: 81 – 91.

Reis M. 2012. A drenagem nas culturas sem solo: um resíduo ou um recurso? (Drainage from soilless culture: residue or resource?). Presented in Simpósio Culturas sem solo e as novas tecnologias. 21 Novembro 2012, Torres Vedras.

Renius, K. 1999. Performance map of a diesel engine. In: Stout, B & Cheze, B. (eds.). Plant Production Engineering. CIGR Handbook of Agricultural Engineering. Volume III. American Society of Agricultural Engineers, ASAE 1999. p. 51.

Rodrigues A. M., Guimarães J. e Oliveira C. 2012. Rentabilidade das explorações leiteiras em Portugal-dados técnicos e económicos. Livro de Resumos, V Jornadas de Bovinicultura, IAAS-UTAD, Vila Real, 30-31 Março. pp. 109-129.

Rosa A., Oliveira P., Sousa B., Rodrigues A., Caço J., Mogo P. and Reis M. 2006. Experimentação em cultura sem solo. Tomate. Universidade do Algarve, Faculdade de Engenharia de Recursos Naturais, Faro. 40 pp.

Rosado, M.M. C. 2000. "Contributo para a integração da componente ambiental na avaliação económica de sistemas de produção agro-pecuários". Ph.D. thesis, University of Évora, Portugal.

Schils, R.L.M., Oudendag, D.A., Van der Hoek, K.W., de Boer, J.A., Evers, A.G., de Haan, M.H., 2006. Broeikasgasmodule BBPRPraktijkrapport Rundvee 90. Animal Sciences Group, Alterra, RIVM, Wageningen, pp. 1–50.

Schunk, D. 2001. Farm Size Economics and Farm Number Development in Illinois. Lessons from a Dynamic Simulation Analysis. Available in the Internet: http://www.centrec.com/resources/Articles/FSDFarming21.pdf Read 2012-09-18

SenterNovem 2005. Ecodriving–the smart dri styleving. Available on the internet: http://www.thepep.org/ClearingHouse/docfiles/ecodriving.pdf Read 2012-09-07.

Sethi V.P., Sharma S.K. (2008), Survey and evaluation of heating technologies for worldwide agricultural greenhouse applications, Solar Energy Volume 82, Issue 9, September 2008, Pages 832–859

Sieviläinen, E. 2008. Viljan laatuseuranta. Available at The Finnish Food Safety Authority–EVIRA.

Siipikarjaliitto 2012. Näin kasvatetaan broileri. Available on internet: http://www.siipi.net/index.php?option=com_content&view=article&id=403&Itemid=19

Siljander-Rasi, H., Valaja, J., Jaakkola, S. and Perttilä, S. 2000. Tuoresäilötty ohra sikojen ja siipikarjan rehuna. Työtehoseuran maataloustiedote 2: 1-6.

Silva L.L. 2012. Personal comunication.

Stielow G. 2003. Rich soil do not need of the fertilization. Journal of Research and Applications in Agricultural Engineering,48(1): 20-22

Suomi, P., Lötjönen, T., Mikkola, H. J., Kirkkari, A.-M. and Palva, R. 2003. Viljan korjuu ja varastointi laajenevalla viljatilalla. Maa- ja elintarviketalous 31: 100 s. + 1 liite.

The Organisation for Economic Co-operation and Development (OECD) (2012): Environmental performance review of Germany. Revised assessment and recommendations. URL:http://www.oecd.org/environment/environmentalcountryreviews/oecdenvironmentalperformancereviewsgermany2012assessmentandrecommendations.htm

TINKER, D.B. (1992) Review paper. Integration of tractor engine, transmission and implement depth controls: I. Transmissions. Journal of Agricultural Engineering Research 54, 1-27.

Tinker, DB, Chamen, WCT, Pedersen, HH (2010) Controlled traffic farming (CTF) -why and how. Conference paper at AgEng2010, Clermont-Ferrand, France, September 2010. Available from CAB Direct

Tokeshi H., Aloes M.C., Sanches A.B., Harada D.Y. 1998. Effective Microorganisms for controlling the phytopathogenic fungus Sclerotinia sclerotiorum in lettuce. Proceedings of the Conference on Effective Microorganisms for a sustainable agriculture and environment. 4th International Conference on Kyusei Nature Farming, Bellingham-Washington USA, p. 131-139

Torrellas, M.; Antón, A.; Ruijs, M.N.A.; Garcia Victoria, N.; Stanghellini, C.; Montero, J.I. (2012) Environmental and economic assessment of protected crops in four European scenarios. Journal of Cleaner Production 28 . - p. 45 - 55. http://www.sciencedirect.com/science/article/pii/S0959652611004471

Tullberg JN, Yule DF and McGarry D (2007) Controlled traffic farming – From research to adoption in Australia. Soil and Tillage Research 97, 272-281

Tüzel, I.H., Tüzel, Y., Öztekin, G.B., Meric, M.K., Whalley, R. and Lock, G. 2009. Response of cucumber to deficit irrigation. Acta Horticulturae 807:259-264.

Tuzel, I.H., Tuzel, Y., Oztekin, G.B., Tunali, U., Meric, M.K. and Serbes, Z.A. 2012. Utilization of deficit irrigation programs to improve water management with leaching limitations. Acta Horticulturae 952:947-952 http://www.actahort.org/books/952/952_120.htm

Valarini P.J., Alvarez M.C.D., Gasco J.M., Guerrero F., Tokeshi H. 2003. Assessment of soil properties by organic matter and EM–microorganisms incorporation. R. Bras. Ci. Solo., 27: 519-525.

Valtioneuvosto 2011. Valtioneuvoston asetus broilereiden suojelusta 28.4.2011. Available on internet: http://www.finlex.fi/fi/laki/alkup/2011/20110375.

Van der Hoek, K.W., Van Schijndel, M.W., 2006. Methane and nitrous oxide emissions from animal manure management 1990–2003. Background document on the calculation method for the Dutch National Inventory Report. RIVM and MNP (Netherlands Environmental Assessment Agency), Bilthoven, The Netherlands, pp. 1–50.

Van der Schans, D., Jukema, J.N., Klooster, A. van der, Molenaar, K., Krebbers, H., Korver, R., Roessel, G.J. van, Meertens, L., Truiman, J., Toepassing van GIS en GPS in de akkerbouw, Nut en rendement van toepassingen op het gebied van geolandbouw, Praktijkonderzoek Plant & Omgeving (Wageningen UR), Lelystad, Nederland, Februari 2008.

Van der Sluis, W. 2007. Intensive poultry production. World Poultry Vol. 23, nº 12: 28-30.

Weimann, G., (1985), Energy Saving in Film Greenhouses, Acta Horticulture 170, 147-152.

Wężyk S., 2004. Poultry waste–threat or opprotunity. (In Polish: Odchody drobiowe–zagrożenie czy szansa). Polskie Drobiarstwo, 1,40-43.

Yamada K., Xu H. 2000. Properties and applications of an organic fertilizer inoculated with Effective Microorganisms. The Haworth Press, Inc. p. 255-268.

Ziegler Th, Mellmann J, Jubaer H, Weigler F (2012): Developments towards energy efficiency in agricultural drying. International Conference of Agricultural Engineering CIGR-Ageng 2012, Valencia, Spain, 8-12 July 2012.

Ziętara W. 2009. Tendencies in Changes of Milk Production in Poland. (In Polish: Tendencje zmian w produkcji mleka w Polsce). Annuals of Agricultural Sciences–Roczniki Nauk Rolniczych, Seria G, 96(1): 27-35.

Ziętara W. 2009. Tendencies in Changes of Milk Production in Poland. (In Polish: Tendencje zmian w produkcji mleka w Polsce). Annuals of Agricultural Sciences–Roczniki Nauk Rolniczych, Seria G, 96(1): 27-35.

Zehetmeier M, Baudracco J, Hoffmann H, Heißenhuber A (2011). Does increasing milk yield per cow reduce greenhouse gas emissions? A system approach. Animal 6: 154-166.