Fossil-energy-free technologies and strategies for EU farmers and solutions in the management of the farm

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1. Introduction

Energy consumption in all economic sectors has increased thoroughly since the 1950s. Agriculture has followed the same route after the green revolution that significantly increased the mechanisation of agricultural practices (main consumer of direct energy) and simultaneously the agricultural inputs applied in field (main indirect energy carriers). Every oil crisis (see Figure 1 and 2 from [1,2]) was the reason for new technologies and strategies to appear as partial or full solutions of fossil energy dependency, but when prices were decreased, conventional fossil-based solutions were recovered in a high extent.

However, there is a continuous crude oil mean price increase from the 1970s and onwards, accompanied by basic commodities similar trend (e.g. wheat fluctuations shown in Figure 3 from [3]). At the same time, the prices of alternative energy sources have decreased and their efficiency has proven solid, always considering their limitations (mainly that they are a fluctuating source of power requiring storage, and sophisticated energy management systems). Therefore, Fossil-Energy-Free Technologies and Strategies (FEFTS) could play a significant role and be considered as permanent solutions for defossilising farms, when and where possible, for both clean energy production and energy efficiency.

This report attempts to provide primarily an overview of how energy is used in agriculture today and how much dependent this sector is in fossil fuels. Then, the results of an EU-wide survey to farmers and experts about their perspectives regarding Renewable Energy Sources (RES) and energy efficiency solutions (EES) are presented to combine the current energy statistics with the impact on agricultural stakeholders' behaviour on adopting or non-adopting FEFTS in European farms. Finally, specific FEFTS solutions are proposed for each type of the major agricultural production systems (open-field agriculture, greenhouses and livestock). Such a study is particularly relevant as it allows stakeholders and policymakers to use our findings to design and implement FEFTS supporting the energy transition and the EU energy targets for 2030 and beyond.

2. Methodology

2.1. Current Energy Status in European Agriculture

AgroFossilFree H2020 project has conducted a study that used an operational definition of energy use in agriculture and attempted to include all operational energy use that is covered by agricultural activities and uses, both directly and indirectly. The system boundary of this study was cradle to farm-gate and includes all energy consumption up until the farm gate. Multiple methodologies were used to calculate and illustrate energy use in EU agriculture. A meta-analysis, which combines the results from multiple scientific studies, is used to estimate energy use in open-field, livestock and greenhouses systems. Data was drawn mostly from LCAs, reports and national data provided to us by AgroFossilFree H2020 project partners for 8 EU countries (Greece, Italy, Spain, Ireland, the Netherlands, Germany, Denmark, and Poland). Depending on the specific agricultural production system, results are combined, which allows us to calculate EU averages in terms of energy per category as well as total energy use per system. In addition, data on direct energy use was also drawn from Eurostat and national surveys, while aggregate figures on indirect energy were calculated by multiplying EU consumption levels of each input drawn from EUROSTAT and national surveys to the energy embodied in each agricultural input presented in the literature and databases. The methodology followed is explicitly analysed in [4-6].

2.2. Stakeholders' perspectives on the adoption of FEFTS in European farms

In the framework of AgroFossilFree H2020 project, a farmers' survey and a series of expert interviews were executed through a multistage process. These were based on a common framework based around the main theories and research findings concerning the generation, adoption and diffusion of energy related technological innovations and best practices. The prepared survey and interview questions went through an extensive round of testing in eight countries. This process was followed by the development of a sampling structure based around country specific production systems allowing for a proportionate sample based on the agricultural systems of each country. In total, 470 farmer surveys were conducted across 8 different European countries (Greece, Italy, Spain, Ireland, the Netherlands, Germany, Denmark, and Poland). These were split between plant and livestock farms and comprising around 50% FEFTS adopters and around 50% non-adopters per country. Regarding expert interviews, those involved in agricultural technology development and innovation processes, 5 stakeholders per country comprising researchers/ academics, industry representatives, extensionists/advisors and/or farmers (representatives of cooperatives/ associations) were interviewed. Data were collected, stored in excel files and analysed with the use of SPSS.23. The full methodology can be found in [7].

3. Main Results

3.1. Current Energy Status in European Agriculture

According to Eurostat, agriculture accounts for 3.2% of the total energy consumption in EU countries, 56% of which derives directly from oil and petroleum products, 17% from electricity, 14% from gas and 9% from renewables and biofuels. However, our results suggest that if the energy use associated with the production and transport of fertilizers and pesticides is included, then the proportion of final energy use for agriculture in the EU-27 would be 62% higher than the current estimates. It should be noted that specifically nitrogen fertilizers are the most significant factor of all indirect energy assets, accounting for 78% of all the energy associated with fertilizers and pesticides in the EU. Indirect energy uses make up the majority of energy inputs in open-field agriculture (mainly nitrogen fertilizers) and livestock systems (mainly animal feed), while direct energy uses (mainly diesel use associated with machinery use) are also significant (Table 1, [4-6]). More specific information for each of the three main agricultural production systems (open-field agriculture, greenhouse, livestock) are given below.

Energy use in open-field agriculture

This review indicates that annual energy use in EU open-field agriculture is at least 1431 PJ, equivalent to around 3.7% of total EU annual energy consumption, with the majority of energy sourced from non-renewable energy sources. Our meta-analysis finds that the production of fertilizer is the largest energy consuming activity in EU agriculture, accounting for around 50% of all energy inputs. On-farm diesel use accounts for 31% of total energy inputs, while the production pesticides and seeds accounts for 5% of total energy inputs. Other energy uses, mainly irrigation, storage and drying, account for 8% of total energy inputs (Figure 4, [4]).

Figure 5 illustrates the total energy inputs for selected open-field crops, while Figure 6 shows that energy use in EU open-field agriculture varies significantly per hectare depending on the crop cultivated, while the energy inputs for most crops range between 15 GJ/ha to 25 GJ/ha [4].

Energy use in greenhouse systems

Our findings illustrate that energy use in greenhouses is varied and generally dependent on fossil sources. High energy systems, which are more dominant in northern Europe, are generally heavily climate controlled and energy use is dominated by heating and cooling processes, while low energy systems, which are dominant in southern Europe, show a mixture of energy uses including heating, cooling, irrigation, lighting, fertilisers, and pesticides. In advanced greenhouse systems, heating is the dominant energy requirement and in some studies accounts for up to 99% of all energy inputs. In less energy intensive systems, overall energy requirements per hectare are significantly less (50–70 times less energy per hectare) as compared to high energy systems, but generally still multiple times higher than the energy requirements of open-field agriculture. The mixture of energy inputs in these systems are split more evenly, depending on the crop and production system, between direct (lighting, heating/cooling, irrigation, machinery use) and indirect (fertilizers and pesticides). The range of total energy consumption in European greenhouses is given in Table 2 [5].

Energy use in livestock production

Our results indicate that energy use in livestock production systems is concentrated in feed, housing, and manure management. Despite significant variations between geographical areas and production systems in the studies, in all main production systems in the EU-27, except for beef, animal feed, which was an indirect energy input, was the main energy input in livestock systems; in most studies, animal feed accounted for around three-quarters of all energy requirements (Table 3). In meat production systems, the main direct energy requirements were for housing and feeding (mainly in the form of electricity) and manure management (mainly through diesel use). In milking systems, the main direct energy-consuming activities were related to milking, milk cooling, and water heating. Finally, Beef production is largest consumer of energy per kg of produce in comparison to other livestock (Figure 7)[6].

3.2. Stakeholders' perspectives on the adoption of FEFTS in European farms

The characteristics of adopters and non-adopters of FEFTS differ; adopters are more likely to be full-time farmers, to have chosen agriculture as their profession (vs. family tradition), dependent in terms of the contribution of agriculture into the family income, to be more satisfied from farming as well as to be engaged in diversified on-farm activities, certification schemes and participate in CAP Pillar II projects. Additionally, FEFTS adopters visit agricultural fairs, field days/demonstrations, or exhibitions more often than non-adopters. In parallel, adopters and non-adopters seem to consider different sources of awareness as being the most important to them. More specific information about RES and EEM is given below [7].

Adoption of renewable energy sources (RES)

The results show that, in general, farmers are aware about RES with less than 7% of those surveyed not having heard about RES. Out of those aware of RES, 45% claimed that they use RES on their farms. Solar energy is by far the most used RES on the farms (76% of RES adopters/users), followed by biomass/biofuels/biogas (36%). Importantly, around two thirds of RES adopters said they had seen (demonstration/other farmer) or tested the technology before getting/purchasing it. 65% of the adopters said that they were motivated to use RES primarily for economic reasons (reduction of energy costs and price of energy sold to others/ outside the farm); reduction of environmental hazards follows with 64%. Furthermore, compliance with regulations influenced adoption in 43% of the farmers (Figure 8) [7]. By contrast non-adopters assert that the main reason for not having/ using RES on their farms mainly owes to the fact that they cannot afford it (40%) followed by their consideration that the available technology is either not the best fitting technology for them or is not compatible with existing technology/ machinery/ equipment in their farm (19%) (Figure 9) [7]. Furthermore, they claim that they would use RES if they would get a subsidy (90%) as well as relevant training (66%).

Adoption of energy efficiency solutions (EES)

In the survey, 84% of sample farmers indicated that they are aware of a range of EES. Out of those aware, 60% claimed that they EES on their farms. The majority of adopters (59%) had seen (demonstration/ other farmer) or tested the technology or practice before getting/purchasing it. Out of those aware, 60% claimed that they use energy-saving technologies/ practices on their farms. The majority of adopters (59%) had seen (demonstration/ other farmer) or tested the technology or practice before getting/purchasing it. Economic reasons, i.e. the reduction of energy costs, was referred to as the main motivation of energy saving technologies/ practices' adopters (45%) followed by the reduction of environmental impact (23%) of the adopters (Figure 10) [7]. Only 1 out of 3 adopters said that a specific subsidy gave them the opportunity to invest in such technologies/ practices on their farm. In general, adopters state that energy efficient technologies/ practices are reliable (85%), easy to work with (82%) and economically justified (81%). On their part, non-adopters stated that the main reason for not having/ using energy saving technologies/ practices on their farms mainly owes to the fact that they cannot afford it (27%), followed by their perception that the best, tailored to their situation/ production system, technology is not available yet (22%) and the small farm size (13%) (Figure 11) [7]. Around two thirds of non-adopters claim that they would use energy efficient technologies/ practices if they would get a subsidy (96%) as well as relevant training (71%).

Policy Implications

According to the interviewed farmers, the most important RES and energy-efficiency technologies/ practices' characteristics that would make them more relevant to farmers' needs are (>80% of farmers) long term reliability, price/ affordability, ease of use, operator safety and compatibility with existing farm machinery. Economic reasons appear to be the dominant factor determining adoption and non-adoption of FEFTS for both RES and EES. This suggests that policy that provides economic incentives for adoption could stimulate a green transition in agriculture. The expert interviews also recommended that policy for the adoption of RES and EES has to be reliable in the long-term, provide sufficient financial incentives and take care of the dissemination of reliable information.

4. Main propositions of FEFTS for each production system

4.1. FEFTS for open-field agriculture systems

Indirect energy inputs of agriculture can be reduced using various FEFTS. Fossil energy use associated with fertilizer use is subject to decrease by increasing the use of organic fertilizers (from agricultural and other organic wastes/feedstocks), using renewable hydrogen as feedstocks and using renewable energy to power the Haber-Bosch process for nitrogen fertilizers' production, minimising fertiliser spreading using precision techniques and transitioning to lower input and more sustainable production systems (such as agroforestry, no-tillage or conservation agriculture). Similarly, energy use associated with pesticide production, could be reduced by minimizing the consumption of manufactured pesticides using smart technologies, increasing their use efficiencies, transitioning to more sustainable production systems, and increasing the share of locally produced organic pesticides [4].

Regarding direct energy inputs, most energy use is associated with tractor use and related to soil tillage, harvesting and sowing. Various FEFTS, such as using more efficient tractor/implement combinations, switching to renewable sources for transport (such as tractors powered by on-farm produced renewable energy sources, for example electricity from agriphotovoltaics or biofuels like biomethane from manure and waste residues), adopting agricultural practices that minimize tillage and improve farm management efficiencies, could have a large impact on overall diesel use [4].

Our findings suggest that almost 8% of open-field agriculture is powered by electricity, which is used mainly for irrigation, storage and drying activities. EU electricity systems are rapidly transitioning to renewable sources (reaching 34% in 2019), which suggests that, in the medium and long term, switching to electricity powered systems for on-farm operations could significantly reduce the share of fossil fuels in direct energy consumption [4].

4.2. FEFTS for greenhouse production systems

Identifying the areas where energy use is concentrated can help support the development and implementation of energy efficiency solutions (EES) and renewable energy sources (RES) interventions that support a transition of the entire greenhouse sector. Our review indicates that energy requirements for heating and cooling in energy intensive systems are so considerable and currently mainly dependent on fossil fuels, that other energy inputs, such as fertilizers, are extremely minor. This suggests that developing RES for greenhouse production, including integrating solar technologies within greenhouse production; biogas and bioenergy; heat pumps and geothermal could considerably reduce their fossil dependency [5].

Studies generally show that improving the design, operation, and technology used in greenhouses can also significantly improve overall energy efficiency for both high energy intensity and low energy intensity systems. Potential EES include the adoption of better insulated transparent materials, using innovative control strategies based around intelligent algorithms, upgrading light sources and other machinery [5].

4.3. FEFTS for livestock production systems

Our results suggested that reducing the reliance on and energy intensity of animal feed, especially imported animal feed, could reduce overall energy use considerably. On the one hand, the EU market for feed is moving towards more locally produced, although a significant deficit in high-protein feed remains, despite a large increase in EU-grown soy and other protein sources. Since a significant amount of the energy associated with feed is for the production of cereals and oilseeds, finding other feedstocks could reduce the energy intensity of feed. For instance, EIP-AGRI (2020) identified five new feed options for pig and poultry farming that would reduce the environmental footprint of animal feed: bakery products, green biomass (grass/clover), insects, micro-algae, and single-cell protein. In addition, multiple studies have shown that grass-fed cattle consume less energy than those fed on other types of feed. However, switching to grass-feeding would require significant amounts of arable land and agricultural inputs, highlighting the importance of a carefully balanced transition [6].

Considering the effect that the livestock sector-in general-has on numerous natural resources, and given the increasing scarcity of land, soil, water, and biodiversity, it is evident that the increasing usage of RES and EES provide a unique opportunity to farmers to reduce their farms' external inputs by producing their own energy and becoming more self-sufficient. With an initial investment, energy can be harvested from variable RES, such as the sun, wind, and water. These sources, in addition to biomass, heat pumps, and geothermal energy, can produce electricity and fuel to adequately cover partly, or exclusively, depending on the size, the on-farm energy demand [6].

5. Conclusions

This report combines an extensive meta-analysis of statistical data and a series of agricultural systems' energy assessments with an EU-wide survey on FEFTS adoption perspectives to produce some recommendations of FEFTS integration in different production systems. From the meta-analysis, it is obvious that there is very limited and fragmented information about the exact energy profile of the agricultural sector and it seems absolutely necessary to develop a common statistical methodology for all EU member states to produce reliable and detailed data to be used for policy optimisation. On the other hand, this fragmentation is also depicted in the survey conducted to 470 farmers across Europe and also on the experts interviews, as they do not seem to have a clear view of how fossil energy solutions influence agricultural production and that FEFTS in different combinations based on each farm needs could be a partial or even a complete substitute for these problematic energy sources. Even though, there are many efficient and cost-effective RES and EES that should be considered by the farming community to modernise their entities. Hence, to achieve high adoption there is a need for a better organised Agricultural Knowledge Information System (AKIS) by increasing the collaboration between Research, Extension, Businesses and Farmers. To do so, research should focus on adapting existing industrial or residential FEFTS solutions to farming needs, while extension/advisory services should play the role of a multiplier by showcasing with demonstrations such FEFTS to farmers in a local context and training them in a continuous mode. Businesses come in the system as technology providers, but always after solid feasibility studies for each farm to avoid failures that can hinder further adoption by other farmers suitable for these specific FEFTS. Closing, the core of the system, the farmer, should identify the challenges of today and activate his/her business to return to the basis of agriculture – circularity, self-dependency and locality.

References

[1] https://www.macrotrends.net/1369/crude-oil-price-history-chart

[2] https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-

economics/statistical-review/bp-stats-review-2022-full-report.pdf

[3] https://www.macrotrends.net/2534/wheat-prices-historical-chart-data

[4] **Paris, B.; Vandorou, F.; Balafoutis, A.T.; Vaiopoulos, K.; Kyriakarakos, G.; Manolakos, D.; Papadakis, G.** Energy use in open-field agriculture in the EU: A critical review recommending energy efficiency measures and renewable energy sources adoption. Renew. Sustain. Energy Rev. 2022, 158, 112098, doi:10.1016/J.RSER.2022.112098.

[5] **Paris, B.; Vandorou, F.; Balafoutis, A.T.; Vaiopoulos, K.; Kyriakarakos, G.; Manolakos, D.; Papadakis, G.** Energy Use in Greenhouses in the EU: A Review Recommending Energy Efficiency Measures and Renewable Energy Sources Adoption. Appl. Sci. 2022, Vol. 12, Page 5150 2022, 12, 5150, doi:10.3390/APP12105150.

[6] **Paris, B.; Vandorou, F.; Tyris, D.; Balafoutis, A.T.; Vaiopoulos, K.; Kyriakarakos, G.; Manolakos, D.; Papadakis, G.** Energy Use in the EU Livestock Sector: A Review Recommending Energy Efficiency Measures and Renewable Energy Sources Adoption. Appl. Sci. 2022, Vol. 12, Page 2142 2022, 12, 2142, doi:10.3390/APP12042142.

[7] **Koutsouris, A.; Kanaki, V.** Report on farmers' needs, innovative ideas and interests; AgroFossilFree H2020 Deliverable 1.3, 2021

FIGURES

Figure 1 - Crude Oil price history ($/barrel) *(Source: [1])*. Notes: Gray areas show global recessions; the graph is in Log Scale; the graph is inflation-adjusted

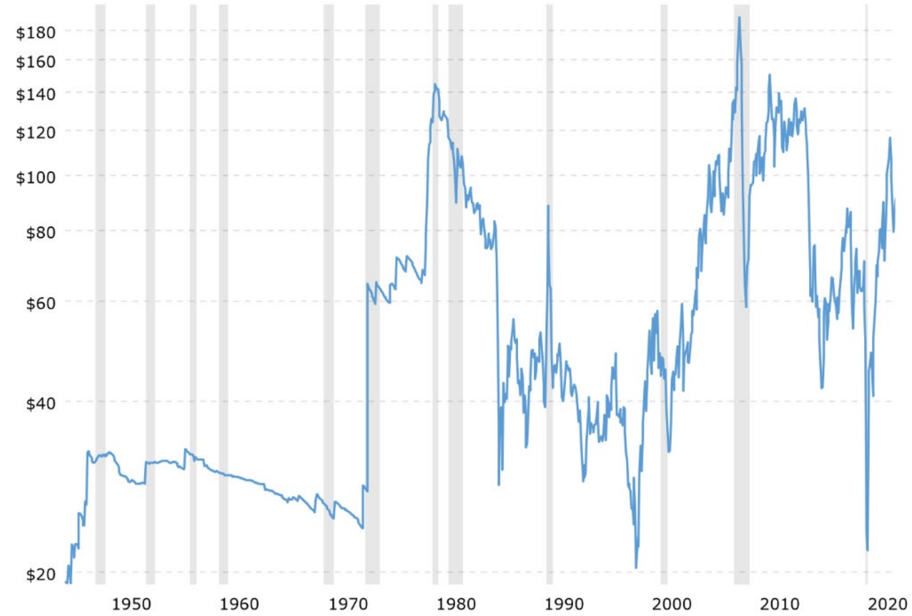


Figure 2 - Crude oil prices 1861-2021 *(Source: [2])*.

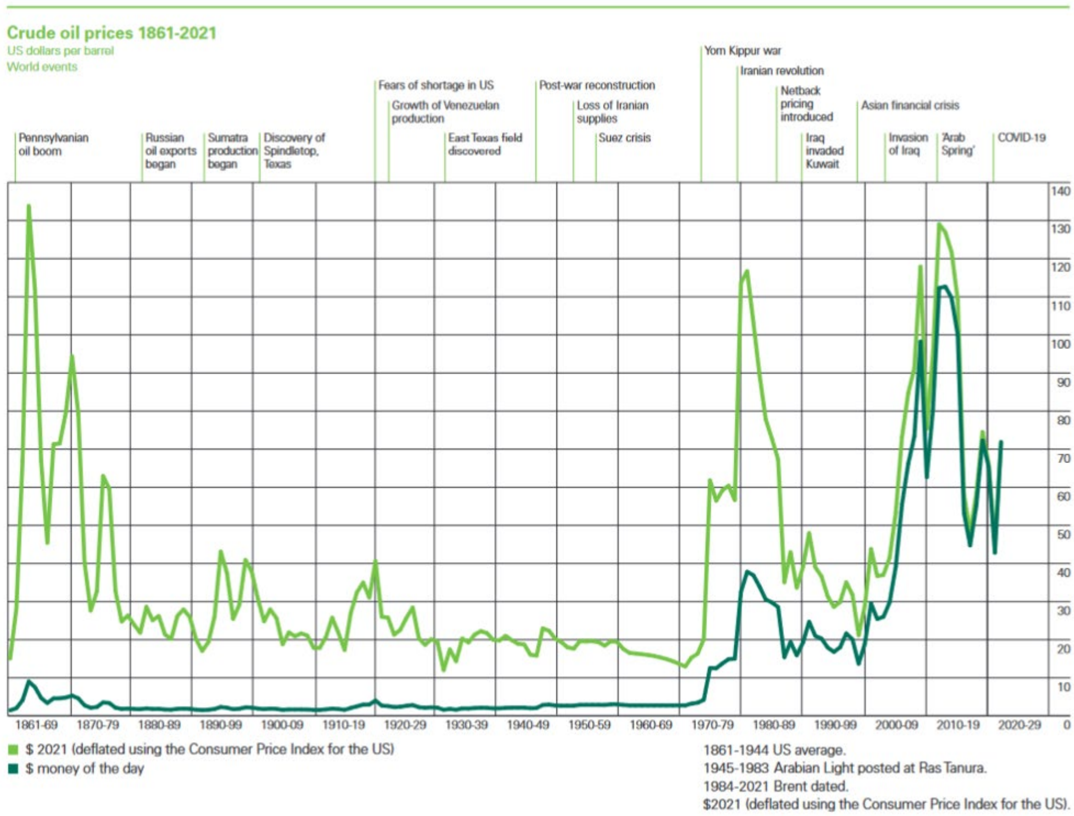


Figure 3 - Wheat price history ($/bushel or 27.216kg), *(Source: [3])*. Notes: Gray areas show global recessions; the graph is in Log Scale

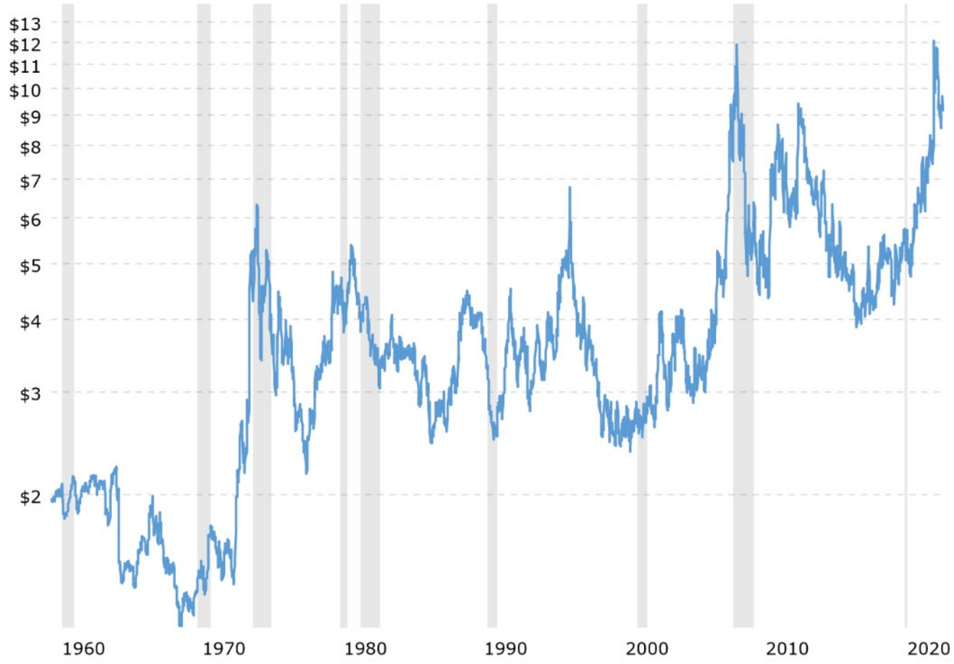


Figure 4 - Energy inputs open-field agriculture EU-27 (%) *(Source: [4])*

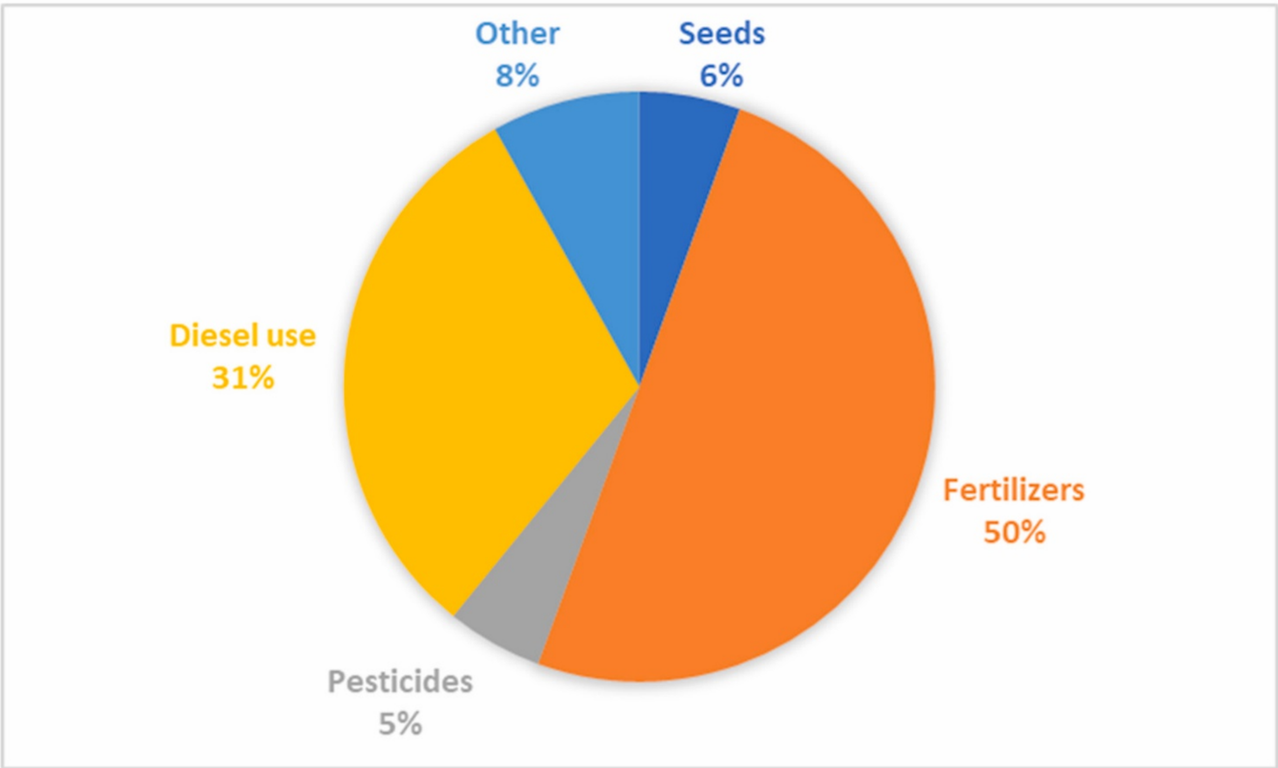


Figure 5 - Total energy inputs for selected open-field crops EU-27 *(Source: [4])*

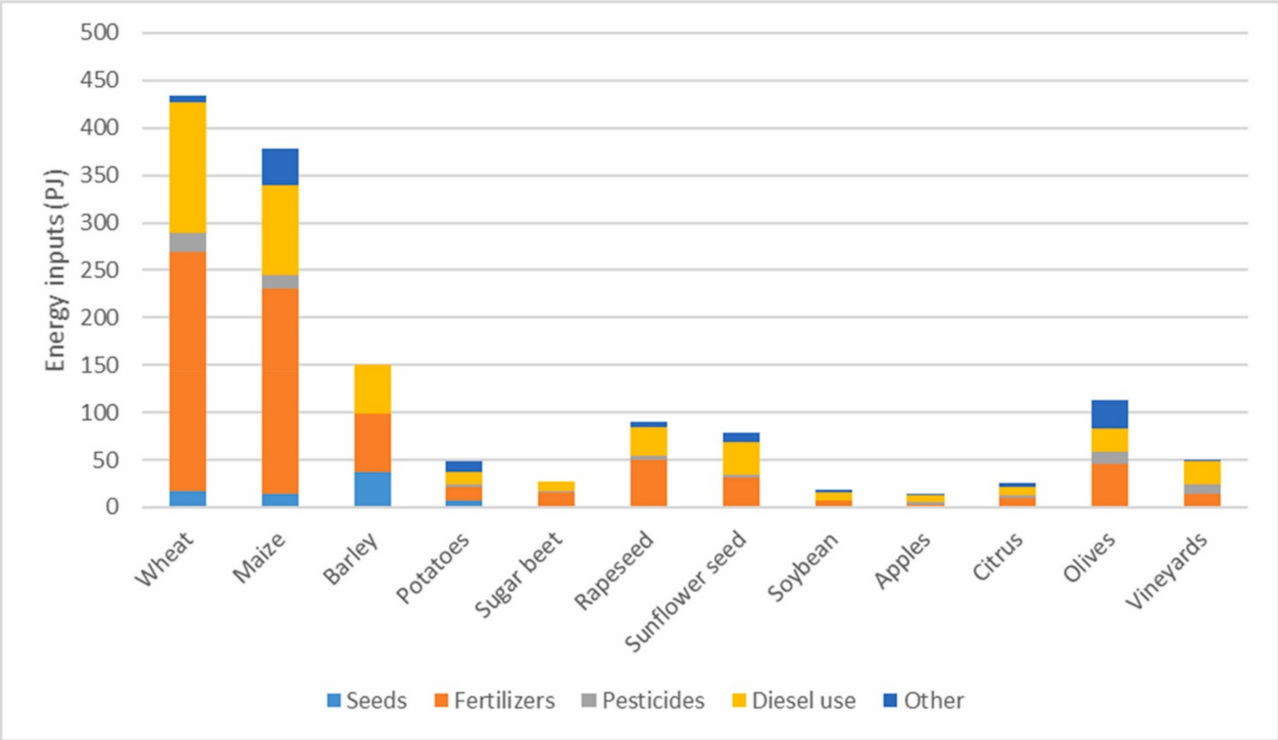


Figure 6 - Energy inputs on a surface basis for selected crops EU-27 GJ/ha *(Source: [4])*

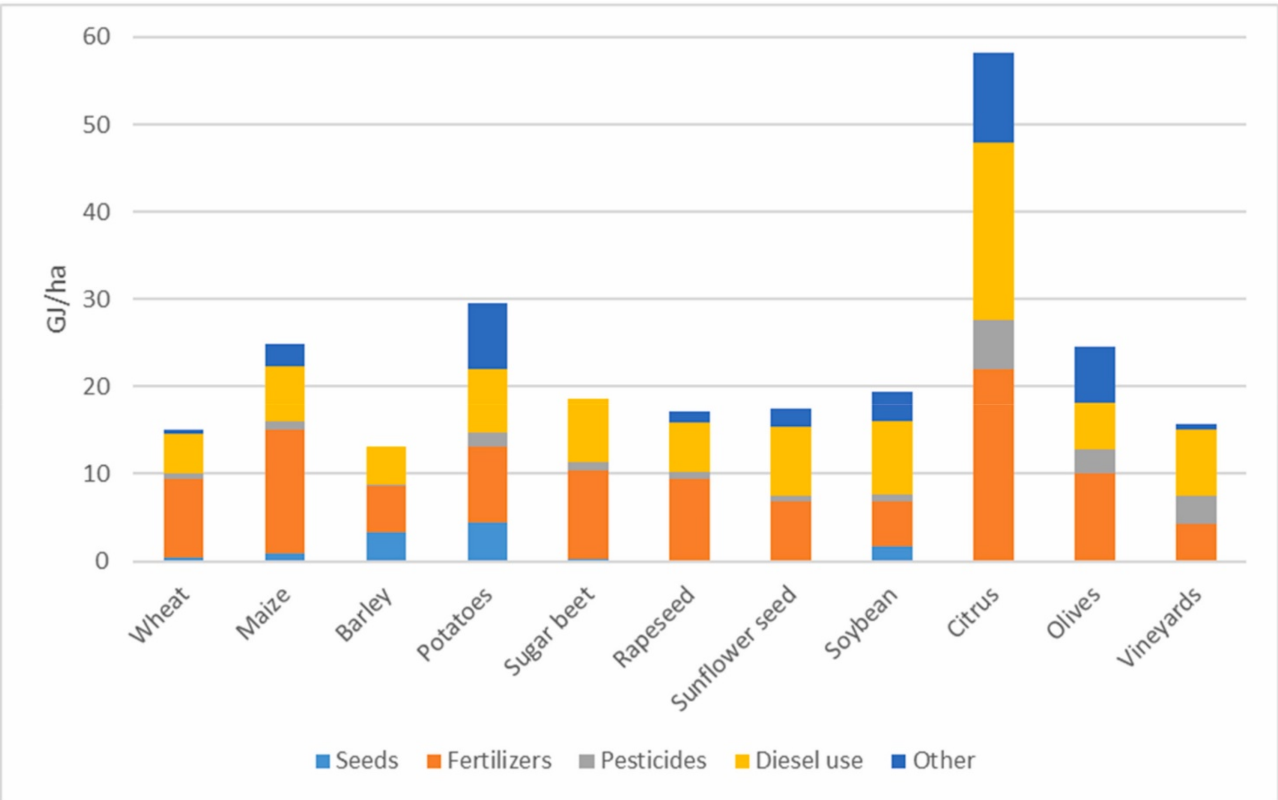


Figure 7 - Range of energy inputs of studies covered in this review according to species MJ/kg *(Source: [6])*

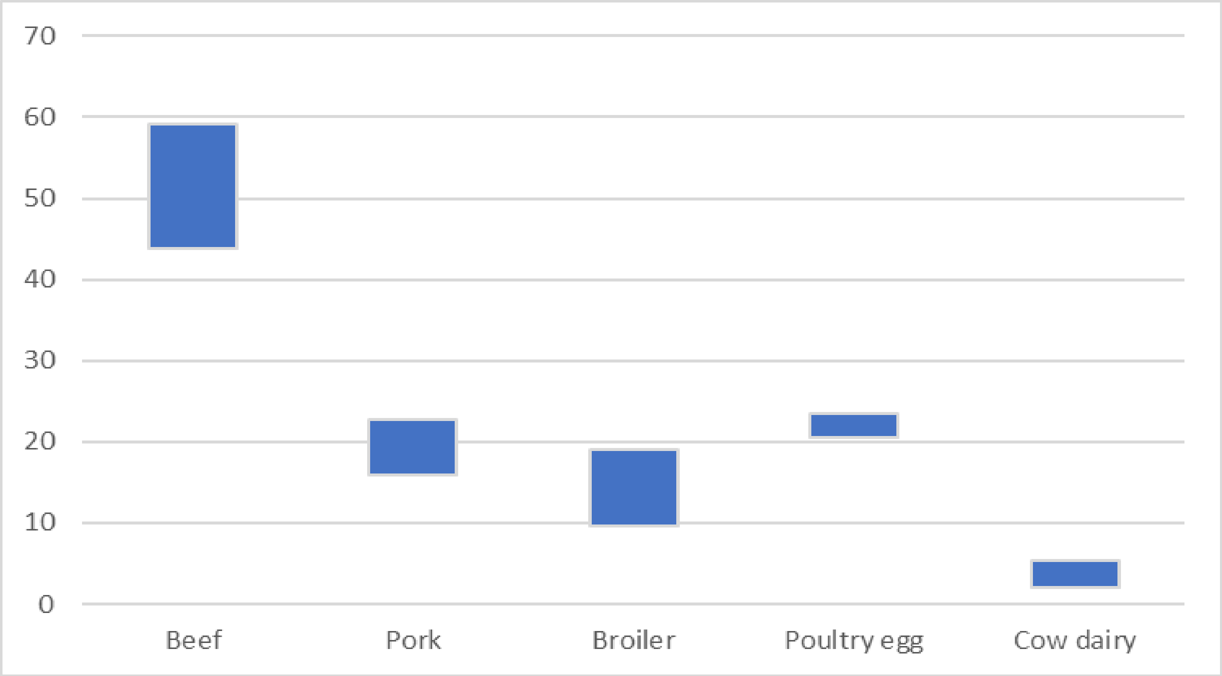


Figure 8 - Farmers' three main motivations for the adoption of RES *(Source: [7])*

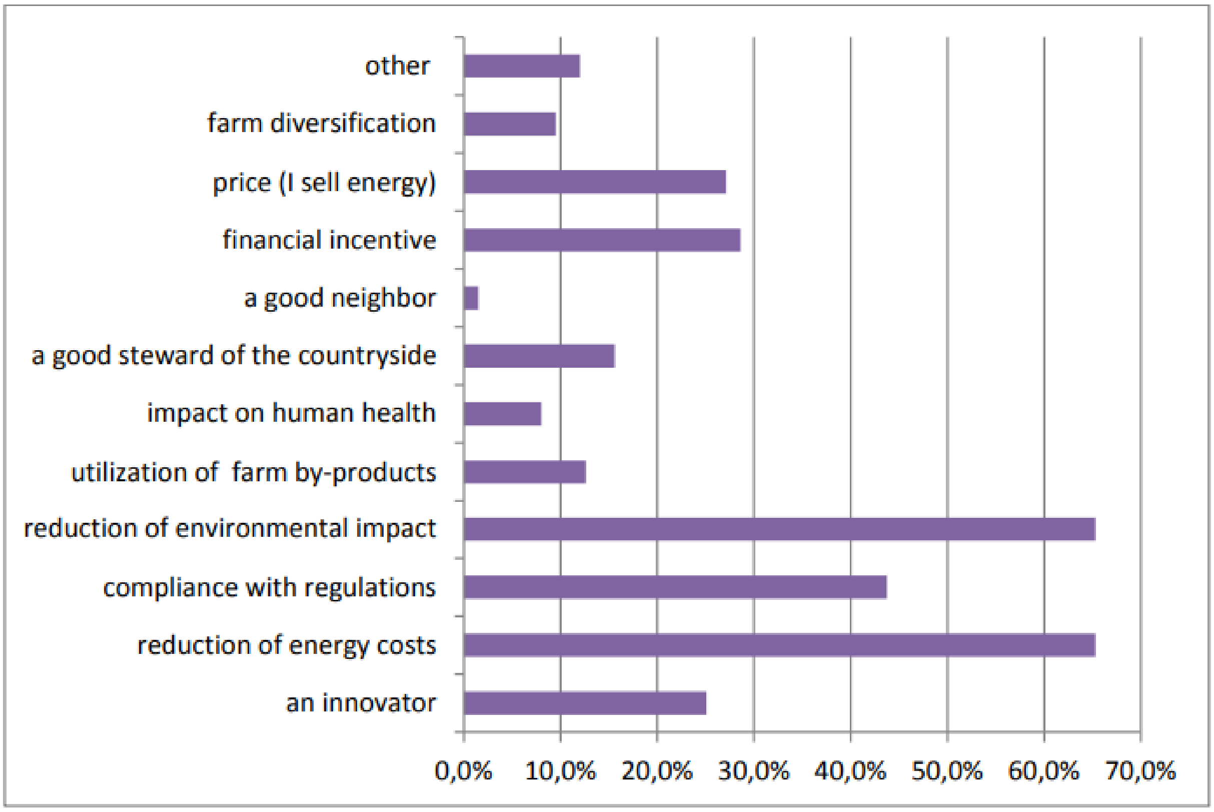


Figure 9 - Most important reason for not adopting renewable energy sources

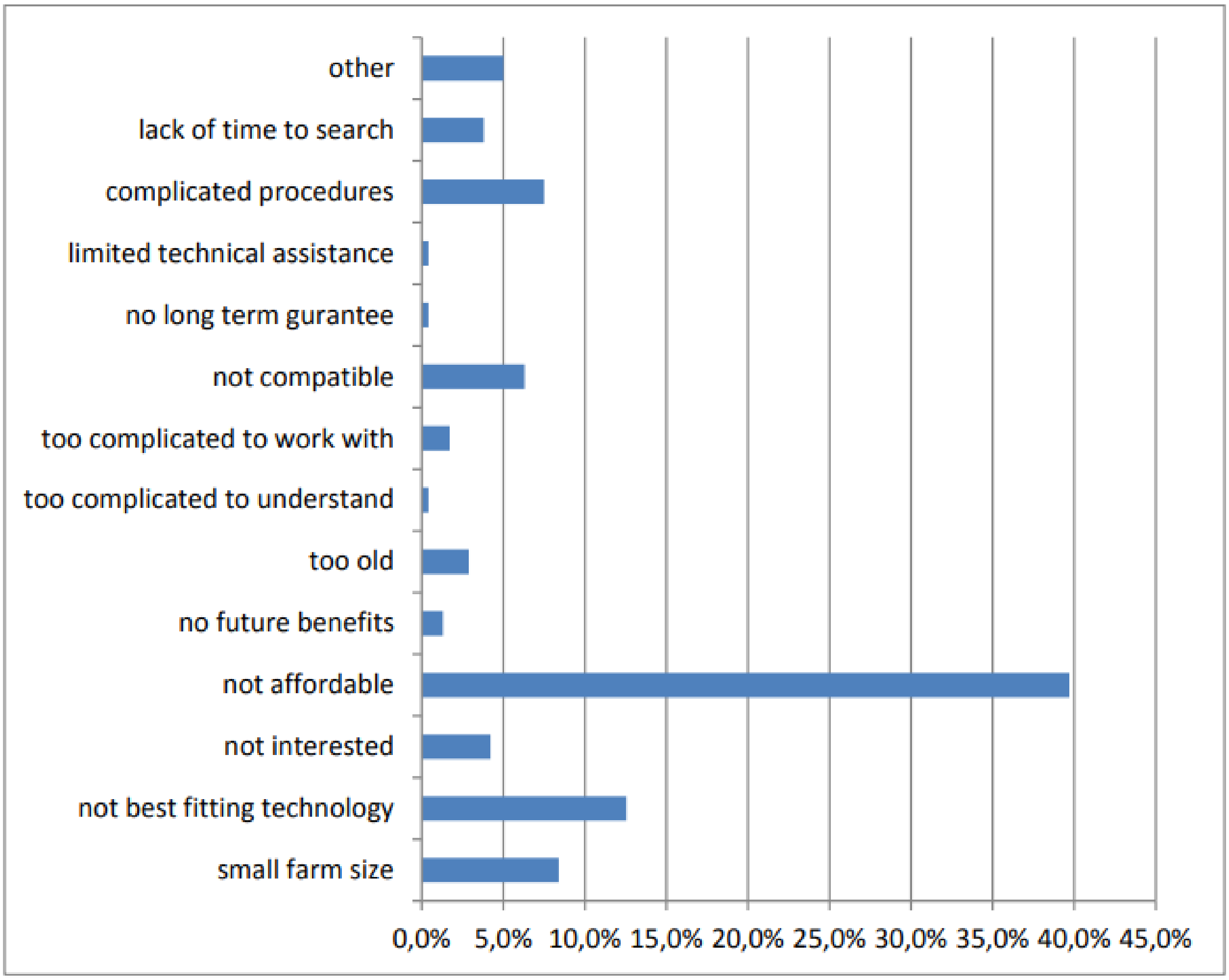


Figure 10 - Farmers' three main motivations for the adoption of energy efficient solutions

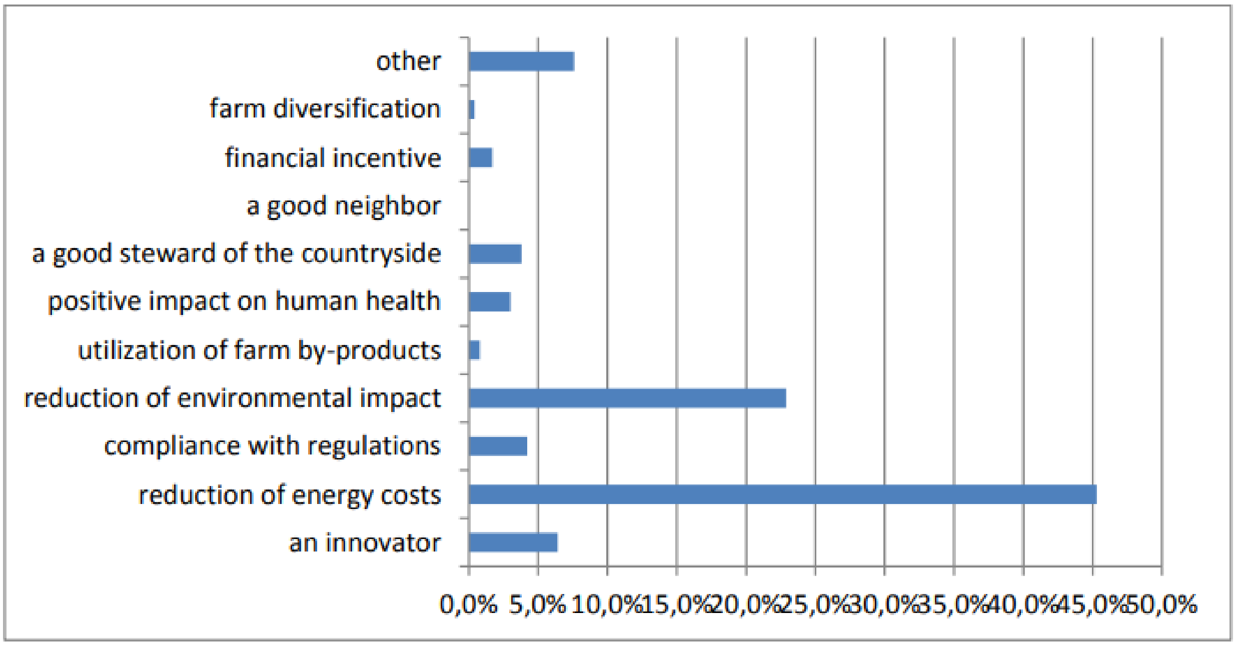
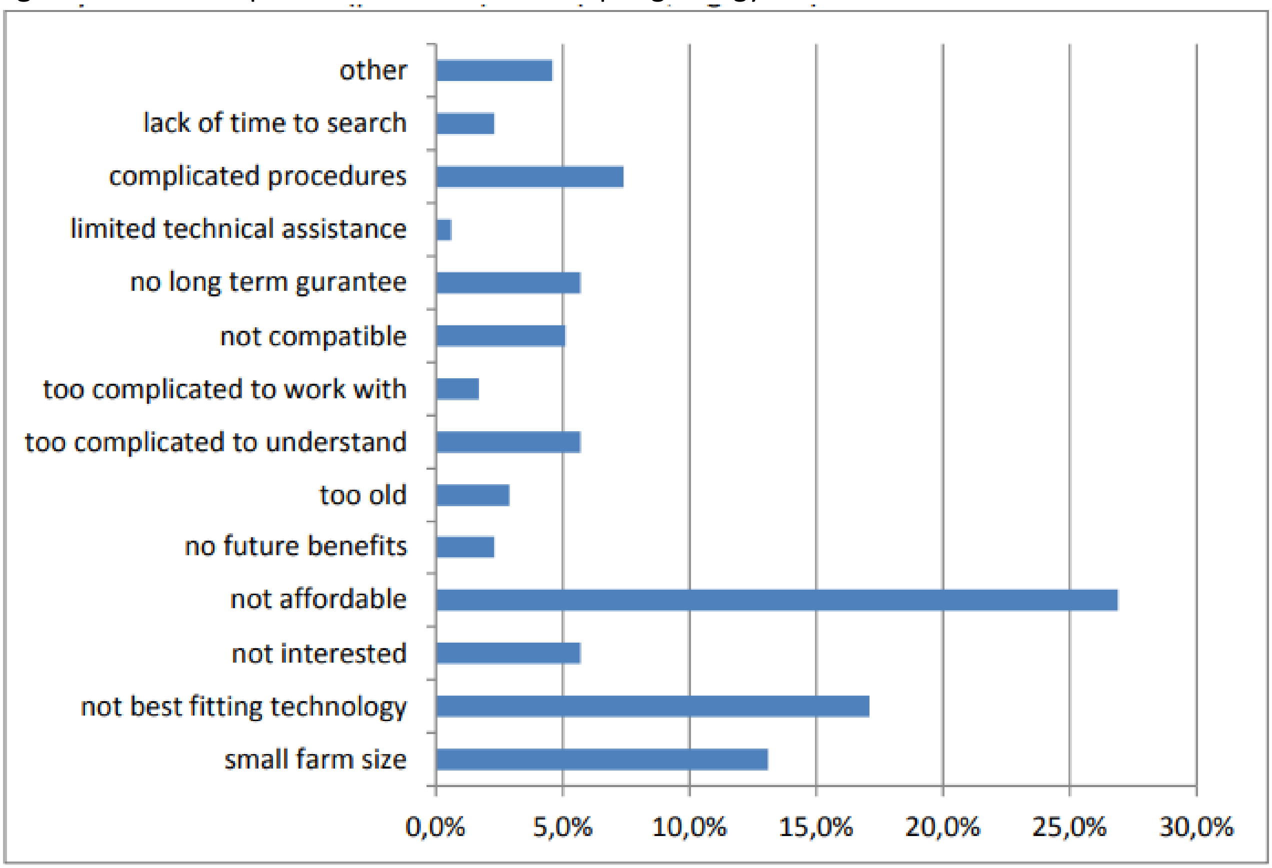


Figure 11 - Most important reason for not-adopting energy efficient solutions



TABLES

Table 1 - Energy inputs in EU agricultural systems (%) *(Source: [4-6])*

[1]Agricultural System		Indirect ()[2]		Direct		Other/unclassified		Total	
Open field	Arable	63%	(769)	31%	(380)	6%	(78)	100%	(1227)
	Orchards and vineyards	51%	(106)	31%	(64)	18%	(38)	100%	(208)
Livestock	Meat	56%		44%				100%	
	Dairy	74%		15%				100%	
[3]Greenhouse	High intensity	1%		99%				100%	
	Low Intensity	23%		27%		50%		100%	

[1] Only crops and systems covered in this study are included

[2] Data in brackets are total energy consumption figures in PJ

[3] The data for greenhouses are simple averages based on studies that provided data on tomatoes, cucumbers and greenhouses and therefore should solely be seen as indicative

Table 2 - Energy consumption per category in EU greenhouses (%) *(Source: [5])*

Energy Consumption per Category	Range of Total Energy Consumption
Heating and cooling	0–99%
Irrigation	1–19%
Fertilizers	1–27%
Pesticides	0–6%
Lighting	1%

Table 3 - Low and high range of energy inputs according to feed and direct energy inputs per production systems MJ/kg *(Source: [6])*

	Animal Feed		Direct Energy Use	
Production System	**Low**	**High**	**Low**	**High**
Cow milk	1.11	4.4	0.54	1.76
Beef	17.34	27.23	9.36	31.97
Pork	11.6	16.41	2.6	11.1
Broiler	6.5	14.82	0.5	6.6
Egg	10.3	13.2	0.6	10.3