Executive Summary:

Today, energy efficiency in agriculture is not a priority at the political and research agenda as it should be. The present research activities are fragmented from an energy efficiency point-of-view and require co-operation between institutes nationally and transnationally from a coherent and collective vision and approach. Which energy efficiency measures should be given priority is rather a result of priorities in other research fields and thus coincidental from the energy efficiency viewpoint. A systemic approach from a coherent strategy would be needed to bring energy efficiency to the next level.

The objective of the AGREE project is to bring the subject of Energy Efficiency (EE) in Agriculture on a transnational research agenda.

After two years of intensive data collection and stakeholder interactions, several publications are available for the public, including an initial inventory on the state of the art of EE in agriculture, an inventory of measures to increase EE, reports on the analysis of drivers and stakeholders and a comprehensive analysis of case studies on economic effects of EE measures. Additionally, based on six national stakeholder meetings, R&D themes were identified and prioritised during a transnational stakeholder meeting in Athens in June 2013. The work resulted in recommendations for 11 R&D priority areas that would support more energy efficient agriculture. The research topics are elaborated in the Agenda for Transnational Cooperation (ATC). All reports are published on the project's website: www.agree.aua.gr

The AGREE consortium has worked together in collecting information to design the operating area of energy use and efficiency improvements in agriculture and to highlight this area by showcasing in a wide range of products and farms. This work has shown that energy efficiency varies widely between agro-climatic zones and countries also but that it can be improved quickly and easily by learning from each other, exchanging best practices and focusing on country-specific applied research. Moreover, the inventory of
energy efficiency measures has resulted in a large list of nearly 500 measures ranging from operational to more strategic levels. The show cases of several production systems of selected agro-products in six European countries have revealed some of the challenges farmers are faced with when trying to improve energy efficiency in practice. One challenge for instance is the interactions and trade-offs between energy use, farm income and greenhouse gas emissions.

Although the technical information collected and produced by the AGREE consortium revealed many opportunities to improve energy efficiency, the question remains on how drivers and stakeholders will influence decision making at the farm level to implement, postpone or ignore energy efficiency improvements.

As a result of the current views on energy efficiency in agriculture, implementing energy efficiency measures will mostly be considered by farmers based on the opportunities they see to save money, favoring low cost investment technology solutions that can be easily implemented. Support could come from governments and to a lesser extent from the supply chain.

When energy efficiency in agriculture has a more pronounced position on the European agenda, the likely result will not only be that more effort is put into R&D but also that the downstream value chain will have an increased influence fuelled by societal demands through NGO’s (the enabling environment).

To ensure implementation of project results, a link has been created with a European network of researchers (ENGAGE) and the European Society of Agricultural Engineers (EuAgEng). The established co-operations will facilitate the result adoption process. Additionally, AGREE has established a close link with the Collaborative Working Group on Agriculture and Energy. This group is embedded in SCAR and the KBBE-Net and is thus positioned to translate the AGREE agenda, into commitment for effective R&D on energy efficiency.

Project Context and Objectives:

The SCAR Collaborative Working Group on Agriculture and Energy has identified the need to put energy efficiency in agriculture on the European agenda. This resulted in a call for a Coordination and Support Action under the 7th Framework Programme (FP7). The topic calling for a project identifying low-hanging fruits was published in the FP7 work programme 2012. The aim was to identify research areas that would bring short and medium term returns on research on the one side. Secondly, it should be assessed what kind of on-farm investments could contribute to energy savings at reasonable costs. This aspect is important as decisions for investment for energy efficiency are competing with possible investments in other on-farm segments that promise to increase productivity or decrease costs of operations. The AGREE project was set up under this call and combined forces of seven European member states with differing agricultural climatic zones to effectively represent the greater proportion of European agriculture.

The objectives of the AGREE project developed from the SCAR CWG aim, were the following:

- Make an inventory of economic feasible energy saving measures either already taken up by the agricultural industry, or at an early stage of introduction to the agricultural industry, in different European countries under various climatic conditions.
- Based on the inventory, propose actions to promote energy efficiency in European agriculture addressing the dissemination pathways and the pitfalls to innovation.
- Initiate transnational sharing of knowledge on energy efficiency measures ready for short term introduction.
- Produce an agenda for transnational research collaboration using a participatory approach. This Agenda will target the potentials offered by several agricultural production systems, building types and designs, ventilation and other climate control processes, use of inputs, agricultural machinery design and use and farm logistics.
- Indicate the added value of transnational R&D on energy efficiency in agriculture.
- Indicate the potential benefits of energy saving in European agriculture by providing evidence for the economic and ecological side-effects of improved energy efficiency in agriculture.
- Involve stakeholders in selected countries and present the AGREE results to funding organizations and R&D networks.

The AGREE project has positioned energy efficiency as its prime indicator while using the following World Energy Council definition: energy efficiency improvements refer to a reduction in the energy used for a given service (heating, cooling, lighting, etc.) or level of activity. The reduction in the energy consumption is associated with technological changes, better organization and management or improved economic conditions in the sector.
This definition implies that energy use is allied with the corresponding level of agricultural production. Thus, increasing energy use efficiency might imply an increase of energy use when production level is stimulated to a higher extent. Or, that decreasing energy use could result in lower energy efficiency if the production level decreased even further as a result.

In the past increasing agricultural production has coincided with an increase in energy use. Koning et al have shown this in a study from 2008 on the evolution of agro-production systems when trying to assess the long-term global food availability. Historically, the evolution of agricultural production systems shows an increase in inputs used to convert more of the solar energy into food and feed. Mechanization and the use of mineral fertilizers and pesticides are prime examples of innovations that have increased the complexity of agro-production systems and at the same time have used more energy. With the need to increase food production in view of an increasing world population and their desire for more Western style diets and a higher share of animal products, it can be expected that energy use in agriculture will rise. The question is whether this will also be true for European agriculture. Yet, increasing productivity will be important from the viewpoint of competitiveness. Therefore, the challenge is to combine increased productivity with increased energy efficiency, which could well imply a step change in the evolution of energy use in agriculture. This will not only require large improvements in existing agro-production systems but could also ask for new designs and innovations that answer to the needs of this step change. “Sustainable intensification” is a phrase often used to describe how agricultural production needs to develop to meet the increased demand for agricultural products.

Project Results:

Following are the main S&T results of the AGREE project according to the three main working packages: WP 2 State of the Art of Energy Efficiency, WP 3 Economic and Environmental Impacts of Energy Efficiency measures and WP 4 The Agenda for Transnational Cooperation.

Work Package 2

The Work Package 2 summarizes:

1. The state-of-the-art on energy use and energy efficiency of agriculture (Report WP 2.1) – to give an outlook for energy use in the main agricultural sectors of arable, perennial, greenhouse and livestock production;
2. The analysis of stakeholders and drivers of energy efficiency in agriculture – to create an image of the enabling environment of energy efficiency in agriculture which will contribute to energy saving potential (Report WP 2.2);
3. The energy saving measures and their potential for energy savings in agriculture – to provide an inventory of energy saving measures categorized according the agro-production sector, farm activities, financial data like investment and payback time and the expected time scale of implementation (Report WP 2.3);
4. Compilation of the three reports above into the synthesis report (Report WP 2.4).

All the data on energy inputs in the EU agricultural sectors, energy saving measures, and stakeholder and driver analyses were provided in individual reports from the six countries involved in the AGREE project: Finland, Germany, Greece, the Netherlands, Poland, and Portugal.

Work Package 2.1

According to European energy statistics the total final energy consumption (FEC) of the EU-27 countries amounted to 49205 PJ in 2008. The FEC of the sector "agriculture/forestry" was estimated at 1071 PJ corresponding to 2.2% of the total FEC in the economy varied between the six study countries from 0.4 to 6.2%. The actual energy consumption of the European agriculture reported in the Eurostat statistics is underestimated. The main reason is that energy which is definitely required for the production of agricultural inputs and the fuels are not allocated or not allocated entirely to the sector of “agriculture/forestry”, e.g. production of fertilizers, consumption of fuels is reported in transportation sector.

Specific energy input has been established for those agricultural products which have a decisive role in the EU foodstuff production, including:

- Crop production: wheat, sugar beet, potatoes, cotton, and sunflower;
- Greenhouse production of tomatoes, cucumber, and sweet pepper;
- Production of perennial crops such as vineyards and olive groves;
- Livestock production such as dairy cows (milk), pigs, and broilers.

In field crop production the ranges of specific energy input across the EU countries are as follows: wheat 2.08-4.29 GJ t-1; sugar beet 0.20-0.29 GJ t-1; potatoes 0.63-0.87 GJ t-1; sunflower 3.98-5.06 GJ t-1; and cotton 15.4 GJ t-1. Direct energy use shares 30-50% of the total specific energy use. The extremely high direct energy use, over 90%, is for sunflower production in Portugal and for cotton production in Greece. For the field crops the main energy input is associated with the use of fertilizers and diesel. Energy input for irrigation, drying and/or storage is important but it depends on geographical location and related climate, and intensity of the production systems.

Greenhouse vegetable production in the Central and Northern EU countries is characterized by a very intensive direct energy input and differs significantly from the production system in the Southern EU countries. The specific energy input in tomato and cucumber production for the Central EU countries are in the ranges: 23.6-63.3 GJ t-1 and 17.9-26.1 GJ t-1 while in the Southern EU countries in the ranges: 0.66-2.33 GJ t-1 and 0.71-1.42 GJ t-1, respectively. Sweet pepper production in the Central EU country – the Netherlands – requires 36.1 GJ t-1. In general, for the vegetables grown in the Southern countries little or even no energy input is needed when grown directly on soil, and only a higher energy input is needed in hydroponic systems.

In the Southern EU countries the total primary energy consumption by perennial production of olive groves and vineyards contributes significantly to the total energy use in agriculture. The specific energy input for olive production is in the range 1.07-1.21 GJ t-1 and for vineyards the figures range from 0.82 GJ t-1 to 2.49 GJ t-1. The ratio of direct to indirect energy inputs is strongly country specific. In the olive grove production in Greece dominates direct energy input while in Portugal – indirect energy input. In the vineyard production direct energy prevails in Germany while indirect energy input prevails in Greece and Portugal.

The livestock production comprises a great share of primary energy consumption in agriculture and they are equally important in any EU countries. The most energy consuming subsector of livestock production is milk production followed by pig and broiler production. In milk and broiler production there is a highly differentiated amount of indirect energy use which is accumulated in feed. However, in pig production energy use for feed is similar across the studied countries, but the specific energy input does depend on the level of direct energy inputs. The ranges for specific energy use in livestock production are as follows: dairy cows 2.71-5.05 GJ t-1, pigs 14.5-22.6 GJ t-1, and broilers 9.8-14.8 GJ t-1. The ratio between direct and indirect energy use in milk production is 2:3 and for pig and especially for broiler production this ratio is in the broader range from 2:3 to 1:5. In any livestock production the main energy input is associated with feed although this indirect input varies between countries. In milk, pig, and broiler production it accounts for 60-85%, 38-62%, and 53-74%, respectively.

The results of the energy use analysis for the 13 subsectors under consideration were scaled up to the national level. Across the concerned EU countries the most energy consuming subsectors are dairy cows, wheat, and pig production. The countries are specific in the most energy consuming subsectors as follows: in the Netherlands – dairy cows, pigs, and tomatoes and sweet pepper production; in Poland – dairy cows, wheat, pigs and potato production; in Finland – dairy cows and pigs, in Greece – wheat and cotton, and in Portugal – dairy cows, olive groves and broiler production.

Work Package 2.2

The implementation of energy efficiency in agriculture is a process which requires integration of agricultural and non-agricultural stakeholders and synchronization of national policies in relation to energy, social-and-economic, and environmental issues. The identification of driving forces for energy efficiency implementation in short and long term will rationalize the operative transfer of energy-efficient technologies and energy saving programs into agricultural practice.

In the long-term the most important drivers for changes in energy efficiency in agriculture are demographic developments, level of education and research, technological developments and climate change concerns. Demographics are important from a global as well as a farm perspective. Their implications will have long term effects on the investment and production strategies of farms. The quality of research and the level of education will determine in the long-run the adoption of new technologies. The pursuit to find appropriate and resource efficient technologies is not the least bit affected by the climate change concerns of the previous years. It might be one of the most important long-term drivers for the implementation of energy efficiency and energy saving measures. Climate change is mostly concerned with emission of greenhouse gases (GHG). The pressure to reduce emissions in all nations will also affect the agricultural sector.
In the short-term, drivers such as taxes, energy prices and legislation (e.g. the Common Agricultural Policy – CAP) are the driving forces for energy saving measures at farm level. In recent years the concerns about the rise in energy prices are of direct impact for higher costs of agricultural production. Taxes are a short term measure to implement policies. National legislations are likely be adopted relatively fast at the farm level.

As a result of the analysis of identified stakeholders in the project countries, the most interested and influential stakeholder are, not surprisingly, the farmers themselves, who are responsible for making decisions on possible investments in energy saving. National government and the EU are the likewise important stakeholders for energy efficiency. As a consequence, these stakeholders should be involved in the process of establishing energy saving strategies and the adoption of energy saving measures at farm level. Other stakeholder groups, i.e. research and nature conservation and animal welfare organizations (NGO’s) are interested but not very influential for the decision making. Nevertheless, they have an important part to provide expertise or a social context to the decision makers. Agricultural input suppliers are in most countries very powerful in the decision making and might be involved if interest is expressed on energy saving issues. As for trade and retail the subject of energy efficiency is not imminent, though it is sometimes part of a marketing strategy, i.e. selling products with low energy footprints. Stakeholders might have different influence and interest in the countries and should be managed accordingly, i.e. farmers’ organizations, agricultural input suppliers. In general, the perception of stakeholders on the subject might be increasing in the future and it is important to provide up to date data knowledge to facilitate the process for improvements in energy efficiency.

Work Package 2.3.

For 13 subsectors of agriculture, 481 energy saving (ES) measures in total were identified and classified into seven categories with a country-specific meaning: 1) type of energy input: indirect, direct; 2) type of ES measure: operational level, systems level, process monitoring, farm management, market orientation, capital goods; 3) importance: from 1-low to 5-high; 4) R&D: yes, no; 5) potential of the measure: achievable at present or not immediately ready for implementation; 6) indication of an investment cost: from €1000 to over €1000000; 7) estimated payback time: from 1 to over 5 years.

In general, ES measures refer to the reduction of main energy inputs, including fertilizers, pesticides, and feed; transportation fuels for tractors and other machinery; fuel use for heating, cooling, and ventilation in farm buildings and facilities; electricity use for pumping, lighting; and energy embodied in buildings and equipment.

The ES measures can reduce both direct and indirect energy inputs and the overwhelming majority of the ES measures (443 out of 481) were assessed in the range from 3 (moderate) to 5 (high) in terms of their importance for energy saving (Table 3). The implementation of the ES measures in agricultural practice is achievable at present (464 out of 481) and will require advanced research (389 out of 481). In the highly industrialized production of pigs and broilers, there are many ES measures which may be implemented with technologies which are present on the market such as improved heat insulation, more efficient ventilation, lighting and cooling systems, as well advanced control of the interior climate. The R&D will be especially important for progress in attaining energy efficiency in agriculture when applied to systems involved in the production process, operational activity and capital goods/farm infrastructure engaged in production. The estimated categories of investment costs related to implementation of energy saving measures vary greatly between subsectors. 1/3 of the total number of the measures can be implemented at a cost under €1000, and 1/3 incurs in costs in the range from €1000 to €25000. The highest investment costs would be associated with saving energy and improving energy efficiency in the greenhouse and livestock production.

In the crop production, energy saving will be considerably affected by the ES measures associated with reduction of diesel use by optimization of parameters of tractors and machinery to the field operation, reduction of energy use for drying and in storage rooms. On the other hand, reduction of indirect energy input is associated with implementation of ES measures related to advanced high-yield and disease-resistant cultivars, application of alternative sources of nutrients and plant protection (organic and green fertilizers, bioactive microorganisms), advanced monitoring of the production process and use of production means in accordance with the soil fertility and plant uptake. The importance of energy saving activities may be country-specific, e.g. in the southern EU countries more importance will be attributed to the ES measures associated with irrigation of cultivated crops while in the central and north-eastern countries – to the ES measures associated with energy effective drying techniques. In the perennial crop production, the majority of ES measures are connected with fertilization, plant protection and field operations. In the greenhouse production, potential reduction of direct energy inputs is associated with the control of greenhouse atmosphere by energy efficient systems of heating, cooling and ventilation as well optimization of production process. There are also important measures connected with new solutions in energy
recovery and the use of other, alternative sources of energy.

The structure of ES measures in the livestock production depends on a country. In Portugal, Poland and Finland many ES measures are associated with animal feeding and welfare while in the Netherlands and Germany most of the reported ES measures are related to electricity use as well buildings and associated infrastructure of livestock production. Energy use in the livestock production may be reduced by increased efficiency of production inputs which condition energy consumption, e.g. water use and cleaning, heat insulation, ventilation, reduction of amount of ammonia in buildings, heat recovery, energy use optimization for a given production system.

Work Package 2.4

Improvements in the energy efficiency of agricultural production have the potential to significantly reduce energy inputs and thereby reducing production costs and greenhouse gas emissions. Energy efficiency analysis depicts the distribution of energy inputs in a given agricultural production system and enables the determination of activities in areas where significant energy savings can be achieved. The implementation of energy efficiency policy for energy saving measures in agricultural practice is a process which requires mobilization of available resources in order to create enabling environment of drivers, developments, and stakeholders.

Work package 3

The central objective of WP3 “Economics and Environment” was the economic and environmental analysis of energy efficiency measures in four regional settings in south-eastern, south-western, north-eastern and north-western Europe. Win-win situations and environmental trade-offs of energy efficiency measures were investigated to identify bottlenecks, constraints and potentials for energy efficiency in agriculture. The economic and environmental effects of energy efficiency measures shall illustrate the financial potential of different energy efficiency measures across Europe as well as the associated environmental gains.

The results of WP3 are the outcomes of the collaboration of the partners of the AGREE consortium, which worked on a common methodology to analyze economic and environmental impacts of energy efficiency measures in agriculture across Europe, identified trade-offs and win-win situations and derived research needs from this information.

Analysis of Case Studies

Case studies with energy efficiency measures were analyzed according to a common methodology in six countries across Europe (Table 1). The aim was to identify constraints, research needs and perspectives for several energy efficiency measures across Europe.

Wheat production

The analysis of cost structures, energy use and impact on greenhouse gas (GHG) emissions are illustrated for the example of wheat production in Germany and Portugal in Fig. 1. The cost structures and pattern of energy use and GHG emissions are similar in Portugal and Germany. In all categories fertilizer use results in highest contribution to costs, energy use and GHG emissions. The effect of fertilizer use on energy use and GHG emissions is higher than the economic effect. The relative economic effects of fertilizer use are higher in Germany than in Portugal due to higher fertilizer use.

In the case study analysis different energy efficiency measures were analyzed for their impact on energy efficiency, greenhouse gas emissions and production costs. Figure 2 shows the results of the analysis for different energy saving measures in wheat production in Portugal and Germany. At this example “no tillage” showed highest energy saving potentials which also provided high GHG mitigation potentials with additional cost savings. It should be noted, that this measure also implies less fertilizer supply. Irrigation contributed to improve energy efficiency, even though energy inputs per ha were higher with irrigation than without. The increased energy input was compensated by increased yields resulting lower energy use per ton product.

(Please see in the attached PDF document the figure 1: Relative contribution of different processing units and inputs in wheat production to economics, energy use and GHG emissions in Germany and Portugal)

(Please see in the attached PDF document figure 2: Impact of different energy saving measures in wheat production on cost savings,
energy use and GHG emissions in Germany and Portugal)

In the German case study “Precision Farming” showed highest energy saving potentials which also provided GHG mitigation and cost savings. Reduced fertilizer supply also resulted in higher energy efficiency and lower GHG emissions per unit wheat. This measure, however, results in opportunity costs for the farmer, so that it is unlikely to be adopted unless specific incentive structures propagate the reduction in fertilizer use.

Dairy production

In dairy production systems energy efficiency potentials were identified in various case studies, which suggested different auspicious as well as economically viable options for energy efficiency measures 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 that a lower replacement rate as well as 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 CO2 savings, it has been shown, that increasing milk production may also increase greenhouse gas emissions. 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 Netherlands’ 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, 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.

Pig and Poultry

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 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.
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 2).

(Please see in the attached PDF document the table 2: Summary of estimated trade-offs between costs, primary energy consumption (PEC) and total CO2 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).)

The energy efficiency measures included in the case studies can be categorized according to the primary intention of implementation:

1) 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) 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 GHG 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 CO2-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 3) 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 3 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 CO2-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 CO2 emissions from respectively fossil energy combustion and negative soil carbon pool balances may be of special importance.

(Please see in the attached PDF-document the table 3:Example on trade-offs between the net energy use and the effects on GHG emissions in the form of nitrous oxide (N2O), methane (CH4) or changes on the soil carbon pool (∆C) 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.)

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 subsystem 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.
Greenhouse production systems

Of the various processes in a heated glasshouse as they are typical in the Netherlands, the one that contributes most (by far) to the environmental impact is burning gas for heating (Fig.3).

(Please see in the attached PDF document the figure 3: Relative contribution of the production processes (direct and indirect) in a standard Dutch glasshouse to global warming (measured by kg CO2 equivalent, left) and total energy use (PEC, right). (Torrellas et al. 2012))

Therefore, the most significant way to save energy, and in general to decrease environmental impact in Dutch glasshouse production is to decrease heating requirement. The case study analysis with three different energy saving measures found that the most promising measure was the use of an innovative double layer cover, coupled to forced dehumidification. It showed the highest 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. The present cost and price structures provide no incentives for Dutch farmers to implement these energy efficiency measures. In southern Europe, where heating is less important, other energy efficiency measures including improved water and nutrient management are of higher relevance.

Opportunities and constraints of energy efficiency measures in agriculture

In arable systems major energy efficiency measures are associated with the use of direct energy of fuel use and indirect energy use with nitrogen fertilizer use. The analysis of different case studies across Europe showed energy saving potentials from 1 % to 43 % of the total energy use (Fig. 4). The highest energy saving potential was identified with reduced tillage in Portugal. Lower relative energy saving potentials was identified by means of precision farming or implementing of efficient dryer technologies. All the selected energy efficiency measures had a positive economic effect on the net return of the production system, which correlates to some extent with the energy savings. However, energy savings can also be cost increasing, which is the case for example with suboptimal fertilizer application, which results in opportunity costs for the farmer. Even though in this case the effect is small, this energy efficiency measure would not be implemented by farmers unless they are forced to do so. Little cost saving potentials may also be a constraint for the adoption of energy efficiency measures, since investments are necessary or production structures need to be changed.

(Please see in the attached document the figure 4: Energy and cost saving potentials of different energy efficiency measures across Europe)

In animal husbandry 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 intensification of feed ratios for ruminants has its drawbacks and 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. 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 highest 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 crosschecked 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.

Conclusions

Energy efficiency is important for establishing sustainable agriculture not only from an environmental but also from an economic point of view. Agriculture is most susceptible to energy price increases because direct and indirect energy use contributes to a substantial share of the production costs in agriculture. Energy efficiency measures in agriculture, however, have different opportunities and constraints which should be addressed appropriately.

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, there is a research need for identifying economically viable “Precision Farming” solutions, which furthermore contribute to energy efficiency and other environmental benefits. Rather simpler measures, which target the fertilizer application in 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 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.

WP4 Research Agenda for transnational co-operation

Objective

The objective of this work package was to produce a research agenda for transnational co-operation to increase energy efficiency in agriculture. For this, a participatory approach was developed in order to include the views of a variety of stakeholders across the value chain and the enabling environment and to include the variety of agro-eco zones across Europe.

Approach

To meet the objective six multi-stakeholder events were organised in the six participating countries Poland, Greece, Portugal, Finland, Germany and the Netherlands. These meetings were all formatted in the same way to ensure that the outcomes would be comparable. This enabled the project team to synthesise the results and to feed this into one transnational stakeholder event, organised in Athens in June 2013. This event brought together one representative from each of the national multi-stakeholder events, the AGREE partners and one representative of the External Advisory Board. The event yielded results that were used to draw up the Research Agenda and in doing this, the participants of the Athens meeting were again involved. Finally, this resulted in the Research Agenda that was presented at the final dissemination event in Brussels in September 2013. The approach is illustrated in Figure 1. Each national stakeholder event resulted in a prioritized list of opportunities to seize and bottlenecks to overcome to increase energy efficiency in agriculture. These were clustered into topics that were fed into the transnational meeting where research issues were collected.

Results

To make agriculture more energy efficient innovations need to be developed and implemented in practice. It is known that the success and failure of innovations is influenced by a set of drivers or aspects of the so-called System Innovation Framework. The prioritized opportunities and bottlenecks were categorized according to these aspects (Table 1). The results show that the different stakeholder events succeeded at including the success and fail factors of innovations and therefore hold confidence that a sufficient wide view was taken.

The transnational meeting yielded a prioritised number of research issues to be attended to when addressing the issue of energy efficiency in agriculture. These research items (58 in total) were clustered into 11 research items that made up the research agenda:

Sensor technology: Sensors can be helpful in closely monitoring the status on the farm of crops, soils, production systems and livestock and so can contribute to energy efficient farming. While more than a decade of innovative research on sensors for "Precision Farming" has provided good solutions for sensing important information from agricultural systems R&D is needed to develop sensors that can be wirelessly connected to databases and analyses software to support decision making. Combining different information types in smart decision support tools is still lacking. This decision making can then lead to the application of the right measure at the right time and place. It became clear from the meeting in Athens that compatibility of data is important to ensure effective communication between soft- and hardware components. The sensors can monitor conditions of direct value such as yield, or
Agro-residue valorisation: agro residues can be used to produce a wide range of products including bio-energy (from chemical action on biomass directly or via fermentation or other biological process), fibers, biopolymers and other bio-based materials, nutrients, proteins and molecules for chemical processes. This can be achieved by some form of biorefinery with the aim to ultimately produce the highest possible economic added value. By doing this, products in other value chains can be partly replaced resulting in an overall decrease of greenhouse gas emissions. This GHG emission reduction can be attributed to the agricultural product value chain where the residues originate from, thus increasing the energy efficiency of this value chain. In those cases where the agricultural residues contain high levels of moisture, the refinery is best located close to the site where the residue is produced allowing nutrients to remain within the area. Comprehensive waste valorization requires not only that new technologies are developed in a future biobased economy, but also that changes or adaptations to the agro production systems are involved and, although this may make it complex, it is a potentially highly rewarding transition. Anaerobic digestion systems are well known and can play an essential role in bio-refinery processes of agro residues to valorize low value organic material that is left over in these processes. However, experiences in Germany showed that incentive structures for inducing the use of agricultural residues have to be created with care without creating unintended side-effects.

Operational groups (energy efficiency networks): research results and best practices should be transferred effectively between researchers, value chain companies and farmers to make sure energy efficiency measures and related information are implemented satisfactorily. These operational groups can be seen as demand driven partnerships around a solid innovation in energy efficiency. They work on focused solutions and could also be used to prioritize R&D. These functionalities come close to those of the current European Innovation Partnership initiative. Putting operational groups on the agenda of the energy efficiency ambition of the agricultural sectors, reflects the conclusion of AGREE that there are many energy efficiency measures already available and ready for use even though some could use research advances to optimize their benefits and make them useful for specific applications for a particular group of farmers with certain conditions and constraints.

Integrative solutions: the transnational meeting concluded that energy efficiency measures should be developed and implemented in an integrative manner, meaning that economic, energy and environmental (resource efficiency) aspects should be considered at the same time while respecting their mutual interactions and trade-offs. This also requires that integrated value chain approaches should avoid gains in one part of the value chain offsetting losses in another part of the chain. This is not so much a separate R&D item but a call for a holistic approach to R&D applied to energy efficiency. This is well supported by the findings of AGREE on trade-offs for individual energy efficiency measures.

Socio-economic scenarios research: in order to improve energy efficiency in agriculture a common vision and ambition based on different future scenarios would be significant in creating awareness and the correct socio-economic incentives to support the desired developments. These developments require existing and new technologies to be developed in a manner that is socially acceptable and economically feasible. An obvious example is robotics applied to harvesting where there is a major potential to directly replace labourers currently used for harvesting. This loss of work for labourers must be considered against the economics, crop quality and increased competitiveness aspects. It could be useful to study the use of risk perception and risk sharing models to smoothen the implementation of new developments. Possible conflicts of interests should be identified beforehand to avoid implementation failing and incentives could be determined that would stimulate a positive change of behavior. Concluding, this agenda point is about targeting R&D to ensure a more effective implementation of technologies that contribute to energy efficiency.

Definition and data exchange: if energy efficiency in agriculture is to be improved, monitoring the progress of the improvement is important. As AGREE has shown, the current statistics on energy use in agriculture do not include all of the primary energy embedded in the different agro products and are therefore not useful for successful monitoring of the progress of energy efficiency in the sector. This needs a European benchmarking tool and/or procedures with standardized data definitions and collection methods. This tool should link with current databases like ECO-invent and BIOGRACE and with existing statistical datasets but should take regional differences across Europe into account.

Decision Support System (DSS) tools for farmers: the stakeholders greatly supported the development of applied models and expert systems to support farmers’ decisions on a variety of measures that influence energy efficiency. It was stressed that these DSS tools should be user friendly and formed and adapted for the decision processes of farmers. Current IT technologies enable such tools and this also links with item 1 of sensor technology. Together these two items, for example, will make valuable use of current and innovative Wireless Sensor Networks, Big Data handling methodologies and databases and cloud based analytical modelling to support farmers, or their immediate advisers, in decision making.
System design tools: it was concluded that to improve energy efficiency, progress is needed both within current system boundaries and beyond these boundaries to optimize current production systems. The latter requires rethinking of current systems and redesigning value chains such that by reshaping them they could be made more energy efficient overall. To this end current value chains need to be analyzed on energy use overall and the results are to be used in System Design Tools to come up with redesigns with a more overall energy efficiency of end products. One could think of nutrient recycling technologies, valorization of side-streams or logistic improvements etc.

Local food strategies: this agenda item links up with the current worldwide attention for local value chains as opposed to global value chains. As such, this item needs a rethink and developments beyond the current system boundaries. It can be expected that to a certain extent local and smart value chains will be more energy efficient. Investigations should be made into which value chains and local food strategies contribute most to increasing energy efficiency of end products and which food strategies perhaps rely too much on global markets to improve energy efficiency. One has to realize that local food strategies are primarily designed to serve other advantages or drivers than energy efficiency so an integrative approach is recommended. In the end, a particular local food value chain could support or endanger energy efficiency, and both situations deserve proper attention.

Soil and water management: soil of adequate quality and ample availability of good quality water are essential for agricultural production. Both aspects determine yield levels to a great extent and determine the amount of energy used per unit of product. Items to be addressed are management of irrigation systems, irrigation scheduling, inclusion of nitrogen fixing crops, energy efficient soil tillage systems and good geometry of fields to ensure efficient trafficking of farm machinery etc. This illustrates the interaction between optimization of the production process in general and specific energy.

Farm machinery: a large part of the direct energy in agriculture, especially arable agriculture and feed for intensive livestock, is associated with diesel use by machinery. Obviously, increased efficiency in diesel consumption by these machines or alternative fuels (biodiesel, pure plant oil, green gas, electricity) adds to increased energy efficiency in agriculture although there are indications that requiring cleaner exhaust emissions can limit improvements to fuel efficiency. Already, for larger commercial farmers, auto-steer technology fitted to tractors is considered to be so obvious an economic and time saver that it is rapidly gaining popularity. This technology, by allowing very accurate matching of machine passes and quicker turns, can readily save 5-10% of all inputs; labour, fuel, seed, fertilisers and pesticides. It also enables the shrewder farmers to move to controlled traffic farming and save further fuel by avoiding excessive, random, trafficking of the soil and so avoids the need to cultivate soil compacted by that machinery. This also allows an improved yield as plants can make better use of nutrients and water in the more friable soil. Although robotic, autonomous guided vehicles, are not yet commercially available for arable use they are being developed and most researchers expect significant fuel savings from lighter slower machines that work longer hours with a better array of sensors that allow more precise, plant specific, operations. An example is that better targeted pesticides, using weed detection sensors, can potentially save over 95% of herbicide using “dot-matrix-printer” type application of minute amounts of herbicide solely to the leaves of the weeds, not to the whole crop. Robotics applied to Voluntary Milking Systems for dairy cows have been commercially available for several years and show an increase of 10% or so in milk yield as cows choose to get milked more than twice a day. Extra sensors on the unit can detect milk quality, oestrus and other aspects that enable higher quality milk to be sold and the cows to be more productive over time so improving the energy efficiency of the feed given to the cattle as output is increased.

(Please see in the attached PDF document the figure 7: Visualisation of agenda items)

These research items covered both improvements within existing system boundaries and improvements that go beyond present day system boundaries. Also, the enabling environment was adequately addressed. Improvement within system boundaries have a relatively low risk of implementation because they have limited effects to how the value chain is organized. On the other hand, the promise of increasing energy efficiency can be considered to be limited. When innovations ask for redesign of the value chain, the promise of contributing to increased energy efficiency is substantial whereas the risk of implementation is also substantial. The enabling environment also needs to adapt to changes in the value chain and their role in innovations is thus of importance as well. For instance, the issue of nitrogen use (one of the important issues of energy use in agriculture) can be covered by optimising nitrogen rates, using precision agriculture systems, recycling nitrogen from urban waste and by agro-clustering of activities to maximize re-use of waste streams among parts of (different) value chains. The complexity of these solutions increases, and with it the risk of success, but also the promise of impact.

The categorization of the research items along the above explained line is illustrated in Figure 7.
Impact

The above mentioned research items are explained and described and finally suggestions for the potential embedding of each of the items is discussed. The suggestions are summarized in the table below.

(Please see in the attached PDF document the table 5:Suggestions for absorption of the R&D areas of the ATC)

This table shows that for a number of the research items there is a very good match to existing R&D platforms (mostly ERA-nets) in Europe. Therefore, it is advised not to set up an ERA-net especially for energy efficiency although the issue has an important integral aspect. Some items cannot be matched with existing platforms and are therefore best absorbed by the SCAR to use them to bring energy efficiency forward. The FACCE-JPI (Agriculture, food security and climate change) can also be considered to absorb some of the items brought forward by the AGREE process. In any case, it is advised to have a coordinating point installed to support the implementation of the agenda in ERA-nets and Horizon2020 and to promote the integrating aspect of the issue of energy efficiency.

The research agenda was presented at the final dissemination event of AGREE in Brussels in September 2013 and was officially handed over to the European Commission, the European Society of Agricultural Engineers and the SCAR/KBBE Collaborative Working Group that initiated the Coordination and Support Action that finally became AGREE. The Research Agenda is also available on the website of AGREE at www.agree.uau.gr.

Potential Impact:

The Work Package 2 summarizes the results from the state-of-the-art analysis on energy efficiency in the EU agriculture and assesses the potential for energy saving measures. The impact of the obtained WP2 results, although mostly indirect, has been considered in the contexts of policy, economic, environmental and social influences.

Potential impact on the EU and national policies associated with energy efficiency and energy savings

- Modification/extension of the EU statistical database on energy consumption in agriculture and agricultural subsectors to make the data fully comparable. Both primary and final energy consumption measures which cover all the energy inputs for agricultural production will facilitate implementation of effective policy on energy efficiency and energy savings in agriculture together with precise calculation of the environmental impact.
- Unification of the source data on energy consumption by agricultural subsectors across the EU countries. The incorporation of all energy inputs including transportation fuels and industrial inputs (fertilizers, pesticides, other chemicals) will enable incorporation in agricultural practice the most efficient energy saving measures.
- The results from the analysis of the structure of specific energy input together with the associated list of energy saving measures for a given production reveal the potential research areas worth a special consideration in R&D programs.

Economic and environmental potential impact

- There is no direct economic and environmental impacts of the WP2 results, however insight into the structure of specific energy input for a given agricultural production point out for energy inputs which promise the significant energy saving effects and cost reduction. As a result it will have an impact on the organization and management of agricultural production (i.e. reduced tillage) as well as it will stimulate indirectly the change of market demands, the creation of new businesses, and competiveness.
- The knowledge on the structure of direct and indirect energy inputs for a given agricultural production point out for fossil resources which may be reduced or replaced by alternative energy sources and in this way indirectly point out for the potential for reduction of GHG emissions.

Social potential impact

- The results bring knowledge on the current primary energy consumption in the EU agricultural production with regard to crop, greenhouse and livestock production subsectors which plays important role in national economies, direct and indirect energy inputs, and specificity of energy inputs depending on geographical location and climatic conditions.
- The 481 energy saving measures described in the report WP2.3 will focus social awareness on the fact that agriculture have a
potential to improve environment by reduction of fossil energy use and mitigation of climate change and there are many energy saving measures which may be adopted in practice. Thus, important social impact is in understanding and acceptation of the activities in rural areas which tend to improve energy efficiency.

Transnational Agenda

During the break-out sessions of the transnational stakeholder meeting in Athens in June 2013 the participants discussed why European co-operation would be profitable or useful. Several suggestions showed international (European) incentives to stimulate energy efficiency. Below is the list of the answers given:

• Common vision and awareness will increase the exchange across Europe of data and results;
• Value chains in the agriculture & food sector are transnationally oriented and there is often involvement of multinational players. This means that system designs require transnational co-operation;
• There is common EU legislation on food labeling. That can be an incentive for cooperation on labeling with an indication of energy use;
• Part of the resources used are regulated on an European level;
• Learning from each other: exchanging best practices, case studies and technological solutions;
• Technology can have multiple implementation areas and product chains;
• Make full use of expertise from across Europe and avoid duplication of efforts and missed results;
• Farmers mobility across Europe is easier if European R&D results are given consistently;
• Researches in some areas becoming aware of potential future problems and broadcasting that awareness transnationally;
• Environmental issues like GHG and water quality are problems on an international level;
• Increasing nutrient use efficiency (nutrients are an important source of indirect energy use) requires international co-operation
• Solving the energy use efficiency problem together will increase the international competitiveness of European farmers.

List of Websites:

http://www.agree.aua.gr/