Priorities for energy efficiency measures in agriculture

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D3.2 Priorities for energy efficiency measures in agriculture

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Andreas Meyer-Aurich, Werner Berg, Simone Kraatz, Hasan Jubaer, Jochen Mellmann, Thomas Ziegler	Leibniz-Institute for Agricultural Engineering Potsdam-Bornim
Tommy Dalgaard	Aarhus University
Hannu Mikkola	University of Helsinki
Janusz Gołaszewski	University of Warmia and Mazury
Chris de Visser	Wageningen UR
Fátima Baptista, Luis L. Silva	University of Evora
Demetres Briassoulis	Agricultural University of Athens
Claudia Lutsyuk	Fachagentur Nachwachsende Rohstoffe, Gülzow

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Preface

This report provides a compilation of energy efficiency measures in agriculture, their opportunities and constraints to implement energy efficient agricultural systems across Europe as a result of the AGREE (Agriculture & Energy Efficiency) Coordination and Support Action funded by the 7th research framework of the EU (www.agree.aua.gr). The report dwells on earlier reports of the consortium, which listed potential energy efficiency measures (Project Deliverable 2.3: Energy Saving Measures in Agriculture – Overview on the Basis of National Reports) and identified trade-offs and win-win situations of various energy efficiency measures in agriculture (Project Deliverable 3.1: Economic and environmental analysis of energy efficiency measures in agriculture). It shows research gaps in crop production, greenhouse production, animal husbandry and system approaches, which can be regarded as priorities for energy efficiency measures in agriculture. The report is an important input for the strategic research agenda, which is one of the main outputs of the AGREE project.

Contents

1. Introduction

Agricultural production in the EU 27 consumes around 1.07 EJ[1] of energy, including energy from diesel and similar fuels, natural gas for heating and electricity. Of the total primary energy consumption, the proportion of direct energy used in agriculture is 61%, but in greenhouse production it may be 98%[2]. Improving energy efficiency in agricultural production is important for reducing energy consumption, dependency on fossil energy input, energy related costs and greenhouse gas emissions.

Improvements may be achieved in production processes, within the farm infrastructure, on the overall organization or at the level of the value chain or the system design.

Currently energy efficiency in agriculture is not as high a priority on the political or research agendas as it should be. Present research activities are fragmented from an energy efficiency point-of-view and require co-operation between institutes, both nationally and transnationally, to provide a coherent and collective vision and approach to R&D. Which energy efficiency measures should be given high priority rather depends upon the priorities in other research fields and therefore, from an agricultural production viewpoint, energy efficiency is somewhat unplanned and unstructured. A systemic approach developed from a coherent strategy is needed to bring the application and further research of energy efficiency in agriculture to the next level.

This report summarizes the findings which have emerged from the intensive analysis of energy efficiency measures in agriculture documented in earlier AGREE consortium reports. The AGREE consortium has made substantial efforts in analysing the potential for different energy efficiency measures in agriculture (D2.3) and has provided an in-depth analysis based on case studies of energy efficiency across Europe (D3.1). These reports have provided a comprehensive overview of actual, and potential, energy efficiency measures in agriculture, together with the estimated contribution of these measures to improve energy efficiency, and the additional R&D needed to achieve the full energy efficiency potential.

[1] Eurostat: Final energy consumption, by Agriculture/Forestry

[2] Estimation on the basis of the results presented in the agrEE Report: "State of the Art on Energy Efficiency in Agriculture. Country data on energy consumption in different agroproduction sectors in the European countries." 2012.

2. Opportunities, constraints of and research needs for Energy Efficiency Measures in Agriculture

Energy use can be reduced simply by reducing the energy input. However improved energy efficiency is only achieved if energy input per unit yield 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 achieved by using improved technologies. However, straightforward adjustments to the level of energy input into agricultural systems can also contribute to better energy efficiency. Koning et al. (2008) have given an overview of the historical food production showing that subsequent innovations in agricultural production systems have led to an increase in (direct and indirect) energy use which not necessarily resulted in higher energy use per crop unit. They suggested two different approaches:

1) to decrease energy use with either a stable or increased production level in current agro-production systems, (this will result in improvements that are moderate but more feasible) or

2) to have a step change in agro-production systems with both an increase in production and a decrease in energy use resulting in a decisive step change away from the historical trend.

This will result in substantial improvements in energy efficiency, but take longer. Such a step change could well be possible if agro-production systems arise that make full use the biological capacity of agricultural systems, including biological nitrogen fixation, of recycling technology and intensive inter-relationships between different agro-production sectors and even non-agro industries (chemical, material, energy) based on organic and nutrient rich residues or energy re-use (agro-clustering).

Energy efficiency measures can provide a win-win situation for the farmer and the environment, but there can be also factors which limit the adoption of energy efficiency measures or that might induce unintentional side-effects. In addition, even if energy efficiency measures prove to be “win-win” there still may be obstacles that limit the adoption of the measures by farmers. For example a farmer may not invest in a technology, even though the economic benefits are clear, because he might not understand or otherwise dislike a particular technology, or the technology may not have a significant comparative advantage over other, different, technologies or he may even find it impossible eto attract the required financial investment or loan. In general farmers will be more interested to invest in those technologies which promise even higher margins than the economically profitable energy efficiency measures. Therefore, not only the absolute profitability but the comparative advantage of an energy efficiency measure needs to be taken into account to show the adoption potential. Of course this comparative advantage is subject to the individual possibilities and options of a farmer. Hence, often no general statement can be given for each of the individual energy efficiency measures. Nevertheless, opportunities and possible constraints can be identified, which indicate research and development potentials of energy efficiency measures.

2.1 Crop production

Energy efficiency measures in crop production can be targeted at different stages in the production chain. Fuel use for field operations, irrigation, drying and storage of the crops are the most important direct energy demanding activities used in arable cropping systems. In addition, mineral fertilizers account for a substantial indirect energy use in cropping systems. In most cases nitrogen is the biggest single energy input in arable farming. Frequently, to produce a crop, as much energy is used in all field and storage operations combined as is used solely for producing the nitrogen fertilizer used for that crop.

It is also worth keeping in mind, that in animal production feed is the main energy input and nitrogen fertiliser is the major input of the feed production. Through this way nitrogen fertiliser is also an important energy input in animal production.

Pesticides mostly account for minor contributions to energy use, but in certain crops and countries, this could also be substantial.

Reduced tillage and controlled traffic farming (CTF)

Reducing tillage is a well-known and effective measure to reduce energy input in arable systems (see for example Cannell 1985, Danfors 1988, Gemtos et al. 1998, Zentner et al. 2004, Arvidsson 2010). Associated benefits typically include lower costs for the farmer and lower GHG emissions (Weersink et al. 1992, Meyer-Aurich et al. 2009). Furthermore, a carbon sequestration effect in the soil due to reduced tillage may further mitigate the net GHG emissions from agriculture (Pretty & Ball 2001, West & Post 2002). Data from a period of ten years presented by Carvalho & Lourenço (2013) showed that direct drilling can reduce the CO_2 emissions by 2 tons of CO_2 ha^{-1} year^{-1} and by 4.7 tons of CO_2 ha^{-1} year^{-1} when the cereal straw is kept on the field. However, depending upon soil and climate conditions, reduced tillage may also lead to lower crop yields, which, in turn, may counteract the positive effects on energy efficiency. In some cases, a reduction in tillage operations may require higher amounts of nitrogen fertilizer, which can also counteract energy efficiency (Meyer-Aurich et al. 2009). But, in direct drilling studies in Portugal with crop rotations, it was found that leaving the straw of a previous crop on the soil surface, the increased soil organic matter allowed, simultaneously, an increase in crop yield and a decrease in applied nitrogen (Carvalho & Lourenço 2013). The individual situation needs to be evaluated in each regional setting. Research needs are seen primarily in identifying potentials for reduced tillage systems according to site-specific conditions across Europe. There has been some research on a systematic analysis of the constraints to reduced tillage across Europe (Lahmar 2010). However considerable further research is needed to identify the potential for, and constraints to, reduced tillage in Europe.

Using Precision Farming techniques, especially GNSS-Real Time Kinematics (RTK) to provide auto-steer of tractors, can provide permanent trackways for Controlled Traffic Farming (CTF). CTF, very common in Australia and increasingly receiving attention in Europe, is primarily a technique to improve soil conditions but regularly shows fuel reduction and yield increase as soil compaction 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). Additionally, autoguide and the more accurate RTK auto-steer can minimise overlap of tractor and machinery passes and thus leads to less driving. At farm level in the Netherlands, this has been shown to reduce diesel use by 10% (de Visser, pers. com). Diesel use is not the only advantage, the use of auto-steering a GNSS navigation system, such as GPS, and preferably combined with RTK to give +/-2cm repeatable accuracy) in a tractor enables very accurate bout-matching and so eliminates the “double dosing” of cultivating, seed application and fertiliser and pesticide applications that normally occurs in strips when the tractor driver tries to match the current machine pass with the previous one. It helps to optimise the coverage of seeds, plant nutrients and plant protection chemicals, so improving crop quality yield while protecting the environment from excessive use of agrochemicals. Research on this technology is progressing but certainly needs more attention to transfer the techniques to farmers across Europe.

Fertilizer management (precision farming, use of organic fertilizer, biological N fixation, reduced inputs,)

Indirect energy from fertilizer use, contributes to the total energy use in arable agriculture by 30 to 50%. Therefore, all measures to improve the efficiency of fertilizer use contribute to energy use efficiency to a great extent. It is broadly acknowledged that precision farming technologies can contribute to improved fertilizer use efficiency and thus to energy use efficiency (Diacono et al. 2013). Different technologies, however, have different potentials, which need to be addressed specifically with regard to the effects on energy use efficiency and environmental effects. The use of Precision Farming technologies themselves do not necessarily result in improved energy use efficiency. Model calculations in Germany have shown, that site specific fertilizer application to wheat with respect to grain quality my may create incentives for application of nitrogen fertilizer at higher rates to achieve the crop quality without additional crop yield (Meyer-Aurich et al. 2010). Therefore, a general statement of the effect of precision farming technologies on energy efficiency is not yet possible and further research is needed to specify the effects of different precision farming technologies on energy use and the environment, even though the beneficial potentials are widely acknowledged.

Fertilizer management could also be improved by using organic fertilizers, or more generally, by making more use of recycled nutrients (for instance nutrients in sewage and agricultural/industrial/municipal waste streams). The exact energy gain is not well researched yet and improved technologies are needed to make recycling optimally efficient. The use of fertilizers from industry and waste recycling makes competitiveness between those two resources important but it is in accordance with the policy of a “circular economy”.

In order to increase carbon sequestration in agriculture it is recommended to use crop rotation, inter-cropping and cover crops. Those practices can positively influence the efficiency and optimize the overall increase in C sequestration due to additional biomass left on the field (Willy et al. 1983, Wang et al. 2010 a,b, Syp et al. 2012). Introduction of crop rotation can enlarge the biomass production which increases carbon sequestration, especially if leguminous plants are introduced into the rotation. In addition, cultivation of legumes can significantly reduce the use of chemical nitrogen fertilizers, which has a positive impact on reduction of greenhouse gas emissions during the production of fertilizers, which is equivalent to decreasing the use of fossil fuels (Zentner et al. 2004, Lemke et al. 2012).

The efficient use of biological nitrogen fixation by legumes can be a major opportunity for improved energy efficiency in agriculture (Peoples et al. 1995). The major arable crops, cereals, oil-seed rape, sunflower and maize do not have the ability to fix nitrogen biologically. Thus a smart integration of legumes such as soya, clovers and lucerne (alfalfa), field beans and field peas in arable rotations is still a challenge to enhance energy efficiency in cropping systems by biological nitrogen fixation (Gaudin et al. 2013). In animal husbandry systems legumes are of great importance as feed especially in cattle production systems. Even though the principles of integration of legumes in crop rotations are well known, many legumes face a reduced area in Europe. Major reasons for the reduction of grain legumes in Europe are low comparative advantage of grain legumes and reduced payments for legumes (Stoddard et al. 2013). Increased cropping of legumes would not only increase energy efficiency but it would also reduce dependence on imported plant protein in Europe. In order to strengthen the legume cropping in Europe research is needed to identify obstacles and cost efficient incentive structures.

A simple reduction in fertilizer application is another possible energy efficiency measure, which can be effective to a certain extent (Meyer-Aurich et al. 2012). In Denmark, a regulation forces farmers to apply nitrogen fertilizer at a rate of 90% of the economical optimum. The opportunities and downsides of a nitrogen tax have been discussed further, for example by Finger (2012).

Irrigation

Pumping of irrigation water can contribute to substantial energy use, especially in southern Europe. Innovative irrigation technologies use water more efficiently and thus use less energy per crop. The innovative systems need to be adjusted to the production systems in the specific farming contexts and cannot be applied to all systems in the same way. A better estimation of crop water requirements, and a better irrigation scheduling management can increase water use efficiency, and thus reducing water and energy consumption. There is a research potential associated with precise soil moisture monitoring techniques and control of water application in accordance with plant demand. It would be a part of precision agriculture, but associated strongly with the progress in designing of more versatile irrigation systems and pumps. 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, due to different soil behaviour when irrigated in either shorter intervals with low water quantity or longer intervals with high water quantity in the moments that the plant has high water demand. From the farmer's perspective, irrigation is often associated with investments; therefore, farmers are not willing to replace the existing irrigation system with a more energy efficient system if the profitability of such an investment is not very high and, as occurs with drip irrigation systems, the practical use in certain crops may be very difficult, for instance retrieving drip-irrigation lines in large fields of vegetables. But in Southern European countries irrigation is the only way to produce several crops at a level that can be profitable to farmers. It is necessary to continue the research in irrigation systems and practices, in order to improve a better water and energy use combined with practical aspects. The evolution from rainfed agriculture to irrigated agriculture that has becoming a reality in some countries, promoted by the investment in new irrigation schemes and structures, highlights the need for more information on irrigation practices to help farmers in achieving a more rational and efficient use of water and energy. Research should also focus on pump designs, that in combination with more efficient electrical or mechanical motors and control strategies, would result in reduction of total energy requirements for a farm. In addition, renewable energy should be further investigated (as there is research on this area at the moment) for irrigation system applications in order to reduce the primary energy that is accounted for when measuring total energy inputs of a farm. In Greece, where most pumping systems are powered by electricity and the energy mix is mainly based on fossil fuels (mostly lignite), renewable energy applications in remote areas would reduce significantly the fossil fuel based energy usage. It is worthwhile noting that several decades ago, traditional wind pumps, adapted to the local landscape, were used to pump water, and also provided attractive landmarks that made a touristic landscape; the modern idea of agro-tourism. Another research topic to be further investigated, as the relevant developments are rapid, would be the application of biodegradable mulching films that could be applied in most agro-forestry plantations and in several crop systems (e.g. cotton) in order to reduce water evaporation and minimize irrigation and weed control needs (i.e. reduce energy for mechanical weed control and the need for herbicides).

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. It is a very energy intensive operation since typically large quantities of water must be evaporated, due to the high moisture content of the harvested products, by heating, ventilating or a combination of both.

In northern Europe grain drying is often necessary, since the water content in the grain is too high for storage free of grain deterioration and insect infestations. Increased uniformity of drying by optimizing the dryer apparatus, minimizing heat losses, maximizing heat recovery, including by the use of heat pumps, and optimizing process control can be expressed in terms of specific primary energy consumption per unit of evaporated moisture. The specific energy consumption 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. Uneven drying is one of the main reasons for elevated energy consumption, poor product quality and deterioration. It is caused by undesired apparatus designs resulting in inhomogeneous drying conditions (Mellmann et al. 2011). For optimizing and developing agricultural dryers, including in-store conditioning and ventilating systems, the fundamentals for computer modelling are often missing (Delele et al. 2013). Here, fundamental research is needed based on process engineering methods (Iroba et al. 2011) to investigate and model the complex physical processes of coupled heat and mass transfer with heterogeneous gas-solids interactions (Weigler et al. 2012, Sunkara et al. 2013). Especially, the complex nature of heat and mass transfer in porous biological products and their drying and sorption kinetics are still largely unknown. These fundamentals form the basis for optimizing and developing innovative apparatus designs and control strategies (Bartlett 2013).

Heat pump assisted dryers have a great potential for saving up to 50% of the primary energy as compared to conventional drying (Jubaer et al. 2013). Therefore, heat pump systems are already applied in several production systems in the food industry, such as, tomatoes, gelatine, fruit, milk and juice concentrates, nuts, grains, cereals, vegetables, herbs, spices, meat and fish. However, the full potential has not yet been exploited, since the operation of heat pump dryers is much more complex than the operation of the single system components. Further research is necessary in order to provide the industry with appropriate, practical, process control systems applicable to different configurations as well as to varying operating conditions (Ziegler et al. 2013). Storage of onions or potatoes require simple ventilation without significant additional thermal energy input, in order to keep the product free from moisture for avoiding growth of microorganisms. However this also requires considerable amounts of electrical energy for the blowers. In agricultural ventilation and cooling processes, likewise inhomogeneity in the process conditions (temperature, air velocity, moisture, etc.) are the main reason for elevated energy consumption. Cooling is an important process for the pre-treatment and post-treatment of agricultural products before and after preservation. Especially high value crops, like perishable fruit and vegetables, often have high requirements of post-harvest treatment, which are often very energy intensive.

2.2 Energy efficiency measures in greenhouse production

Greenhouses in northern European countries require high direct energy consumption for heating. Large research programs in the Netherlands have been launched to develop greenhouse production systems that allow for substantial reductions in energy use (“Kas als

Energiebron", translated as "Greenhouse for Energy Production", www.kasalsenergiebron.nl). The associated technologies are very promising, but also require high investments. At the moment, greenhouse farmers in the Netherlands have financial drawbacks as their installed Combined Heat and Power engines become less economically feasible as electricity prices have dropped relative to gas prices. In view of these problems, many greenhouse farmers are looking for interactions with the industrial sector where heat is a waste stream and where co-operation between industry and greenhouse farming could result in a win-win situation. Research that has been carried out in the Netherlands allows an optimal design of greenhouses in terms of investments and energy use, depending on the local climatic and market conditions (Vanthoor 2011). This tool could help determine the most energy efficient design of greenhouses depending on their location.

The above mentioned approaches like implementation of CHP in the greenhouse energy generation system and use of waste-heat streams from industry may be implemented in the on-going greenhouse production. Such modernisation should be accompanied with application of a set of other energy saving measures such as advanced control of the greenhouse environment in association with a system for retention (thermal screens) and storage of energy. The research potential for improvement of energy efficiency in greenhouse production results from systemic approach combining a set of energy saving measures with growth and development of single plants.

With the introduction of highly efficient LED lighting there are discussions that, in northern Europe, it could be more energy efficient to have solid well-insulated buildings with low levels of heat energy but using artificial LED lighting rather than any natural light, or to use "vertical farming" techniques with layers of crop to minimise the heated volume of the greenhouse (Tinker pers comm).

In Southern Europe greenhouses are divided into two main categories with different energy consumption characteristics: namely heated and unheated greenhouses. The majority of the greenhouses are plastic greenhouses (i.e. covered by special polyethylene based greenhouse films). Research priorities for the heated greenhouses of S. Europe are to some extent similar to those of the Northern European greenhouses. However, the alternative energy resources, mainly solar energy and biomass, and recently geothermal energy, play a significant role. Funded research so far has focused mainly on passive systems and energy savings.

On the other hand, the unheated greenhouses rely exclusively on renewable solar energy, combined with appropriate greenhouse design and materials, for adjusting the microenvironment to the agronomic requirements of the crops. These crop production systems, although sustainable and more efficient with respect to energy consumption than the heated greenhouses, have been poorly studied so far. Their productivity is considerably lower than that of heated greenhouses. It is important from both the environmental and the economic point of view to investigate techniques which can improve the productivity of the unheated greenhouses, such as heat storage systems. In general, the introduction of advanced technologies in a passive system, such as the unheated greenhouse, makes its operation complex, so it has to be assisted by computational tools. Therefore, the development of operational strategies and control tools for unheated greenhouses is an important research priority.

Another important research topic concerns the greenhouse design and materials. Energy efficiency of a non-heated greenhouse is very much affected by the greenhouse design parameters and the properties of the materials used. Energy efficiency for greenhouses in southern Europe also concerns cooling during summer time. This is also affected by the greenhouse design (e.g. ventilation design, cooling by evaporation, etc.) and materials (e.g. shading, reflection properties, etc.).

Ventilation management, such as nocturnal ventilation, offers a great potential for the control of humidity dependant diseases in greenhouses of the 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, with impacts on energy consumption, production costs and GHG emissions. Moreover, in unheated greenhouses the energy is divided almost evenly into that for producing the structure, the equipment and the fertilisers (Montero et al. 2012). Reductions in consumption of 35% in N, 20% in P, 17% in K and 20% in water use with closed systems were reported by Reis (2012). This shows the potential for a better management of fertigation to reduce significantly the energy requirement in Mediterranean greenhouse systems. More research is needed in order to develop integrated control systems adapted to unheated greenhouses.

Furthermore, the application of energy saving innovations in greenhouses is not straightforward and generic in most cases. This is particularly true in the case of unheated greenhouses, where the design has to take into account local climatic and orientation conditions. As a result, greenhouse builders have to invest in design methodologies and software for modelling the greenhouse performance, similar to Building Simulation tools used for the design of offices, houses and industrial buildings. The development of such design methodologies and software tools is another research priority to be considered.

2.3 Animal housing (lightweight construction, insulation)

Construction materials used in animal housing facilities contribute to energy use efficiency indirectly by their energy cost (indirect energy) including the insulation, which eventually leads to reduced direct energy demand. Even though significant indirect emission savings can be achieved with lightweight construction these gains need to be depreciated over the life time of the housing. In contrast, insulation provides direct energy savings especially in northern Europe on a yearly basis.

Heat recovery from outlet ventilation air would save a lot of energy in pig and broiler husbandry in Northern Europe. Heat can be recovered also from manure. At the same time ammonia losses from manure are reduced and the air quality in animal houses is improved. Energy efficiency should be considered at a higher level than purely on the on the process or at the farm level. Regional, or even national, energy efficiency studies would probably reveal possibilities for exploitation of waste energy and waste streams which can be considered as indirect waste energy available for use.

In Mediterranean climate zones, housing for most livestock sectors (e.g. sheep, cow housing) can be lightweight, as the direct heating needs are low and only apply for a short period of the year. However, in these countries, characterised by hot and dry summers, cooling is sometimes necessary to control high temperatures, for example in dairy farms in order to avoid losses in productivity. Evaporative cooling systems and roof insulation can be used, but more research is needed in order to find the appropriate equipment design and materials and the influence on animal behaviour and welfare, affecting productivity and energy efficiency.

Specific livestock sectors such as intensive poultry farming are considered major energy consumers. More specifically, broilers require temperatures ranging between 24°C and 32°C, thus requiring either heating or cooling. A recently started Greek project (*GreenPoultry*: *Assessment of techniques and technologies for reducing the environmental footprint of poultry facilities*) seeks, among other objectives, to reduce the environmental footprint of broiler facilities through a sustainable reduction of released GHGs along with a decrease in energy consumption. This will be potentially achieved through modification of the birds' diet, of the construction of the poultry facilities and of electromechanical (E/M) systems such as ventilation, through reducing the energy demand and through the manure management strategy. An alternative solution, that also needs further research,, is organic or extensive poultry farming. With the corresponding increasing market demand for these type of products , as in most livestock sectors, this alternative may also lead to improved energy efficiency per unit of product.

Livestock production is expected to be impacted by climate change with increased temperature, which requires higher cooling efforts in animal husbandry systems. There is a need for the investigation and development of new materials, building elements and construction principles for better insulation so that the temperature inside the buildings can be passively reduced and not through the use of additional direct energy for ventilation and cooling systems.

2.4 Systems approaches

Efficient feeding strategies

A major share of the energy requirements of livestock production is the supply of feed components in the diet of animals. The energy inputs of feed depend mainly on the site conditions such as fertilizer application, the yields achieved and cultivation requirements (Kraatz 2012). Improved resource efficiency in the production of feed will lead to increased energy efficiency in livestock production processes. Therefore it is necessary to consider feed production, in specific areas, with respect to its outcomes and to improve the management of feed production when indicated. As diet composition, in particular, influences the energy efficiency of livestock production, it is important to ensure that the nutrients are balanced for a performance orientated diet for the animals in order to improve the energy efficiency of food production from livestock.

An increase in animal performance leads to improved energy efficiency but this may only occur up to a certain extent and, for example, in dairy farming it has been shown that this effect reduces with increasing milk yields because of the higher energy inputs required in the higher performing diets (Kraatz 2012). Farm specific management strategies have to be developed which consider the holistic view of the individual livestock operation to gain more product from the energy used.

Furthermore, the time to rear the replacements for a livestock operation influences the energy efficiency. With shorter productive lives, the energy requirement needed for the replacement livestock increases and has a stronger influence on the energy efficiency of the livestock farming system. An increased productive life for dairy cows can improve energy efficiency and this can be achieved by changes to the animal husbandry and feeding strategies as well as with specific breeding strategies. There is still limited knowledge about energy efficient feeding strategies, especially with respect to different breeding strategies, and this suggests that a systematic research programme is required.

Waste stream valorisation

The utilization of agro-residues for chemical, feed, material or energy production 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 biofuels or to produce raw materials for the production of bioplastics or other polymers. Also, manure from animal husbandry systems can be used to produce biogas, or be used directly to produce materials for non-food purposes. In both cases nutrients can be extracted to produce alternatives to mineral and artificial fertilizers. Another example is to use trimmed green leaves such as those from sugar beet, cabbage, carrots, witloof chicory or green peaswhich can be used to produce proteins for food and feed, while the fatty acids can be used to produce polymers and the remnants can be used to produce energy.

A special category of agricultural waste stream that can be utilized by recycling and energy recovery of the non-recyclable materials, is agricultural plastic waste, mainly in the form of bags used to supply inputs and for protecting vegetable crops and stored hay. A systematic research project, carried out recently at European level, has investigated this possibility but legal issues need to be resolved, both at the level of the European Commission and at national level for widespread use to be achieved (Briassoulis et al. 2010, Briassoulis et al. 2012). Common to the valorisation of all waste streams is that the production of additional goods, such as energy or materials, can avoid energy use in other production chains, which can be accounted for as credits within life cycle assessment accounting methods. A central issue in all these examples is that nutrients can be recycled which can contribute to improved energy efficiency in arable farming,

Agro-clustering

A systems approach to increase energy efficiency can be offered by the concept of agro-clustering. In this concept clustering of companies between and within value chains are physically brought together to create win-win situations by close interaction between processes (Smeets 2009). This can bring sustainability to a higher level and holds the promise to increase both production and energy efficiency. An example from northern Europe is a large tomato nursery using waste heat from a sugar processing plant to keep the tomato plants at a suitable growing temperature but it also uses waste CO2 from the processing plant to improve the photosynthesis of the tomatoes[3].

3. Priority setting

The efficient use of energy is a political objective based on the two criteria of limited availability of fossil fuel resources and the environmental effects, including climate change, associated with GHG from energy use. Therefore, priorities should be arranged according to the potential of various measures to mitigate both the use of energy and the negative environmental impacts of energy use. Furthermore, energy use is an important cost item in the total cost budget of a farm. An increase in energy costs will affect different agricultural systems to different extents and those energy efficient production systems will have a comparative advantage, which may also impact on the structure of agricultural production.

Energy efficiency measures must be attractive, from the point of view of farmers, to be considered in the decision of a farmer to adopt a specific technology. This means that energy efficiency measures must be economically viable to be successful and this means that financial support or regulation should be considered to support the measures, at least initially while expertise and the market for a particular measure increases and economies of scale reduce the cost of those measures. Important criteria for evaluating energy efficiency measures are effectiveness, potential for research and development, environmental co-benefits and the potential economic effects on the agribusiness. The measures must not

[3] http://www.britishsugar.co.uk/tomatoes.aspx

increase work or production risks, worsen working conditions of workers, reduce the quality of products, reduce animal welfare or be unsustainable from the environmental point of view. A list of energy efficiency measures in agriculture with their potentials and constraints have been published in a special report by AGREE[4]which discusses and suggests the research needs in the various agricultural production processes across Europe.

Priorities for publicly funded research and development on energy efficiency measures should focus on the benefits to society associated with the energy efficiency measure. This is a difficult task and probably one of the most important research needs associated with priority setting in research. Pannell et al. (2013) have proposed approaches for ranking environmental projects based on benefit cost ratio or a benefit cost indicator, which could be used in this regards. One of the most difficult tasks is to determine the benefit of research on efficiency measures. In this context the stakeholders who benefit also need to be brought into the equation. This is primarily a political question, which certainly needs further attention.

4. Summary and Conclusions

This report provides research gaps and priorities for energy efficiency measures in agriculture across Europe, based on the analysis of the Coordination and Support Action AGREE (Agriculture & Energy Efficiency) funded by the 7th research framework of the EU (www.agree.aua.gr). The analysis from seven countries (Portugal, Netherlands, Germany, Denmark, Poland, Finland, Greece) shows the potential impact of different energy efficiency measures across Europe and research needs to improve energy efficiency. Potentials and constraints were identified for the categories: crop production, greenhouse production, animal housing and systems approaches. It was found that indirect energy use is a major factor in agricultural processes which needs to receive more attention. Especially energy use associated with the use of nitrogen fertilizer dominates most of the energy use in crop production and via feed also in animal husbandry. Systems approaches should be applied to take the whole value chain into account and tackle the most important drivers of energy use in agriculture. Direct energy use is most important in drying, irrigation and heating processes, where efficiency potentials can still be identified. Fuel use due to tillage and farm operations often have only a moderate impact on the whole energy efficiency at farm level. Anyhow, in extensive production systems this energy use can be of crucial importance. In many cases reduced tillage and new emerging auto-guidance systems are expected to provide multiple benefits which promise to lead to higher energy efficiency in agriculture.

[4] Energy Saving Measures in Agriculture – Overview on the Basis of the National Reports. Agriculture and Energy Efficiency (AGREE). Project Deliverable 2.3

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