EIP-AGRI Focus Group
Enhancing production and use of renewable energy on the farm

MINIPAPER: “Flexible symbiosis for energy, food, feed and other bio-based products”

Authors

Myrsini Christou	CRES-Centre for Renewable Energy Sources, Athens, Greece
Henning Eckel (Editor)	Association for Technology and Structures in Agriculture, Darmstadt, Germany
Rita Fragoso	University of Lissabon, Portugal
Janusz Golaszewski	University of Warmia and Mazury, Olsztyn, Poland
Dolores Hidalgo	CARTIF Technology Centre, Valladolid, Spain
Kari Koppelmäki	University of Helsinki, Finland
Anna Trettenero	Alfalfa Energia srl Società Agricola, Province of Pavia, Italy

May 2018

funded by European Commission

1. Introduction – motivation

Sustainable agricultural production systems aim at integrating production of food, feed, energy and other bio-based products. In a symbiotic model two or more businesses are integrated in a collaborative approach aiming to enhance resource efficiency and sustainability of agricultural production; not only on farm level but also on local scale in cooperation with communities, other farms, and local food processing industries. Such symbiosis will create a synergy between agriculture and the rural energy system stabilizing farm income and security of energy supply.

Many concepts fostering integration of agricultural production and energy supply are already in place or will be in the near future (Siegmeier et al. 2015, Koppelmäki et al. 2016, Arranz-Piera et al., 2018; Majumdar and Pasqualetti, 2018; Marucci et al., 2018; Venanzi et al., 2018). This integration can be addressed directly to farms or based on a broader co-operation of different stakeholders.

However, there is still a lack of awareness on the potential assets and drawbacks of the concepts among farmers, consultants and decision makers in municipalities, regions, governments and funding organisations. Therefore, the aim of this paper is to provide (i) basic principles of agro-energy synergies, (ii) available options, as well as (iii) suggestions for research, demonstration and know-how transfer in this specific field.

2. Flexibility in Energy production and use

To integrate energy generation into agricultural production processes, a flexible approach is necessary. On-farm energy systems should be seen as components of the rural energy system. Moreover, the on-farm energy systems need to be flexible in switching between the use of energy in agricultural production and the supply of energy to the local grid including local neighbourhood. Each system has to be designed context-specifically.

Flexibility is necessary regarding the use of resources for energy production (flexibility of input), the form of energy carrier provided (flexibility of output) and the on-farm use of energy (flexibility of energy use).

To implement this, a thorough analysis taking into account available land, production profile, waste and residues streams, energy demand, available natural resources (wind, solar radiation and water), available financial resources and workforce should be done for each specific farm. Furthermore, an analysis of the options to sell excess energy to the heat or electricity grid or to provide fuels to customers outside the farm should be carefully checked. The aim is to explore the on-farm available energy resources and to adapt energy generation to farm energy demand in a connection with the local energy system.

With regard to "flexibility of output", the form of energy, which is needed on the farm, has to be taken into account as well as the amount and the time of energy use. Technology can be adapted to various energy needs, for example varying temporal energy demand at farm level or in the grid. An example for this is electricity production on demand by biogas. An important issue regarding this flexibility is "coupling of energy sectors" which means shifting between various energy products and combined production of heat, electricity and fuels on demand (i.e. power to heat, bio-methane for CHP (Combined Heat and Power) technologies, biofuels for mobility). Furthermore, fertilizers or soil improvers originating from bioenergy processes may also be considered as output and are important means to close nutrient cycles and ensure long-term soil fertility.

Another aspect of "flexible output" is the production of industrial bio-based products, i.e. chemicals like lactic acid, succinic acid, citric acid, ethanol, and others, from fermentation processes and conversion of post processing waste to energy. Those bio-refinery approaches may be linked to the decentralized energy production. Innovative bio-based non-food production might be integrated with biogas plants, where thermal power from CHP can be efficiently utilised and the post processing wastes can be used as input of the digestion process.

funded by European Commission

As energy demand of farms is concerned, the first step should be to promote energy efficiency, analysing the farms options to reduce energy demand by replacing out of date equipment and ensuring proper maintenance of all applications and machines on the farm.

On the energy demand side, flexibility is crucial for balancing energy supply and use. The basic idea is to decouple energy production and use or shift energy demand to periods with high availability of renewable energies. By doing this the share of fluctuating renewable energies in the energy supply of farms can be increased. Examples of this are the production of ice-water for milk cooling in times with high energy supply from renewables, or adapting the time of feed preparation with mills having high energy demand to these periods. Many of those concepts might be improved using energy storage systems (see EIP-AGRI mini paper on energy storage). These need a thorough technical and economic evaluation, especially energy storage systems, before the investment.

3. The symbiosis of agricultural production and energy

There are many ways of combining agricultural production processes with the provision of energy. Symbiosis means that energy generation is an integral part of agricultural production or processing, providing advantages for both agriculture and energy sectors.

The energy requirements of the farm are covered as far as possible by renewable resources like biomass, wind, solar radiation and water, depending on local availability. Furthermore, the farm is integrated into the local energy system, delivering excess electricity or heat to the grid or the neighbourhood.

The examples described below include biomass technologies as well as non-biomass technologies suitable for farm-scale applications.

Biogas in organic farming systems

A key issue in organic farming is the sufficient nutrient supply for crop cultivation. This is mainly achieved by growing leguminous crops like clover (KTBL 2007) and using manure. If leguminous crops and manure are part of the substrates of a biogas plant, an easily accessible nitrogen source becomes available. Biomass is degraded by microorganisms in the fermentation process, resulting in an ammonium rich digestate, suitable as a fertilizer (N) and soil improver (C). This means that integrated organic production and energy generation provide not only energy but also mitigate potential nutrient deficiencies in soils (Siegmeier et al., 2015).

In stockless organic crop farms, a biogas plant could function as a replacement for cattle. Producing biogas from green manure crops and crop residues converts the green manure biomass, which is traditionally incorporated into the soil, into mobile fertilizers which can be applied at the time when the nutrients are most needed. This has the potential to increase productivity in organic farming without importing new inputs to the system (Möller, 2009).

Integration of livestock farming and biogas production

Fermentation of livestock manures provides on-farm generated energy for farming operations and therefore constitutes positively a symbiosis as defined above. Advantages of manure digestion include improvement of nitrogen availability, improved physical properties (flow), reduction of odour and improved hygienic properties (Mirosz et al., 2015). Especially in large livestock farms, for example dairy systems, biogas technology has the potential to supply a significant share of electricity and heat needed on the farm. Due to the low energy content of manures, small-scale biogas plants adapted to the available amount of substrates are used for manure digestion (Paterson et al., 2016).

Biogas production based on diverse crop rotations and residues

A biogas plant, integrated into the farm concept, encourages sustainable agricultural practices, such as conservation agriculture, and uses locally available agricultural by-products and waste. An efficient multiple feedstock processing generates bioelectricity and thermal energy and/or bio-methane. The biomass circulation is closed by the use of digestate as organic fertilizer, which allows slow release of nutrients and reduces the need for mineral fertilization.

The use of maize silage as main substrate for biogas production is largely criticised because of local restrictions in crop rotation, negative impacts on the prices for land lease and conflicts between the use of the land for food and feed production. Therefore alternative substrates like sorghum, clover grass mixtures, sunflower, sugar beet, Jerusalem artichoke, various cereals and wild flower mixes are tested for biogas use (FNR 2013). Crop rotations integrating these species are being tested extensively (Glemnitz et al., 2015). In many cases biogas yields are lower as compared to maize (Herrmann et al., 2016) but it was found that the combination of energy and cash crops within a crop rotation tends to reduce negative environmental effects of energy cropping on humus balances or biodiversity. Moreover, in some European regions, where corn is produced for grain, part of the production often does not meet quality standards for food or feed, due to mycotoxin contamination and cannot be sold. In such cases, corn grains for instance might be considered a residue and biogas or ethanol processing represent a market opportunity for farmers.

Integration of bioethanol and biogas as an example of industrial symbiosis on farm

In circular bio-economy, bioenergy production and use on farm start on the field and loop back into the field. Sustainable production of biomass is encouraged as a long-term agronomic strategy. This includes diverse crop rotation and conservation agriculture techniques, with minimum disturbance of the soil (see EIP-AGRI Focus Group on “Moving from source to sink in arable farming”). Minimizing energy requirements all along the process is crucial for efficient bioenergy production. Farmers produce both for feeding the biogas plant and for the market, thus diversifying their crops and the risks. Side stream products are reused in different ways, depending on the context. Heat from CHP is used and, in this example, besides biogas processing energy requirements, it represents the primary energy source for a small-scale bioethanol plant. Residues of corn production, such as previously mentioned grains with high mycotoxin levels, are turned into feedstock for bioethanol processing. Side stream ethanol plant distilled grains are used wet as feedstock for the biogas plant, along with other biomass and residues. Digestate from the biogas plant is then transported back to the soil, where it serves as slow release organic fertilizer. The symbiotic loop is closed promoting a circular bioeconomy. A biogas plant is flexible by nature and several options for innovative symbiotic approaches can be proposed, designing for biorefineries associated to the plant and related side stream products processed back into the plant. It is crucial that farmers play an active role into the overall process. Only farmers can provide for closing the symbiotic loop into the field in a sustainable way.

Combining feed and biofuel production on farm level

Combined production of feed and biofuels is another example of how synergy effect could be created. In this case, oil crops like rapeseed are cultivated and processed in local oil mills. The vegetable oil is used as fuel for farm agricultural machinery. At the same time the oilseed cake supplies high value protein rich feed, replacing import of soybean (TFZ, 2017). The technology for producing vegetable oil in small-scale oil mills is available as well as the necessary standardisation of fuel quality. Farm machinery, suitable to use vegetable oil, was developed by agricultural engineering companies; although to a limited extend due to the small market. Subsidies for fossil fuel use in agriculture currently restrict the economic feasibility of this concept. Still local biofuel production and use in agriculture in combination with feed supply is a mature concept with distinct advantages with regard to climate and resource protection, as compared to fossil fuel use and feed imports.

Combining crop and solid fuel production

The SRF (Short Rotation Forestry) or SRC (Short Rotation Coppice) perennial systems implemented on farms enable parallel production of the feedstock for solid biofuels and agricultural crops. The woody biomass harvested in cycles can be used to produce wood chips for heating purposes. The trees, mainly willow and poplar, are planted in strips located between agricultural crops. The trees serve as a windbreak, helping to avoid soil erosion and at the same time constitute a habitat for birds and other species (Brandle et al., 2004). Furthermore, agroforestry systems have the potential to improve habitat connectivity (Glemnitz et al.,

funded by European Commission

2013). On agricultural sites with low nutrient availability, short rotation coppice offer a chance to use these sites regardless of the unfavourable condition for crop production (Eckel et al., 2008).

Integration of food production, processing, energy and the local market (Agro-ecological symbiosis)

One example of a "symbiotic production model" is a concept of Agro-ecological symbiosis (AES) which integrates primary production, food processing, energy and the local market demand and brings together competences and experiences from different areas (Fig. 1) (Koppelmäki et al., 2016). Agro-ecological symbiosis (AES) is a model in which food production is arranged in the mode of industrial symbiosis and industrial ecology. Industrial symbiosis refers to an operation in which the partners of the symbiosis are located in geographical proximity which allows for local co-evolution. Products are sold to fill the local demand but also on a larger scale.

Combining food processing, crop production, and energy production, increases the overall sustainability of the local food system. See box for a practical example of this concept.

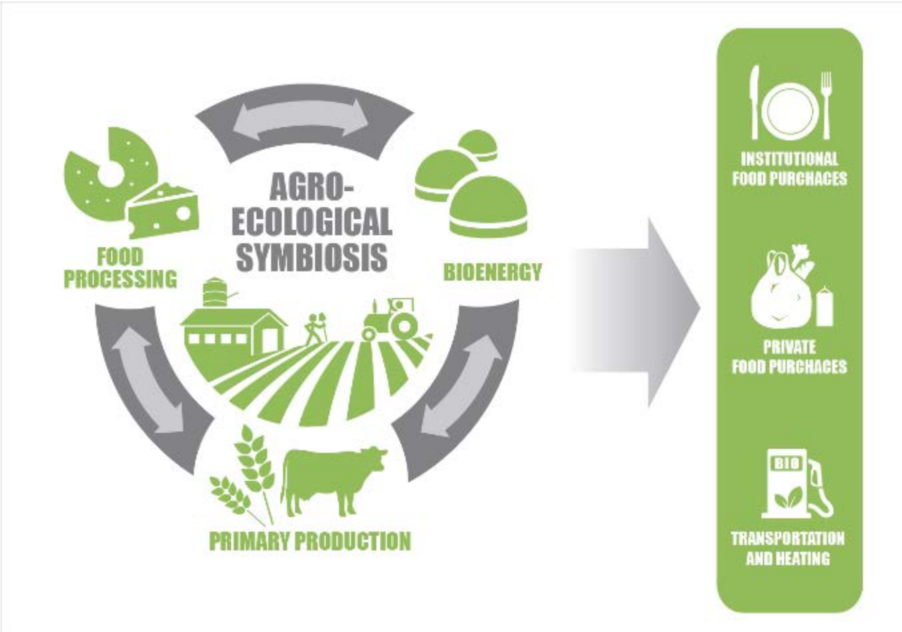


Figure 1: AES-network project (http://blogs.helsinki.fi/palopuronsymbioosi/aes-verkosto)

Integration of solar systems with agricultural production

Agro-photovoltaic systems on agricultural land offer the chance to combine crop production and generation of renewable electricity. The solar panels are installed above the field with a larger space in between as compared to conventional ground mounted systems. This allows the cultivation of a large range of plants underneath the panels (Beck et al., 2012; Majumdar and Pasqualetti, 2018; Marucci et al., 2018) and avoids conflicts between food production and energy.

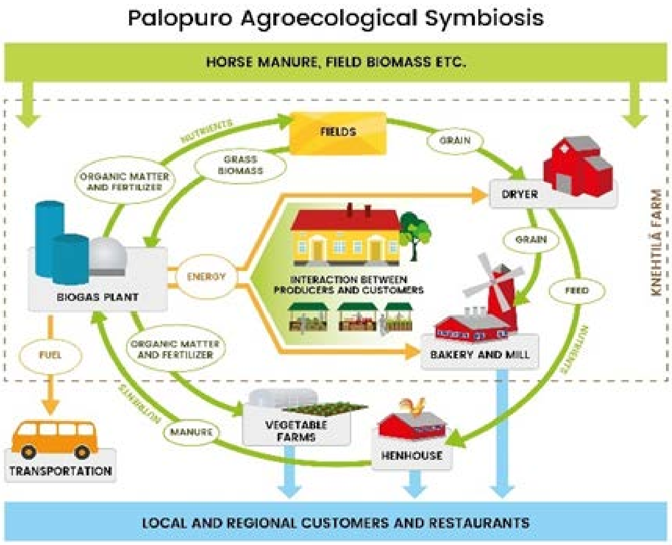
Harmonisation of energy production and use on farms

Many farms have the means to produce renewable energy, namely electricity, on their premises. This offers the chance to produce energy for self-consumption and to benefit from synergies between energy production and the energy consuming processes on a farm. The easiest way to adapt energy consumption to the fluctuating availability of electricity from solar or wind energy systems is to shift energy demand. This is for example possible for feed preparation or cooling devices for milk (Hartmann et al., 2016). In combination with energy storage systems, self-consumption of electricity produced on farm can be significantly enhanced.

Box 1
The concept of Agro-ecological symbioses in Palopuro/Finland

The first practical implementation of AES is forming in the village of Palopuro, Southern Finland. More information about Palopuro AES: http://blogs.helsinki.fi/palopuronsymbioosi/

Palopuro AES consists of three organic farms. The center of Palopuro AES is Knehtilä farm, an organic cereal farm (380 ha). Other farms include a neighbouring henhouse and a vegetable farm.



The biogas plant will function as "the heart" of nutrient recycling in the system. Green manure leys, crop residues and manures will be used as a feedstock for biogas production with recycling nutrients back into fields to enhance productivity in the form of digestate.

Biogas will be produced in a batch type dry digester (gross energy of 2 500 MWh) from green manure leys and other fallows, horse manure and chicken manure. The investment will include two silos, which will be loaded with biomass every three months, an upgrade unit and a fuelling station. The batch type process is more suitable for crop farms compared to continuous process because it requires less work to operate the biogas plant. The energy produced will be used at the farms (grain drying, bakery, heating, machinery) and the surplus will be sold for passenger cars.

The model has several environmental benefits: (1) The energy produced converts the farms and food processing from energy consumers to energy producers;(2) the energy consumed at the farms is equal to approximately 1/3rd of the total energy produced;(3) Biogas production reduces climate emissions by 770 t CO_2eqv. In a comparison to the current situation, (4) the risk for nutrient leaching is reduced because the grass biomass will be harvested instead of leaving it to decompose in the field before winter, which is the conventional practice.

The biogas plant is owned by the regional energy company, a technology provider (Metener ltd.), and Knehtilä and Lehtokumpu farms. The business model makes the investment feasible for farms. In addition to economic advantages, the energy company offers knowledge from the energy sector, which is often lacking. Also, the farmer is not responsible for marketing the biogas. The biogas plant will begin operations in autumn 2018.

The model will be also replicated in a larger scale in the municipality of Mäntsälä and surround areas in Southern Finland. The on-going AES-network project (https://blogs.helsinki.fi/palopuronsymbioosi/aes-verkosto/) is examining the availability of biomass in this region that would not be competing with food production if used for biogas production. This project is also looking for farmers who are interested in participating in biogas production and investment plans will be made with those interested. There is a great potential in Finland for farm-scale biogas production based on biomass from agriculture.
The area of land in Finland that could be used for concepts like Palopuro is 200.000 ha.

4. Conclusions

Farms consume a lot of energy, a large share of which is accumulated in biomass and organic residues such as wood residues, straw, and manure, which can be used to generate energy. Many technologies are available to exploit these organic resources. Additionally non-biomass technologies like photovoltaics, solar heat systems, wind and geothermal energy may contribute to the farms energy supply.

These resources might be used to provide energy for the farm itself, but also to deliver a substantial contribution to rural decentralised energy systems. To coordinate agricultural production and energy issues, flexibility of energy production systems and energy consumption is necessary.

The combination of agricultural processes with the energy supply on farm, at local or regional level offers advantages for both sectors. A key issue is the engagement of the relevant stakeholders, the farmer itself, consultants, technology suppliers, licensing authorities and energy customers in the proximity of the farm.

One of the main challenges regarding the use of bio-resources for energy production is to exploit these resources without hampering food or feed production or install production systems with low sustainability. Options to combine crop production and energy provision are available (Souza et al., 2017) and need to be developed to enable the installation of synergetic systems for example using biogas technologies as described above. The amount of land available for energy cropping varies in a large range in different studies (Kluts et al., 2017).

The interrelationships that exist in different facets of the energy-environment/food/feed/land interface are complex and sensitive but the future of biomass energy depends on the interplay of these factors, which are highly important to the sustainability of biomass production. To be acceptable, biomass feedstock must be produced sustainably. Abandoned agricultural land, degraded and other marginal land rehabilitated by bioenergy plantations, and surplus agricultural land made available through intensification of agriculture, are potentials for considerable biomass production.
According to Seay and You (2016), a system approach where the agricultural, energy, and environmental sectors are considered as components of a single system, has the potential to significantly improve the economic, social, and environmental sustainability of bioenergy production. Closing the loop through the optimization of all resources is essential to minimize conflicts in resource requirements as a result of increased biomass feedstock production.

Implementation of agro-energy systems needs thorough analyses of the specific local situation and the legal framework. Many best practice cases are available as examples and inspiration.

5. Identified knowledge gaps and demand for research, development and know-how transfer

Alternative substrates for biogas technologies

There is a need to unlock the potential for alternative biogas substrates, based on farm residues and wastes and alternative energy crops. Using residues and wastes will improve the energy balance of biogas technologies and reduce the pressure on the available land and by this will support the implementation of synergetic systems as described above. To enable the use of these substrates, technologies for pre-treatment of lignocellulosic material, like straw and poplar (brushwood), have to be developed and evaluated regarding their performance in practice. Furthermore, the options for cultivation and handling of alternative plants for use in the biogas process should be investigated. Examples for this would be the cultivation of flower strips in order to increase biodiversity or the use of landscape management material in biogas plants. Additionally, integration of biogas technology in the livestock manure management of farms should be designed in order to raise the share of manures, which are treated in biogas plants.

Flexibility of electricity production by biogas plants

Research is needed to improve the flexibility of biogas plants regarding the production of electricity as demanded by the grid. This includes on demand supply with substrates in combination with fast reacting fermentation, gas and heat storage systems as well as business models for these concepts, taking into account the integration of farm operations and bioenergy production.

Energy storage to coordinate energy production and consumption

On farm energy storage, namely electricity, is a way to enhance electricity self-supply of farms. Especially if photovoltaic systems are in use, batteries could help to harmonise energy production and on farm use as well as enable useful grid feed-in concepts. For this, research is needed on low cost storage systems and energy management systems (see Minipaper on energy storage).

One option are organic flow batteries, which need research for optimization.

funded by European Commission

Furthermore, the options to use CO_2 from biogas upgrading for methane production (Power-to-Gas) as an energy storage option should be explored especially regarding technical optimisation, reduction of costs and the legal framework.

Bio-hydrogen for transport

An alternative pathway for biogas technology is the production of bio-hydrogen using “dark fermentation”. Research is needed to optimise the process and evaluate its feasibility as advanced perspective for biogas optimization.

Energy management on farm level

Advanced energy management systems enable farms to increase the efficiency of energy use and the performance of the production systems for example in livestock husbandry. This relates to the control of ventilation systems, heating, lighting, feed preparation and other applications. New tools are needed to enable this advanced efficiency and to facilitate the integration of fluctuating renewable energy production. Cutting the dependency on external energy supply and increasing the energy efficiency of production processes helps to face increasing energy prices.

Sustainability aspects

According to the Renewable Energy Directive of the EU (RED + RED II (draft)) biofuel production should fulfil certain sustainability criteria. Therefore, there is the need to establish a clear methodology for the calculation of greenhouse gas emissions, considering all the carbon effects. Therefore, research should contribute to set reference values for GHG emissions, taking into account ecosystem services, co-products from the production and use of fuels.
At an operational level, it is necessary to invest in human resources through qualification and appropriate training. Easy to handle guidelines on the best practices for sustainable biofuels production should be prepared in order to ensure that farmers and other plant operators know-how to adopt the best possible performance of agro-energy systems. Cooperation between the industrial and agricultural sectors must be promoted at all levels of the agro-energy value chain (production, processing and distribution), the example of agro-ecological symbiosis (AES) previously mentioned in this paper could be used as benchmark for the creation of other local systems.

Policy for standardisation and certification

In order to promote the deployment of energy from renewable sources on agricultural areas in symbiosis with agricultural production, there is a need for coordination between the different authorisation bodies, at the European and national levels.

The regulations for biomass-based energy and biofuels has been developed for few decades. At the same time, there is no regulations on the sustainability requirements for symbiosis of agricultural production and energy generation at the farm level. Symbiosis of a given RES technology in accordance with the farm production relies on techno-economic analysis. Most of the technologies are still very expensive and the payback period for investment is very long thus, the typical farm will hardly decide on the investment. In such calculations, numerous sustainability requirements should be taken into account, including external costs related to society’s health and wellness. There is no regulations, which will combine techno-economic analysis with environmental, life-cycle costing and social impacts. Research of those aspects will facilitate political decision and finally to promote RES development in rural areas by new standardisation and certification schemes for combined multi-productivity at the farm level.

At regional/national level, there is the need to define and implement support policies to contribute to the competitiveness and sustainability of the agro-energy sector. Economic incentives, based on sustainability requirements, might be necessary to promote agro-energy in relation to fossil fuels. For the latter environmental and social costs are so far not internalised.

Business models to increase profitability in farm-scale energy production

Despite the variety of technologies, potential applications and related business models available for production of renewable energy and energy efficiency for farms, only a small subset of them present the

necessary characteristics for a large scale, standardized and economically sound deployment compatible with the capital market's investors' requirements (balanced risk and return) (Pombo et al. 2017).
Appropriate business models should be developed and the relevant know-how transferred to farmers and consultants. Furthermore, there is a need for business models on local or regional level to ensure, farmers are enabled to play a significant role in the development of decentralized rural energy systems. For more details, see Mini-paper on "Business models and funding".

Legal and administrative barriers

A number of legal and administrative barriers for on-farm renewable energy systems exist nowadays. It is necessary to present a common position of the farmers at local, regional or national level in order to promote a better framework for distributed renewable energy in general and for on-farm renewable energy systems in particular (see RESFARM www.resfarmprojekt.eu).

6. Suggested topics for operational groups

Energy self-supply on farms

The aim should be to explore the options for energy self-supply on farm level. The analysis should include technical options as well as economic considerations and should result in recommendations for farmers and farm-advisors how to implement self-supply concepts.

Low cost pre-treatment of biomass for biogas and bio-methane production

Some of the substrates or biogas production, namely lignocellulosic biomass, require pre-treatment before being fermented. Low cost technologies for this pre-treatment should be tested regarding technical feasibility and gas yields. A LCA should cover the whole production chain of the biomass form the field to the gas production and should include low carbon footprint techniques such as no-till with crop rotation and cover crops.

Low-tech concepts for biogas upgrading to bio-methane

Upgrading of biogas to bio-methane widens the range of uses of biogas. Currently mostly large-scale biogas plants qualify for upgrading technologies. Low cost technologies for upgrading, suitable for farm size biogas plants, should be tested regarding technical and economic feasibility.

Small-scale ethanol production

Task of the group should be to look into the options of combining small-scale ethanol plants with biogas production on farm level. Technical feasibility as well as environmental and economic aspects should be analysed.

Biogas digestates as fertilizer

Digestates from fermentation processes are valuable fertilizers. The group should look into the technological options of producing tailor made fertilizers from digestates and develop business plans including marketing options.

Circular bio-economy processes on farm

The available biomass on farms offer a large range of options to combine bioenergy with the production of food, feed, chemicals and material. The group should look into the options to establish closed-loop concepts on farm level.

Non-conventional substrates for biogas production

A large range of materials, which is in principle suitable for biogas production, is so far not exploited for this purpose. The group should aim at identifying these materials, define ways for mobilisation and options to enhance quality and minimize upgrading requirements.

funded by European Commission

7. Projects

Helpsoil

Conservation Agriculture techniques along the Po Valley, northern Italy. Strength, weakness and sustainable solutions to improve environmental benefits.
www.lifehelpsoil.eu

Recare

Information and guidance to prevent and remediate against soil degradation
www.recare-project.eu

Soilcare

Selected promising soil-improving cropping systems across Europe are monitored with stakeholder involvement, and assessed jointly with scientists. Specific attention will be paid to adoption of soil-improving cropping systems and agronomic techniques within and beyond the study sites.
www.soilcareproject.eu

Resfarm

Develops a framework to promote, operate and finance renewable energy systems on farms. www.resfarmproject.eu

Bioenergyfarm

Promotes micro-scale biogas installations for co-digestion manure and feed leftovers from the farm (includes feasibility studies; barriers regarding the legal and financial framework; guidance to policy makers). www.bioenergyfarm.eu

Agroecological Symbiosis

http://blogs.helsinki.fi/agroecologicalsymbiosis/

8. References

Arranz-Piera, P., Kemausuor, F., Darkwah, L., Edjekumhene, Joan Cortés, I., Velo, E. (2018): Mini-grid electricity service based on local agricultural residues: Feasibility study in rural Ghana, Energy, 153, 443-454.

Beck, M., Bopp, G., Goetzberger, A., Obergfell, T., Reise, C., Schindele, S. (2012): Combining PV and food crops to Agrophotovoltaic – optimization of orientation and harvest. In: Nowak, S.; European Commission: 27th European Photovoltaic Solar Energy Conference and Exhibition, EU PVSEC 2012, Frankfurt, Germany, 24 - 28 September 2012.

Brandle, J.R., Hodges, L., Zhou, X.H. (2004): Windbreaks in North American agricultural systems. Agroforestry Systems, 61, 65–78.

Eckel, H., Hartmann, S., Schroers, J.O., Döhler, H., Scholz V., Ruiz Lorbacher, F. (2008): Poplar and willow production on farmland. LANDTECHNIK Bd. 63, Nr. 6, 351-353.

FNR (2013): BIOGAS-an introduction. Fachagentur Nachwachsende Rohstoffe, Gülzow.

Glemnitz, M.; Eckner, J.; Aurbacher, J.; Kornatz, P.; Müller, J.; Heiermann, M.; Peter; C. (2015): Crop rotations as "cornerstone" of sustainable energy cropping – Integrative evaluation of their agronomic, ecologic, economic and resource efficiency effects. In: Biomass and energy crops V, Association of Applied Biologists, 20–22.10.2015, Brussels, Belgium, Wellesbourne, 117–128.

Glemnitz, M., Platten, R., Krechel, R., Konrad, J., Wagener, F. (2013): Can short-rotation coppice strips compensate structural deficits in agrarian landscapes? Aspects of Applied Biology 118, Environmental Management on Farmland, 153-161.

Hartmann, S, Graf, J., Neiber, J., Puchta, M., Reinhold, G., Remmersmann, T., Wilms, D. (2016): Strom speichern, Eigenverbrauch steigern, KTBL Heft 110, KTBL Darmstadt.

funded by European Commission

Herrmann, C., Plogsties, V., Willms, M., Hengelhaupt, F., Eberl, V., Eckner, J., Strauß, C., Idler, C., Heiermann, M. (2016): Methane production potential of various crop species grown in energy crop rotations. LANDTECHNIK 71(6), 194–208.

Jin, V. L., Baker, J. M., Johnson, J. F., Karlen, D. L., Lehman, R. M., Osborne, S. L., Sauer, T. J., Stott, D. E., Varvel, G. E., Venterea, R. T., Schmer, M. R. and Wienhold, B. J. (2014): Soil greenhouse gas emissions in response to corn stover removal and tillage management across the us corn belt. BioEnergy Research, 1-11.

Johnson, J.M.F., D.W. Archer, D.L. Karlen, S.L. Weyers, and W.W. Wilhelm (2011): Soil management implications of producing biofuel feedstock. p. 371-390. In J. Hatfield and T. Sauer (eds.) Soil management: Building a stable base for agriculture. American Society of Agronomy Series. American Society of Agronomy and Soil Science Society of America, Madison, WI.

Kluts, I., Wicke, B., Leemans, R., Faaij, A. (2017): Sustainability constraints in determining European bioenergy potential: A review of existing studies and steps forward. Renewable and Sustainable Energy Reviews 69 (2017) 719–734

Koppelmäki, K., Eerola, M., Kivelä, J. V., Hagolani-Albov, S. E., Helenius, J. P., Winquist, E. & Virkkunen, E. (2016): Challenges for the New Rurality in a Changing World: Proceedings from the 7th International Conference on Localized Agri-Food Systems 8-10 May 2016, Södertörn University, Stockholm, Sweden. Rytkönen, P. & Hård, U. (toim.),171-172

KTBL (2007): Biogas im ökologischen Landbau. KTBL Heft 65. KTBL Darmstadt

Lal R. (2015b): A system approach to conservation agriculture. Journal of Soil and Water Conservation 70(4), 82A-88A.

Lal, R., Pimentel, D. (2007): Biofuels from crop residues. Soil & Tillage Research 93(2), 237-238.

Majumdar, D., Pasqualetti, M.J. (2018) Dual use of agricultural land: Introducing 'agrivoltaics' in Phoenix Metropolitan Statistical Area, USA, Landscape and Urban Planning, 170, 150-168.

Marucci, A., Zambon, I., Colantoni, A. Monarca, D. (2018) A combination of agricultural and energy purposes: Evaluation of a prototype of photovoltaic greenhouse tunnel, Renewable and Sustainable Energy Reviews, 82, Part 1, 1178-1186.

Mirosz, L., Amrozy, M., Trząski, A., Wiszniewska, A. (2015): What Policymakers should know about micro-scale digestion, Report of the EU-Project "BioEnergy Farm II - Manure, the sustainable fuel for the farm". National Energy Conservation Agency (NAPE), Poland

Möller, K. (2009): Influence of different manuring systems with and without biogas digestion on soil organic matter and nitrogen inputs, flows and budgets in organic cropping systems. Nutrient Cycling in Agroecosystems, 84, 179-202.

Paterson, M. (2016): Implementation Guide For Small-Scale Biogas Plants. BioEnergy Farm II Publication, Vol. 1.2, Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V. (KTBL), Germany

Pombo, J., Regueiro, R. M. (2017): Technical, financial and legal alternatives for on-farm clean energy technologies. RESFARM project, deliverable 3.7.

Seay, J. R., You, F. (2016): Biomass supply, demand, and markets. In: Biomass supply chains for bioenergy and biorefining, 85-100. Holm-Nielsen, J., & Ehimen, E. A. (Eds.). Woodhead Publishing.

Siegmeier, T., Blumenstein, B. & Möller, D. (2015): Farm biogas production in organic agriculture: System implications. Agricultural Systems, 139, 169-209.

Souza, G., Ballester, M. V., de Brito Cruz, C.; et al. (2017): The role of bioenergy in a climate-changing world. Environmental Development, 23, 57–64.

TFZ (2017): Climate protection by rapeseed oil fuel. TFZ Kompakt 13. Technologie und Förderzentrum, Straubing

Venanzi, S., Pezzolla, D., Cecchini, L., Pauselli, M., Ricci, A., Sordi, A., Torquati, B., Gigliotti, G. (2018) Use of agricultural by-products in the development of an agro-energy chain: A case study from the Umbria region, Science of The Total Environment, 627, 494-505.

funded by European Commission