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AGROFOSSILFREE

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Report on framework, methodology and standards

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Abstract

The aim of this document (Deliverable 1.2 of the AgroFossilFree project), is to provide the conceptual background along with assessment templates to support the project partners in their common empirical research on innovation processes related to renewable energy and energy-saving technologies and practices. The document, in the first place, includes the common framework, i.e. main theories and research findings concerning the generation, adoption and diffusion of energy related technological innovations and best practices. It is worth noting that innovation adoption and diffusion is undoubtedly multifactorial; moreover, heterogeneity of farms and farmers as well as of contexts and the technology under research affect the uptake of novel technologies and relevant practices. Furthermore, the document includes the assessment templates for farmers (survey) and experts (interviews). Therefore, the document provides the rationale and the tools based on which AgroFossilFree research will take place in the next phase(s) of the project.

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INTRODUCTION

The document at hand constitutes Deliverable 1.2 of the AgroFossilFree project and provides the conceptual background along with assessment templates in order to support the project partners in their common empirical research on innovation processes related to renewable energy technologies and energy saving practices/technologies.

According to the GA, in the first place, AgroFossilFree will strive to assess end-user needs and interests, and identify factors influencing adoption and diffusion of relevant technologies and best practices, taking into account regional specificities. This will be achieved through targeted surveys and interviews with farmers and selected advisory/extension services in partner countries.

In order to accomplish this task, the current common framework for the understanding and the analysis of innovation processes has been elaborated (see: PART A). Based on such an analysis, a common methodology on how to assess the needs and grassroots-level innovations of the main stakeholders in the field of renewable energy and energy saving technologies/ practices, notably farmers, was produced. The relevant assessment templates (see: Part B) are flexible, meaning that adjusted versions will be used for assessing the needs of the main stakeholder groups.

Therefore, the following sections of D1.2 concern:

- PART A: a framework which will facilitate the project partners to perform the assessment of innovation processes comprising: 1) general innovation theories and 2) relevant research
- PART B: assessment templates (per stakeholder group) for identifying stakeholder needs and innovative ideas.

PART A: CONCEPTUAL FRAMEWORK

1. Innovation: an introduction

1.1 Definition of innovations

Innovations are, in general, defined and understood as something that is new for an individual/ a community which may help in doing things better, making things easier or solving problems, etc. According to Rogers (1983: 11) *"[A]n innovation is an idea, practice, or object perceived as new by an individual or other unit of adoption"* to which Van den Ban and Hawkins (1988: 100) add the phrase "… *but which is not always the result of recent research*". This addition is very important in agriculture implying that something that is known in one area may be an innovation when introduced in another area of the same region/country.

More recently OECD (1997) and Eurostat (2009) define innovation as the implementation of a new or significantly improved product (good, service or practice), a new marketing method or a new organisational method in business practices, workplace organisation or external relations. Therefore, innovation is not identical to invention; the latter is the first occurrence of an idea and the former the first commercialization of the idea and in many cases there is a considerable time lag between the two.

The adoption of an innovation is considered as a mental process by an individual or of a group and it starts with becoming aware of the innovation and ends with its practice. Adopting an innovation means change but it must be noted that not everything that is new is good, or that not everything that is old is bad, or that innovation does not necessarily imply progress (Hoffmann, 2006).

1.2 Taxonomy of innovations

Innovations may be distinguished by type. In the 1930s, Schumpeter introduced a well-known classification of innovations as follows: introduction of a new product or a qualitative change in an existing product; process innovation new to an industry; the opening of a new market; development of new sources of supply for raw materials or other inputs; changes in industrial organisation (OECD, op. cit.). Economists have given particular attention to the first two ones, i.e. product innovation and process innovation (Fagerberg, 2003) and have identified several kinds of innovations within technical change.

More recently, in the framework of AgriSpin (H2020) project[1], Knierim et al. (2015) suggest that one can distinguish between the following types of innovation:

- Product innovation: This involves the introduction of a good or service that is new or significantly improved with respect to its characteristics or intended uses. This includes significant improvements in technical specifications, components and materials, incorporated software, user friendliness or other functional characteristics.
- Process innovation: This has to do with the implementation of a new or significantly improved production or delivery method, including significant changes in techniques, equipment, and/or software.
- Marketing innovation: This involves the implementation of a new marketing method involving significant changes in product design or packaging, product placement, product promotion or pricing.
- Organisational innovation: This deals with the implementation of a new organisational method in a firm's or another collective's practices, collaboration organisation or external relations.

Furthermore, innovations can be differentiated according to the degree they deviate from the current setup: 'incremental', 'continuous' or 'marginal' innovations refer to continuous improvements (i.e. they occur more or less continuously, although at a varying rate in different industries/services and over different time periods) vs. 'radical' or 'discontinuous' innovations referring to discontinuous events, as for example the introduction of a totally new type of machinery (Freeman et al. 1982; Fagerberg, 2003)[2]. Furthermore, Henderson and Clark (1990) add the distinction between 'modular' innovation implying a change in the components (modules) of a product or service and 'architectural' innovation that is a

[1] Space for Innovations in Agriculture; http://agrispin.eu/

[2] To this Freeman et al. (1982) add 'new technological systems' with respect to 'constellations' of innovations, which are technically and economically inter-related, and 'technological revolutions' (i.e. change of paradigm) concerning far-reaching and pervasive changes embracing several 'new technology systems'.

change in the way these components are combined (design or architecture of the product or service) (for a comparison of typologies see Garcia and Calantone 2002).

Furthermore, successful innovations are often the result of synergy among three dimensions: technical, organizational and institutional. Leeuwis and Aarts (2011) highlight that innovations are a combination of the implementation of new technologies and practices (hardware), new knowledges and way of thinking (software) and new institutions or organization (orgware). Hence, innovations can be considered as 'sociotechnical hybrids' (Flichy 1995).

1.3 Innovations: structures and process

Innovations can be seen from multiple perspectives. Knierim et al. (2015) distinguish between: a) the structural perspective (Fig. 1) highlighting the environment in which innovations occur, including actors with different capacities, functioning within different organizational structures, all of which occur within certain social, political, or national environments; and b) the dynamic perspective (Fig. 2) according to which the innovation process is described as an iterative cycle or a line with several loops that repeat and adjust over time.

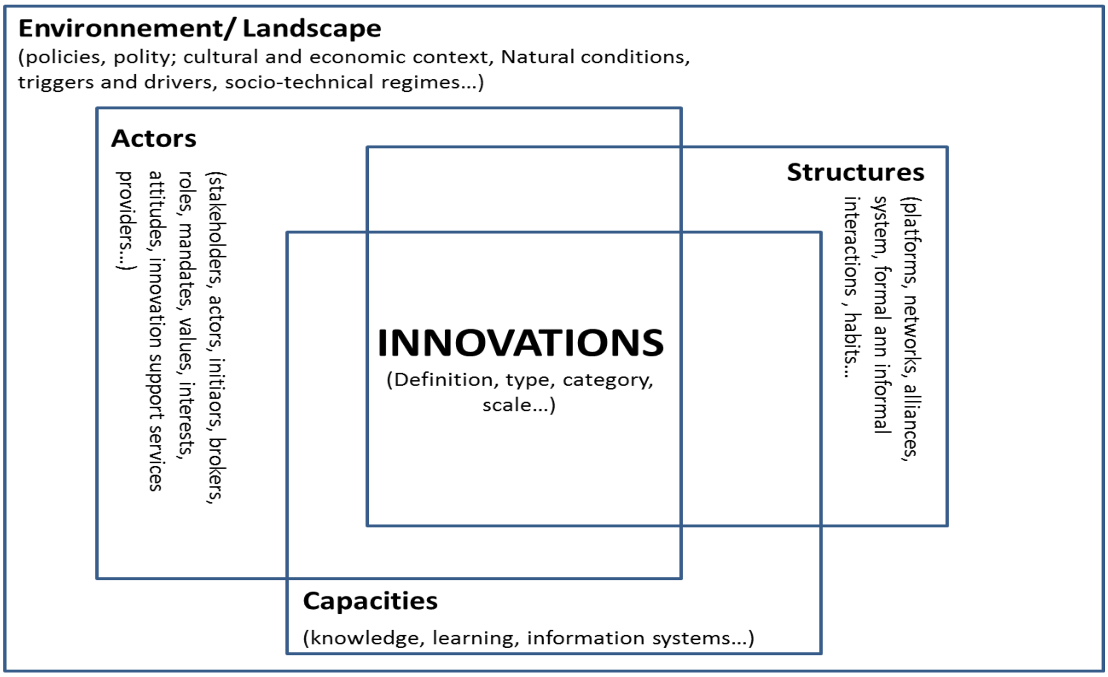

Figure 1: The structural components of innovation

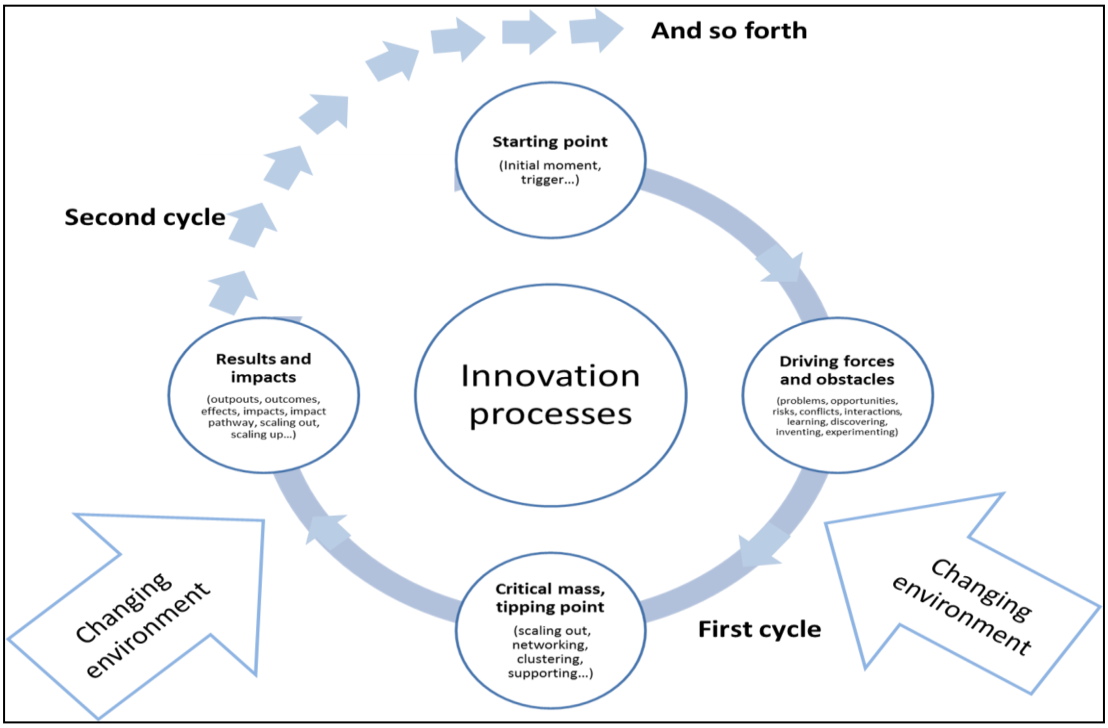

Figure 2: The dynamic process of innovation

1.4 Innovation models

Many scholars have also been occupied with the identification of innovation process models or generations, i.e. with the description of the phases of the process from idea to commercialized product. The most well-known among them is Rothwell's (1994) who distinguishes five generations:

- first generation – technology-push models (1950s – first half of 1960s);
- second generation – market-pull models (second half of 1960s – early 1970s);
- third generation – coupling model (early 1970s – early 1980s);
- fourth generation – integrated innovation process models (early 1980s – early 1980s);
- fifth generation models – integrated, interconnected, parallel and flexible innovation process models (since early 1990s).

Rothwell's analysis is considered almost universal given that either other taxonomies can be accommodated or recent trends, such as networking, can be treated as "flexible", "parallel", "interactive" and "interconnected" process. Nevertheless, based on Chesbrough (2003), a sixth model, that of open innovation, may be added to the list (Table 1).

Table 1: Innovation generations

Model	Generation	Characteristic
Technology push	First	Simple linear sequential process, emphasis on R&D and science
Market pull	Second	Simple linear sequential process, emphasis on marketing, the market is the source of new ideas for R&D
Coupling model	Third	Recognizing interaction between different elements and feedback loops between them, emphasis on integrating R&D and marketing
Interactive model	Fourth	Combinations of push and pull models, integration within firm, emphasis on external linkages
Network model	Fifth	Emphasis on knowledge accumulation and external linkages, systems integration and extensive networking
Open Innovation	Sixth	Internal and external ideas as well as internal and external paths to market can be combined to advance the development of new technologies

Furthermore various theories/ models have been developed addressing the generation, adoption and dissemination/ diffusion of innovations. Following, major theories of innovations, focusing on agriculture and extension, including the Diffusion of Innovations - DOI (re: Technology Transfer; Transfer of Technology – ToT model), contemporary views of innovations (Agricultural Innovation Systems – AIS) as well as other theories (the Technology Acceptance Model (TAM), Strategic Niche Management (SNM) and the Triggering Event) will be briefly dealt with.

2. Diffusion of Innovations (DOI)

Technology transfer, or transfer of technology (TOT), is the process of transferring (disseminating) technology from the places (and the groups) it was generated to wider audiences (users). Technology transfer is thus an integral part of the conventional extension process involving the transfer and spread of technology/ technical innovation and know-how from innovative technology developers through those who communicate it (extensionists) to the farming population.

The TOT model of the research-extension-farmer linkage was based, on the one hand, on the general faith in science and commitment to modernization (Röling 1988) and, on the other hand, on the tenets of DOI theory. For the purposes of this piece of work the basic concepts, i.e. innovation, diffusion and adoption will be briefly dealt with, along with the main the components of DOI, i.e. a) the model of adoption as a sequential process of five stages; b) a classification of innovations according to five characteristics; and c) a description of the diffusion as a normal bell-shaped curve with farmers being categorized in five categories according to their appearance on the curve.

Then, *"[D]iffusion* is the process by which an innovation is communicated through certain channels over time among the members of a social system" (Rogers 1983: 5). Diffusion is "a special type of communication" (Lamble 1994: 33) with the latter being "a process in which participants create and share information with one another to reach a mutual understanding" (Rogers op. cit.). In the diffusion process the information flows through networks. The nature of networks and the roles of opinion leaders play in them determine the likelihood that the innovation will be adopted.

The individual decision-making (adoption) process that occurs when individuals consider adopting a new idea, product or practice can be described as follows (Rogers 1962: 81-86):

- Awareness: the individual is exposed to the innovation; awareness is usually driven by sources outside the community.
- Interest: The individual is interested and actively seeks out more/new information.
- Evaluation: The individual mentally examines the innovation (or mentally applies the innovation) using the available information.
- Trial: The individual actually tests the innovation to see if reality matches expectations, usually with small-scale, experimental efforts.
- Adoption: The individual adopts (decides to continue the full use of) the innovation.

Rogers and Shoemaker (1971: 99-133) presented an alternative adoption model of four steps (knowledge-persuasion-decision-implementation) to which later Rogers added a fifth one, ‘confirmation’ (Rogers 1983: 174). Therefore the adoption process was formed as follows (Rogers 1983: 163-209; see Fig. 3):

- Knowledge: the individual is exposed to the new innovation.
- Persuasion: the individual is showing more interest in the innovation (becomes more psychologically involved) and is seeking more information about it; s/he forms a favourable or unfavourable attitude toward the innovation (affective domain).
- Decision: the individual evaluates the positive and negative aspects of the innovation and decides whether to accept/ reject the innovation; s/he engages in activities that lead to a choice to adopt or reject the innovation, including trial - if the innovation is trialable.
- Implementation: the individual puts an innovation into use.
- Confirmation: the decision to adopt or reject is not the terminal stage of the process; the individual seeks reinforcement of an innovation decision that has already been made, but s/he may reverse this previous decision if exposed to conflicting messages about the innovation.

The speed with which each individual passes through these 5 stages varies depends on the particular innovation’s characteristics which influence its adoption. These are: relative advantage (the degree to which it is superior to ideas it supersedes); compatibility (the degree to which it is consistent with existing values and past experiences of the adopter); complexity (the degree to which it is relatively difficult to understand and use); divisibility (the degree to which it may be tried on a limited basis); and communicability (the degree to which the results may be diffused to others) (Rogers 1983: 210- 240). Furthermore, the communication channels used in the various stages of adoption process are differentiated (op. cit. 197-201).

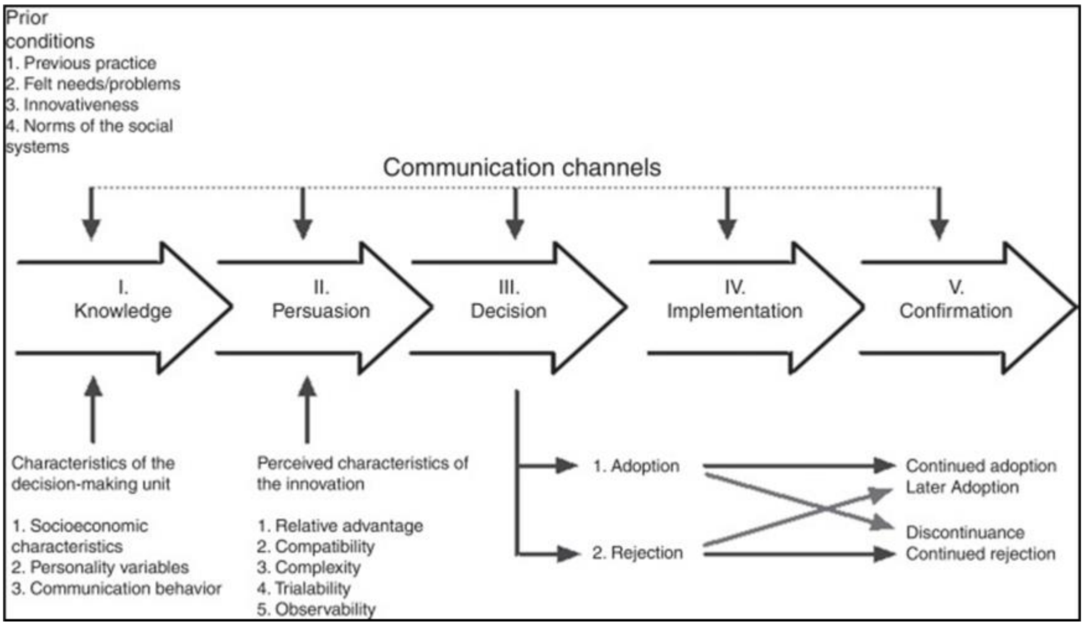

Figure 3: The adoption process

Innovation diffusion research has attempted to explain the variables that influence how and why users adopt an innovation. Based on innovativeness (i.e. earliness or lateness of adoption; Rogers 1983: 242) and the fact that "adopter distributions closely approach normality" (Rogers op. cit.: 246), five ideals of adopter categories are recognized, as follows: (1) innovators ('venturesome'), the first ones to try out a new idea, accounting for 2.5% of the adopters; (2) early adopters ('respected'), who adopt a little later, making up for 13.5%; some time later (3) the early ('deliberate;), and (4) the late majority ('skeptical') follow one after the other, accounting for 34% each; finally (5) laggards ('traditional'), who make up for 16%, are the last ones to adopt (see Fig. 4). Moreover these categories differ systematically in a number of ways, i.e. in the characteristics of individuals that make them likely to adopt an innovation (Rogers 1983). For example, innovators have been found to be relatively young, better educated and 'better-off', to have more land and be specialized as well as to have multiple information sources and to be more cosmopolites; on the contrary, laggards tend to rank at the opposite extremes with respect to the aforementioned characteristics, with the other categories ranking between the two extremes (Rogers op. cit.: 240-270). A summary of Roger's generalisations (op. cit.) with respect to such characteristics is presented in Appendix 1.

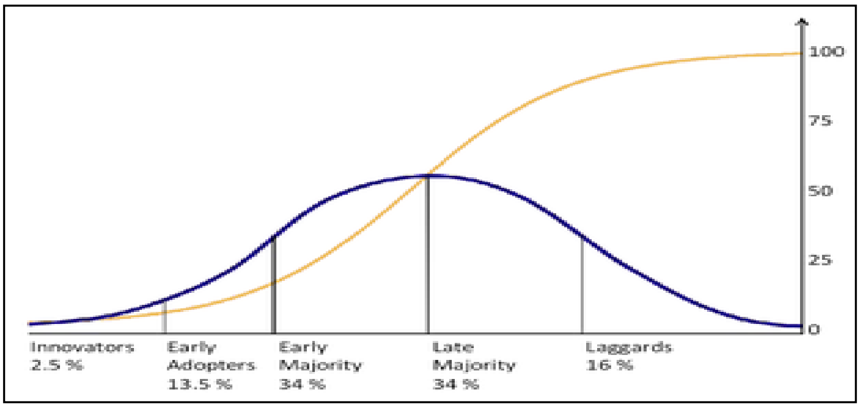

Figure 4: The innovation Adoption Curve

Given that extension agents are not be able to work closely with all farmers in their districts (as they are outnumber by farmers), they can increase their impact by cooperating with opinion leaders (Van den Ban and Hawkins 1988: 115) since following Rogers (1983: 331) “Change agent success is positively related to the extent that he or she works through opinion leaders”. This is so as, on the one hand, the two parties are similar in certain attributes, i.e. they are homophilous, a fact that increases the effectiveness of their communication contact (Rogers op. cit.: 321-322). On the other hand, opinion leaders fulfil important functions with regard to innovations: they pass on and interpret information on the basis of own opinions and experience, set an example for others to follow and ‘legitimise’ or reject changes (give their approval or disapproval) (Van den Ban and Hawkins 1988: 113-114). Therefore, the so-called ‘progressive farmer’ strategy followed within the TOT (or the classical/centralized diffusion) model can be depicted as follows:

research -> extension -> progressive farmers -> other farmers (trickle-down process).

Progressive farmers coincide with opinion leaders who, in turn, largely coincide with early adopters given that they adopt many innovations, but usually are not the first to adopt them; they are well educated and enjoy sound financial positions in their communities; they lead an active social life and have many contacts outside their immediate surroundings; and, they have a special interest in their subject (Van den Ban and Hawkins op. cit.).

2.1 Critique to the TOT model/ DOI theory

As aforementioned, (classical) DOI claims that innovations originate from scientists, are transferred by extension agents and are applied by farmers. Agricultural research and extension based on this, Transfer-of-Technology model (ToT), has a long history of innovations and increased effectiveness in food production. However, this ‘linear’ model has limitations and has been severely criticized on a number of grounds.

Nitch (1982) summarizes the critiques addressed to DOI in terms of its three basic assumptions: assumptions about content; assumptions about the dissemination process; and assumptions about learning (see also Rogers 1976). The first assumption states that “adoption of the technology recommended by extension is a desirable and rational behavior” which results in a strong pro-change, pro-innovation and pro-technology bias (Nitch op. cit.).

The second assumption refers to the diffusion process which is seen as a communication process (information dissemination among farmers) and a trickle down process from individual early innovators to other farmers. This assumption takes as a given that information is relevant and applicable for a majority of farmers as well as that interaction/communication between farmers actually takes place. Therefore, the model is open to criticisms as being oversimplified (i.e. ignoring the complexity of multiple situational and individual factors) and ignoring the increasing stratification of social interaction (op. cit.). Röling et al. (1976: 69) underline the fact that “differences in resources endowment … may imply great differences among farm households in their capacity to benefit from innovations”. In this respect, Röling (1982: 95) underscores “the untenability of the assumption that farmers are homogeneous in basic attributes so that a uniform innovation is relevant to all farmers”; later Röling (1988: 70) demarcated the heterogeneity of the farming population in terms of psychological characteristics, life cycle differences, access to resources and access to information. It follows that “small producers are not necessarily 'laggards', but will respond rationally and favourably to realistic opportunities" (Ascroft et al. in Röling 1982: 90).

Finally, the third assumption equates learning with adoption, with learning occurring as a result of exposure to information. This is open to criticisms with reference to the concepts of learning and knowledge advocated by DOI. The fact that it does not acknowledge farmers' experience and knowledge as well as that advice is often seen to come out of a 'black box', since the reasoning behind it is not transparent, are further issues (see: Röling and Wagemakers 1998). As Garforth (1982: 44) argues "bias arises because the information offered by extension services is more appropriate to larger farmers and richer members of the community".

Moreover, Ascroft et al. (in Röling 1982: 90) stress that in our times "innovations come in rapid succession" which along the fact that "early adopters reap 'windfall profits'" implies a self-reinforcing process resulting in the widening of gaps between early and late adopters (Röling 1988: 75). This is known in DOI as the 'issue of equality' (Rogers 1983: 133), i.e. that "diffusion processes lead to inequitable development" (Röling et al. 1976: 71). Rogers (1976: 137) recognizes the "propensity for diffusion to widen socioeconomic gaps in a rural audience" and argues that, on the one hand, new ideas (1983: 382) and technological innovations (1983: 264) and, on the other hand, change agents (thus, the extension service) tend to widen the gaps between advantaged and disadvantaged groups of farmers (1983: 391).

Despite such criticisms, including Rogers' own revision of his initial theory, "the diffusion generalizations often become normative for the practice of change agencies" (Röling et al. 1976: 65-66). Indeed, DOI has been the most widely used innovation theory (in research and academia). Modifications have also been proposed as for example from the Hohenheim school (Knierim et al. 2015) and notably from the ICT research community, including 'The chasm' (Moore 1999; Fig. 5) and the Gartner Hype Cycle for Emerging Technologies (see Linden and Fenn 2003, Fig. 6).

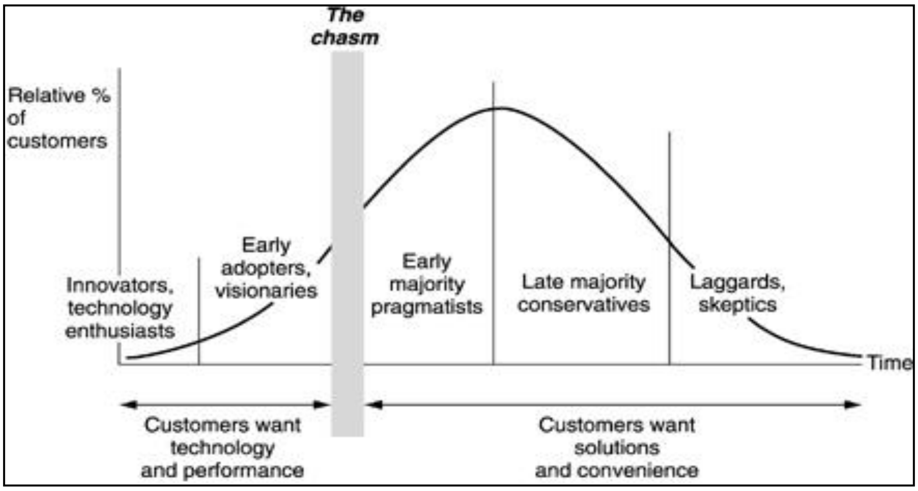

Figure 5: The chasm

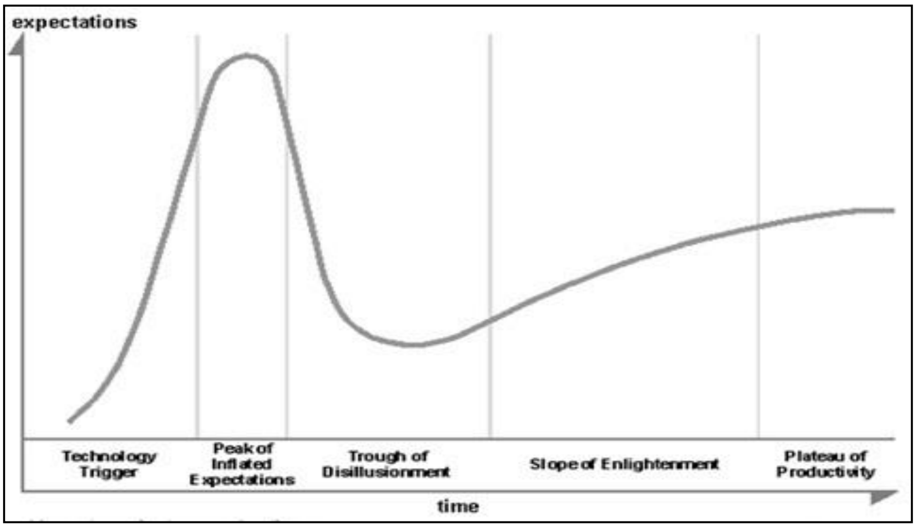

Figure 6: The Hype Cycle.

3. From transfer to co-generation (interactive innovations)

As already mentioned, the 'diffusion of innovations' (DOI) theory, also known as the transfer of technology or knowledge (TOT/TOK) model, has been dominant in agricultural development and beyond. However, it has lost utility owing to a two-fold process. On the one hand, alternative proposals have, since the 1970s, flourished, based on the realisation of the inadequacy of linear and mechanistic thinking in understanding the source and thus the solutions of problems. Prominent among these alternatives have been systemic approaches (see: Ison 2010). Such approaches look at a potential system as a whole (holistically) and focus on the relationships (important causal inter-linkages or couplings) among a system's parts and on system dynamics, rather than the parts themselves. On the other hand, in spite of its long history of innovations and increased effectiveness in food production, DOI has been, as aforementioned, heavily criticised, including the fact it fails to respond to complex challenges and rapidly changing contexts.

Nowadays, the attempts to solve the current, increasingly complex problems with a view to sustainability make clear that this is a particularly complicated task. When dealing with such problems (and sustainability) there may be little useable science, high levels of inherent uncertainty, and severe potential consequences from decisions that have to be made. Moreover, the realisation that real-world problems do not come in disciplinary-shaped boxes calls for the cooperation of diverse academic experts and practitioners. Such a problematique also points to the fact that there is no single privileged point of view for complex problems' analysis which, in turn, reinforces new forms of learning and problem solving integrating perspectives and insights. As a result, new, 'integrated' (cross-disciplinary) forms of learning and research strive to take into account the complexity of an issue and challenge the fragmentation of knowledge; they accept local contexts and uncertainties; they address both science's and society's diverse perceptions of an issue through communicative action; and, they work in order to produce practically relevant knowledge (see, inter alia, Funtowicz and Ravetz 1993; Nowotny 2003; Pretty 1995; Collinson 2000, Leeuwis 2004; Darnhofer et al. 2012; Cristóvão et al. 2012). New concepts, theoretical contributions and metaphors are thus flourishing nowadays to help understand and predict the links between the social, ecological and economic systems, meet the real world challenges and address sustainability as well as to organise various forms of 'cross-disciplinarity' into a coherent framework (see Koutsouris 2008a).

Especially with a view to sustainable agriculture, participatory approaches, involving farmers, extension workers and researchers in group work and joint experimentation (Röling and van de Fliert 1994; Somers 1998; Leeuwis 2004; Ingram 2008), thus discovery and experiential learning (Deugd et al.1998; Röling and van de Fliert 1994; Röling and Jiggings 1998), are deemed suitable for the development and adaptation of relevant knowledge and practices.

Subsequently, the emphasis has gradually shifted towards learning, i.e. the processes of human interaction from which learning emerges (LEARN Group 2000, Röling and Wagemakers 1988).Crucially, according to Röling and Jiggins (1998) the shift to sustainable agriculture concerns a systemic change thus requiring 'double loop' learning, i.e. a profound change in assumptions and strategies underlying subsequent actions (Argyris and Schon 1974) or a move from traditional, first-order practice to second-order change, i.e. change in perspective or level (Ison and Russel 2000). Moreover, Röling and Jiggins (1998) argue that the move towards an 'ecological knowledge system' (vs. the 'conventional knowledge system') means the need to move from a praxeology (i.e., theory informing practice, and practices feeding new theory) of 'transfer of knowledge' to a 'facilitating knowledge' one, focusing "on enhancing the farmers' capacity to observe, experiment, discuss, evaluate and plan ahead" (Deugd et al. 1998: 269). This new praxeology thus calls for an alternative extension pedagogy entailing stakeholders' participation in experiential learning and knowledge exchange (Woodhill and Röling 1998).

Social learning (SL) lies at the heart of such multi-stakeholder processes. It refers to the collective action and reflection that occurs among stakeholders as they work towards mutually acceptable solutions to a problem pertaining to the management of human and environmental interrelationships (Keen et al. 2005, Wals 2007). SL, thus, advocates an interactive (participatory) style of problem solving with outside intervention taking the form of facilitation (Leeuwis and Pyburn, 2002: 11). SL supports multiple loop learning (Argyris and Schon 1996) or adaptive learning (Webler et al. 1995); such a learning process can be designed as a deliberative process to achieve interaction among stakeholders leading to concerted action, with facilitation being the key form of external support (SLIM 2004).

Extension for sustainable agriculture therefore implies a (social) mechanism for facilitating SL (Allahyari et al. 2009) i.e. participatory processes of social change, through shared learning, collaboration, and the development of consensus about the action to be taken. Consequently, a new extension approach aiming at participatory and group learning and networking with extension agents acting as facilitators is required (see: Garforth and Lawrence 1997).

3.1 The emergence of Agricultural Innovation Systems

During the last decades, a number of new, systems of innovations (SoI) approaches have emerged which emphasise the multiplicity of determinants that influence the innovations' development, diffusion, and use. They also stress that innovation emerges from networks of actors involving interactive learning process; therefore, contemporary 'interactive' approaches emphasise the iterative, adaptive nature of innovation. Additionally, for SoI, innovations do not concern only new technological arrangements but new social and organisational arrangements as well.

In agriculture, the Agricultural Knowledge and Information Systems (AKIS) framework broadened the scope of Agricultural Knowledge Systems (AKS; aiming at integrating farmers, education, research and extension; Fig. 7), by including actors beyond research, extension and education. AKIS is defined as "*a set of agricultural organizations and/or persons, and the links and interactions between them, engaged in the generation, transformation, transmission, storage, retrieval, integration, diffusion and utilization of knowledge and information, with the purpose of working synergistically to support decision making, problem solving and innovation in agriculture*" (Röling and Engel 1991 in EU SCAR 2015: 16; see also Rivera and Zijp 2002).

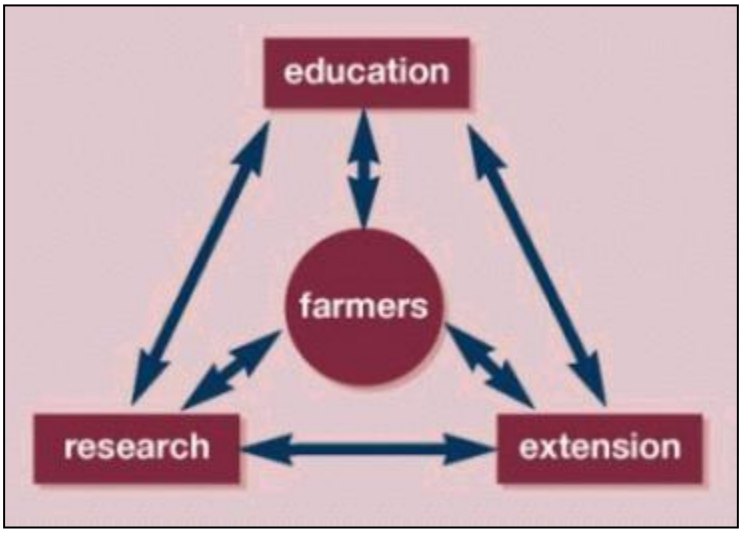

Figure 7: The Agricultural Knowledge System

More recently, Agricultural Innovation Systems (AIS), along with Agricultural Knowledge and Innovation Systems (AKIS), emerged embracing the totality and interaction of actors involved in innovation and extends beyond the creation of knowledge to encompass the factors affecting demand for and use of knowledge in novel and useful ways (Klerkx and Leeuwis 2008a, Klerkx et al. 2010, Leeuwis 2004; Rivera et al. 2005; World Bank, 2006; EU SCAR 2012 - see Fig. 8). AIS furthermore claims that the process of innovation is messy and complex with new ideas being developed and implemented by actors who engage in networks and make adjustments in order to achieve desired outcomes. Nowadays, as aforementioned, innovation studies increasingly focus on learning itself, with emphasis on facilitation and the processes of human interaction from which learning emerges (LEARN Group 2000, Röling and Wagemakers 1988).

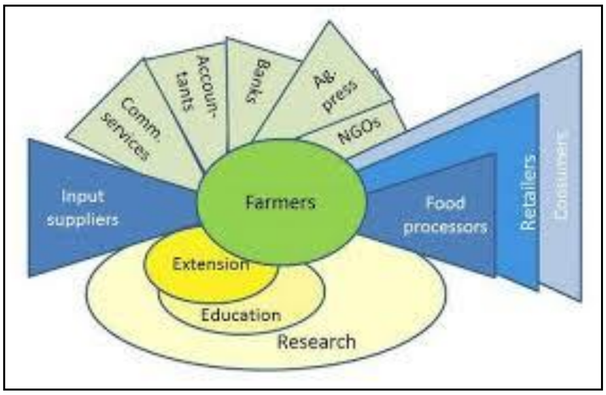

Figure 8: Agricultural Knowledge and Innovation Systems/Agricultural Innovation Systems

3.2 The Innovation Spiral

Within such a problematique, in the frame of the project 'AgriSpin' (Space for Innovations in Agriculture; http://agrispin.eu/) a new methodology was trialed and developed, namely cross-visits (see: Wielinga, 2016). A cross-visit typically lasted 3 – 5 days and involved a mixed team of between 7 and 10 project partner members who visited the host country in order to study, through in-depth discussions with farmers and other key actors, 3 to 5 innovation cases. The main tool used during the cross-visit was the Innovation Spiral. The Spiral identifies seven stages in an innovation process, from the initial idea until the embedding stage of the innovation. According to Wielinga and Koutsouris (2018) the stages are as follows:

1. *Initial idea*: Someone has an idea in response to a problem or an opportunity. New ideas can also emerge from creative group interaction. Exposure to the world beyond the comfort zone is often a trigger for new initiatives.
2. *Inspiration*: Others become inspired and form a "warm network" around the initiative. These are likeminded people with similar ambitions.
3. *Planning*: The warm network of initiators organises itself, and negotiates space for development with managers and financers who are in control of the conditions.
4. *Development*: In the relatively safe environment thus created, the initiators develop new practices and evidence of their effectiveness. For doing so, connection is made with relevant experts from experience or/and science.
5. *Realisation*: The new practice is introduced in the world outside the safe pilot area. This usually involves competition or negotiation with stakeholders who are affected by the changes caused by the new practice. Once this practice is widely accepted as being valuable, it can be called an innovation.
6. *Dissemination*: Other people become interested and implement the innovation. This can occur by itself, and it can also be promoted.
7. *Embedding*: The innovation becomes common practice, and structures adapt to the new reality. In this stage, gatekeepers, managers and policymakers who control the structures are the actors involved.

In each stage in Spiral of Innovations there are different key activities to be performed, actors to be involved and typical pitfalls to be avoided (Fig. 9).

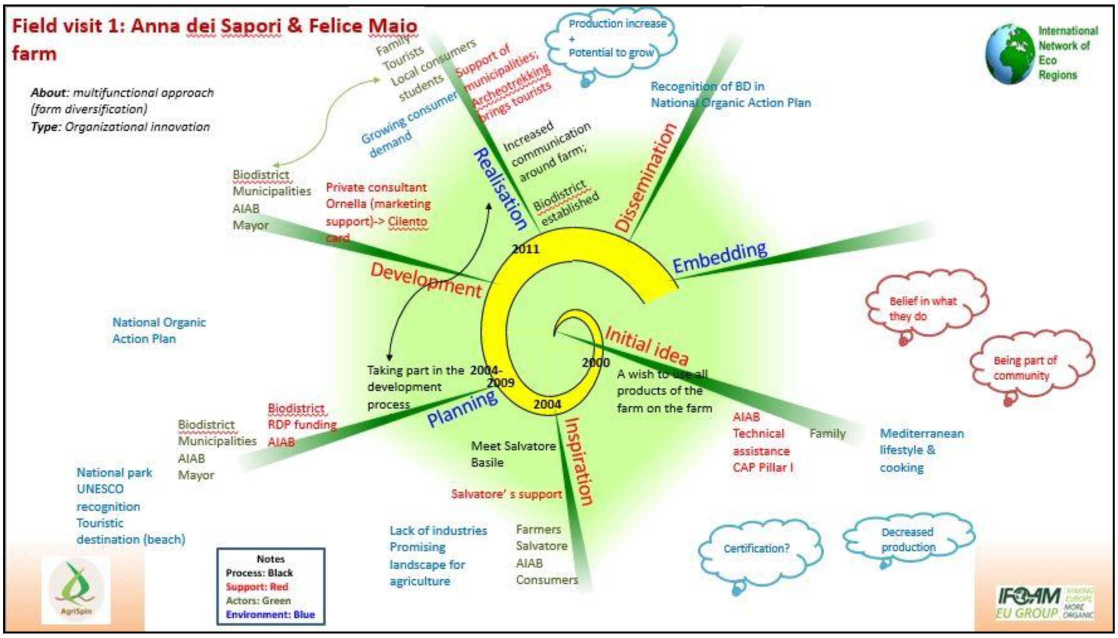

Figure 9: Example of a filled in Spiral of Innovations in a case study in Campania Region, Italy

3.3 The intermediation era

As already pointed out, SoI approaches build on networks. Networks, that is, "sets of formal and informal social relationships that shape collaborative action" between (heterogeneous) actors "that transcend organisational structures and boundaries" (Dredge 2006: 270), have attracted increased interest from quite a number of disciplines. Importantly, networks are not limited to (tangible) resources' coordination and actors' collaboration; they evolve to (collective) learning processes, utilising, empowering and developing local knowledge thus also allowing innovations development (Dredge, 2006; Zach, 2012). SoI concepts and approaches building on such a rationale (i.e., that, networks, encouraging the sharing of knowledge, are preconditions for innovation), focus on processes (instead of emphasis on structures) with particular attention given to (social) co-ordination and networking.

Moreover, in order to avoid or overcome gaps (cognitive, information, managerial or system) resulting in network and institutional failures (for a review see: Klerkx and Leeuwis 2009) growing attention is given to various types of (process) 'intermediaries/facilitators'. Such 'intermediaries' are increasingly found, particularly in literature, as third parties, (knowledge/technology) brokers, bridging organizations, intermediaries, boundary organizations and so on (see: Howells 2006). Howells (2006: 720) employs the broad term 'innovation intermediary' according to the following working definition: "*An organization or body that acts as an agent or broker in any aspect of the innovation process between two or more parties. Such intermediary activities include: helping to provide information about potential collaborators; brokering a transaction between two or more parties; acting as a mediator, or go-between, bodies or organizations that are already collaborating; and helping find advice, funding and support for the innovation outcomes of such collaborations.*"

It is thus quite clear that such 'intermediaries' are involved, taking an independent systemic role, in process facilitation rather than in the production (i.e., source) or dissemination (i.e., carrier) of innovation (Van Lente et al. 2003). Or, according to Haga (2005) they are involved in 'indirect' innovation processes (i.e. in enabling individuals and enterprises) rather than in direct ones (i.e. on actual innovation projects).

And while facilitation, "designed to help make groups perform more effectively" (Auvine et al. 2002) has a long history[3] brokerage is new, particularly innovation brokerage. An 'innovation broker' is defined as "*an organization acting as a member of a network … that is focused neither on the organization nor the implementation of innovations, but on enabling other organizations to innovate*" (Winch and Courtney 2007: 751) or "*a type of boundary organization that specializes in brokering or facilitating innovation processes involving several other parties, but does not itself engage in the innovation process*" (Devaux et al. 2010), i.e. a 'facilitator of innovation' (see: Den Hertog 2000; Winch and Courtney 2007; Van Lente et al. 2003). Innovation brokers are in general seen as beneficial to the innovation process by closing system gaps and acting as animators or catalysts.

Klerkx and Leeuwis (2008b) identify three major functions of an innovation broker: a) demand articulation, b) network formation and c) innovation process management (see also Kilelu et al. 2011; Juho and Mainela 2009, Devaux et al. 2010). Furthermore, Klerkx and Leeuwis (2008a) argue for the differentiation between 'animateurs' involved in the early pre-competitive stages of the innovation process (fulfilling tasks such as foresight, problem diagnosing and needs articulation, scoping and filtering (selection of collaborative partners), and network brokerage roles) and intermediaries involved in the process in a later stage (fulfilling tasks such as gatekeeping and knowledge brokering; knowledge testing and validation; knowledge commercialisation; accreditation, validation and regulation, and standards work; independent advice and mentoring on protecting intellectual property; and evaluation of the outcomes of innovation collaboration).

A number of examples of innovation brokering is also found in Nederlof et al. (2011) in which, within the framework of innovation platforms, Heemskerk et al. (2011) identify and discuss a number of brokering functions: facilitation, linking and strategic networking, technical backstopping, mediation, advocacy, capacity building, management, documenting learning, championing. Brokers thus provide three lines of support, i.e. developing a common vision and articulating related demands; scoping, scanning, filtering and strategic networking; and innovation process management. The authors notwithstanding the identification of a number of training instances for brokers stress that a good broker goes beyond training as well as that it takes time and interaction for brokers to develop their skills; they also underline that brokering is a time-demanding and costly job, thus concluding that the brokering is "[E]asier said than done" (p. 52). Furthermore, Klerkx and Gildemacher (2012) provide a typology of innovation brokers while also identifying key policy issues and providing a number of recommendations for practitioners, policy makers and project leaders. Nevertheless, it is quite clear that the broker role is still very new.

In the frame of the project 'AgriSpin' (Space for Innovations in Agriculture; http://agrispin.eu/) project, the role(s) of Innovation Support Services has been depicted as follows (Ndah et al. 2018; Table 2).

As already noted, intermediation (facilitation and brokerage) has yet to be thoroughly described, operationally defined, or well evaluated. Explicit attention has thus to be given to

[3] Facilitators' tasks can be summarised as a) to facilitate the group process, b) to teach and c) to be an expert on technical aspects of farming (Leeuwis 2004).

theoretical developments; without a nuanced understanding of the concepts, terminology, and controversies, study findings will be difficult to interpret and guidance to practice change may become untenable.

Table 2: Innovation Support Services (ISS) functions

ISS functions	Brief definition of function
1. Knowledge awareness and exchange (ISS1)	*All activities contributing to knowledge awareness, dissemination of scientific knowledge, or technical information for actors. For instance, providing knowledge based on information dissemination forums (website, leaflets), meetings or demonstrations and exchange visits.*
2. Advisory, consultancy and backstopping (ISS2)	*Advisory, consultancy and backstopping depict targeted supportive activities aimed at solving problems regarding for instance, a new farming system or new value chain design. The provision of advice (technical, legal, economic, environmental, social etc.) during the innovation process based on demands of actors and the co-construction of solutions, all fall in this category.*
3. Demand articulation (ISS3)	*It involves services targeted to help actors to express clear demands to other actors (research, service providers, etc.). This is targeted support of the innovator towards enhancing his /her ability to express the needs from other actors.*
4. Networks, facilitation and brokerage (ISS4)	*Provision of services to help organize or strengthen networks; improve the relationships between actors and align services to be able to complement each other (the right service at the right time and place). It also includes activities aimed at strengthening collaborative and collective action.*
5. Capacity building (ISS5)	*Provision of services aimed at increasing innovation actors' capacities at the individual level and at the organizational level. The services may comprise the provision of classical training and of experiential learning processes.*
6. Enhancing / supporting access to resources (ISS6)	*Provision of services for innovators aimed at enhancing the acquisition of needed resources to support the process. This could be facilitating access to inputs (seeds, fertilizers etc.), facilities and equipment (technological platforms, labs etc.) and funding (credit, subsidies etc.).*
7. Institutional support for niche innovation and scaling mechanisms stimulation (ISS7)	*Provision of institutional support for niche innovation (incubators, experimental infrastructures, etc.) and for out scaling and up scaling of the innovation process. This refers to support for the design and enforcement of norms, rules, funding mechanisms, taxes, and subsidies etc. that facilitate the innovation process or the diffusion of innovation.*

In terms of AIS, a new extension approach aiming at participatory and group learning and networking with extension agents acting as facilitators is required. Cristóvãoet al. (2012) highlight the importance of a "new extension approach aiming at participatory, group learning and networking with extension agents acting as facilitators" (p. 214). Therefore, new extension approaches are emerging, operating on systemic perspectives and aiming at enhancing the interaction between a variety of actors; they thus focus on 'exploration', i.e. with the sharing and synthesising thus with the creation of new knowledge. As above-mentioned, a major role of the new extension is that of the co-learning facilitator aiming at the development of shared meaning and language between dialogue partners in order to stimulate change and develop solutions and innovation.

It is important to note that the EU innovation policy for rural development has established the Agricultural European Innovation Partnership (EIP-AGRI). This policy instrument relies on partnerships and 'bottom up initiatives', mainly through 'Operational Groups', so to bridge the gap between actors across the value chain (especially between research and practice) and facilitate the co-generation of innovations through the employment of facilitators/ innovation brokers (Regulation (EC) No. 1305/2013; see also EU SCAR 2012, 2014, 2015).

4. Other innovation and adoption theories

4.1 Technology Acceptance Model (TAM)

Davis (1989) and Davis et al. (1989) proposed the Technology Acceptance Model (TAM) to address why users accept or reject information technology. The model examines the mediating role of perceived ease of use (PEOU) and perceived usefulness (PU) in their relation between systems characteristics (external variables) and the probability of system use (Fig 10). Perceived usefulness is the extent to which a person believes that using the technology will enhance his/ her job performance, and perceived ease of use is the extent to which a person believes that using the technology will be free of effort (Davis 1989). Behavioral intention is defined as the extent to which an individual intends to perform a specific behaviour (Davis et al. 1989). TAM thus posits that the impact of other external variables on behavioural intention is fully mediated by these two beliefs of usefulness and ease of use (Legris et al. 2003; Yi and Hwang 2003)

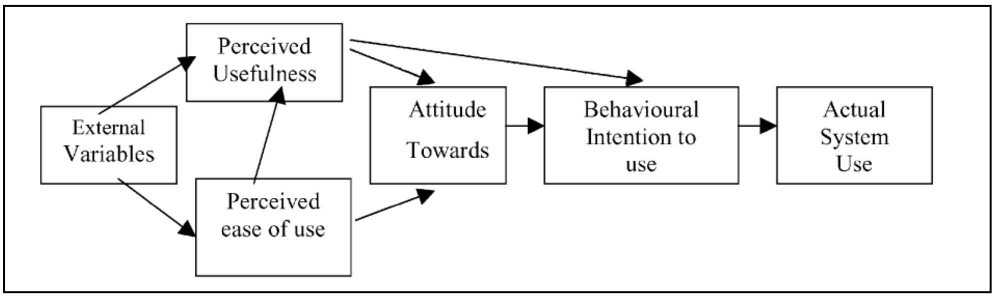

Figure 10: The TAM model

The model is an adaptation of Fishbein and Ajzen's (1975) Theory of Reasoned Action (TRA, Fig 11) aiming at explaining and predicting the behaviours of people in a specific situation.

Both TRA and TAM propose that external variables intervene indirectly, influencing attitude and subjective norms (or their relative weight) in the case of TRA, or PEOU and PU in the case of TAM. However, Davis et al. (1989) dropped subjective norm, i.e. "the individual's perception of a referent other's opinion about the individual's performance of the behavior" (Fishbein and Ajzen 1975, p. 302), from the (initial) TAM model due to its uncertain theoretical and psychometric status (Yang and Choi 2001). According to Moore and Benbasat (1991) TAM's perceived usefulness and perceived ease of use are essentially the same as diffusion theory's relative advantage and complexity.

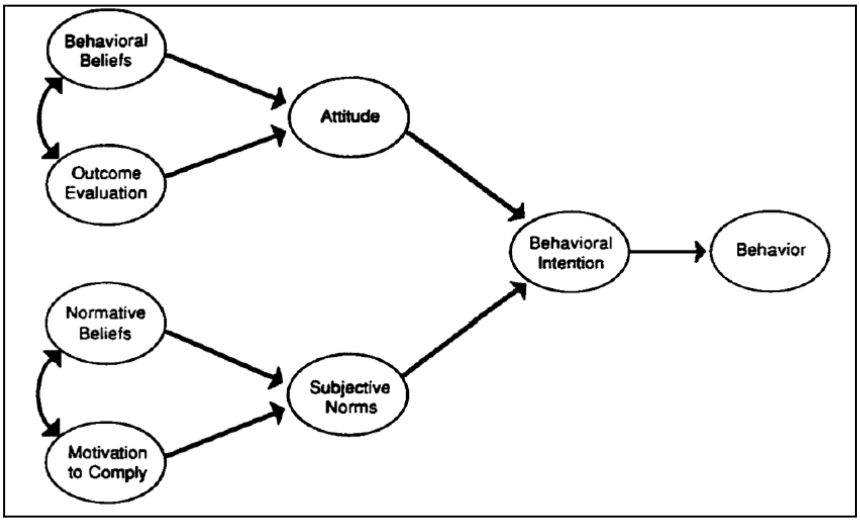

Figure 11: The TRA model

TAM has become very popular; it has been validated across a variety of technologies and study settings (Yi and Hwang 2003) and cited in most of the research that deals with user acceptance of technology (Lee et al. 2003; Chuttur 2009). In parallel, TAM provided a starting point for many extensions and elaborations; many researchers (including Davis) extended/ refined the model (included more variables and reconsidered the nature of relationships (Lee et al. 2003; Chuttur 2009; Lai 2017). Such experimentation yielded the TAM2 model (Venkatesh and Davis 2000; Fig. 12) which is, in turn, largely based on the Theory of Planned Behavior - TPB (Ajzen, 1985; Fig. 13).

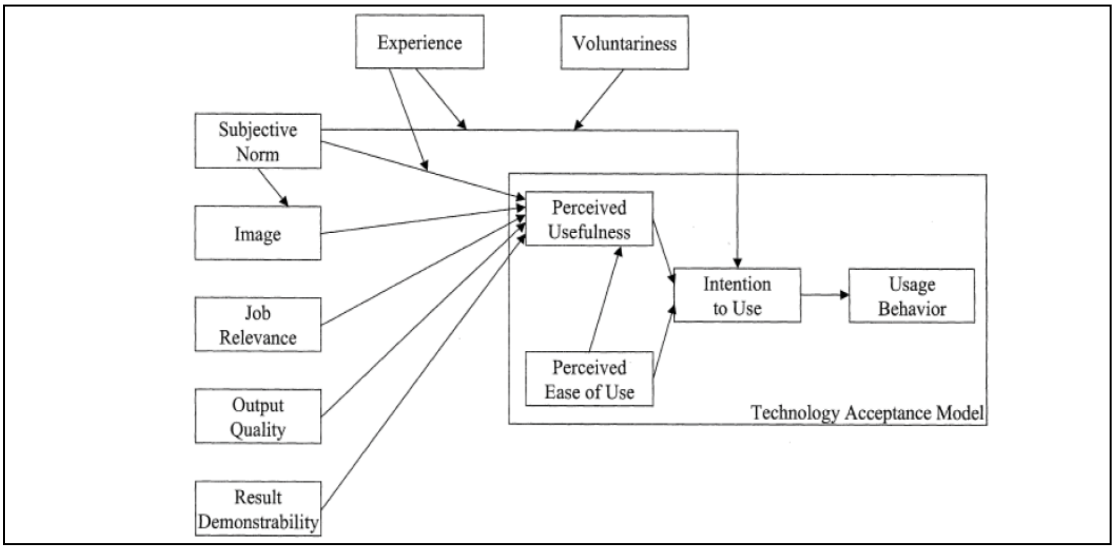

Figure 12: The TAM2 model

TAM2 added two groups of constructs to the initial TAM model; social influence (image, subject norms and voluntariness), and cognitive (result demonstrability, job relevance and output quality), in order to improve the predictive power of perceived usefulness (Taherdoost 2018). The aspiration for TAM2 was to keep the original TAM constructs intact and "*include additional key determinants of TAM's perceived usefulness and usage intention constructs, and to understand how the effect of these determinants changed with increasing users' experience over time with the target system*" (Venkatesh and Davis 2000: 187).

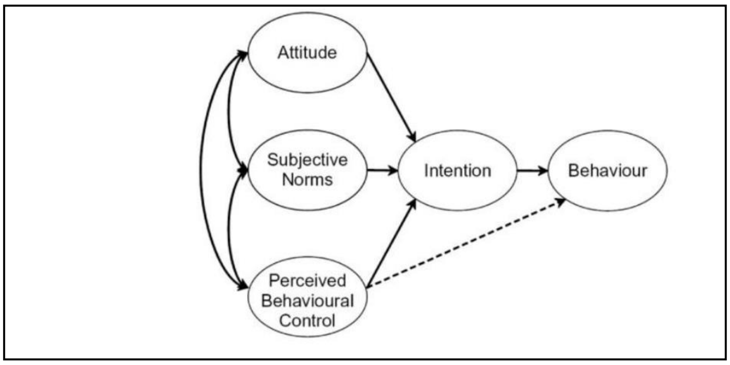

Figure 13: The TPB model

Finally, Venkatesh and Bala (2008) developed an integrated model of technology acceptance known as TAM3 (Fig. 14). In this version four different types including individual differences, system characteristics, social influence, and facilitating conditions are used to determine perceived usefulness and perceived ease of use (Lai 2017). An account of the main constructs and their measurement dimensions used in TAM biomedical studies, according to Holden and Karsh (2010: 165), are shown in Appendix 2.

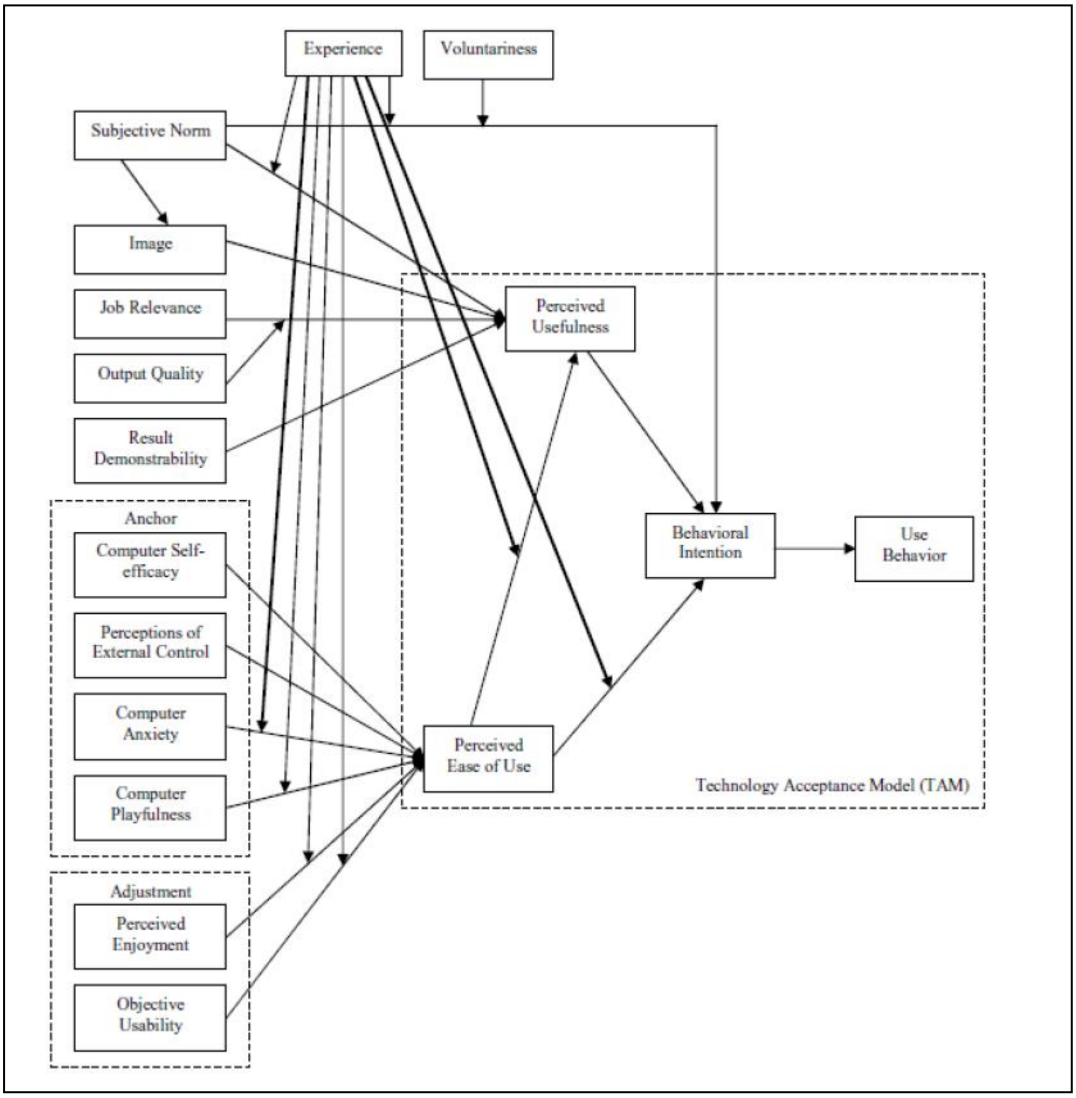

Figure 14: The TAM3 model

4.2 Strategic Niche Management

In neo-evolutionary economics technological evolution is driven by the interaction of social, economic and technological factors (co-evolution); in this respect, 'technological regimes' were defined by Rip and Kemp (1998: 38) as "*the rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artefacts and persons, ways of defining problems - all of them embedded in institutions and infrastructures*". The concept has been further refined (Geels 2004); 'socio-technical regimes' refer to the alignment of the rules (regulative, normative, cognitive) upheld by different social groups centred around a technological regime. The evolutionary approach, occupied with radical innovations resulting in system transformation, has evolved into a multi-level perspective which, besides socio-technical regimes, includes 'niches' and 'socio-technical landscapes'. The latter concern the relatively hard material and immaterial context of societies, with the former being the breeding places of radical innovations (Raven 2005).

The understanding that technologies are embedded in broad and complex systems (regimes) implies that new technologies of a more radical nature, such as the ones concerned with environmental sustainability, require adaptations in all major system parameters (Kemp et al. 1998). Niches then offer (temporary and partial) protected spaces or 'incubation rooms' for more sustainable technologies (radical novelties) to develop and grow. Strategic Niche Management (SNM) is a process approach aimed at modulating the dynamics of socio-technical change through the creation and management of spaces for the use of new technology (Weber et al. 1999).

Within SNM, an important distinction concerns experimental projects and niches (Weber et al. 1999; Hoogma and Schot 2001). While the niche level is a global or field level carried by experimental projects in different locations, the latter experiment with innovation which is either new or radical; thus they may not have the explicit aim to contribute to system innovation in the long run. In any case though, the trajectory towards the establishment of a niche passes through the establishment of local experimental projects. SNM literature defines the following steps for establishing a local project: selection of the most promising candidate technology, identification of the most appropriate experiment, and set up/ implementation of the project.

Relevant research has reached a number of recommendations concerning each of these steps (Caniels and Romijn 2006; Mourik and Raven 2006) as follows. Experiments should start simple and add complexity in later stages, there has to be a change agent championing the innovation and the new technology must be broad enough so that different options are kept open. Following, the experiment has to be chosen so that it constitutes a challenge for stakeholders but which is achievable within a reasonable time frame; on parallel user-producer communication is initiated. The third step basically concerns high-quality learning and network building. These require that the project is set up in terms of documentation (goals, aims, expectations, methodology, rules etc.); existing stakeholders' strengths (knowledge and skills, networks, assets etc.) are utilized within a reflexive experimentation framework (Kemp et al. 1998; Weber et al. 1999); project partners are actively involved and have a sense of ownership over the project; opportunities for interaction of an effective constellation of stakeholders with external actors are provided by a manager who will be able to manage dynamically the network and keep the momentum going.

Niche formation, in general, has been found to consist of three interrelated sub-processes (Raven 2005): matching innovation's promises and stakeholders' expectations, development of experimentation-based learning, and creation of cooperating actor network. Expectations are a means to facilitate the construction of a shared agenda, guide the process and attract resources. The initial voicing of expectations is followed by the shaping of specific and coherent expectations; the shaping of robust expectations takes place concurrently with the formation of a network.

As also seen in the case of AIS approaches, SNM also claims that networks can, among others, facilitate innovation. Nevertheless, the construction of networks is a demanding task. The role of the network manager/ alignment actor (Rip 1995) is extremely important in disseminating information, extending the network and setting up experiments. This actor will have to manage the whole process, provide a space secure enough for partners to voice their expectations, identify the frame of thinking that drives actors as well as to orchestrate the participation of outsiders whose participation may have both advantages and pitfalls.

Finally, learning rests in the heart of the innovation processes and should be an explicit goal of the exercise; niches are important because they provide locations for learning processes. While there is a range of strategies for learning which can be utilised in local experiments, the critical issue concerns the distinction between first- and second-order learning (as seen in previous discussion on Social Learning). First-order (single-loop) learning refers to instrumental issues within a given frame of thinking while second-order (double-loop) learning is reflexive thus leading to changes in the frames of thinking of actors. Most learning processes are single-loop thus oriented at maximising the potential of technology; double-loop learning occurs within heterogeneous networks (bottom-up partnerships) that aim at changing the system (Hoogma et al. 2002).

The SNM framework has been utilized in various innovation studies in a range of fields, including agriculture and food production (Roep et al. 2003; Wiskerke 2003; Wiskerke and Roep 2007; Koutsouris 2008b; see also Barbier and Elzen 2012; Elzen et al. 2017).

4.3 The triggering event

Sutherland et al. (2012) argue that, while minor changes in farming happen incrementally, a change involving the reorientation of a considerable amount of farming activities or resources happens most often in response to 'trigger events'; in other words, a trigger event, i.e. the accumulation of experiences on the part of the farm manager which results in the acknowledgement that a major change in farming activities needs to occur, is usually required in order to instigate a change process. They thus propose the 'triggering change cycle' (Fig. 15) as a way to illustrate the fact that farm managers are usually involved in minor incremental changes to the farm operation, until an event or opportunity occurs which leads to a decision to actively consider a major change.

According to the 'triggering change cycle' conceptualization 'path dependency' (stage 1) means that the system is resilient thus limiting the incentive for major change; only incremental change may occur along the existing trajectory. The 'trigger event' (stage 2) implies that the farm manager encounters or anticipates one or more triggers (e.g. changes) leading to a 'trigger event', i.e. the realisation that system change is necessary. As a result, 'active assessment' (stage 3), meaning that scanning for information and alternative options intensifies, follows, including actions such as the practical assessment (trials) of options and networking. Then, a decision is made and 'implementation' (stage 4) of a 'new system' begins (including financial investments as well as the development of new skills and knowledge and the establishment of new social and business networks). Finally, (all aspects of) the new system' is evaluated and if deemed successful the system is 'consolidated' (stage 5); if not, the farm manager returns to stage 3. This way, if the new system is deemed successful, the process 'returns' to stage 1.

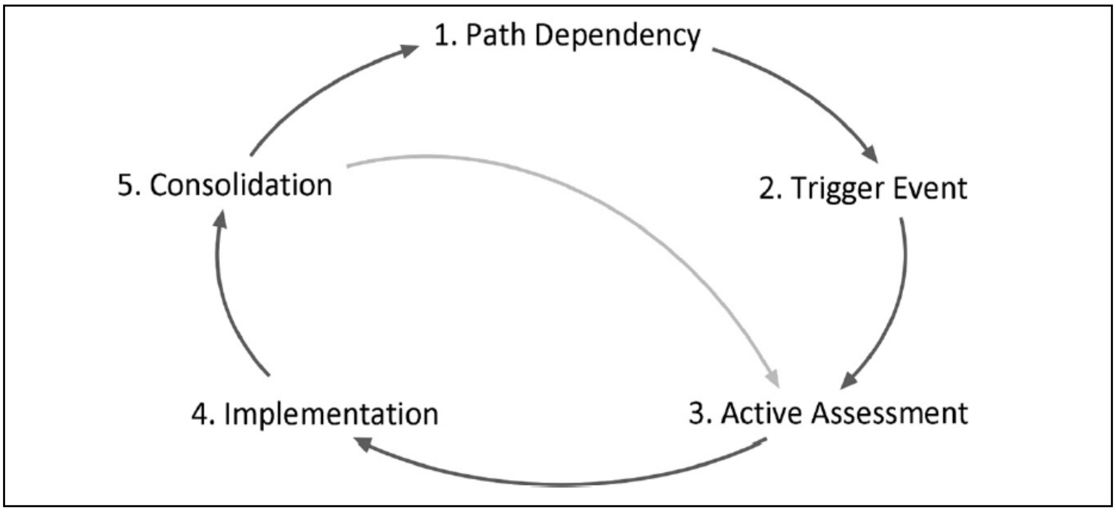

Figure 15: The 'triggering change cycle'

As the authors note, the 'triggering change cycle' conceptualization has many similarities to Rogers' DOI (see section 2) but differs in the identification of 'triggers' and 'trigger events', the iterative and multiple nature of change, and the scale at which change is enacted. They also claim that their conceptualisation addresses the magnitude and complexity of change far beyond DOI especially when dealing with multiple possible 'innovation' options[4] .

5. Renewable Energy Sources

5.1 Introduction

Renewable energy sources - RES[5] (hydropower, biomass, geothermal, wind and solar) represent an alternative to traditional fossil fuels in terms of both reduced impact on the environment and not being subject to depletion while also contributing to the achievement of targets set by the Kyoto Protocol – which, in turn, implies avoiding sanctions for signatory States in case of defaults (Tate et al. 2912, Ghorbannezhad et al. 2018, Rikkonen et al. 2019, Sgroi et al. 2014). However, according to IRENA et al. (2018) multiple barriers (i.e. awareness and capacity; costs; financial; infrastructure; institutional and administrative; market; public acceptance and environmental; and regulatory and policy barriers) inhibit further development and uptake of RES in both developed and developing country contexts. Such barriers vary based on specific markets and renewable energy technologies; moreover, they can overlap, implying that even if one is overcome, others may become apparent.

Following we will focus on on-farm RES, i.e. on the energy generated on farms by using wind, PV, solar thermal, hydro, geothermal or biomass resources. Such energy is generated

[4]The exploration of 'triggering change cycle' is a main pillar of the H2020 project "Agricultural Knowledge: Linking farmers, advisors and researchers to boost innovation (AGRILINK)"

[5] Energy is renewable when the source it derives from is infinite and replenishes itself naturally. Energy is sustainable when it can be used at current rates without depleting supply. Both terms can apply to the same source (Brown et al. 2019).

by installations paid and/or operated by either farms and/or other legal entities (whether owned and/or managed by the farmer or not), and includes:

- primary, intermediate and final RE that is both produced and consumed on the same farm,
- final or intermediate RE that is consumed on one farm but produced on other farms,
- final energy that is produced on the farm and that is exported,
- final or intermediate RE produced on farms from biomass or waste from non-farming activities,
- intermediate and final RE produced not on farms but using biomass or waste produced on farms (Pedroli and Langeveld, 2011).

The most important RES are outlined below.

Solar systems transform radiant energy emitted from the sun into energy that can readily be used, typically through solar panel systems. It is a flexible and scalable RE solution owing to the modular nature of panels within such systems. It is distinguished between small scale (e.g. panels on residential roofs) or large scale (e.g. multi-megawatt solar farms) solutions (Brown et al., 2019)

Photovoltaic (PV) solar systems are widely used due to their relative low cost and their widespread success as well as their incorporation within agricultural operations to offset expenses or generate additional cash flow (Brown et al., 2019). Therefore, there are many examples of integrated systems on farms, which often have large roof surfaces at their disposal, for solar PV electricity generation. According to EIP-AGRI focus group (2018), key to the success of such systems are the proper incentives along with the continuous cost declines of PV systems; on the other hand, key challenges are grid capacity and dealing with fluctuations over the year, which also affects market prices, to which suitable electricity infrastructure and competition with good quality farmland can be added. Furthermore, solar thermal systems are widely used depending on climatic conditions and energy demand on the farm. Again, variability during the year is a challenge and such systems are typically deployed in combination with other heat supply options (EIP-AGRI focus group, 2018).

Wind energy has become competitive on land areas with good wind regimes, i.e. places where the wind blows steadily for sustained periods on a regular basis (Brown et al., 2019). In this respect, the amount of electricity produced by a wind turbine depends on wind speed and wind exposure and electricity output increases with turbine height. Usually small (e.g. up to 0.5 MWe) are more popular at individual farms, although they often have lower revenues and return on investment. On the other hand, larger wind turbines require large investments and such projects are often realised by energy companies with famers leasing their land. Furthermore, electrical infrastructure must be sufficient (EIP AGRI focus group, 2018). Although wind turbines take up far less space as compared to solar systems, i.e. they allow for easier use of surrounding land, they face a number of restrictions, on top of the aforementioned wind speed/ exposure, such as: nearest property line (regulations usually prohibit wind turbines from being placed on the edge of a property), distance to the nearest building (noise can be a limiting factor at very close distances), visibility from heavily populated areas, and bird flight patterns[6] (Brown et al., 2019). Moreover, as EIP AGRI focus

[6] To these, proximity to the nearest airport, as some height restrictions may apply, has also to be considered.

group (2018) note landscape impacts and the resulting opposition by home owners and other actors has to be taken into account; thus, spatial planning and stakeholder engagement, including cooperative models (sharing revenues with local communities), may be crucial for the successful implementation of such projects.

Biomass, according to the Directive 2018/2201[7] concerns the "biodegradable fraction of products, waste and residues of biological origin from agriculture, including vegetal and animal substances, forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of waste, including industrial and municipal waste of biological origin".

According to Bioenergy Europe Factsheet on biomass for energy (2019), agricultural biomass includes the following:

- crops such as corn, sugarcane and beets;
- oilseeds such as several plants of brassica family (e.g. rapeseed), sunflower seed and soybeans;
- agricultural residues such as: herbaceous crop residues such as cereal straw, corn stover, rice straw;
- permanent crop residues, e.g. orchard prunings and plantation removal wood;
- agro-industrial by products, such as olive cake, grape marc and sunflower husks;
- grassy and woody energy crops;
- leguminous crops; and
- animal waste (manure).

Biomass is used for the generation of heat and the production of electricity with a wide range of commercially available technologies. For example, there is a wide range of boilers for the use of wood chips or straw pellets available which can produce hot water as well as heat. Costs of heat supplied mostly depend on the costs of the biomass resource; in general, when biomass residues are available on farm, it can be an attractive renewable energy option to cover farms' needs for heat or hot water. In the case of electricity production, the small capacities needed usually lead to higher costs, unless combined heat and power generation is attractive due to specific on-farm energy needs[8]. Again, costs and environmental performance depends strongly on biomass resources and availability (EIP AGRI focus group, 2018).

Biofuels are renewable energy sources which have shown great potential to serve as a substitute to petroleum-derived diesel. From all types of biofuels, biodiesel is the most common for on-farm production and use as it substitutes diesel fuel, which is the most commonly used liquid fuel in agriculture. Biodiesel is mainly derived from vegetable oils or animal fats by transestefication of lipid acids. Another biofuel of interest is Bioethanol that is an alternative for gasoline fuel, but does not play a significant role in typical European farms. Bioethanol is an alcohol produced by microbial fermentation, mostly from carbohydrates produced in sugar- or starch-bearing plants. Biofuels are categorised based on the type of feedstocks used: the biofuel produced from edible resources is classified as

[7] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=EN

[8] The available technologies also play a role with regard to electricity production alone: overall energy efficiency is fairly low for combustion systems while, on the other hand, gasifier-engine combinations are complex to operate - although they could do better (EIP-AGRI Focus Group, 2018).

the 1st generation while that from non-edible resources is classified as 2nd generation biofuel (Azad et al., 2016). The 1st generation biodiesel is produced from vegetable oils found in arable crops (soybean oil, sunflower oil, olive oil, canola oil, mustard oil, etc.) and the 1st generation bioethanol comes from food crops (corn, sugarcane and wheat, etc.); it is thus somewhat unpopular (and debated) as it competes directly with the food supply leading to increased food price and creating pressure on land usage possibly resulting in increased GHG emissions (EIP AGRI focus group, 2018; Azad et al., 2016). They are commercially available and their use depends on policy targets and incentives as, in general, they are not considered competitive against fossil fuels in the European context. Small-scale pressing of oil crops to produced pure plant oils (PPO) is considered suitable at farm level (for example for machinery fuelling to substitute diesel fuel) although not widely deployed in Europe (EIP AGRI focus group, 2018).

On the other hand, the 2nd generation biofuels are produced from non-edible biomass (jatropha, karenja, beauty leaf oil, castor oil, moringa, waste cooking oil, agricultural wastes, forest residues, organic wastes and various types of biomass); based on non-edible, biodegradable and capable of growing on marginal land plants, the shortcomings of the 1st generation biofuels can be overcome, thus increasing the potential to become a sustainable alternative of petroleum based fuels (Azad et al., 2016). However, most of the conversion technologies, currently at demonstration phase, are complex, capital-intensive and generally not suitable for farm scale deployment (EIP AGRI focus group, 2018).

Biogas is a form of biofuel derived from the decomposition of organic matter such as agricultural waste, municipal waste, plant material, sewage, and food waste. Biogas can be combusted to provide a convenient, controllable, and portable source of energy. It may be fed through a natural gas pipeline, converted into electricity and pumped through the grid, for electricity and/or heat production or as gaseous fuel to power combustion-reliant systems such as diesel trucks, tractors, etc (Brown et al., 2019). In general, there is considerable commercial experience with biomass digesters for varying farm sizes (mostly for manure treatment[9] in intensive dairy and pig farming) with the produced biogas being used directly for heating but also for on-site power generation (or combined heat and power generation) with dedicated gas engines. Nevertheless, according to EIP AGRI focus group (2018), smaller scale digesters in order to be profitable require either policy incentives and/or become integrated with methane emission reduction and nutrient recycling and/or solving organic waste treatment measures.

Geothermal energy is less common among the RES, mainly due to its scattered availability based on local geothermal activity. Nevertheless its applications are important for agricultural and agro-industrial uses, notably in greenhouse heating; aquaculture; agro-industrial processes; and soil heating of open-field plant root systems. In general, direct use applications are more widely available as compared to the use of geothermal resources for electricity generation (Nguyen et al., 2015; IRENA, 2019). Its potential depends, on the one hand, on the underground situation and especially the depth at which good quality heat is available and, on the other hand, on governments' at both national or local levels mechanisms (policy and financial instruments, involvement of local communities and fair distribution of the benefits arising from the geothermal exploitation, etc.). Generally, such projects are complex, require considerable capital and infrastructure and are conditioned by legislation, especially the relevant to groundwater resources protection ones (EIP AGRI focus group, 2018).

[9] Digestion of cultivated crops for biogas production is more controversial (EIP-AGRI Focus Group 2018)

Therefore, farmers can choose among quite a number of alternatives regarding clean energy supply as, for example, the installation of wind turbines, solar panels, micro-hydro schemes[10], etc. on a small portion of their farmland, the utilization of biomass from crop residues, animal manure etc. for gas production, and so on. According to Sims et al. (2015), many of the above mentioned energy production systems could be combined in innovative 'smart grids', comprising a multitude of small generators using local renewable energy resources. Such grids are under close evaluation concerning their suitability for a range of options ranging from agricultural uses (including electric vehicles) to the provision of electricity to remote rural communities.

5.2 Barriers to the diffusion of Renewable Energy Sources

Following, some examples on the barriers concerning the adoption of some RES are presented as found in recent papers and reports mainly addressing developed countries.

5.2.1 Solar energy

Karakaya and Sriwannawit (2015) based on literature review note that, in general, although PV systems have become much more competitive, their diffusion still remains low due to the fact that the cost of PV systems is still perceived as high and also because of barriers related to the policy dimension and technology management.

Research in Austria (Brudermann et al., 2013), addressing the adoption process of PV in the agricultural sector, showed that despite farmers' strong eco-attitudes at the end of the day economic aspects dominate decision making. The so-called network effects (social influence[11]) were found to play a clear role in the adoption process. On the other hand, problems with building permits, lengthy procedures regarding grants as well as changes of subsidized feed-in tariffs were found to be major barriers or constraints to adoption. According to the authors, governments should encourage bottom-up initiatives and support network structures that foster related developments; continue and expand suitable funding policies; and, develop/provide adequate political mechanisms so as to avoid negative rebound effects. Finally, the authors note that an 'unexpected outcome' of their research is that the adoption of renewable technology by farmers increases their belief in technology-based solutions to environmental problems and that all such future initiatives need to be accompanied by specific educational measures in order to minimize such negative feedback effects.

Ge et al. (2017) claim that farm/ farmer characteristics such as young owners or managers; poultry farms; diversified farms (engaged, for example, in tourism, processing of farm products, etc.); farms with a higher percentage of severely disadvantageous area; farms with larger rough grazing area or farms with a higher percentage of owned area are more likely to adopt/install solar panels. The authors especially note that the level of solar radiation on the farm does not seem to be a significant factor in the decision to install solar panels.

[10] Hydro power is the harnessing of energy from the flowing waters that are converted into useful mechanical form thereby generating electricity by using a generator (Jawahar and Michael, 2017).

[11] Implying that as soon as people in one's personal environment adopt PV, barriers to adoption become much weaker.

Based on a case study of a farm that has installed PV panels on greenhouses, in Sicily, Italy, Sgroi et al. (2014) argue that the sudden and unexpected Italian PV development is mainly attributable both to the reduction of the PV installation costs and the high government incentives which, in turn, identified the PV industry as one with low risk and high profitability[12]. They noted that for the target-farm the revenues deriving from electricity sales and especially from the incentive tariff are so important that they represent the majority of farm revenues, thus relegating the agricultural activity to a marginal role.

In their research in Southeastern Spain, Carreño-Ortega et al. (2017) in the first place noted that despite the enormous potential for PV systems, especially in greenhouses, little is being done to exploit it; the authors attributed such a situation to policies which have even restricted its implementation and constitute an obstacle, both for achieving environmental commitments and for socioeconomic development. The authors, estimating that the forecasts and commitments for 2020 will finish far below the initially established objectives, made a plea for precise energy policy strategies to fulfill the commitment for 2030.

In their national look at determinants of adoption of *wind and solar energy* generation on U.S. farming operations, Borchers et al. (2014) found that certain farm characteristics (such as livestock operations, owned acreage, operators with internet access, organic operations, and newer farmers) increase the propensity to adopt solar and wind generation. Furthermore, it was found that certain state characteristics (such as solar resources, per capita income levels, and predominantly democratic voting) increase the odds of farm adoption. The authors recognized the importance of following best practices in the design of policy, and argue for synergies of successful policies (e.g. net metering and interconnection), since policies are most effective when enacted in combination. Finally, the authors suggested that some types of farms may be more sensitive to policy instruments which, along with the suggestion that unequal application of renewable energy policies may impact the farm sector, imply the need for a careful evaluation of the possibilities of heterogeneity on policy influence by farm-level characteristics.

Research focusing on farm operated *wind and solar* installations[13] in California, Beckman and Xiarchos (2013) found that environmental practices (organic or conservation techniques), size, Internet connection, tenure and residence on farm as well as higher electricity prices positively influence renewable energy adoption. Contrarily, age (or longer time in farming) and income share are found to have a negative influence on adoption. The authors also noted that a cattle farm has a higher probability for adopting renewable energy, while the probability of adoption decreases for fruit operations. With regard to the size of the installed system the authors claim that it is determined by economic factors such as the total value of production, acre value, the presence of a hired manager, whether farming is the operator's primary occupation and other distinct characteristics[14] but, surprisingly, not by the price of electricity. Finally, the authors underlineδ the need for

[12] The authors note that such a success was not anticipated by the government who had to continuously reshape legislation aiming, among others, to avoid financial speculations and paying at great cost the growth of PV sector.

[13] Excluding methane digesters since, according to the authors, along with being limited to livestock producers, they are also very large investments, typically installed by the largest operators.

[14] The authors mention the following examples: conservation practices increase the probability of adopting a commercial size system while organic operations have a higher probability of adopting small and off grid systems; larger systems are installed on fruit operations, but the probability of adoption is low; cattle and organic operations with higher probability of adoption, adopt small systems sizes.

further research on the influence of resource availability and installation costs which would add further insight on the economic incentives for renewable energy adoption.

Research on solar and wind system adoption on US farms (Xiarchos and Lazarus, 2013), examined how adoption is influenced by economic (energy prices[15]) and policy factors (RPS[16], net metering[17], interconnection[18], financial incentives[19]). The researchers noted that although technology adoption is an individual choice determined by specific farm-level characteristics, analysis at State-level can explain underlying variation in adoption rates at that level and even inform micro-level analysis. Their results suggest that States with more organic acres per farm and more Internet connectivity have higher adoption rates. Higher solar electricity adoption rates were found where energy price and solar resource were higher. Electricity price influenced State adoption rates for wind systems. In general, distinctions between wind and solar energy are not dramatic. Among the policy variables examined only RPS showed a large and systematic effect on State adoption rates.

5.2.2 Wind energy

In the first place, it has to be noticed that according to Sims et al. (2015), in 2012, wind energy costs in Europe were estimated at around 10% higher than coal- or gas-fired energy plants.

Furthermore, Ge et al. (2017) claim that, in Scotland, farms in high latitude; on land with high wind speed; with large crop and fallow land; large mixed agricultural land or large improved grass land or large sheep flocks are more likely to install wind turbines while those engaged in tourism are not. Similarly, USDA-SARE (n.d.) suggest to potential investors of small wind electric systems, on top of estimating their needs for electricity and the returns, to be sure that there is enough wind, that they have enough space and that towers are allowed in the neighbourhood or rural area (or that the terrain is flat with no tall obstacles nearby).

Research in North East Scotland (Sutherland and Holstead 2014) showed that farmers undertake wind energy production in order to increase their long-term economic viability through business diversification and profitable capital investment; environmental considerations although included in farmers' rationale were not of primary importance. Economic risks and transaction costs were found to be the main obstacles to turbine development; thus some farmers chose to reduce turbine size or rent land to developers. According to these authors, the increasing complexity and uncertainties associated with establishing a turbine development threatens on-farm wind energy production; the risk that the appropriate sites for turbine development will be occupied by non-local owners (such as

[15] I.e. electricity and petrol prices. Of course, the economics of a renewable energy installation are also dependent on the resource potential available for energy production.
[16] Renewable Portfolio Standards (RPS) require a minimum amount of renewable electricity sales, or generating capacity, that electricity utilities must achieve according to a specified schedule of dates and mandates.
[17] Net-metering policies are aimed at small-scale distributed generation installations. Those policies allow utility customers with renewable energy systems to be compensated for electricity generated in excess of what they consume.
[18] Interconnection standards stipulate the technical specifications and procedures by which the renewable energy systems will connect to the distribution grid.
[19] Tax incentives, rebates, and grants encourage the use of renewable electricity by making its installation more cost effective.

large-scale energy companies), leading to the loss of a potential economic boost for local economies is also underlined. On the other hand, on-farm renewable energy production may lead to increased environmental awareness among farmers, thus to more economically and environmentally sustainable agricultural practices.

In their exploration of the economics of small wind turbine installations on a dairy farm in Michigan, Harsh et al. (2010) noted that, given the wind resource is sufficient, the federal tax and U.S. Department of Agriculture incentives as well as state policies such as net metering can make wind turbines a good investment.

5.2.3 Biomass

According to Sims et al. (2015) the costs of delivering supplies to an agri-food conversion plant vary widely depending on scale, average transport distance, and type of biomass; thus, they can be significant. The collection and storage of animal wastes and crop residues on the farm implies costs while energy crops have relatively high costs since they include production, harvesting, transport, and storage costs.

According to Ge et al. (2017) biomass energy systems are more likely to be adopted by farmers/ farms with characteristics such as: younger managers; farms with owned land; large mixed agricultural or rough grazing land area; engaged in commercial forestry, farm products and wood processing or in providing tourism, accommodation and leisure as well as in case the occupier of the farm spends time on other paid work; or, if the household consumes more than half of the value of the farm's production.

According to Bourguignon (2015) the use of biomass feedstocks to produce heat, electricity and transport fuels poses a number of challenges. Such challenges include the availability of biomass as a resource, the possibility that burning will have detrimental impacts on air quality, the probability that the removal of residues may have an impact on soil properties and the risk of biodiversity effect through biomass extraction. Beyond considerations of resource-efficiency, the report also points to the lack of consistency between EU bioenergy, forest and waste policies; the partial reflection, in incentive schemes, of GHG emissions from bioenergy; and the absence of coherent sustainability regulation at EU level regarding biomass for electricity and heat.

A recent report by Bioenergy Europe (2019) also addresses the challenges pertaining biomass use for energy production. Biomass mobilization is reported to be key for further deployment; the disperse nature of biomass implies that advanced logistic systems must be optimized. Solutions such as measures to support increased agricultural productivity (with attention for soil and ecosystem services), the mobilization of unutilized potentials (contaminated or abandoned lands), the improvement of harvest logistics in favour of the establishment of regional clusters for the sharing of harvesting and baling equipment and storage facilities, the provision of incentives to local supply chains (for both residues and energy crops), and the creation of forms of agro-industrial integration, such as integrated biomass logistics centres, are thus proposed. Another important barrier is agro-biomass quality, given its extreme variability especially when it comes to residues or herbaceous material. This creates both legal uncertainties and market barriers. Therefore, the promotion of good practices throughout the agro-biomass value chains to maintain proper quality, the further development of technical standards, the introduction of certifications and the conversion of low quality material to intermediate product are recommended.

Especially important for the current review are the knowledge gaps mentioned in the report. The proposed solutions to overcome such a barrier include (the financing of) capacity building projects as well as research projects, the dissemination of information on incentives, best practices in relation to the quality of energy crops and agricultural residues, best available technologies and biomass valorisation opportunities, thus promoting bioenergy value chains.

The last barrier included in the report concerns the value chain in the sense of low market prices and tight profit margins for residues which lead to suboptimal residue collection. To overcome such a barrier different measures may be adopted, such as addition of more value onto farm residues, economies of scale, the promotion, standardization and certification of agro-biomass fuels, the provision of incentives (appropriate legislative measures and dissemination of best practices) in relation to residues demand, the improvement of harvest logistics and the highlighting of intangible benefits achieved through agro-biomass utilization (e.g. avoidance of pollution from open-field fires, creation of sustainable image for local communities and products, etc.).

Research in central France (Bocqueho and Jacquet, 2010) concluded that under the particular agronomic and economic conditions switchgrass and miscanthus for biomass are less profitable than traditional cropping systems (rape/wheat/barley rotation). Nevertheless, the authors argue that the two crops can become highly competitive as diversification crops when appropriate contracts are offered to farmers, despite the additional liquidity they require.

With respect to the adoption of energy crops, as argued by Khanna et al. (2017), it involves two decisions: to grow or not to grow and how much land to convert from a status quo use to the energy sector. The authors state that through their experiment in the U.S. (Illinois, Indiana, Kentucky, Missouri, and Tennessee) they found robust evidence that high discount rates, high upfront establishment costs and need for crop-specific investments create disincentives for adoption and allocation of land to energy crop production. Contrarily, contracts that impose lower upfront costs and crop-specific investments on a farmer are more likely to lead to participation by farmers and to more allocation of land to an energy crop; furthermore, low-quality land is more likely to be converted.

Research in south-west Scotland (Warren et al., 2016) addressing the case of SRC (short rotation coppice) willow as an energy crop showed that while farmers do not oppose in principle to the concept of SRC willow production, they regard it as a financially risky, overly committing and inappropriate crop for their farms; thus, even large potential profits would be insufficient to persuade many farmers to adopt SRC. Such an overwhelmingly negative attitude on the part of the farmers is related to their identity, lifestyle, farming culture and the perceived priority of food production. In this respect, the authors claimed that there is need for policies which are more precisely tailored to the motivations, viewpoints and risk perceptions of the target audience. Moreover, given the heterogeneity of farmers, no incentive or policy design will be equally persuasive for all.

To such considerations, Sherrington et al. (2008) in their UK based paper added that farmers need trusted information to make decisions, which predominantly come down to financial considerations at an individual farm level.

Research in Southern Spain (Giannoccaro and Berbel, 2012) has shown that features such as the farmer's engagement in off-farm employment and education level as well as farm's specialization and the size of land owned affect the adoption of energy crops on farm. To these the authors add the farmer’s expectation about market price and job opportunity which affect the profitability of food and fibre crops in general and thus energy crops.

5.2.4 Biofuels

According to Christou et al. (2018), although biofuels can contribute to climate change abatement their potential is much lower than the potential for electricity generation from PV and wind power while also requiring larger land areas. It is therefore argued that biofuels can be a solution under specific circumstances, particularly in the case of biomass production on arable land. It is argued that both pure plant oil and biodiesel (although the second one requires a little higher production effort) can be seen as complementary pathways to energy self-sufficient farming while other fuels (biogas, bio-methane, etc.) could become additional complimentary solutions insofar current obstacles (i.e. poor effective energy density of gaseous fuels; poor efficiency; high economic efforts of transformation processes in the case of advanced biofuels) could be overcome. Furthermore, the focus group underlined the need for full tax exemption and exemption from restrictive requirements and bureaucratic procedures in order to promote sustainable use of biofuels for fuelling agricultural machines.

On their part, Azad et al. (2016) reviewed the socio-economic aspects of sustainable biofuels in Australia pointing to a number of barriers and incentives. As far as barriers are concerned, technological challenges emerge as one of the most important pointing to the need for more sophisticated technology making possible more advanced biofuel/biodiesel production. In parallel, on the one hand, the availability and continuous supply of feedstocks and, on the other hand, the price of biofuel (as compared to petroleum diesel), were identified as important factors. In this respect the authors proposed that government should play an important role to promote biofuels by publicity (i.e. raising awareness to use biofuel) and the development of appropriate policies and rules (as for example some price compensation).

Callahan and Grubinger (2015) run a project work on the adoption of biomass fuels for heating (clean burning bio-mass furnaces) vegetable greenhouses in Vermont and showed that growers’ receptivity to change declines when fossil fuel prices stabilize or decline as well as when regulatory or marketplace incentives for carbon reductions are lacking (although growers are aware of, and generally concerned about, the contribution of fossil fuel combustion to GHG emissions). Furthermore, the difficulty to use any alternative biomass fuel available, as it may be technically illegal (i.e. not officially endorsed), poses a problem to growers. The short length of the heating period is another problem as it implies that the payback period is longer than it would be if the systems were operated for more time each year (in case of multi-purpose use of heating systems). Moreover, technical assistance to correctly size, install and control the systems was found to be critical to the growers. Finally, it was noted, that a grower’s proposal for the establishment of a growers (learning) group to facilitate continued learning and sharing of knowledge and experiences was welcome by project leaders.

Research in Spreewald region (Germany) exploring the likelihood that farmers would install a biomass plant on their farms and their reasons for accepting or rejecting it (Busse et al., 2019) showed that acceptance is relatively low. The proponents of biomass plants stated an ethical acceptance of and interest in technology, a need for a new heating system, the availability of sufficient feedstock, and a perceived unproblematic readiness of technology—all these factors in combination. On the other hand, refusers stated one of the following:

ethical concerns about ‘burning hay’, satisfaction with current oven, low availability of feedstock, or a perceived low readiness of technology. Other factors affecting adoption were the existence of procedural justice, trust in coordinating actors, and a demonstration plant.

The assessment of the economic feasibility of rapeseed Pure Plant Oil (PPO) use as a self-supply agricultural biofuel in Italian context (Viccaro et al., 2019) showed that two factors are especially important: on the one hand, EU aids which, by reducing risk, can help to promote inland biofuel production and, on the other hand, the establishment of farmers' associations which can create an optimum-sized supply chains and, given the high cost of the initial investment, can make such investments profitable. According to the authors, agricultural policy would further support the promotion of sustainable biofuel production if, besides the support to the initial investments, it incentivized energy crop cultivation by promoting conservation agricultural practices. Overall, the authors believe that, given the barriers to large-scale (next generation) biofuel production, PPO produced in small-scale in local cooperatives can be used as self-supply agricultural biofuel. This result is supported by Ettl et al. (2018) who state that using rapeseed oil fuel instead of diesel fuel offers a huge potential for reducing GHG emissions.

Through an expert survey, Ettl et al. (2014) converged to the same conclusion. They state that PPO and biodiesel have reached the highest technical level of development (high operational reliability, low engine wear, advanced emission behavior and good compatibility to exhaust gas after-treatment technology), regarding renewable fuels with an existing infrastructure; thus, in short or medium term especially PPO and biodiesel are rated to substitute fossil diesel in tractors, reduce GHG emissions and increase regional added value significantly. Furthermore, PPO is particularly suitable for regional production on a smaller scale with high added value. They also showed that, in line with other literature, experts agree that rapeseed oil according to current knowledge is the best way to drive tractors sustainably with biodiesel reaching nearly the same level of consent.

The authors believe that in order to increase the share of PPO used in agricultural machinery relevant measures must be taken at European level, including: the harmonisation of taxation of fossil diesel fuel used in agriculture and forestry; tax incentives for biofuels, used in the agriculture and forestry sector; investment grants for PPO compatible agriculture and forestry machinery; public relation work and consultation/engagement of all stakeholders – notably farmers; and, of course, increase of fuel efficiency and saving of fossil fuels

Recent experimentation in Bavaria by Emberger et al. (2021) indicates that it is technically possible to operate a modern forest harvester with PPO from rapeseed in compliance with emission requirements thus contributing to climate, soil, and water protection in forestry. Recent research (Ettl et al., 2020) also indicates that the usage of locally produced pure rapeseed oil fuel in plant-oil-fuel-compatible agricultural machines seems to be possible despite uncertainties concerning both economic aspects and the long-term operation reliability and limited exhaust emissions which currently hinder market entry.

An evaluation of the alternatives[20] against the dominant diesel-fuelled internal combustion engine for non-road mobile machinery (Remmele et al., 2014) also showed that the use of rapeseed oil fuel and biodiesel in internal combustion engines for agricultural and forestry work machinery is most advantageous for more climate protection and resource saving and

[20] Including electrical drive with energy supply via fuel cells with hydrogen or using accumulators.

is simultaneously rapidly applicable. In this respect, long term reliable policies[21] are deemed necessary in order to support the application of rapeseed oil fuel and biodiesel in agriculture and forestry without economic losses; this is, in turn, foreseen to incentivize the agricultural machinery industry to develop climate and resource protecting machinery.

5.2.5 Biogas

In the case of biogas power plants, Sims et al. (2015) argued that feed-in tariffs paid for electricity which cannot be used on-farm, can be crucial for economic operation; this is so, unless there is a cost avoided from not having to dispose the organic waste feedstock, or as a result there are more reliable electricity supply systems than the national grid can provide in many rural areas. The authors maintained that biogas plants can be operated more economically if there is also a profitable use for the heat; unfortunately, in most cases the local heat demand is found to be insufficient.

According to Brown et al. (2019), in California, on top of biogas inherent benefits, it is important that governments create strong incentives for the implementation of biogas energy facilities. This is so since there exist many regulatory and permitting obstacles (which despite the fact that they aim to ensure the safety of natural gas users makes biogas distribution much harder) as well as challenges in transporting natural gas from the farm (e.g. remote dairies) to the end user.

Research exploring the incentives influencing the adoption of anaerobic digesters in the USA (Sam et al. 2017), in the first place, pointed to past research according to which anaerobic digestion (AD) systems need constant monitoring and management while successful farm owners with AD systems have greater mechanical knowledge and access to technical support; the best farms for AD systems raise cattle, hogs, or poultry[22] and the ones which raise larger herd sizes; farms in warmer climates are better for AD systems; profitability of on-farm AD systems depends on the farm’s ability to sell electricity at a favorable wholesale price to a utility and operating the on-farm power-generating unit at near or full capacity as well as to herd size. The authors distinguished between the financial (including grants and loans, performance-based incentives, and tax incentives) and the regulatory incentives (e.g., interconnection standards can be established to allow renewable energy to be connected to the electricity grid) provided by the states. These are discussed in detail for the period 2002-2014 to conclude that the implementation of Renewable Portfolio Standards (RPS), performance-based incentives (such as feed-in tariffs), and other mandates for increasing the consumption and purchase of renewable energy are more effective at encouraging the adoption of AD systems than interconnection and net metering[23] as well as that continuing support at the state level is crucial for the growth of AD systems in the US.

In their examination of biogas production in Germany, being considered one of the most influential innovations in German agriculture in recent decades, Appel et al. (2016)

[21] Here, the German Energy Tax Act is cited, according to which fuels from biodiesel and rapeseed oil or other vegetable oils are supported by complete reimbursement of the energy tax (although, it is estimated that, currently, this does not represent a competitive advantage for the regenerative fuels biodiesel, rapeseed or other vegetable oils).

[22] Farms with stable year-round manure production, esp. manure with less solid content, and in which approximately 50% of the manure is collected on a daily basis are better for AD systems.

[23] Net metering is a way for residential and commercial customers who generate their own electricity from AD systems to feed excess electricity back into the grid.

concluded that, due to the strong political support provided[24], biogas production became an attractive investment opportunity, especially for large (in terms of size and financial resources) farms, leading, on the one hand, to a boost in biogas production and, on the other hand, to distortions within the agricultural sector, including increasing land rental prices. The latter threatened smaller biogas farms as well as farms that were not able to invest in biogas; additionally, since a significant share of the value added is transferred via increased rental prices to land owners, on average, biogas farms could not increase their profitability. In this respect, the amendment of the previous German Renewable Energy Act (REA) in 2014, which reduced support levels substantially, partly attenuated some of these effects. Nevertheless, according to the authors, the previous policy will cast a long shadow. Finally, the authors wondered on whether policies that would ease investments for smaller and less competitive farms, mainly through the provision of additional subsidies for smaller plants, are justified given the increased guaranteed support required for smaller investments which in the end has to be paid by someone as well as side effects like higher land prices.

In their research in Europe (Germany, Denmark, Netherlands and Austria) and the USA, Bangalore et al. (2016) argued that the observed differences in the adoption rates of agricultural AD is the outcome of differences in policy incentives, notably the feed-in tariff rather than comparative technological advantage or abundance in feedstock availability. In this respect, the stable financial support of a feed-in tariff [25] provided to investors in agricultural AD, particularly in Germany, led to wide adoption. The authors noted that capital investments (the upfront capital costs.) are barriers to adoption and use of agricultural AD among farmers and thus recommended that governments should design, on the one hand, regulations that increase the cost of pollution and, on the other hand, a stable policy overtime that subsidizes investment in renewable technologies (i.e. feed-in-tariffs).

In their global review of AD for biogas, Vasco-Correa et al. (2018) underlined the differences found worldwide with respect to the implementation of AD technology which they attributed to a complex set of conditions including the economic and environmental implications of the technology and the stimuli provided by a variety of polices and incentives. The authors, beyond technological limitations and feedstock availability, identified a number of financial challenges and risks (high capital and long-term operation and maintenance costs including equipment, labour, and training) and argue in favour of a variety of incentives[26] to offset them, generate revenue and facilitate AD technology to compete against established technologies. According to their review, the primary factor influencing the steady growth of AD technology, in both developing and developed countries, has been 'regulations and incentives'. Such policies and regulations can be classified into three categories: renewable energy-related policies and regulations; comprehensive agricultural regulations; and, waste management-related policies (Figure 16).

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[24] Guaranteed feed-in tariffs (which mean a guaranteed price for the delivered electricity) for a period of 20 years and priority access to the electricity grid provided strong incentives for farmers to invest in biogas plants.
[25] Feed-in tariff (FIT) is a policy mechanism designed to accelerate investment in renewable energy technologies by offering long-term contracts to renewable energy producers.
[26] Such as: feed-in tariffs (FiTs), credits for carbon reductions, credits for renewable energy, credits for renewable transportation fuel, credits for nutrient load reduction, payments for producing renewable heat, and tax exemptions.

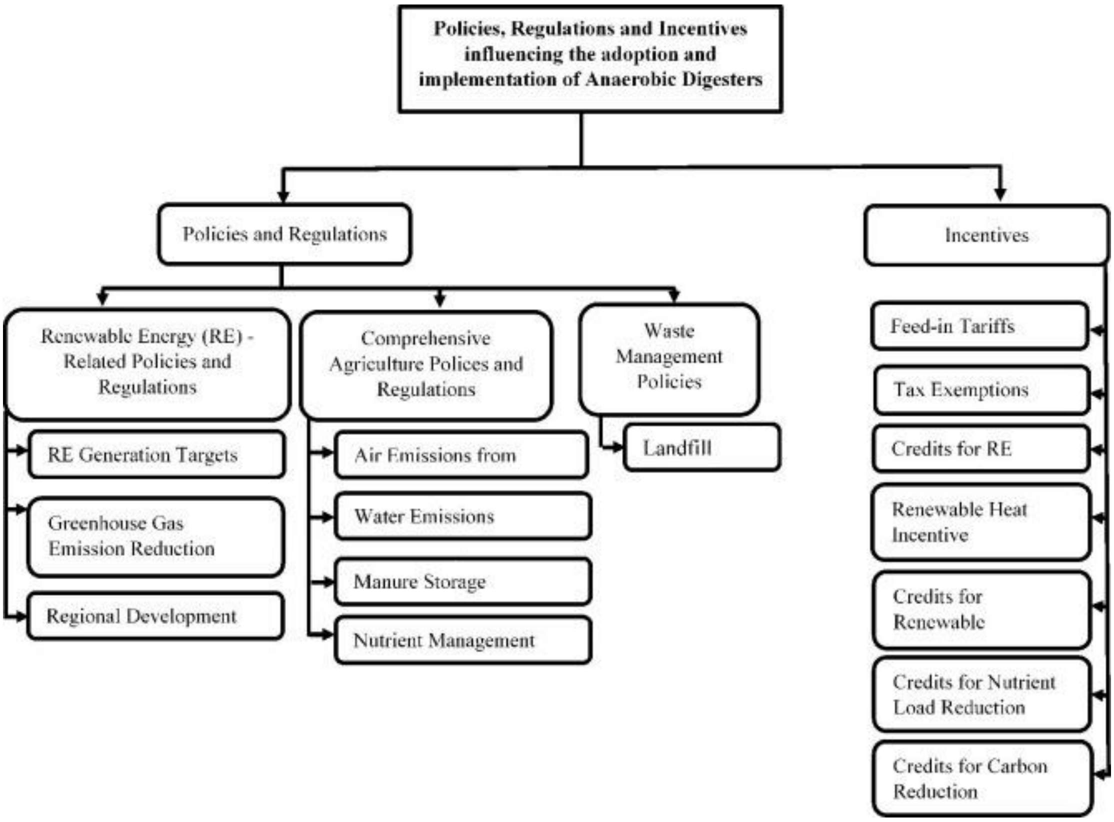

Figure 16: Policies, regulations and incentives

In a recent research exploring the factors behind the limited uptake of on-farm AD in the UK's Midlands region (Ackrill & Abdo, 2020), in the first place, the authors reviewed the barriers identified by previous AD research in the UK such as set-up costs (costs of infrastructure and required equipment), an uncertain and unstable policy environment affecting returns, lack of effectiveness of various funding schemes and incentives, lack of information about AD, community objections, suitable market infrastructure, and note that critical for AD adoption is economic viability, itself conditional on a regular supply of feedstocks. They distinguished the barriers identified through their own research into political and institutional, AD awareness, and economic and technical (Table 3).

Table 3: Barriers to on-farm AD in the East Midlands

Main Themes	Sub-Themes
Institutional and Political Barriers	Planning and regulatory complications Multi-level governance (MLG) complications Opposition of local communities Stability of regulations and regulatory measures
Awareness of AD	Awareness of AD technologies and regulations Awareness of UK government's RE incentive measures
Economic and Technical Barriers	Supply of feedstock to on-farm AD Grid connectivity Availability of finance Type and size of farms and farming business

Based on this analysis, they propose a range of incentives and policy responses to increase on-farm AD uptake, notably, coordinated information gathering and dissemination, streamlined planning processes, improved access to finance, and stable policies. It is worth mentioning that research interviewees also argued for help to bring farmers together so as to benefit collectively from AD units as well as for the availability of smaller AD units.

Exploring the role of energy policy in agricultural biogas energy production in the Visegrad countries[27], Chodkowska-Miszczuk et al. (2017) concluded that although the adoption of the relevant legal framework was necessary to enable agricultural biogas energy production it was not enough to stimulate significant developments in agricultural biogas energy production; the latter was achieved only after the certain financial support systems took effect making, in turn, the production of agricultural biogas energy economically efficient for investors.

Older research (Wilkinson, 2011) came to similar results for Germany. The authors argued that the German experience suggests that regulation on its own was not sufficient to encourage large numbers of farmers to invest in AD; it was the introduction of generous feed-in-tariffs for renewable energy which promoted investment in on-farm AD. They further pointed out that increasing construction costs and the rising cost of energy crops can put the financial viability of AD plants at risk even under such favourable incentive schemes; to avoid unsustainable costs of such schemes they pointed to the need for efficiency improvements in AD. Meanwhile the authors made some interesting points; first, that the farming system in Germany, i.e. the fact that biomass production based on the use of manure slurry and bioenergy crops (e.g. maize for silage) is complementary to intensive animal production, played a critical role in the diffusion of on-farm AD plants; second, that AD systems have helped German farmers comply with the EU Nitrates Directive (91/676/EEC) and third, that cultural factors (production-oriented German farmer's identity) also played a role in the rapid adoption of AD. The range of factors that may influence the adoption of on-farm bioenergy systems is illustrated in Table 4.

Table 4: Drivers and barriers associated with the adoption of on-farm bioenergy systems

Description	Scale
Geopolitical	Regional, national, supranational and international
Environmental policies – International treaties; Climate change mitigation; Public health; Waste management.	
Energy security – Self-sufficiency and diversification of risk.	
Agricultural policies – Rising costs of farm subsidies, quotas and support programmes.	
Farm systems	Local, regional.
Compatibility of existing farm systems and associated infrastructure with bioenergy technology; Human skills and educational development; Access to R&D and technology providers.	
Social	Local, regional and national.
Quality of life – environment, health and education.	
Social cohesion – mitigation of rural depopulation, regional development and rural diversification.	
Values and cultural patterns – compatibility with farmers' values, goals and aspirations.	
Economic	Local, regional and national.
Regional, national level – employment, income and wealth creation; Regional growth and development; Trade balance and export potential; Increased productivity and competitiveness; Labor and population mobility; Improved infrastructure; Induced investment; Support of related industries.	
Local level – Access to soft loans, infrastructure grants, premium tariffs and other financial incentives; Profitability of existing farm business and opportunities for future income generation.	

[27] Czech Republic, Hungary, Poland and Slovakia.

For Ettl et al. (2014) the lack of infrastructure is a significant barrier for the use of gaseous fuels like biomethane in agriculture and forestry. According to Thuneke et al. (2016), experiments in Bavaria have shown that the retro-fitted dual-fuel technology allowing simultaneously use of biomethane or natural gas and diesel as ignition fuel was welcomed by the staff who operated it. They also showed that operating range in dual-fuel mode might be one hurdle in everyday use while a gas filling station nearby is an important precondition. According to the researchers, further optimisation potential is suspected.

5.2.6 Geothermal

According to FAO (Nguyen et al. 2015), agricultural uses are a very important part of overall geothermal energy application and this potential has stimulated the direct application of geothermal energy in many south-eastern European countries. FAO underlines the role of the public sector in geothermal energy development in promulgating the necessary policy coordination and legislation and in providing fiscal incentives to attract investors. Governments allocate geothermal resources and coordinate funding, facilitate exploration for geothermal resources, fund feasibility studies and promote research regarding geothermal energy's potential uses.

Furthermore, the report identifies three major constraints and challenges to the use of geothermal energy (focusing on developing countries): policy and regulatory barriers; technical barriers; and financial barriers. The first ones include (the lack of) clear government policies and legislation in terms of creating an enabling environment for geothermal investment and resource mobilization and in encouraging investments; the lack of financial resources to make the necessary investments in geothermal exploration and utilization including the restricted budgets devoted to R&D and, (the lack of) the right institutional framework, and coordination and consultation among relevant stakeholders. Technical expertise and infrastructure to support geothermal systems are referred to as the major technical barriers. With regard to financial barriers, besides the abovementioned lack the financial resources to enable investments in the development of geothermal systems, one of the main barriers to geothermal energy investments is the high upfront cost of geothermal energy technologies. To these, the challenge of providing technologies and services to consumers at affordable prices, while ensuring that the industry remains sustainable must be added.

In the same vein, according to IRENA (2019), the wider adoption of all geothermal energy applications is restricted by a variety of barriers, including high upfront investment, risk related to the appraisal of geothermal resources, inadequate policy and regulatory frameworks, and a shortage of qualified workforce. It should be also taken into account that there might be lack of awareness of geothermal direct use and its benefits and/or long distances between the geothermal heat consumer and the geothermal wells that may not be economically viable, unless a single large or several smaller customers (presenting heat demand profiles matching the temperatures of the geothermal resource) are located nearby.

Despite the fact that, for IRENA, there is no one-size-fits-all approach, and regulations and policies must be adapted to the local contexts and market maturity, their analysis of the experience of countries that have successfully deployed geothermal energy or are at an early stage in the journey, clearly shows that public policy plays a crucial role in creating the conditions for private investment. Such a role implies the establishment of adequate and transparent licensing procedures (re: exploration, development, construction, and operation phases) covering all geothermal applications; the development of tailored policy instruments and support schemes (such as non-recoverable grants, convertible grants or guarantee funds) to address key financial barriers; the integration of geothermal energy in development and industrial plans, along with the involvement of local actors and the promotion of partnerships to attract industry to settle near the geothermal area; the provision of support to pilot projects and feasibility studies in order to improve knowledge of the geology and assess compatibility with specific productive activities; the development of capacities (re: limited experience of public authorities and shortage of qualified workers) for downstream direct use operations; ensuring the wise management of the resource for long-term environmental and economic sustainability (including the reduction of relevant to these sustainability pillars social resistance); and, the support of international cooperation and the facilitation of insight sharing about technical, policy, regulatory and financial solutions[28].

5.2.7 Aftermath

In general, based on the preceding literature review, the adoption and diffusion of RES is constrained due to a number of barriers which can be summarized as follows:

a) technical barriers, i.e. resource availability, technology (design, installation and performance), skill requirements (personnel);

b) awareness and capacity barriers, i.e. lack of sufficient information and knowledge about RES (including training programmes);

c) economic barriers, i.e. costs and financial issues (high upfront capital/investment costs and lack of relevant financial tools/products for RE enterprises, availability of (investment) subsidies) and low profit margins for farmers;

d) market structure (inconsistent pricing structures for renewables, distortions in market power, low fossil fuel prices, fossil fuel and nuclear subsidies, and a failure to incorporate social and environmental externalities into costs);

e) policy uncertainty (bad policy design, discontinuity of policies, unfavourable or inconsistent policies);

f) institutional and administrative barriers (absence of clearly defined responsibilities including administrative decentralization; difficulty with land acquisition; complicated, slow, lengthy or opaque processes - re: planning, licensing, permissions, etc.);

g) infrastructure barriers, i.e. availability of needed infrastructure to incorporate renewable energy into the energy system (grid integration, weak grid infrastructure, lack of required upgrades for transmission and distribution infrastructure, lack of district heating or adequate cooling infrastructure, absence of appropriate engines in vehicle fleets);

h) socio-cultural barriers, i.e. societal structure, norms and value system, public acceptance (on a socio-political, market, and community level), risk perception, behavioural or lifestyle issues as well as many personal and psychological factors (age; social class; educational attainment; political belief; environmental concern;

[28] For the government's grants for geothermal heat in the Netherlands, see https://www.government.nl/topics/renewable-energy/government-stimulates-geothermal-heat

perceived fairness; trust; time to research, find, consider, apply for, and implement clean energy technology; level and sources of income) and peer effect; and

i) farm location and conditions, i.e. location/climatic and geographic conditions, farming system and type of land tenure, connectivity, planning restrictions, financial viability of the farm/enterprise.

6. ENERGY EFFICIENCY IN AGRICULTURE

Following a literature review, some of the main energy efficiency technologies and (best) practices, including sustainable agriculture and climate-friendly practices, are outlined.

For FAO (2011), the reduction of the amount of energy used per unit of food produced throughout the entire food chain (energy intensity) depends upon behavioural changes, the development and deployment of more low-carbon farming and fisheries practices, and new technologies with improved energy efficiency specifications. The report takes notice of the fact that in the past, given that energy costs have been a small component of the total operating costs for many food businesses, incentives to reduce energy demands have not been strongly promoted. Nevertheless, today, there is renewed interest in improving energy efficiency as energy costs have increased and more businesses set targets to reduce their carbon footprints. Moreover, they underline that opportunities to reduce the energy intensity can come from modifying at no or little cost existing farming and processing practices, requiring, in turn, behavioural changes. Another option is the introduction of new modern efficient equipment which, nevertheless, may require significant capital investment not available by farmers. For the authors, energy conservation and efficiency measures can be achieved in several ways at all stages along the food chain summarized in Table 5. Finally, it is argued that context specific situations must be taken into account with regard to the application of energy efficiency alternatives (e.g. while high tech and capital intensive options may be suitable for large scale systems, increasing direct and indirect energy inputs over time in order to improve productivity and water use efficiency with a view to support agro-ecological farming practices may be more appropriate for small scale systems).

Table 5: Examples of energy efficiency improvements

	Directly	Indirectly
Behind farm gate	• Fuel efficient engines / maintenance. • Precise water applications. • Precision farming for fertilizers. • Adopting no-till practices. • Controlled building environments. • Heat management of greenhouses. • Propeller designs of fishing vessels.	• Less input-demanding crop varieties and animal breeds. • Agro-ecological farming practices. • Reducing water demand and losses. • Energy efficient fertilizer and machinery manufacture. • Electronic identification of fish stock locations and markets.
Beyond farm gate	• Truck design and operation. • Variable speed electric motors. • Better lighting and heat processes. • Insulation of cool stores. • Minimizing packaging of food. • Technology transfer and education. • Improve efficiency of cooking devices.	• Improving road infrastructure. • Reducing food losses at all stages. • Matching food supply with demand. • Changing diets away from animal products. • Lowering obesity levels. • Labelling of food products.

Source: FAO, 2011

The Commission Staff Working Document (2016) on energy efficiency policy points to market and regulatory failures which, in turn, imply that large amounts of cost-effective investments in energy efficiency will not take place. Such failures and barriers include: information failures; split incentives; short investment horizons in both companies and households; lack of awareness of the 'business case behind energy efficiency investments'; high transaction costs for small projects; capital market failures; and, lack of clear signals for companies to become actors in an energy efficiency market.

In his paper concerning the role of various actors in the USA (federal government, states and private entities) with regard to energy efficiency in agriculture, Levine (2012) underlined the existence of 'numerous' barriers such as variations in geography, climate and industry structure along with a lack of information and access to the capital needed to implement efficiency upgrades. He therefore claims that putting together federal programs to address these barriers are important in driving the market towards efficient equipment and practices. The author further commented on the success of Rural Energy for America Program (REAP), the largest and most successful program, which helped large numbers of farmers to recognize the importance and benefits of becoming more efficient. Funding for REAP is divided into programs for energy efficiency and renewable energy system improvements, energy audits, and feasibility studies. According to the author, energy audits are one of the most important ways efficiency can be promoted, as they allow farmers to assess how much energy their operations consume and identify target areas for improvement. The author concluded that a combination of federal, state, local, and private sector investments, can promote efficiency improvements thus reducing energy use and improving the overall function of America's agriculture.

According to Beckman et al. (2013), in their USDA report, various conservation programs provide economic incentives—including financial incentives, technical assistance, and education for farmers—to adopt practices that conserve on use of energy and other inputs. It is noted that, assuming the cropping mix is fixed, the extent to which producers can substitute away from energy-related inputs without compromising output levels depends on the availability of alternative production practices and technologies. In the USA, adoption has been most probably induced through higher energy prices and favourable policies and funding. The latter include State-level production mandates through a Renewable Portfolio Standard, Federal and State tax credits, USDA conservation programs (e.g., funding for farm-based RES operations) as well as net-metering and interconnection standards which are especially suitable for small, customer-scale generation such as that occurring on farms.

In Germany, according to Meyer-Aurich et al. (2012), the introduction of the Renewable Energy Sources Act in 2000 and the accompanying extension of bioenergy production had a great impact on the structure of agricultural production in terms of the sharp increase of the number of farms integrating biogas-plants as well as of raising demand for land and associated land use conflicts/competition. The authors suggest that following DESTEP demographic, economic, social, technological, ecological and political) analysis the factors related to energy efficiency can be illustrated as in Table 6.

The analysis of these factors in Germany led the authors to the identification of potential drivers and their importance on energy efficiency in agriculture as shown in Table 7.

Table 6: Factors related to energy efficiency in agriculture

External factor	Factor related to energy efficiency in Ag
Demographic and social	• Demographic change and impact on agricultural sector
Economic	• Energy market (price, supply)
Technological	• Technological developments
Ecological	• Environmental impact of agriculture • Climate change
Policy	• Legislation (CAP) • Funds

Table 7: Potential Drivers and their importance on energy efficiency in agriculture

Driver		Importance	
		Short Run (< 3 years)	Long Run (> 5 years)
Demographic drivers	•Demographic change and impact on agricultural sector		minor
Economic drivers	•Energy market (price, supply)	medium	
Social drivers	•Farm structure •Level of education and research		minor
Technological drivers	•Technological developments		medium
Ecological drivers	•Environmental impact of agriculture •Climate change		medium
Political drivers	•Legislation (CAP) •Funds	major	

Through their stakeholders' analysis the authors pointed to the fact that although farmers have an intrinsic interest of energy saving in agriculture, their interest to invest in energy saving technologies may be constrained by financial liquidity or alternative opportunities for capital investment, especially in renewable energy systems on farms (wind, solar, biogas), due to the incentives provided by the Renewable Energy Sources Act. Overall though, energy efficiency in agriculture was not found to be a very important issue for stakeholders[29] involved in this research. The authors underline the crucial role that education and access to information (especially through extension services) can play in raising farmers' awareness on on-farm energy efficiency; research funding of energy efficient technologies in agriculture may also contribute.

Diakosavvas (2017), in his OECD report, first, pointed to the fact that, although adoption of no-tillage techniques is rising rapidly in several countries, it has not been 'mainstreamed' by farmers or policy makers. This owes to a number of factors hindering greater adoption which include: insufficient knowledge about the practice; farmer attitudes and aspirations; lack of appropriate machines; lack of suitable herbicides to facilitate weed management; the high opportunity cost of crop residues for feed; lack of herbicide-tolerant crop varieties for some crops and climates; and inappropriate policies.

[29] That is, farmers (including their organizations); governmental institutions, non-governmental institutions (NGOs), and industry and consumers.

Furthermore, he noted that the adoption of precision-agriculture technologies is limited to only a few countries and sectors, in particular amongst large-scale arable farms in Europe, the United States and Australia. Main obstacles to further dissemination are: knowledge and technical gaps, high start-up costs with a risk for insufficient return on investment, as well as structural (e.g. small farm size) and institutional constraints.

With regard to the obstacles contributing to the limited uptake of energy-efficiency opportunities, the author ascertained that they are multiple, including: subsidised pricing of energy, inadequate pricing of energy-use externalities, a shortage of financing, imperfect information, organisational inertia with respect to energy-efficiency investment opportunities by stakeholders in both the private and government sectors and systematic behavioural biases in consumer decision making.

According to the author, there are four broad groups of barriers that can be identified: structural, behavioural, availability and policy (Table 8, 9).

Structural barriers encompass issues such as, on the one hand, limited know-how on implementing energy-efficiency measures (including low educational attainments and ageing) and, on the other hand, fragmented and under-developed supply chains. Behavioural barriers include situations in which limited awareness or end-user inertia inhibit the pursuit of an opportunity or lead the decision-maker to making a decision based on imperfect information (for example, lack of reliable information on costs and benefits and limited awareness of energy consumption differences). Availability barriers include situations in which the decision-maker is interested in and willing to pursue a measure, but cannot adequately access it as, for example, lacks capital. Policy barriers pertain to policy-induced market distortions which result in market conditions hindering energy efficiency (for example, energy subsidies encouraging excessive energy consumption or reduction of incentives for investment in renewable energy).

Table 8: Challenges associated with pursuing energy efficiency

Fundamental attributes of energy efficiency
- *Low-mind-share*: Improving energy efficiency is rarely the primary focus
- *Difficult to measure*: Evaluating, measuring and verifying savings are more difficult than measuring consumption, impairing investor confidence

Opportunity-specific barriers
- ***Structural***
  - *Human capital*: Ageing farmers, impeding adoption of potential energy-efficiency technologies
  - *Insufficient knowledge*: Limited know-how on implementing energy efficiency measures
  - *Fragmentation*: Fragmented and under-developed supply chains
- ***Policy***
  - *Pricing distortions*: Regulatory, tax or other distortions
- ***Behavioural***
  - *Risk and uncertainty*: Regarding ability to capture benefit of the investment
  - *Lack of awareness/information*: About product efficiency and own consumption behaviour
  - *Custom and habit*: Practices that prevent capture of potential
- ***Availability***
  - *Capital constraints*: Inability to finance initial outlay; limited access to capital for energy efficiency investments
  - *Technology availability*: Insufficient supply or low diffusion of technologies
  - *Installation and use*: Improperly installed and/or operated

Opportunity-specific solution strategies
- *Information and education*
- *Incentives and financing*
- *Third-party involvement*

Components of an over-arching strategy
- *Recognise energy efficiency as an important energy resource*
- Identify methods to *provide upfront funding*
- *Forge greater aligment* among stakeholders
- *Foster innovation adoption and development of new energy-efficient management practices and technologies*

Table 9: Key barriers to energy efficiency and potential policy responses

	Barrier	Effect	Remedial policy tools
Awareness	Evaluating, measuring and monitoring energy efficiency is difficult	Opportunity not visible to decision-makers, impairing investor confidence	Measurement protocols and efficiency metrics; benchmarking; audits and reporting
	Low awareness of the value of efficiency	Energy efficiency is undervalued.	Raising awareness and communication efforts; information and education
Policy	Policy-induced market distortions	Market conditions do not encourage efficiency	Removal of energy subsidies and other market distortions
	Energy market failures	Environmental externalities	Emissions pricing (tax, cap and trade)
	Unfavourable perception or treatment of risks	Financing cost of efficiency projects is inflated, or energy price risk is under-estimated	Better information on project and energy price risks, mechanisms to reduce efficiency project risk
Structural	Limited know-how on implementing energy-efficiency measures	Energy efficiency implementation is constrained	Capacity building programmes
	Fragmented and under-developed supply chains.	Efficient opportunities are more limited and more difficult to implement	Programmes aimed at better market integration and overall economies Forge greater alignment among stakeholders
Availability	Inability to finance initial outlays; liquidity constraints; limited access to capital for energy-efficiency investments	Under-investment in efficiency	Financing and loan programmes to stimulate capital supply for efficiency investments; support of new efficiency business; and financing models
	Technology availability and diffusion	Insufficient supply Low diffusion of technologies	Foster innovations and diffusion of technologies through R&D tax credits, public funding and incentives for early market adoption
Behavioural	Lack of awareness and information about food-consumption efficiency and own consumption behaviour.	Food waste	Education, information, product standards

6.1 Agricultural machinery

With reference to the energy efficiency of machinery, Pichlmaier et al. (2013) argued that it is dependent on many aspects, as it includes not only the efficiency of the prime source itself but also machine and process operation. Furthermore, the driver competence and performance to operate the machine efficiently has a huge impact and thus needs to be enabled and maintained. The three areas of vehicle, process and operator efficiency are shown in Figure 17.

Moreover, the EIP-AGRI focus group on on-farm renewable energy (Segerborg-Fick and Engstroöm, 2018) argued for electromobility in view of the automatization of farm work and precision farming which, in turn, enables sustainable intensification. For the success of such an endeavour the group considers that research is required on: a) the business models (farmers' independence), b) infrastructure (fats charging and battery capacity), c) logistics (efficient transport systems), and d) demonstrators and demonstration farms to develop, test, and to create market pull for the new technology.

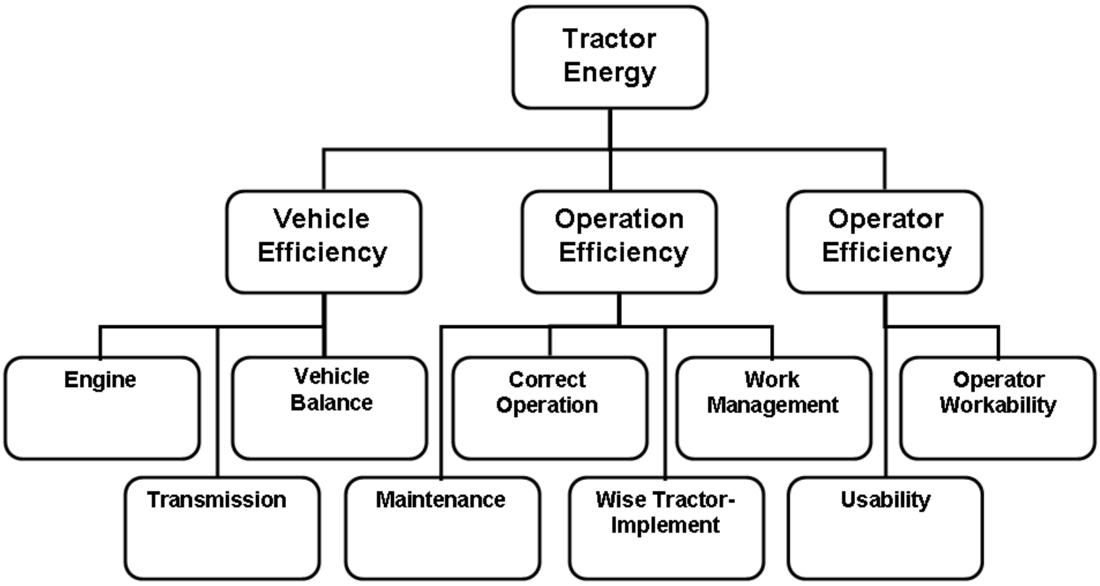

Figure 17: Aspects of machinery efficiency.

With regard to controlled traffic farming (CFT) [30] Chamen (2015) distinguished between short term and permanent barriers. Among the latter, inertia as well as the need for more discipline and planning with CTF and devising ways of improving in-field efficiency were considered of major importance. Short-term constraints included farmers' mindset (limited belief that change can be made) as well as the lack of appropriate machinery. The author pointed to the need for researchers and farmers to work in partnership in well funded projects as well as the need for extension to be involved in dissemination of CFT which has thus far relied on dedicated individuals.

Chamen et al. (2006), based on the drivers for and obstacles against CFT adoption raised by a farmer group (actively engaged in assessing the pros and cons of CFT based on their 18-month involvement in a field assessment and demonstration on a commercial scale) categorized them into benefits, concerns and barriers. Benefits include reduced production costs, increased yields, improved cropping reliability (particularly with low input systems and spring sowing), greater flexibility in cropping (including more spring-sown crops), improved timeliness, improved soil structure and drainage, reduced need for subsoiling, reliable way of cutting costs without risking yield, improved water infiltration and elimination of overlap for all operations. The main concerns refer to issues such as the realisation of CFT benefits in practice and on a farm scale, farmers' know-how (e.g. how to set out fields, get the tracks in the right place first time and keep them there), permanent tracks perform in wet conditions, dealing with straw, reliability of satellite guidance systems and delivered accuracy, consistency – need to have a simple and easily followed system, incompatibility between crops, crop row spacing and machinery systems and warranty issues with axle extensions carried out on farms or by non-licensed third parties.

Finally, identified barriers concern the incompatibility of existing equipment, the costs of conversion, mind-set (famers cannot conceive that CTF has any benefits to deliver or perceive it too difficult to convert to CTF), CTF not being on many people's agenda, farmers'

[30] Controlled traffic farming (CTF) restricts compaction to precise traffic lanes, where it improves wheel performance, allowing natural, uncompromised soil processes and productivity over most of the field.

attitude (not wishing to be an early adopter and taking a wait-and-see position), lack of capital to change, difficulty to see the negative outcomes of compaction in the main body of fields, partners not having the same objectives or lacking key machines in the case of share farming, the need for contractors to have equipment that matches all customers' needs, incorrect association of CTF only with min till and direct drilling and extra discipline and planning needed.

According to Pickel (2019) although subsidy policies can stimulate the uptake of environmentally beneficial technologies and practices with regard to agricultural machines, it is more important that these are stimulated by market.

6.2 Buildings

Next some examples on research concerning greenhouses and livestock with regard to energy-efficiency in buildings are outlined.

According to Cuce et al. (2016) heating demand represents 70% to 80% of the total energy consumed by a conventional greenhouse, due to the poor constructional features and insufficient thermal resistance of facade materials utilized in greenhouses systems. Through a comprehensive review focusing on key strategies of energy saving and climate control technologies for greenhouses, mainly renewable and sustainable based solutions[31], the authors concluded that up to 80% energy saving can be achieved through appropriate retrofitting of conventional greenhouses with a pay-back period of 4–8 years depending on climatic conditions and crop type. Furthermore, the authors insist that novel energy-efficient, low-cost and eco-friendly solutions are definitely required for farmers to minimize their cost on cultivation and thus to maximize their profits.

On their part, Iddio et al. (2020) in their review of existing strategies on energy efficient control operation for greenhouses, argued that, due to the complex nature of greenhouse microclimate, energy-efficient operation requires the use of appropriate sensors with their cost and accuracy still posing a barrier to full adoption by everyday growers. Additionally, growers from small to medium-sized greenhouses or indoor growth facilities require low-cost systems. The authors concluded that the cost, reliability, and accuracy of these sensors could be further improved.

In an older paper, Campiotti et al. (2012) argued that while the integration of renewable energy resources and technologies (geothermal, biomass and PV technologies) into existing greenhouse agriculture represents a great opportunity in European horticulture, the documentation of the technical and economic performance and reliability of local available renewable resources as well as the of impact of renewable energy installations on greenhouse horticulture productivity and agriculture territory are still pending. The authors believe that the governments and the authorities should encourage growers and companies by providing incentives to improve the energy efficiency and to foster the application of renewable resources.

[31] Such as photovoltaic (PV) modules, solar thermal(T) collectors, hybrid PV/T collectors and systems, phase change material (PCM) and underground based heat storage techniques, energy-efficient heat pumps, alternative facade materials for better thermal insulation and power generation (heat insulation solar glass, PV glazing, aerogel and vacuum insulation panel, polycarbonate sandwich panels), innovative ventilation technologies using pre-heating and cooling(high performance wind catchers)and efficient lighting systems

Although not addressing agriculture, Owen et al. (2013) propose the following scheme, as shown in Figure 18, in relation to the adoption of air-source heat pumps (ASHPs) which can respond to the dual challenges of tackling fuel poverty and reducing carbon emissions.

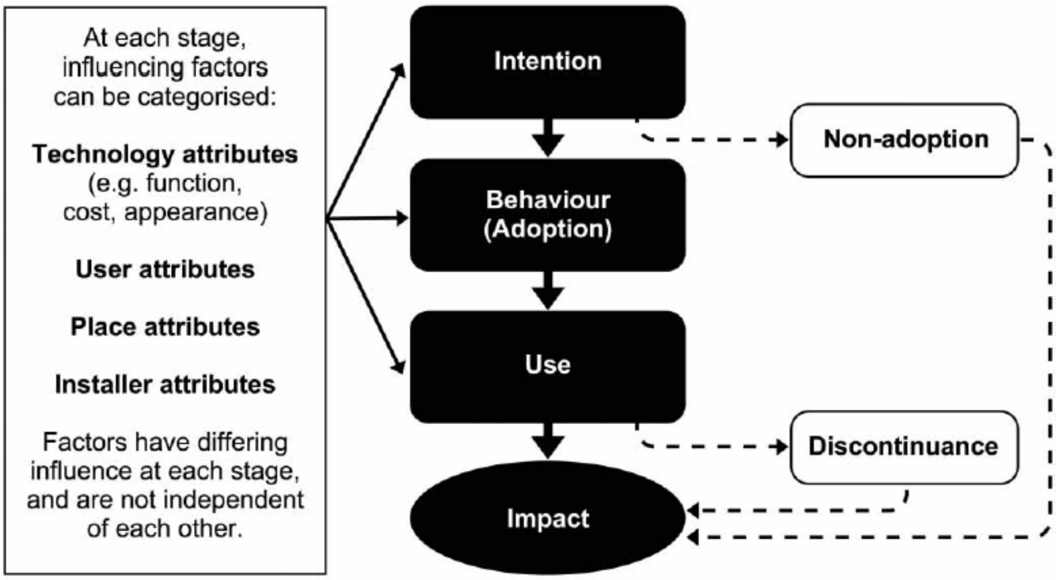

Figure 18: Conceptual framework for the adoption, use and impact of domestic green technology

6.3 Precision Agriculture

With regard to precision agriculture relevant literature reviews can be found in the respective deliverables of the Smart-AKIS (Kernecker et al. 2016) and INNOSETA (Koutsouris and Kanaki, 2018) projects. Therefore, below some indicative literature is outlined.

Schimmelpfennig (2016) in his USDA report aiming to estimate factors associated with Precision Agriculture (PA) technology adoption rates and the impacts of adoption on profits, claimed that labour and machinery used in production and certain farm characteristics, like farm size, are associated with adoption as well as with two profit measures, net returns and operating profits with the impact of these PA technologies on profits for U.S. corn producers found to be positive, but small.

Using primary information from 971 arable crop growers across five countries (Belgium, Germany, Greece, the Netherlands and the UK) Barnes et al. (2019a) found that besides size and income differences (reflecting the economic cost barrier to adoption of PA, i.e. high cost entry) and age (probably reflective of literacy in operation of more computationally intense machinery), an attitudinal difference, in terms of optimism towards the technology's economic return, leads to higher adoption probability. Other positive drivers include farmers' innovative and information seeking behaviour as well as subsidy (such as income support payments under the Common Agricultural Policy, which provide a hedge for risk taking and therefore, indirectly, support adoption of newer technologies) and taxation. Finally, for the authors, more indirect interventions, such as informational campaigns and, in general, investment in learning (by extension/advisory services to fill industry's support gap), notably demonstrations in different regions and contexts to prove the viability of economic return, may be highly effective.

Based on the same sample, Barnes et al. (2019b) further explored the intended adoption of PATs. Results indicate that the main barriers to intended adoption focus on the high cost element of the initial investment, leading to longer payback periods and limiting returns and uncertainty towards the potential for improved profitability to recoup this investment. Additionally, non-adopters were found to have more belief in their knowledge of field topology and being generally older than current adopters. Those among the non-adopters who claimed that intend to adopt PA technologies (PATs) in the future are more favourable to a wider range of incentives than current adopters, especially with regard to economic certainty of investment and payback periods, a factor to be taken into account at policy level.

Therefore, the authors argued that to increase adoption of PATs a range of financial and non-financial incentives is needed. With regard to non-adopters the provision of technical support or training is recommended. For those already using PATs, regulatory pushes appear to determine their willingness to further adopt PATs, including other than direct agricultural regulation and infrastructural frameworks, such as rural broadband coverage and the supporting data analytical services.

With regard to livestock, based on a survey undertaken in 2015 in Australia Gargiulo et al. (2018) aimed to identify the relationship between herd size, current precision technology adoption, and perception of the future of precision technologies. The authors argued that larger dairy farms are more keen adopters since an increase in the average herd size implies increased labour (re: availability, cost, skill level, and efficiency) and animal management pressure (re: routines and protocols to monitor and manage larger scales of operation) on farmers, thus potentially encouraging the adoption of precision technologies for enhanced management control. The authors also pointed to the need for greater clarity to ascertain farm system-level benefits (both monetary and non-monetary) associated with the use of some precision technologies, to minimize investment uncertainty for farmers and to guide technology development.

Based on a systematic literature review of studies on determinants of adoption of PAT in order to build a conceptual framework that consolidates the determinants of adoption of PAT by farmers, Antolini et al. (2015) concluded that the adoption drivers of major influence are related to socio-economic, agro-ecological, institutional, technological and behavioural factors, sources of information and perception of the farmer as shown in Table 10.

Authors' review concerning the factors influencing PAT adoption led them to propose that producers with larger farms, higher level of education, who are younger, have other sources of income besides agriculture, with greater availability of financing sources, who participate in associations and cooperatives, have more access to sources of information about PAT, have a positive perception regarding the use of PAT (including simplicity) and have the opportunity to experiment the technology on a smaller scale are more likely to adopt PAT. Additionally, adoption is influenced by negative past experiences and difficulties in adopting certain technology (negatively) as well as by the crop type.

Research addressing the main socio-economic determinants of adoption of precision agriculture in Denmark and Germany (Tamirat et al., 2018) showed that farm size, farmer age and demonstration and networking events like attending workshops and exhibitions significantly influence farmers' adoption decision adoption.

Table 10: Determinants of PAT adoption

Categories	Variables
Socioeconomic Factors	Age, Education, Family Size, Activity Experience, Ability to obtain and process information, network, credit, risk aversion, producer organization level, farm management
Agro-Ecological factors	Land domination, farm specialization, total area, revenue, variable rate fertilizer application, livestock sales, asset / liability ratio, value of production, yield, corporate structure, income, and farm profitability, quality of soil,% of primary crop of the total area, % of the total area harvested area, % of the farm area divided y municipal area, activity / non-agricultural employment and others.
Institutional Factors	Distance from the fertilizer distributors, Region, using of future contracts, development pressure and distance to the main market.
Information Sources	Access to information sources, use of consultants, perceived extension services in the implementation of agricultural practices and other.
Farmer Perception	Perceived profitability with the increased use of technology and importance of PAT (current and future).
Behavioral Factors	Producer behavioral profile; Intention to adopt variable rates technology for input application
Technological Factors	Type of adopted technology, computer use, farm irrigation structure, prescription use of inputs made on the farm.

Research (Thompson et al., 2029) evaluating large commercial crop farmers' (crop acreage of 1,000 acres or more) perspectives of four key PATs (variable rate fertilizer application, precision soil sampling, guidance and autosteer, and yield monitoring) in terms of the benefits they provide to their farms (increased yield, reduced production costs, and increased convenience) suggested that farmers recognize that management time and effort will be required to fully leverage and implement a profitable precision agriculture system as well as that producers' perceptions are also affected by the technologies they use. In this respect, PAT developers and marketers need to evaluate each technology vis-à-vis farmers' decision-making rationale to adopt them or not; for example, convenience attributes vs. cost reduction or yield improvement can influence technology adoption. This is also true for PA educational programs which also need to consider the perceived benefits that, from the farmers' point of view, these technologies provide.

Lima et al. (2018) in their assessment of the uptake of Electronic Identification (EID) technology among English and Welsh farmers argued that farmer's beliefs are expressed through three factors: external pressure and negative feelings, usefulness and practicality as illustrated in Figure 19.

They argued that legislation involving a mandatory aspect of EID tagging lacked an overall approval of the sheep industry which, in turn, made non-adopters (overwhelmed by complexity or scepticism in future ability of technology) to declare that the government puts pressure upon farmers to adopt technology (while adopters found EID as practical and useful and believed in the usefulness of the EID technology in terms of benefits related to health, productivity, veterinary consultation, abattoir feedback, traceability and breeding value). It is worth mentioning that adopters comprised farmers with higher information technologies literacy and intending to intensify production while flocks managed with EID tools had significantly lower farmer- reported flock lameness levels. The authors conclude that the adoption of EID technology is influenced by three correlated factors: `practicality', `usefulness' and `external pressure and negative feelings' and suggest that communication campaigns stressing the positive effects EID tools on flock performance and strengthening farmer's capability in use of technology are likely to enhance the uptake of this technology in sheep farms.

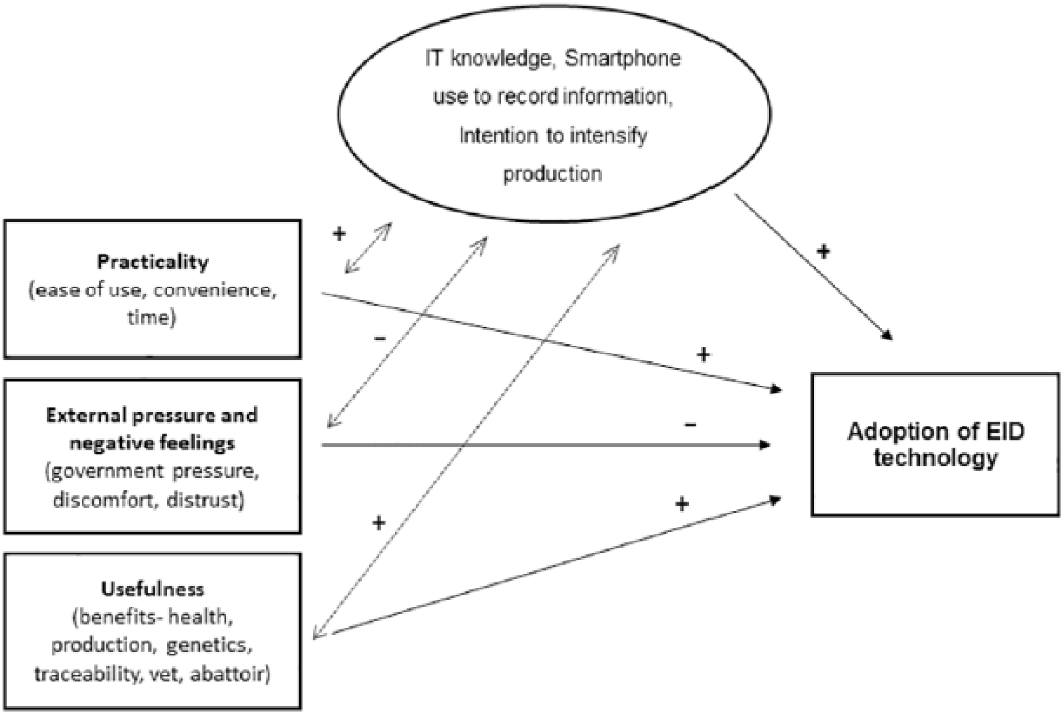

Figure 19: Framework obtained from results of this study with regards to factors associated with EID technology adoption (+ and ± signs indicate direction of associations).

Rose et al. (2016) in their investigation of the factors affecting the uptake and use of decision support tools by farmers and advisers in the U.K. named fifteen factors which are influential in convincing farmers and advisers to use decision support tools, as follows. First, according to the analysis of interviews with both farmers and advisors a number of core factors was identified: performance expectancy (perceived benefit in terms of decision-making and productivity); ease of use; peer recommendation; trust (i.e. the use of tools from trusted sources on the part of the farmers and the evidence- base behind tool development on the part of advisers); cost (including the fact that tools were more likely to be trialled if they were free or if a grant was provided for purchase); habit (i.e. the regular tendency to make a decision in a particular way); relevance to user (i.e. tailored to the farmer's situation); and, farmer-adviser compatibility (i.e. knowledge exchange between the two groups). Additionally, the analysis revealed a number of modifying factors, i.e. factors which do not directly affect behavioural intention to use a decision support tool but modify the strength of the core factors, which in turn affects uptake. These are: age; scale of farming; farming type; and, IT education. The authors also identified facilitating conditions (i.e. whether the farmer can actually use the DSS which was found to depend on the possibility of mismatch between tool and end user workflow, poor internet access and phone signal, and compatibility with existing systems) which they group under the enabling factor. Finally, they identified a number of driving factors: compliance (i.e. the tool helps in terms of legislative or market requirements); level of marketing; and, manufacturer presentations. The authors emphasized that two driving factors are particularly influential and seem to outweigh many other factors: level of marketing and compliance. The analysis is illustrated by the authors as shown in Figure 20.

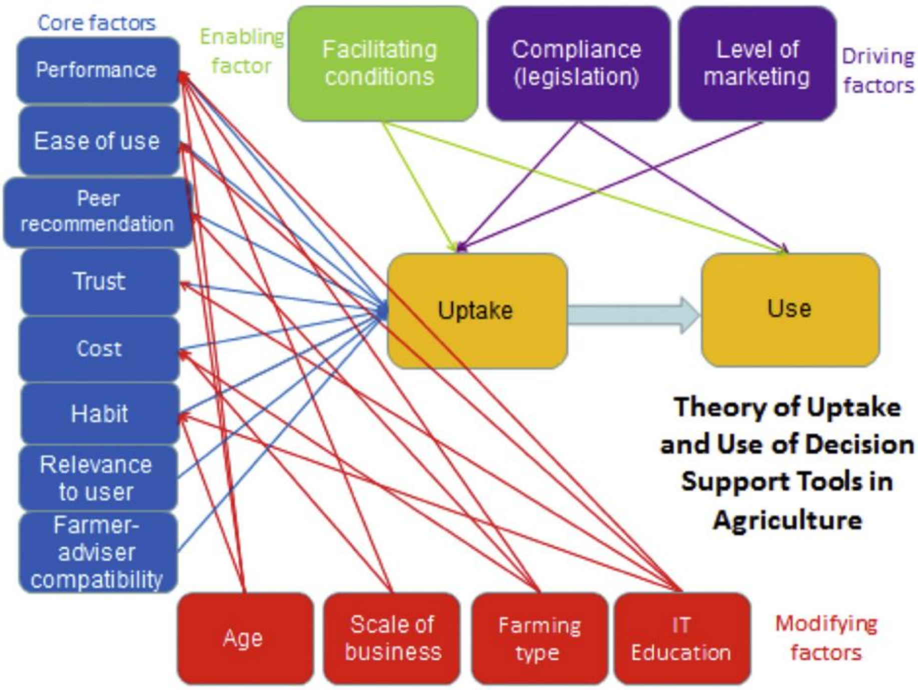

Figure 20: Theory of uptake and use of DST in agriculture.

6.4 Sustainable agriculture, climate-friendly and best management practices

Based on their literature review Rodriguez et al. (2009) state that previously identified barriers to adoption of sustainable agriculture practices (SAP) refer to the generation and spread of information, economic limits, social factors, farmers' characteristics, attributes of sustainable practices, and infrastructure conditions.

Among economic factors, the cost of materials and equipment, the uncertainty of profitability or increased risk, loss of productivity, labour supply, at-risk economic situations, and farm program policies along with risk (real or perceived) and farmers' poor economic situation are included. Barriers related to the supply of information are the rapidly evolving knowledge and information needs, the lack of available information for farmers, and change agents' lack of information and knowledge; the lack of available, reliable or locally relevant information may be a further obstacle to adoption. Farmer's characteristics include age, attitudes and beliefs as factors which are mentioned as barriers to adoption. To these, property rights issues are added. Finally, social infrastructures refer to the supporting context of neighbours, kin and peer farmers that shapes a farming subculture or farming style, the availability and accessibility of support resources and marketing infrastructure.

In their qualitative study, based on a web-based survey instrument, Rodriguez et al. (2009) explored the barriers to adoption of SAP in the US South. They confirmed that many of the factors identified in their literature review are present in their case, i.e. initial and transition costs and the financial situation of the farmers; farmers' lack of knowledge or education concerning SAP; inadequate/lack of information sources; lack of on-farm trials and demonstrations; the lack of support to sustainable agriculture on the part of the agricultural knowledge and information system, along with change agents' beliefs; and, corporate influence on national agricultural policy. On the other hands, factors such as resistance to change on the part of the farmers, the compatibility of the new practices with existing ones (i.e. with ongoing habit and pattern), the complexity of sustainable practices, lack of farmer examples and peer pressure, finance and infrastructure, land tenure and age were found to influence SAP uptake.

The authors pointed especially to the fact that despite having support from technical assistance providers, farmers are rarely adopting SAP. This is so as, according to the authors, change agents often are not well prepared to attend to farmers' needs, particularly the needs of specific farming situations. Moreover, government support programs often fail to encourage adoption due to lack of funding, inappropriate design and ineffective targeting of incentives. Therefore, strategies such as improved management of the existing information, careful design of economic support programs and extension efforts are recommended.

Grover and Gruver (2017) with reference to a need to better understand the management decisions of smallholder farmers within their regional context, to promote environmental, social and economic sustainability, carried out research in East Central Indiana. Through their literature review the authors stressed that according to motivational studies farmers balance a number of factors when trying to achieve 'good practice' (as defined by each individual) on their farms as well as that regionally specific factors play a decisive role in inducing or deterring farmers from adopting more sustainable farming systems. The latter include market conditions (price levels, consumer willingness-to-pay, transportation and supply chain transaction costs, labour markets, local agricultural policy and proximity to urban areas) and social and geographic circumstances which shape the regional conditions. These authors showed that most studies fail to account for the multitude of factors that influence attitudes and do not adequately recognize the importance of location and individual farmer circumstances in shaping attitudes and behaviours.

Several important themes emerged from this research related to perceived barriers of smallholders regarding sustainable farm management, including: low level of awareness about local foods among consumers; being overburdened by excessive or inappropriate regulations and disadvantaged by government subsidy structures that favour large-scale production; availability of time and labour to expand their operations or implement new practices, environmental/ecological factors; and, lack of networking and access to educational support (with Extension favouring conventional farming). The authors showed that subtle regional factors significantly impact farmers' decisions, thus underscoring the importance of local context in crafting agricultural policies and outreach efforts.

With the aim to identify key socio-economic barriers that inhibit the adoption and diffusion of Community-Supported Agriculture (CSA) technological innovations in Europe research was conducted in the Netherlands, France, Switzerland and Italy (Long et al., 2016). The results of their literature review are illustrated in Table 11 and Figure 21. Especially with reference to pro-environmental technology adoption barriers in agriculture, the authors stressed the role of, on the one hand, the interaction of sources of information and how they influence perception of benefits of adoption (including imitation within adopter groups as well as influences such as technological advisers or advocates) and, on the other hand, financial cost of the technology or innovation to the adopter (or, the commercial and practical realities). To these, conflicts between new technological innovations and traditional methods, the use of scientific jargon and a lack of appreciation of the 'day-to-day' reality on a farm by researchers and the producers of technological innovations can be added. The authors, with reference to CSA, mention that a) R&D and policy give little consideration to 'on-the-ground realities' and user centred innovation or co-creation and b) that the cost of technology adoption is relatively high, thus proposing tax-breaks in an effort to reduce the costs associated with technological innovations.

Table 11: Overview of barriers to the adoption of pro-environmental technologies

Barrier		Sources
Economic	High initial investments Poor access to capital Hidden costs Competing financial priorities Long pay-back periods (ROI) Switching costs/existence of installed base High implementation costs (actual and perceived) Uncertain returns and results Temporal asymmetry between costs and benefits Over discounting the future	(Bogdanski, 2012; Brunke et al., 2014; Cullen et al., 2013; del Río González, 2005; Faber and Hoppe, 2013; Hoffman and Henn, 2008; Luken and Van Rompaey, 2008; Luthra et al., 2014; McCarthy et al., 2011; Montalvo, 2008)
Institutional/regulatory	Low institutional support Use of overly scientific language (Jargon) Farmer's knowledge not considered in R&D Lack of regulatory framework Prohibitively prescriptive standards	(Bogdanski, 2012; Eidt et al., 2012; Luthra et al., 2014; Montalvo, 2008)
Behavioural/Psychological	Lack of management support/awareness Conflict with traditional methods Overly complex technologies Results/effects of technology difficult to observe Farmer's beliefs and opinions Low trust of advisers or consultants/lack of acceptance Irrational behaviour Negative presumed assumptions	(Brunke et al., 2014; Eidt et al., 2012; Hoffman and Henn, 2008; Johnson, 2010; Ratten and Ratten, 2007; Sneddon et al., 2011; Vishwanath, 2009; Wheeler, 2008)
Organisational	Lack required competencies/skills Poor readiness Poor information Inability to assess technologies Overly short-term/perverse rewards Organisational inertia/habitual routines	(Brunke et al., 2014; Faber and Hoppe, 2013; Johnson, 2010; Luken and Van Rompaey, 2008; Luthra et al., 2014; Montalvo, 2008)
Consumers/Market	Poor information Lack market attractiveness/do not align to preferences Uncertainty Consumers/farmers level of motivation Market uncertainty	(Bogdanski, 2012; Bohnsack et al., 2014; Brunke et al., 2014; del Río González, 2005; Johnson, 2010; Luthra et al., 2014)
Social	Social/peer pressures	(Montalvo, 2008)

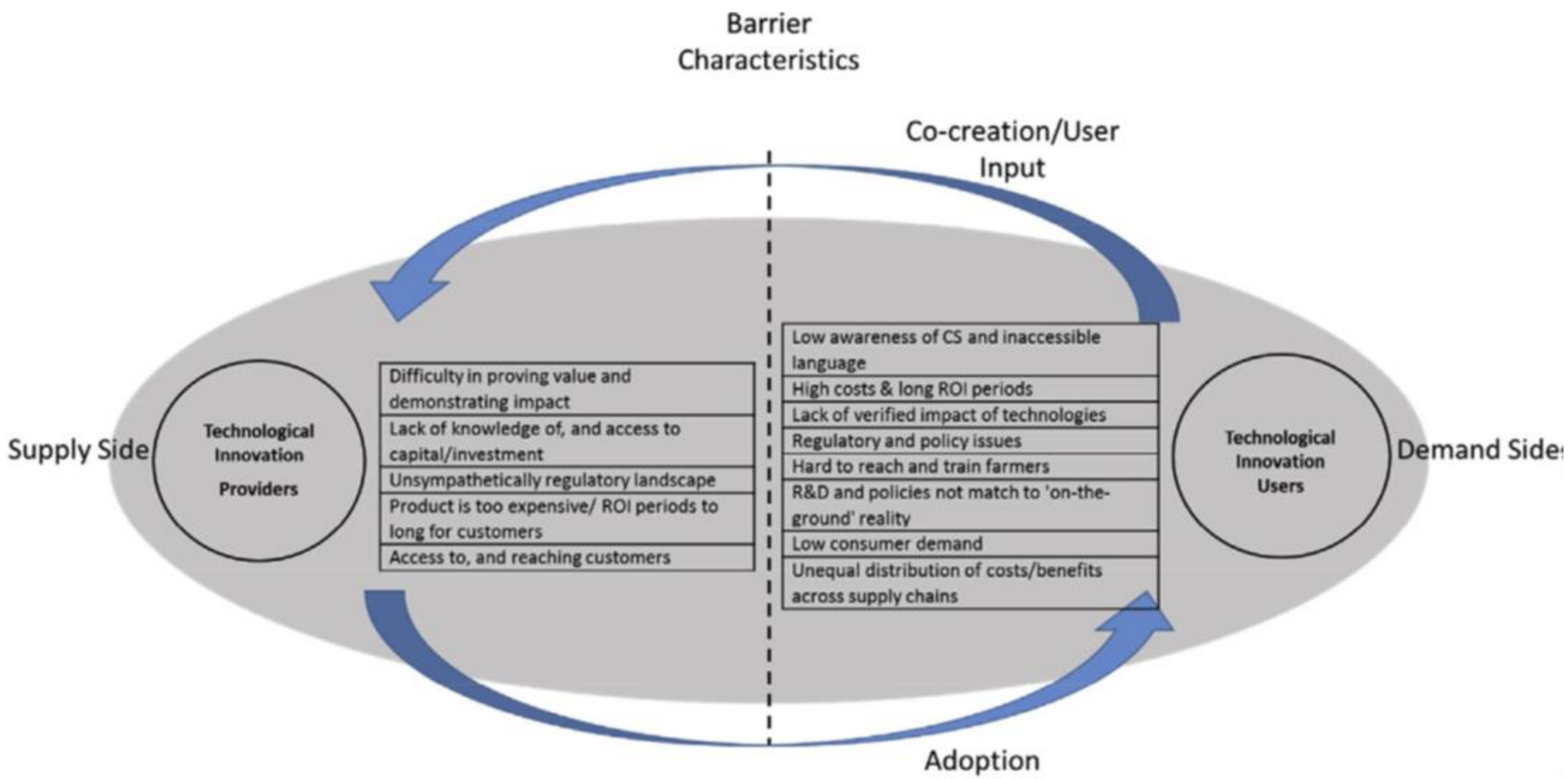

Figure 21: Overview of barriers to the adoption of pro-environmental technologies

Barriers Hampering Climate Smart Agriculture Technology VS Barriers Hampering Climate Smart Agriculture Technology

Providers [1]	Users [1]
a) *Proving value of the product/demonstrating impact:* **hinders the selling of their technological innovations**	***Lack of verified impact of technologies****:* needed assurances over the impacts of technologies, which is lacking with CSA technologies. Lack of supporting impact studies.
b) *Lack of knowledge of, and access to capital/investment*: **expansion and other business objectives requiring financing were unable to be pursued;**	***R&D and policies do not match to 'on-the-ground' reality***: policy and research is often made and conducted away from the farm, meaning that it neglects many 'day-to-day' realities faced by farmers. In turn, this means that technologies that are developed or subsidies do not match the demands or needs of farmers.
c) *Unsympathetic regulatory landscape*: **issues** with the policy and regulatory landscape**, acted as barrier to their ability to successfully diffuse their technological innovations.**	***Regulatory and policy issues:*** **Policy and regulatory barriers** related to issues such as some countries placing greater emphasis on climate mitigation over adaption, or for example he lack of a clear carbon price. Inconsistencies between national and EU level policies were also highlighted.
d) *Products too expensive/ROI periods overly long*: **Technology providers found that potential customers felt that their technologies were too expensive and/or had ROI (Payback time) periods that were too long.**	***High costs and long ROI periods****:* potential users noted that they were too expensive; high upfront costs and/or overly long ROI periods.
e) *Access to, and reaching customers*: **identifying potential specific customers segments or where identified, finding successful avenues to contact and sell through.**	***Low awareness of CSA/inaccessible language***: CSA was reported to be a little-known phrase among potential users of CSA technological innovations. In addition, it was noted that many potential users only spoke their mother tongue – difficulties in diffusion, restriction to native countries.
	Low consumer demand**.** **The central hindrance noted by potential users was that consumers were unwilling to pay a price premium for CSA products.** Lack of demand for products produced in line with CSA principles
	Unequal distribution of costs/benefits across supply chains*:* Mismatch where many of the economic benefits are located downstream, with consumer products companies or retailers, whilst many of the environmental/climate benefits are located on the farm.

Source: Own synthesis

According to Wreford et al. (2017), in their OECD report, the uptake of 'climate-friendly' technologies and practices remains, in general, low. Thus based on a comprehensive review of the literature, the authors attempted to provide an analysis of the barriers that may prevent farmers from adopting climate-friendly practices. With regard to barriers at the farm level, structural conditions, economic barriers, social and cultural factors and behavioural and cognitive barriers are recognized as significant ones. Structural conditions include land tenure, infrastructure (re: climate-friendly practices) and complementary inputs as well as farmer age and succession plan. Economic barriers refer to actual or perceived lack of financial benefits and the cost of adopting new technologies or practices, particularly capital costs related to the purchase of specialized machinery and associated technology, along with access to credit. Social and cultural factors play an important role in farmers' decisions as, for example, farmers' focus on production and thus the demand that agriculture should be exempt from GHG emission reduction efforts; on the other hand, their strong emotional or cultural attachments to their land and land use are more likely to encourage them to protect the land for future generations. Finally, farmers may be exposed to a range of behavioural and cognitive barriers such as perceived long time horizons, uncertainty and risk management which along with the competing pressures they face may prevent them from adopting climate-friendly practices.

Furthermore, it is noted that farmers' propensity to adopt climate-friendly practices may also be influenced by sector-wide or national factors, stemming in part from policies and activities of other actors. Here factors such as the lack of knowledge about climate-friendly measures, their benefits and how to implement them as well as the credibility of the source, farmers' engagement in competitive contract system that focusing on yields, the absence of and poorly designed climate policy as well as misaligned agricultural policies (for example, input subsidies, production support, tax exemptions supporting production, etc.) are included.

Overall, the report identified four categories of barriers to the adoption of climate friendly practices in terms of their relative importance and policy relevance. The high priority barriers (recognised as important with sufficiently robust evidence in the literature) are: the farm-level barrier of an actual or perceived lack of financial benefit; the national-level barrier of the actual or perceived effect on production, insufficient information and education; and the limited and undeveloped climate policy. The next group of barriers has significant influence but not as strong supporting evidence as the previous ones; this group includes: the cost of adoption; hidden and transaction costs; access to credit; and social and cultural factors. According to the authors, perceived carbon leakage and misaligned policies also fit into this category. The third category concern barriers which could limit certain practices and these are: land tenure and infrastructure. The fourth group includes variables which may not be the most critical, including: behavioural and cognitive factors, farm succession, industry cooperation, administrative barriers and policy distortions. The latter are barriers not considered significant across OECD countries.

OECD (2012) review of the determinants and motivational influences related to climate change mitigation and adaptation in agriculture (Figure 22) concluded that that the main factors which influence adoption vary with types of techniques; farmers' behaviour is influenced by both financial and non-financial incentives; the relationship with neighbouring farmers is significant vis-à-vis adoption; and, farmers' attitude and beliefs must be taken into account when designing appropriate incentives. Furthermore, the authors underline that psychological and socioeconomic factors simultaneously influence adaptation decision while also stressing that the variation of factors such as climate, soil, or the way a practice is adopted implies that the benefits and trade-offs of the practice will also vary.

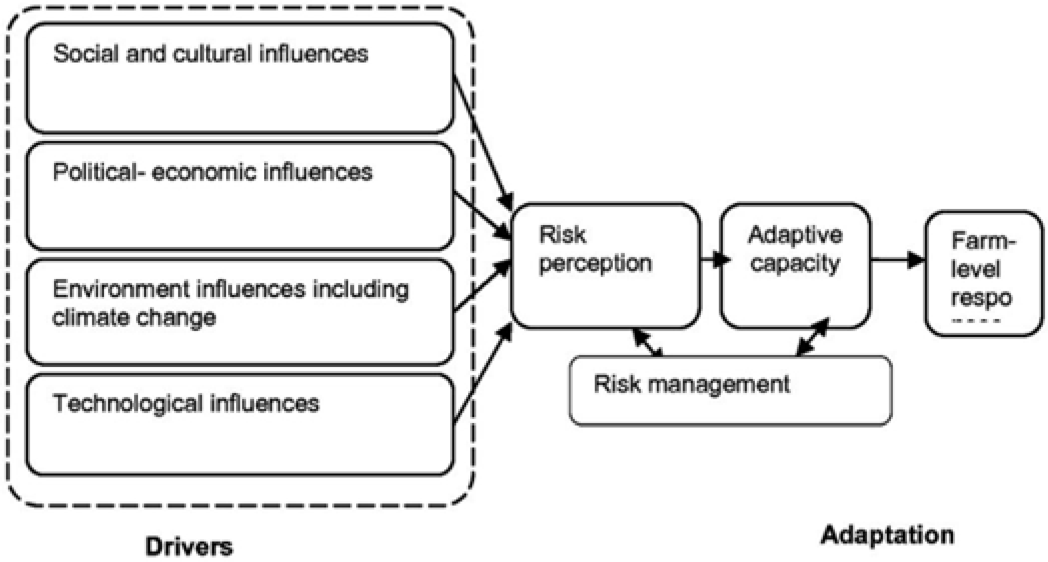

Figure 22: Framework of farm-level adaptation

Dessart et al. (2019) in their review of behavioural factors that influence farmers' decisions to adopt (voluntary adoption, no matter if government supported or not) environmentally sustainable practices[32] suggested that farmers' decisions are not entirely rational - as espoused by neoclassical economic perspective. Additionally, the authors identified behavioural factors significantly influencing farmers' decisions to adopt specific sustainable practices in specific cultural contexts. Overall, the authors claimed that the exploration of behavioural factors enriches economic analyses of farmer decision-making and distinguish them in three clusters: dispositional factors; social factors and cognitive factors (Figure 23).

Dispositional factors are the most distal and affect many decisions; they refer to farmers' internal propensity to behave in certain ways and are relatively stable, internal variables related to a given individual, such as personality, motivations, values, beliefs, general preferences and objectives. More specifically, they include personality (extraversion; openness; conscientiousness), resistance to change, risk tolerance and risk management, concern (moral concern, environmental concern), farming objectives (conservation and lifestyle objectives, economic objectives).

Social factors may be proximal or distal and refer to farmer's interactions/ interpersonal relationships with other individuals (e.g. other farmers or advisors) and include social norms and motives which may push farmers to adopt (or not) a particular practice or more sustainable practices in general. For example, it is known that farmers are more likely to adopt sustainable practices when most neighbouring farmers have done so. This cluster comprises descriptive norms (i.e. what other people actually do), injunctive norms (i.e. what people ought to do; what they think others expect from them to get, in turn, social approval), and signalling motives (farmers' local public image and status). With reference to

[32] I.e., farming practices whose main expected benefit – relative to conventional practices – is the provision of positive externalities on biodiversity, water, soil, landscapes and climate change; conservation tillage, crop rotation, reduction of fertilisers, pesticides and fungicides, rotational grazing and landscape preservation are examples of such sustainable practices

the latter it is important to note that some sustainable farming practices are invisible to the general public and therefore receive little public recognition.

Finally, cognitive factors are proximal and relate to learning and reasoning. The factor comprises farmers' perceptions of the relative benefits (perceived environmental benefits; perceived financial benefits and effects on production; perceived efficacy of sustainable practices), costs and risks (perceived financial risk and perceived environmental risks) associated with a particular sustainable practice or whether they feel that they have the appropriate knowledge and skills to adopt this practice.

Therefore, the results of this study verify the complex framework farmers navigate when making decisions on the farm while additionally pointing to the existence of subtle regional factors which significantly impact farmers' decisions, thus, according to the authors emphasizing the importance of local context in crafting agricultural policies and outreach efforts.

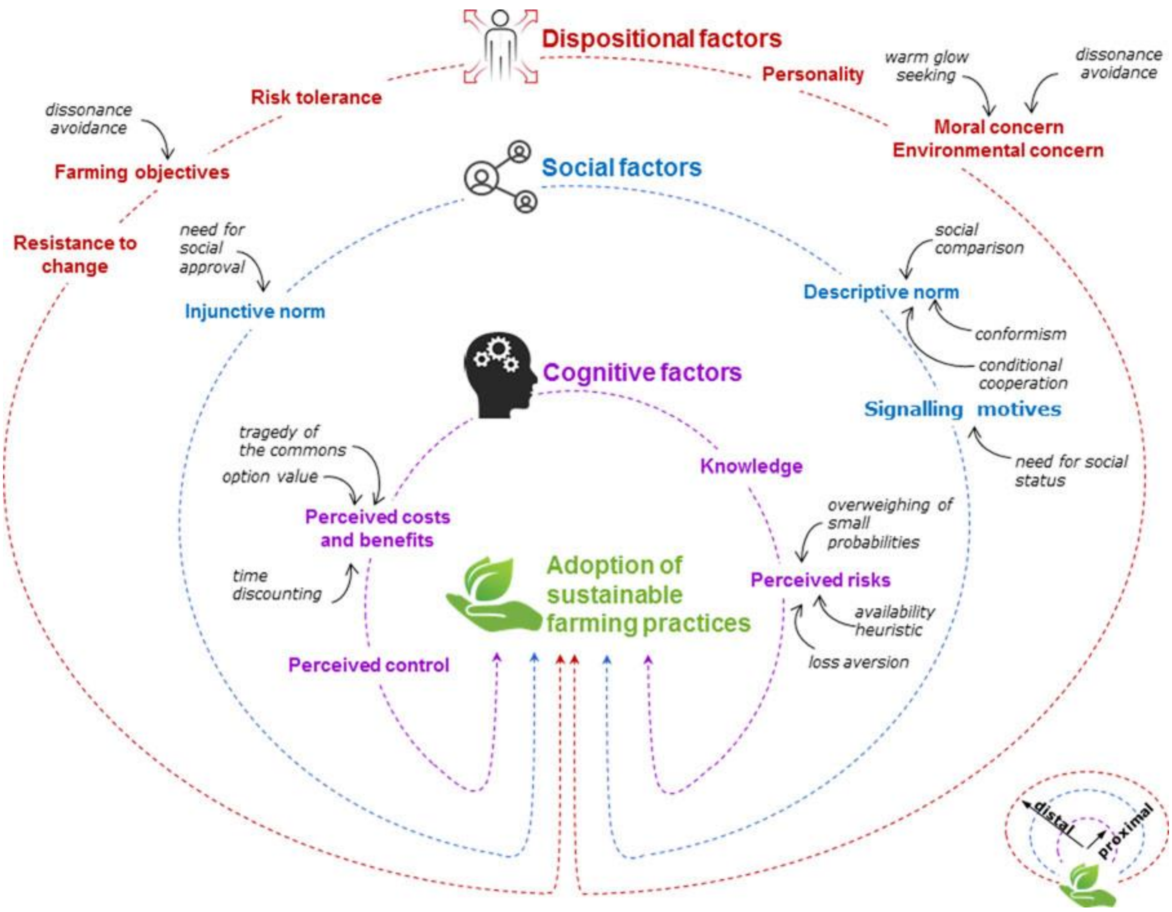

Figure 23: An integrated framework of behavioural factors affecting farmers' adoption of environmentally sustainable practices.

MEMO: Mechanisms and biases in italics. Within each cluster, behavioural factors are not necessarily situated at the same distance (proximal-distal) to the adoption of environmentally sustainable practices.

Liu et al.'s review (2018) of the findings of Best Management Practices (BMP) adoption studies led them to claim that certain factors, studied in isolation (access to credible information, government subsidies, environmental consciousness, and profitability of practices) show a clear and positive effect on BMP adoption while the effects of some other factors (farm size, land tenure, diverse operation, farmer experience, education, age, gender, political views, and social political beliefs) were unclear or debatable. According to their review, the authors claim that further progress has been made to elucidate the roles of social norms and peer pressure and the influence of macro factors such as geographic regions, policies, markets, business, with their associated uncertainty and risks. Moreover, this review showed that farmers' time preference and characteristics of the BMPs, as well as the interactions among these practices, have been introduced/ examined in the literature while more attention is being paid to information, farmers' risk preference and farmers' environmental attitudes. Thus the authors suggest that future research should focus on study scale, on measuring and modelling of adoption as a continuous process, and on incorporation of social norms and uncertainty into decision-making. More research is needed on uses of social media and market recognition approaches (such as certificate schemes and consumer labelling) to influence BMP adoption.

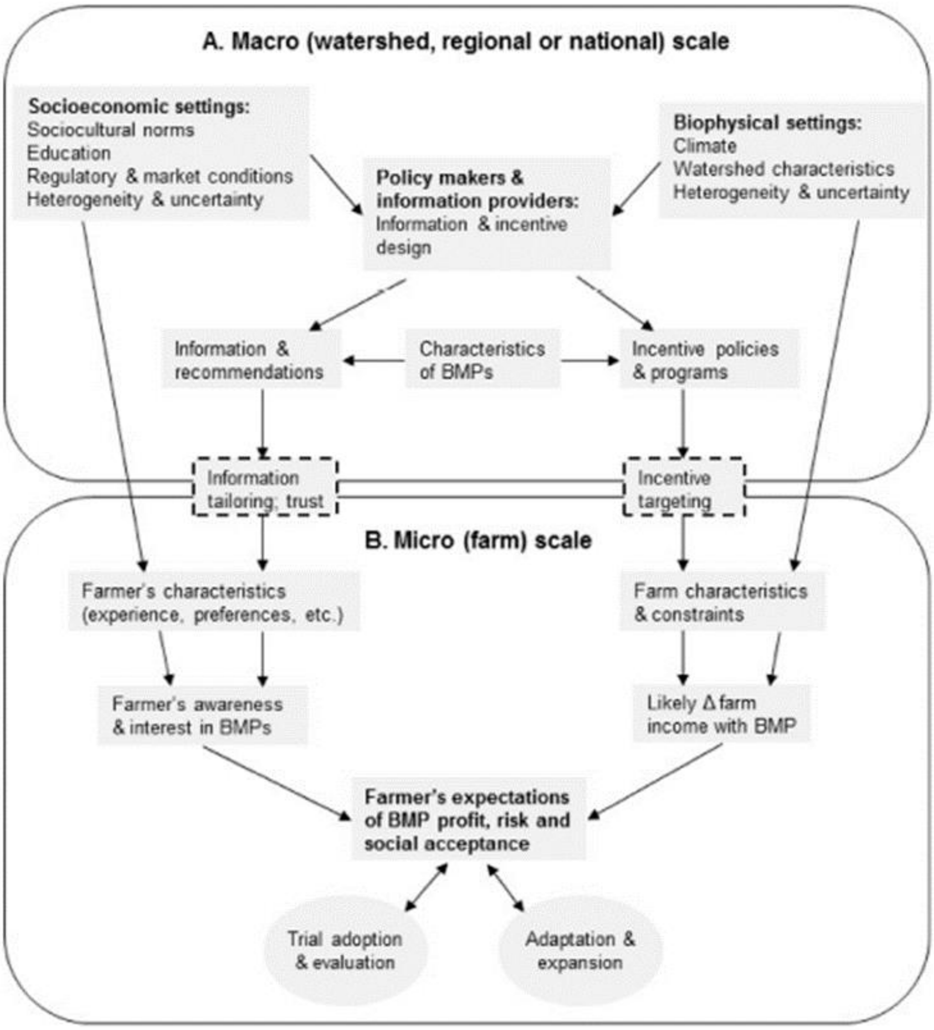

Figure 24: Conceptual framework of BMP adoption.

Memo: Boxes and arrows denote influences; rounded boxes denote scales; ovals represent actions related to BMP adoption; dashed boxes denote elements that may or may not be present

With regard to fertilization, Weber and McCann (2015) based on data from the 2010 USDA Agricultural Resource Management Survey of corn producers examined the factors affecting adoption of eco-innovations such as N soil testing, plant tissue testing, and N transformation inhibitors. The authors concluded by pointing to the importance of relevant information dissemination as well as that the information source for N recommendations is a crop consultant (extensionist). They also pointed to the need that such extension activities be modified based on the audience and the technology.

6.5 Aftermath

As in section 5, multiple factors are identified which impede the adoption of energy-efficient technologies and practices on the part of farmers. Despite the fact that authors do on agree on a common categorization scheme, these are found to include: several characteristics of the farmer (as well as range of behavioural and cognitive barriers) along with structural characteristics of the farm; economic barriers (especially the cost of adopting new technologies or practices along with actual or perceived lack of financial benefits); socio-cultural factors; lack of awareness, reliable (and locally relevant) information and/or extension/advisory support and training; and, policy barriers.

7. Conservation agriculture: Soil management and conservation practices

7.1 Introduction

The case of conservation agriculture (CA), with its soil conservation practices (SCP) and reduced tillage (RT) practices are particularly interesting for both energy reduction and carbon sequestration.

According to the review paper of Knowler and Bradshaw (2007), there are few if any universal variables that regularly explain the adoption of conservation agriculture. Although the review reveals some support for a number of assertions concerning the adoption of conservation agriculture, it is also clear that many of them contain many ambiguities and inconsistent results. For example, many classic adoption variables such as farm characteristics and socio-demographics are mostly insignificant, and if significant, both positive and negative impacts are found in current research (Lalani et al., 2016). Such inconsistency in the factors that influence adoption may be partly attributed to site-specific and context related factors; the variety of methodologies used to make assessments has to be taken also into account (Townsend et al., 2016). It has been noted that effects of the factors in question, differ between studies, even when considering the same agricultural innovation (Case et al., 2017). Furthermore, the perceived advantages and disadvantages of innovations vary not only between practices but also between producers. Thus, among others, the effect of several factors to the adoption process is differentiated according to the adoption category of the responders (Khanal et al., 2019). In many cases there is no consensus on the benefits or costs to adoption, indicating that the practice characteristics interact with farm and farmer situational characteristics to influence practice perception and adoption. Nevertheless, relative advantage is very important and could be one of the most important motivations for adoption as well as relative disadvantage is the most important limitation (Reimer et al., 2012).

Barriers hampering adoption process exist on both the demand (end users) and supply (technology provider) side (Long et al., 2016).

7.2 The demand-side motivations or barriers

7.2.1 Farmers' characteristics

The demand side barriers refer to farmer's personal and behavioural characteristics such as farmers' socioeconomic characteristics, informational, skills and experiential barriers.

In the first place, when the benefits of adoption are unknown to the farmer the adoption process is hindered (Calatrava and Franco, 2011; Rochecouste et al., 2015; (Corbeels et al., 2014). Furthermore many farmers have insufficient knowledge about conservation agriculture and its management (Harper et al., 2018). The lack of information regarding the best conservation practices and their impact on the level of soil erosion increase the uncertainty faced by the potential adopting farmer and the perceived risk of the innovation (Calatrava and Franco, 2011). Thus reducing risk and 'uncertainty' (i.e. absence of sound knowledge or the decision maker having incomplete information) is paramount in the adoption process (Lalani et al., 2016). Sometimes though, even when adequate information is available, misunderstandings about the main principles and processes of CA occur as, for example, about the capacity of the soil biosphere to improve and restore itself when left unploughed or when covered by cover crops (Harper et al., 2018).

The awareness of threats and farmers' perceptions of the importance of the soil erosion problem is equally important (Calatrava and Franco, 2011). For Knowler and Bradshaw (2007), farmer awareness of, and concern for soil erosion or other soil problems is probably the more critical factor affecting adoption. Thus, farmer awareness or perception of the presence of soil problems is frequently found to positively correlate with the adoption of soil conservation practices like no-till.

On the other hand, high investment of time and effort to acquire new farming skills may lead farmers not to be willing to allocate personal resources to secure training (Napier et al., 1991). In general, for many farmers insufficient time to implement is a major barrier to adoption (Harper et al., 2018; Greiner and Gregg, 2011). On the contrary, land operators possessing the farm management and technical skills necessary to integrate and maintain conservation practices into their operations, were found to be more favourable to adoption (Napier, 1991). Furthermore, new unfamiliar practices not widely practiced or endorsed by trusted peers, regardless of benefit, will result in slow adoption (Rochecouste et al., 2015).

Land tenure/ownership issues were also found to influence adoption (Napier, 1991; Calatrava and Franco, 2011). For Reimer et al. (2012), land ownership restrictions are an important issue limiting adoption while for Greiner and Gregg (2011) uncertainty over the future of the property results in uncertainty and reluctance toward adoption. However, Knowler and Bradshaw's (2007) review of 13 analyses that assessed the impact of land tenure on conservation agriculture adoption shows that two supported the hypothesis that that owned land is better maintained by farmers than leased land, another two refuted it and the remainder found no significant relationship. As Reimer et al. (2012) argue, some producers (who rent a land) may be eager to adopt an innovation, but the landlord may not and this is especially true for structural innovations.

Additionally, farmers' risk attitudes have also been studied extensively in the literature but have overall been found to be insignificant determinants of adoption (Reimer et al., 2012).

Membership in producer organizations has been identified as a positive influence on adoption, although again this finding has not been identified in all analyses. Farmers that are members of a Farmer Field School or participants of other organizations have a significantly stronger positive attitude towards CA (Lalani et al., 2016). Framers' participation in agricultural policy program and soil erosion agri-environmental measure has also been shown to promote adoption (Calatrava and Franco, 2011)

With regard to farmer's age, this variable has been regularly assessed but is difficult to link to the adoption of conservation agriculture given that studies have shown inconsistent results (Knowler and Bradshaw, 2007). However, Fantappiè et al. (2020) cite studies that found a positive correlation with younger farmers' age with the adoption of SCP.

Farmers' education, be it specific or general, commonly correlates positively with the adoption of conservation agriculture practices; however, some analyses have found education to be an insignificant factor or even to negatively correlate with adoption (Knowler and Bradshaw, 2007). However, Fantappiè et al. (2020) cite studies that found a positive influence of educational level on the adoption of agro-environmental measures. Furthermore, it has been shown that farmers' previous agricultural training or use of advisory systems correlates positively with the adoption of conservation agriculture practices (Calatrava and Franco, 2011).

Another variable concerns the farmer's overall agricultural experience with assessments revealing both positive and insignificant correlations with adoption (Knowler and Bradshaw, 2007). Investigations into the impact of various labour arrangements (family vs. hired) largely reveal no significant correlation with conservation agriculture adoption (Knowler and Bradshaw, 2007). Inconsistent are the research results concerning the correlation between conservation agriculture adoption and the level of non-farming income and the degree of dedication to farming. However, such a result might be justified when it is considered that alternative income sources could provide additional resources for conservation or, concomitantly, diminish the priority of agriculture within the household, thereby reducing interest in conservation (Knowler and Bradshaw, 2007). Furthermore, succession is commonly found in the literature to be related with the willingness for investments and adoption of soil conservation practices, probably because of the CA's long-run benefits on the soil (Calatrava and Franco, 2011).

With respect to wealth, it is regularly hypothesised that the adoption of conservation agriculture, or indeed any new technology, requires sufficient financial well-being, especially if new equipment is required. In support of this view, a majority of analyses that investigated the impact of income, gross income and farm profitability on adoption revealed a positive correlation. However, negative correlations and a number of instances of insignificance preclude an unqualified conclusion to this effect (Knowler and Bradshaw, 2007). Other authors claim that investment capacity to purchase or modify equipment may affect the relative advantages of a practice (practice beliefs) and the intention to adopt (Corbeels et al., 2014; Reimer et al., 2012). Fantappiè et al.'s (2020) research suggests that the poorest small farms request more technical advice service in order to make the application of SCP more profitable.

Finally, there is evidence that individual characteristics influence perceptions of relative advantage and relative disadvantage (cost and benefits associated with the practices) and thus the attitudes towards innovation. Individuals are likely to vary in their perception of a given practice's relative advantage or disadvantages (Reimer et al., 2012). Generally, configured farmers perceptions toward practices (benefits and costs) influence expressed willingness to adoption (Napier, 1991; Napier et al., 1988; Townsend et al., 2016). Specific or general attitudes also have an influence on adoption. In many studies, farmers' attitude is found to be important predictor of intention (Lalani et al., 2016). For example, general attitudes toward farming and the environment have an influence on adoption (Napier et al., 1991; Reimer et al., 2012) while Bijani et al. (2017) found out that the variable "attitude towards soil conservation "was the most powerful predictor of "soil conservation concerns".

7.2.2 Farm characteristics

Farm size is a commonly discussed variable in adoption studies within which it is regularly hypothesized that owners of larger operations are more willing to invest in new technologies. However, given the observance of positive, negative and insignificant correlations, the overall impact of farm size on adoption is clearly inconclusive (Knowler and Bradshaw, 2007). Other researchers (Fantappiè et al., 2020) found though that large scale farms were the most adopters and claim that farm size had the strongest influence on the choice of the SCP and on the type of perceived advantages.

Research has also found correlation between the adoption of TR and farm-specific factors such as weed burden (Townsend et al., 2016), no-tillage and soil type, i.e. that larger number of adopters are associated with clayey rather than sandy soils, as well as between no-tillage and (non)availability of irrigation (Pagliacci et al., 2020).

Moreover, wider agro-climatic and environmental system characteristics were found to influence adoption. For example, motivations to adopt soil conservation practices have been found to be far more appealing for steeper slopes and more eroded lands. Nevertheless, many other studies show that in deeper soils the incentive to conserve appears on the long run (Calatrava and Franco, 2011). With respect to rainfall (effect on erosion), which is an often assessed factor in conservation agriculture adoption, mixed results have been found (Knowler and Bradshaw, 2007). With regard to the climate, according to Townsend et al. (2016) in the US RT can have beneficial yield effects in drier, warmer climate conditions and is thus more suited to areas with these conditions while in the UK, where water-stress is less common, there is likely to be less incentive to adopt RT.

7.2.3 Socio-cultural factors

Local and personal contacts play, in general, an important role in adoption of a technology (Lalani et al., 2016). As aforementioned, observation of other producers' actions is considered a significant motivating factor for farmers with a high intention to use CA (Reimer et al., 2012; Lalani et al., 2016). The social environment in which farmers operate is important. As mentioned above, their associations can be encouraging or act as a constraint to on-farm conservation (Greiner and Gregg, 2011). Similarly important is social pressure from (important) referents (Lalani et al., 2016). In their study Bijani et al. (2017) claim that the variable "social pressures on soil conservation" predicted farmers' "soil conservation behaviours" better than other factors.

Other factors identified as being important in research refer to the lack of labor availability which is associated with reduced the uptake of the innovation (Lalani et al., 2016; Greiner and Gregg, 2011); to cultural entrenchment with ploughing in the sense that ploughing and moldboard ploughing are practices that are deeply rooted in cultural traditions implying that cultural traditions of intensive tillage based farming are barriers (Harper et al., 2018); to social capital, especially kinship and 'connectedness to others' have been shown to positively influence the adoption of conservation technology - although not all studies have found this to be significantly so (Knowler and Bradshaw, 2007); and, the increase in social prestige that can be an additional benefit of the adoption beyond direct economic gains (Reimer et al., 2012).

7.2.4 Economic Impact and costs

Many researchers have found that economic factors are important in affecting adoption. In the first place the level of investment and the expected costs (inputs, equipment, etc.) required by the farmer are crucial factors in relation to adoption (Corbeels et al., 2014; Rochecouste et al., 2015). In this respect, when the total investment and expected costs are low the adoption is promoted (Napier, 1991) while, on the contrary, the larger the investment required, the slower the adoption process is (Rochecouste et al., 2015). Thus, for many farmers insufficient capital to invest and cover the high cost of no-till equipment is a major barrier to adoption (Harper et al., 2018; Greiner and Gregg, 2011). In the same vein, when the required capital to maintain is low the adoption is easier promoted (Napier, 1991). The perceived high levels of relative advantage such as reduced inputs are also important in increasing adoption of conservation practices (Knowler and Bradshaw, 2007). Similarly, production's costs reduction stemming from the adoption of a practice is an important motive toward adoption; obviously, an increasing cost of essential inputs when implementing or maintaining the new practices is perceived as a relative disadvantage by farmers (Fantappiè et al. 2020; Knowler and Bradshaw, 2007).

On the other hand, the perceived financial risk, productivity concerns and suspicion of adverse impacts on productivity/ profitability may hider adoption process (Napier et al., 1991; Greiner and Gregg, 2011; Corbeels et al., 2014). Farmers will be favorable to adoption when they are convinced that they will benefit from adopting such practices (Napier et al., 1988). For example, farmers adopt SCP to which they attribute a positive effect on profitability, linked either to an increased productivity and/or to the reduction of management costs (Fantappiè et al., 2020). Thus, the (expected) financial benefits are frequently identified as the key driver of whether or not soil conservation practices are adopted (Napier et al. 1991; Rochecouste et al., 2015; Townsend et al., 2016; Fantappiè et al., 2020); the new practices should produce a clear net economic gain as a return on investment (Napier et al., 1991; Rochecouste et al., 2015). In this respect, it has been shown, for example, that effective profitability represents the main efficient stimulus to the adoption of SCP (soil conservation practices), much larger than farmers' ecological attitudes, or the presence of subsidies, especially in the smallest farms (< 20 ha) with lower profit margins (Fantappiè et al., 2020). Furthermore, innovations that produce short-term net benefits make farmers more eager to adopt them (Napier et al., 1991).

Finally, market demand may hamper the innovation's adoption. For example, a key factor that explains the limited CA adoption in mixed crop-livestock farming systems is the fact that crop harvest residues are preferably used as fodder for livestock, preventing their use as soil cover (Corbeels et al., 2014).

7.2.5 Technical and management considerations

With reference to innovations' attributes it has been noted that, for example, the adoption of SCP can be limited by technical constrains which, in turn, requires the provision of technical advice to the farmers (Fantappiè et al., 2020). In general, one may initially refer to Rogers' categories (see above).

With reference to compatibility, Knowler and Bradshaw (2007) and Reimer et al. (2012) state that compatibility with farming system and farmers' needs is important in increasing adoption of conservation practices. For Reimer et al. (2012) it is rather obvious that the gap between current farming management and innovations' management requirements influence the adoption process in the sense that when the level of change in equipment, timing, and overall farm management required is too significant, an innovation is viewed as 'incompatible' with farmers' current farming system. Additionally, innovations viewed as not necessary and/or practical have less possibilities to be adopted (Greiner and Gregg, 2011; Reimer et al., 2012).

With regard to observability, Reimer et al. (2012) note that it has two components: 1) practice observability, being able to see the actual practice in place, and 2) benefit observability, the ability to see the benefits accruing from the practice. Timing is thus very important; in other words, the particular time horizon that real impacts materialize and are visually observed is a very important factor. In this respect, the performance and benefits of CA especially in the short term promotes adoption (Corbeels et al., 2014) although CA benefits are largely found in the long-term (Lalani et al., 2016). On the contrary, changes that take years to show are less likely to be adopted (Rochecouste et al., 2015). For example, the lack of an immediate increase in farm income with CA explaining in many cases the non-adoption of CA (Corbeels et al., 2014). And this is true especially for smallholders who have often short-term time horizons, thus future benefits do not adequately outweigh their immediate needs (Corbeels et al., 2014).

With reference to trialability, research has shown that practices which can be tried out on a small scale prior to full implementation are more likely to be adopted and this applies to several practices of conservation agriculture such as conservation tillage, as producers can try on a limited basis prior to making the additional investment in new equipment, etc. (Reimer et al., 2012). Furthermore, for complex innovations, which are in fact a system of different techniques (i.e. conservation agriculture, precise agriculture, etc.), there is always the possibility to introduce part of it in a stepwise way by including the less complex, easy and inexpensive aspects of it (Lalani et al., 2016). Most often, farmers are seen to experiment and tend to adopt one or two of the CA principles as an eventual entry point to full adoption; farmers go through a gradual learning process before full adoption (Corbeels et al., 2014).

Another attribute of innovations, namely the relevance of conservation efforts in the context of the land operators' situation and farming operation (i.e. farmers' production objectives and constraints), has been pointed out as a very important factor influencing adoption (Napier, 1991; Napier et al., 1988; Lalani et al., 2016; Corbeels et al., 2014; Greiner and Gregg, 2011). Therefore, the relevance of a practice to farmers' needs is very important as it is relevance in relation to need or threats of a specific local climatological context (Rochecouste et al., 2015). This in turn implies that universal approaches to policy and practice may limit the understanding of different contextual factors and alternative pathways (Napier, 1991; Napier et al., 1988; Lalani et al., 2016; Corbeels et al., 2014; Greiner and Gregg, 2011).

Finally, with reference to complexity, Napier (1991) verifies that an innovation which necessitates little use of complex technologies and is easy to implement, is more possible to be adopted; thus, the more complex the process, the less likely it is to be adopted (Reimer et al., 2012; Rochecouste et al., 2015) as it also requires expenditure for professional support (Rochecouste et al., 2015). Lalani et al. (2016) and Knowler and Bradshaw (2007) claim that it is not always the actual complexity or difficulty to implement but mainly the perceived ease (i.e. farmers' perception of CA as easy to use) or difficulty in using a technique, while Reimer et al. (2012) maintain that sometimes agricultural innovations which appear simple may imply significant and complex changes to the farming system.

Perceived high levels of relative advantage such as time-savings are important in increasing adoption of conservation practices (Lalani et al., 2016; Knowler and Bradshaw, 2007; Reimer et al., 2012). It is also quite obvious that practices require little labor to execute and to maintain are favourable to farmers (Napier, 1991; Lalani et al., 2016; Corbeels et al., 2014; Fantappiè et al., 2020). Increased operational requirements associated with some practices (time and resources necessary to maintain and/or increased time and effort required to manage) is a barrier to adoption (Reimer et al., 2012. Thus saving time and efforts needed to implement a certain practice is a positive factor to adoption (Fantappiè et al., 2020).

Furthermore, when a practice does not require a high-level of knowledge/skills to be used effectively, it has an advantage towards adoption (Napier, 1991; Rochecouste et al., 2015; Lalani et al., 2016). Perceived advantages such as improvements of product quality (at least for the European farmers; Fantappiè et al., 2020)) and the environmental (Knowler and Bradshaw, 2007; Reimer et al., 2012) enhance innovation uptake. On the contrary, perceived risk associated with technology Reimer et al. (2012) or specific practices has been noted as one of the more important factors limiting adoption as in the case of conservation tillage, when conservation tillage is generally seen as the riskiest of all the conservation practices (Knowler and Bradshaw, 2007). In case the relative disadvantages are perceived as easy to overcome or farmers have access to actual support the negative effect of these factor is decreased (Harper et al., 2018).

7.3 Supply side motivations or barriers:

7.3.1 Policy and regulatory barriers

In the supply tier, issues such as policy, regulatory and socio-economic barriers are addressed. In the first place, with reference to economic support and incentives it has been shown that the absence of policy support from governments, have greatly slowed the diffusion of these types of technology. Especially important in this respect are specific government incentives for adoption of conservation tillage (Harper et al., 2018). Assistance is most suitable to help overcome significant initial investments and transition costs as well as in cases where adoption is unprofitable from the individual farm perspective (Knowler and Bradshaw, 2007). Thus authors make reference to or call governments to make available cost-sharing schemes or credit and financial support programs (with reference to eligible farmers who are operating farms on highly erodible land (Napier, 1991); tax benefits where conservation behavior is required of all farmers (Knowler and Bradshaw, 2007), income support programmes (Rochecouste et al., 2015; Knowler and Bradshaw, 2007) as well as various forms of direct subsidies or specific subsidies (i.e. agri-environmental measures; Knowler and Bradshaw, 2007; Costantini et al., 2020) in order to encourage the adoption of conservation practices and especially conservation tillage. This is more so in cases in which an innovation that produce short-term lower farm profits (Kragt et al., 2012) or where conservation is not profitable to the individual farmer but would provide substantial public benefits (Knowler and Bradshaw, 2007). To these, the provision of carbon credits for farmers who reduce GHG emissions, sequester carbon or use RT practices (Rochecouste et al., 2015; Townsend et al., 2016) as well as the facilitation of farmers' actual access to resources (infrastructures, machineries, spare capital for maintenance; Corbeels et al., 2014), may be added.

As already mentioned in the case of RES, inconsistency of agricultural and development policies to conservation policies have been referred to as a barrier to adoption. For example, there could be national policies emphasizing expansion of agricultural production at the expense of the physical environment at the same time with a conservation programme (Napier, 1991).

7.3.2 Scientific and technological uncertainty

Moreover, it is difficult to assert the real/exact benefits of some practices as the research conclusions are strongly influenced by contextual factors (Lalani et al., 2016; Townsend et al., 2016; Corbeels et al., 2014; Harper et al., 2018); therefore, for example, existing CA systems from elsewhere in the world cannot be transferred (Knowler and Bradshaw, 2007). In addition, according to Napier et al. (1991), there is lack of consensus of what constitutes appropriate agricultural packages and that the perceived lack of a best practice industry standard or a consolidated industry position on the matter, brew up uncertainties that have adverse effects on adoption of soil conservation practices. A further important barrier is the limited availability of conservation tillage equipment (Townsend et al., 2016; Harper et al., 2018; Calatrava and Franco, 2011; Knowler and Bradshaw, 2007); it is thus clear that favorable commercial availability of no-till equipment would have the opposite effect (Rochecouste et al., 2015).

7.3.3 Networks and support

Poor networking and communication between stakeholders is a commonly cited barrier with regard to the diffusion of innovations, including CA (Napier et al., 1991). In this respect, unambiguous and accurate information on innovation as well as its active promotion through multiple information sources have been found to positively influence adoption (Knowler and Bradshaw, 2007). Thus, farmers' access to knowledge and technical advice is a crucial factor that can alleviate many of the above mentioned barriers (insufficient awareness and knowledge, lack of confidence about the performance and benefits of CA, technical skills necessary to integrate and maintain conservation practices, management of innovation's relative disadvantages, compatibility and complexity issues, etc). Lack of external support (notably of extension services) is indisputably a factor that adversely affects adoption of soil conservation practices (Greiner and Gregg, 2011; Fantappiè et al., 2020). Therefore, the availability of and farmers' easy access to technical and farm management training programs and continuous technical information and assistance is deemed necessary (Napier, 1991; Napier et al., 1991). However several issues and barriers have mentioned concerning the role of advisors in CA promotion, such as advisors reluctance to engage with CA, the lack or limited experience of advisors with conservation tillage and the need to broaden the knowledge base of CA for advisors (Harper et al., 2018).

7.4 Compost, manure and mulches

Similar, more or less, are the results of research especially concerning the adoption of alternative organic fertilizers, although differences may occur between these alternatives.

Farmer's age was found to influence the likelihood of future interest in alternative organic fertilizers such as organic waste products; lower age increased the interest in adoption of manure separation technologies (Case et al., 2017). However, as far as the adoption of pruning residues as mulch is concerned farmers' youth was not found to be relevant (Calatrava and Franco, 2011). The adoption of the latter practice was also found to be influenced by farmer's experience; the probability of adopting this practice is smaller when experience as a farmer is less than 10 years. This may be related with the uncertainties of using pruning residues as mulch has for less experienced farmers (Calatrava andd Franco, 2011). The lack of relevant knowledge also influences the use of practices such as on-farm production of compost and compost application (Viaene et al., 2016). Also, lower education level, increased interest in adoption of manure separation technologies (Case et al., 2017). Not surprisingly in terms of adoption studies, additional factors influencing innovation uptake are level of income, succession (Calatrava and Franco, 2011), access to capital/ credit (Case et al., 2017), land tenure/ownership (Viaene et al., 2016), membership in agriculture cooperatives (Chen et al., 2020), the type of farm operations done by the farmer (for example, farmers who exclusively focus on managerial duties or their technical staff may be more open to new practices; Calatrava and Franco, 2011) along with attitudes towards risk, the environment, the specific technology/practice and the future of the farm (Case et al., 2017). According to Calatrava and Franco (2011) literature shows how, in general, all factors that widen the farmer's planning horizon and stimulate him or her to take decisions with relevance on the long run have a positive effect of the adoption of conservation practices. Moreover, awareness of others farmers using a practice (Case et al., 2017)and the possibility of observing them are considered significant motivating factors for farmers (Reimer et al., 2012; Lalani et al., 2016).

Various farm characteristics (size, conventional or organic, slope and location) may also influence the adoption of innovations although not always significantly or in the same way. For example, larger farm size, increased interest in adoption of manure separation technologies (Case et al., 2017) but this variable was not found to be significantly related with the adoption of mulch (Calatrava and Franco, 2011).

Additionally, various aspects of the economics of the innovation/practice are important. Of major importance is the investment needed. For example, the monitoring and managing equipment for on-farm composting have been noted to be too expensive for an individual farmer (Viaene et al., 2016); switching to a new fertilizer may need some new instruments, like new spreaders, and new knowledge, implying additional costs to farmers (Chen et al., 2020). On top of this, the cost of the practice is considered by the farmer; for example, low costs lead to favorable attitude towards adoption of organic waste composting products (Chen et al., 2020). Transportation costs are also major factors affecting the willingness of farmers, especially smallholders, to accept manure (Case et al., 2017) or composting (Chen et al., 2020).

On the other hand, the expected benefits influence heavily farmers' decision to adopt and innovative technology or practice. For example, the perceived superior return of applying composting fertilizers as compared to chemical fertilizers owing to their relative price or spreading costs (Chen et al., 2020).

As far as the innovations per se are concerned, factors such as the uncertainty of organic fertilizer nutrient contents (Chen et al., 2020), compost variable quality, composition, origins and nutrient concentrations (determining its maturity and stability), along with the risk for weeds and diseases (Viaene et al., 2016), unpleasant odor of the organic waste products such as manure for neighbours (Case et al., 2017) along with access to an alternative type of organic fertiliser (Case et al., 2017; Chen et al., 2020) were found to be also very important in terms of adoption. Another factor influencing uptake is time, i.e. lack of the required time to compost when feedstock is available or vice versa (Viaene et al., 2016) or the time needed to monitor the process of on-farm composting and compost application which may compete with the farmers' primary activities (Viaene et al., 2016); in general, labour consuming innovations are expected to decrease adoption of conservation practices.

Furthermore, except for financial benefits other perceived advantages on a practice influence farmer decisions, such as the relative environmental advantages and impacts of using organic waste composting products (Chen et al., 2020). Additionally, according to adoption literature, innovations which produce short-term benefits make farmers more eager to adopt them; however, in the case of compost, farmers first experience the actual higher short-term costs, while the benefits manifest particularly on the long-term (Viaene et al., 2016).

As may be expected, government support, supportive regulations and policies, including subsidies on organic fertilizers, encourage and facilitate the market of organic waste-based fertilizers and farmers to adopt such products (Chen et al., 2020). In parallel, complex, confusing, and often contradictory legislative landscape should be avoided (Viaene et al., 2016).

With regard to the above mentioned innovation attributes and technical problems, these have to do with a wide range of supply side deficiencies as, for example, the lack of organic waste processing facilities, the lack of distribution systems to transport processed organic fertilizers to farmers and the lack of data on the availability of local solid organic waste (Case et al., 2017; Viaene et al., 2016; Chen et al., 2020).

Furthermore, lack of dissemination of knowledge about the regulations and policies make it difficult for the farmers to adopt related technologies (Viaene et al., 2016). Accessibility of farmers to technical information, assistance and training, promote (on top of possible subsidization of environmentally-sound farming practices) adoption of these practices (Calatrava and Franco, 2011). Therefore, the role of extension services in providing information and assistance can be highly effective, especially in the case of new to the farmers or emerging technologies (Viaene et al., 2016).

8. Concluding remarks

The current AgroFossilFree Deliverable (D1.2), in the first place, aims at providing a review of the concept of innovation and the processes of innovation generation, adoption and diffusion. Such a review aims at providing an understanding on farmers' innovation-related decision-making, including the key-factors, such as farmers' and farms' characteristics, biophysical, socio-cultural and institutional environment, which influence the process of adoption, that is, if and how innovations are adopted.

Given the aims of AgroFossilFree the review was based on papers and reports exploring, more or less, related to RES and energy-saving topics and meta-analyses of innovation (technology and best practices) adoption, mainly in the developed world. As noted, innovation adoption and diffusion is undoubtedly multifactorial. Nevertheless, despite some generally accepted factors affecting the adoption of innovations (technologies and/or practices), the heterogeneity of both farms and farmers affects what is adopted, to what extent, and when. Moreover, the inconsistent evidence found in the literature review further points to the need for caution regarding, on the one hand, the use and measure of variables and, on the other hand, the different contexts (biophysical environment and cultural-historical patterns) within which research is conducted along with the characteristics of the technology under research. Reference has also to be made to the role of extension/advisory services and consultants which, in the framework of AKIS, influence farmers' awareness, knowledge and skills.

The preceding review (theories and research results) has provided the rationale for the construction of the assessment tools for farmers' survey and experts' interviews in the AgroFossilFree partner countries (see Part B).

PART B: ASSESEMENT TEMPLATES

Following the two templates to be used in farmers' survey and experts' interviews are presented. Given the preceding literature review an effort was made to address as many factors (multifactorial approach) as possible while taking into account the number of themes to be addressed, farmers' time constraints and the project's resources. The templates are the result of the multi-actor (MA) approach taken in the project.

Furthermore, a draft of a document concerning research Ethics, i.e. "Survey Participant Information Sheet and Consent Form" is also included in Appendix 3.

I. Farmers' questionnaire

Country:
Questionnaire Code:

Questionnaire

Intro:

Name ____
Telephone number ____________________________
Email ____

Farm

1. Region:

2. How would you describe the places where your fields are located?
    1. Flat (% of fields)
    2. Hilly (% of fields)
    3. Mountainous (% of fields)

3. **A. Production system**
    1. Plant production
    2. Animal production
    3. Mixed

B. Please specify number of hectares/animal heads and other activities (if any) according to production system selected (multiple selection possible)

1. Arable (i.e. cereals, open field vegetables, root crops, etc) ________ ha.
2. Permanent crops (i.e. vineyards, orchards, etc) ________ ha.

3. Other land (i.e. permanent grassland, etc) ______ ha.
4. Greenhouse _____ ha.
5. Dairy cows: __________________number of heads
6. Beef - meat production: ________number of heads
7. Sheep: ______________________number of heads
8. Goats: ______________________ number of heads
9. Breeding sows: _______________number of heads
10. Laying hens: _________________number of heads
11. Broilers (Poultry): _____________number of heads
12. Farm-based added-value/diversification activities, i.e. packaging and/or other processing unit, agrotourism (hostel, rooms, restaurant), etc.
    1. Yes (Please specify: _____________________________________)
    0. No

☐ Other useful info? (Interviewers' Notes): ______________________

4. How do you characterize the farm as compared to the country average? – Interviewer's ESTIMATION)?
    1. Very small
    2. Small
    3. Medium
    4. Big
    5. Very big

5. Legal status of farm:
    1. Family farm
    2. Company
    3. Cooperative farm
    4. Other____________________________

(Only if "family farm" was chosen in Question above answer Q6; if not, go toQ7)

6. The agricultural/farming income's contribution to the household income is estimated at about: ___________%

7. Total area cultivated (ha):__________

8. Of which:
    1. Land owned (ha):__________
    2. Land rented in (ha):__________
    3. Land rented out (ha):__________
    4. Other: __________

9. Participation in certification schemes? (PGI/PDO, integrated farming, organic farming, Global G.A.P., any livestock specific scheme, etc.) [Yes=1, No=2]
    - Yes (Please specify:____)
    - No
    -

10. Does the farm receive direct payments? (Pillar 1 of the CAP)[Yes=1, No=2]

- Yes
- No

11. Does the farm receive any other subsidies (Pillar 2 of the CAP)? (diversification, young farmers' scheme, agri-environmental measures, organic farming, farm modernization scheme, etc.)[Yes=1, No=2]
    - Yes (Please specify:____)
    - No

12. Does the farm receive any subsidies related to RES and/or energy-saving measures?
    - Yes (Please specify:____)
    - No

RES

13. For which of the following on-farm energy production technologies have you heard about?
    1. Solar (PV, PVT, thermal)
    2. Wind turbines
    3. Biomass/biofuels/biogas
    4. Heat pumps (Geothermal or aerothermal or hydrothermal)
    5. Hydro
    6. Any energy storage system
    7. Other (please specify) ………………………………………

If S/HE HAS HEARD [if NONE -> Q36]

14. Which are the three most important sources of information, from which you **heard about** such on-farm energy production technologies?
    14.1 Most important: ___________________________

    14.2 Second most important: _____________________

    14.3 Third most important: _______________________

MEMO (possible answers to Q14)

1	On my own experience
2	National or regional agricultural (public, cooperative) extension/advisory services
3	Private advisor
4	Technology manufacturers/ dealers
5	Technical press
6	Internet

7	Farmers' (discussion) group
8	Other farmers/peers (not including farmers' group)
9	Other (please specify)

15. Do you **use any of these technologies on your farm?**
    Yes
    No

    If YES [if NO -> Q 31]

Adopters (Users)

16. If YES, which one(s)? (numbers)
    16.1 _____________________________
    16.2 _____________________________
    16.3 _____________________________

17. Did you see (demonstration/ other farmer) or test the technology before getting/purchasing it? [Yes=1, No=2]
    - Yes
    - No

18. Which were the most important sources of information/support for its **assessment** (evaluation which led to adoption/use) [incl. your own experience]?
    18.1 Most important: _____________________________

    18.2 Second most important: ______________________

    18.3Third most important: _______________________

19. Which were the most important sources of information/support for its **establishment and use** [incl. your own experience]?
    19.1 Same as above (Q18)

    19.2 Most important: _____________________________

    19.3 Second most important: ______________________

    19.4Third most important: _______________________

MEMO (possible answers to Q18 & 19):

1	On my own experience
2	National or regional agricultural (public, cooperative) extension services
3	Private advisors

4	Technology manufacturers/ dealers
5	Technical press
6	Internet
7	Farmers' (discussion) group
8	Other farmers/peers (not including farmers' group)
9	Other (please specify)

20. How/where do you use the energy produced on your farm?
    1. Heating and cooling of buildings
    2. Lighting
    3. Farming field practices
    4. Agricultural machinery and vehicles
    5. Sales to external consumers
    6. Other

21. Did the introduction of energy producing technology change the way you practice farming? [Yes=1, No=2]
    - Yes, (How? ____)
    - No, (Why? ____)

In the next few questions, you will be asked if you disagree or agree with the following statements.
(1=Strongly Disagree, 2=Disagree, 3=neutral 4=Agree, 5=Strongly Agree)

22.	It is easy to work with this technology.	1	2	3	4	5
23.	It is easy to get technical support for the equipment.	1	2	3	4	5
24.	This technology is economically justified / the cost-benefit of this technology is as you expected.	1	2	3	4	5
25.	Sharing costs with other farmers has allowed you to use this technology.	1	2	3	4	5
26.	This technology is reliable.	1	2	3	4	5
27.	The equipment requires a lot of maintenance.	1	2	3	4	5

28. Who repairs and maintains the equipment? *(Tick all that apply)*
    28.1 You (farmer being interviewed) [Yes=1, No=2]
    28.2 Supplier/retailer/maker of equipment [Yes=1, No=2]
    28.3 Independent company [Yes=1, No=2]
    28.4 Public service [Yes=1, No=2]
    28.5 Other farmer [Yes=1, No=2]
    28.6 Other ________________

29. Which are the three most important reasons **that motivated you** to use this technology?

29.1 Most important ________________________

29.2 Second most important __________________

29.3 Third most important ___________________

MEMO (possible answers to Q29):

1	Being an innovator	
2	Save money through the reduction of energy costs	
3	Compliance with regulations	
4	Reduce environmental impact	
5	Utilize farm by-products	
6	Positive impact on human health	
7	Being a good steward of the countryside	
8	Being a good neighbor	
9	Financial incentive: Subsidy and/or tax exemption	
10	Financial incentive: price (I sell energy to others)	
11	Farm diversification	
12	Other (please specify):	

30. Did a specific external subsidy for RES give you the opportunity to invest in the selected technology?
    1. Yes (which ____)
    2. No

Non Adopters (Non Users)

31. Which of the following **information/tests would you trust** before deciding to establish (buy/use) such a technology?

31.1 Most important _____________________________

31.2 Second most important _______________________

31.3Third most important _________________________

MEMO (possible answers to Q31):

1	Demonstration
2	Cost benefit model to reflect farm specifics
3	Video
4	Conversations with unofficial contact (neighbor, other farmer)
5	Conversations with official contact (advisor, official, someone paid for their service)
6	Personal test/trial
7	See other farmers using it
8	Results on other farms

9	Other (please specify):

32. What would be the main reasons/incentives/motivation to apply such a practice? Multiple answers possible.
    32.1 subsidy or other financial incentive [Yes=1, No=2]
    32.2 sharing costs with others [Yes=1, No=2]
    32.3 getting training/support on how to use it [Yes=1, No=2]
    32.4 Other (please specify) _________________ [Yes=1, No=2]

33. What are your (**five**) most important reasons for **NOT** adopting such a technology? **(1= most important; 5= least important)**
    33.1 Most important ___________________________
    33.2 Second most important _____________________
    33.3 Third most important_______________________
    33.4 Fourth most important _____________________
    33.5 Fifth most important _______________________

MEMO (possible answers to Q33):

1	Land is too small
2	Not the best fitting technology available yet (tailored to my situation/ cultivation system)
3	Not interested
4	Not affordable (due to high upfront costs)
5	Do not see future profit benefit
6	I am too old (to change)
7	Too complicated to understand its use (not compatible with current skills and knowledge)
8	Too complicated to work with it/not user friendly
9	The technology/practice is not compatible with existing technology/ machinery/ equipment in my farm
10	The guarantee of long term efficiency of the technologies/practices is limited
11	Limited guarantee of (technical) assistance when asked/needed
12	Very complicated procedures (slow, lengthy or opaque processes - re: planning, licensing, permissions, etc.)
13	Do not have time to search, consider, apply for, and implement such technology/ practice
14	Other (please specify):

34. Have you watched other farmers using any such technology on his/her farm? [Yes= number No=0]

    34.1 Yes (Which _________________ **continue with QUESTION35**)
    34.2 Yes (Which _________________ **continue with QUESTION35**)
    34.3 Yes (Which _________________ **continue with QUESTION35**)
    34.4 No (**continue with QUESTION 36**)

35. (**Only if "yes" was chosen in QUESTION 34**): Did this raise your interest in any such technology? [Yes= number No=0]
    35.1 Yes (which one:_______________)
    35.2 Yes (which one:_______________)
    35.3 Yes (which one:_______________

Energy-saving

36. Have you **heard about energy saving practices**, such as**:**

Practices on Open-field farms relevant with:

36.1 Efficient vehicles (biofuels or electricity fuelled, maintenance (e.g. tyre pressure), logistics/planning)
36.2 Efficient tools (pumps or drip systems for irrigation, conveyors, refrigerators, mills/grinders, dryers)
36.3 Precision agriculture (seed/fertilizer/pesticide/lime/manure/water reduction)
36.4 Conservation agriculture (crop rotation, intercropping, soil coverage, no/minimum tillage)
36.5 Other

Practices on Greenhouses relevant with:

36.6 Efficient buildings (windows, BMS (building management system), lighting)
36.7 Efficient vehicles (biofuels or electricity fuelled, maintenance (e.g. tyre pressure), logistics/planning)
36.8 Efficient tools (pumps or drip systems for irrigation, conveyors, refrigerators)
36.9 Precision indoor agriculture (seed/fertilizer/pesticide/lime/manure/water reduction)
36.10 Other

Practices on Livestock facilities relevant with:

36.11 Efficient buildings (windows, BMS (building management system), lighting)
36.12 Efficient vehicles (biofuels or electricity fuelled, maintenance (e.g. tyre pressure), logistics/planning)
36.13 Efficient tools (milking machines, feeding equipment, conveyors, refrigerators, mills/grinders, dryers)
36.14 Precision Livestock (feed/medicine/manure reduction, animal healthcare)
36.15 Other

If YES [if NO -> Q57]

37. Which are the three most important sources of information, from which you **heard about** such energy saving practices?

    37.1 Most important: ___________________________

    37.2 Second most important: ____________________

    37.3 Third most important: ______________________

MEMO (possible answers to Q37)

1	On my own experience
2	National or regional agricultural (public, cooperative) extension/ advisory services
3	Private advisor
4	Technology manufacturers/ dealers
5	Technical press
6	Internet
7	Farmers' (discussion) group
8	Other farmers/peers (not including farmers' group)
9	Other (please specify)

38. Do you **use any of these practices on your farm?**

Yes

No

If YES (if NO -> Q52)

Adopters (Users)

39. If YES, which one(s)? (numbers)

39.1 ______________________________

39.2 ______________________________

39.3 ______________________________

40. Did you see (demonstration/ other farmer) or test the technology before getting/purchasing it? [Yes=1, No=2]

- Yes
- No

41. Which were the most important sources of information/support for its **assessment** (evaluation which led to adoption/use) [incl. your own experience]?

41.1 Most important: ______________________________

41.2 Second most important: _______________________

41.3Third most important: ________________________

42. Which were the most important sources of information/support for its **establishment and use** [incl. your own experience]?

42.1 Same as above (Q43)

42.2 Most important: ______________________________

42.3 Second most important: _______________________

42.4Third most important: ________________________

MEMO (possible answers to Q41 & 42):

1	On my own experience
2	National or regional agricultural (public, cooperative) extension/ advisory services
3	Private advisor
4	Technology manufacturers/ dealers
5	Technical press
6	Internet
7	Farmers' (discussion) group
8	Other farmers/peers (not including farmers' group)
9	Other (please specify)

43. Which are the three most important reasons that motivated you to apply such a practice/ such practices?

43.1 Most important _________________________

43.2 Second most important __________________

43.3 Third most important ___________________

MEMO (possible answers to Q43):

1	Being an innovator	
2	Save money through the reduction of energy costs	
3	Compliance with regulations	
4	Reduce environmental impact	
5	Utilize farm by-products	
6	Positive impact on human health	
7	Being a good steward of the countryside	
8	Being a good neighbor	
9	Financial incentive: Subsidy and/or tax exemption	
10	Financial incentive: price (I sell energy to others)	
11	Farm diversification	
12	Other (please specify):	

44. Did a specific external subsidy other than the direct farm payment give you the opportunity to invest in/ apply the selected practice?

3. Yes (which ____)
4. No

45. Did the introduction of energy saving technology/practice change the way you practice farming? [Yes=1, No=2]

- Yes, (How? ____)
- No, (Why? ____)

In the next few questions, you will be asked if you disagree or agree with the following statements.
(1=Strongly Disagree, 2=Disagree, 3=neutral 4=Agree, 5=Strongly Agree)

46	It is easy to work with this technology/practice.	1	2	3	4	5
47	It is easy to get technical support for the equipment.	1	2	3	4	5
48	This technology/practice is economically justified / the cost-benefit of this technology/practice is as you expected.	1	2	3	4	5
49	Sharing costs with other farmers has allowed you to use this technology/practice.	1	2	3	4	5
50	This technology/practice is reliable.	1	2	3	4	5
51	The equipment requires a lot of maintenance.	1	2	3	4	5

Non Adopters (Non Users)

52. Which of the following **information/tests would you trust** before deciding to follow (establish/use) such a practice?

52.1 Most important ______________________________

52.2 Second most important ________________________

52.3Third most important __________________________

MEMO (possible answers to Q52):

1	Demonstration
2	Cost benefit model to reflect farm specifics
3	Video
4	Conversations with unofficial contact (neighbor, other farmer)
5	Conversations with official contact (advisor, official, someone paid for their service)
6	Personal test/trial
7	See other farmers using it
8	Results on other farms
9	Other (please specify):

53. What would be the main reasons/incentives/motivation to apply such a practice? Multiple answers possible.

53.1 subsidy or other financial incentive [Yes=1, No=2]

53.2 sharing costs with others [Yes=1, No=2]

53.3 getting training/support on how to use it [Yes=1, No=2]
53.4 Other (please specify) _________________ [Yes=1, No=2]

54. What are your **five** most important reasons for **NOT** following any of the abovementioned practices? **(1= most important; 5= least important)**

54.1 Most important ___________________________
54.2 Second most important _____________________
54.3 Third most important______________________
54.4 Fourth most important _____________________
54.5 Fifth most important _______________________

MEMO (possible answers to Q54):

1	Land is too small
2	Not the best fitting technology available yet (tailored to my situation/ cultivation system)
3	Not interested
4	Not affordable (due to high upfront costs)
5	Do not see future profit benefit
6	I am too old (to change)
7	Too complicated to understand its use (not compatible with current skills and knowledge)
8	Too complicated to work with it/not user friendly
9	The technology/practice is not compatible with existing technology/ machinery/ equipment in my farm
10	The guarantee of long term efficiency of the technologies/practices is limited
11	Limited guarantee of (technical) assistance when asked/needed
12	Very complicated procedures (slow, lengthy or opaque processes - re: planning, licensing, permissions, etc.)
13	Do not have time to search, consider, apply for, and implement such technology/ practice
14	Other (please specify):

55. Have you seen other farmers using any such practice on his/her farm? [Yes= number No=0]

55.1 Yes (Which _________________ **continue with QUESTION56**)
55.2 Yes (Which _________________ **continue with QUESTION56**)
55.3 Yes (Which _________________ **continue with QUESTION56**)
No (**continue with QUESTION 57**)

56. (**Only if "yes" was chosen in QUESTION 55**): Did this raise your interest in any such practice(s)? [Yes= number No=0]
56.1 Yes (which one:_______________)
56.2 Yes (which one:_______________)
56.3 Yes (which one:_______________

Carbon sequestration

57. Have you heard about any farming practices concerning
    a. Manuring and fertilizing (organic and inorganic)
    b. Conservation tillage (minimum, zero/no-till)
    c. Crop residue management
    d. Cover crops/ crop rotation

If YES (if NO -> Q66)

58. Which are the three most important sources of information, from which you **heard about** such energy efficiency practice?

58.1 Most important: ___________________________

58.2 Second most important: ____________________

58.3 Third most important: ______________________

MEMO (possible answers to Q58)

1	On my own experience
2	National or regional agricultural (public, cooperative) extension/ advisory services
3	Private advisors
4	Technology manufacturers/ dealers
5	Technical press
6	Internet
7	Farmers' (discussion) group
8	Other farmers/peers (not including farmers' group)
9	Other (please specify)

59. Do you **use any of these practices on your farm?**
    Yes
    No

If YES (if NO -> Q62)

60. Which are the three most important reasons that motivated you to apply such a practice/ such practices?

60.1 Most important _________________________

60.2 Second most important __________________

60.3 Third most important ___________________

MEMO (possible answers to Q60):

1	Being an innovator	
2	Save money through the reduction of costs	
3	Compliance with regulations	
4	Reduce environmental impact	
5	Utilize farm by-products	
6	Positive impact on human health	
7	Being a good steward of the countryside	
8	Being a good neighbor	
9	Financial incentive: Subsidy and/or tax exemption	
10	Financial incentive: price (I sell energy to others)	
11	Farm diversification	
12	Other (please specify):	

61. Did a specific external subsidy other than the direct farm payment give you the opportunity to invest in/ apply the selected practice?

5. Yes (which ____)
6. No

(Go to Q 66)

62. What are your (**five**) most important reasons for **NOT** following any of the abovementioned practices? **(1= most important; 5= least important)**

62.1 Most important ____________________________

62.2 Second most important ______________________

62.3 Third most important________________________

62.4 Fourth most important ______________________

62.5 Fifth most important ________________________

MEMO (possible answers to Q62):

1	Land is too small
2	Not the best fitting technology available yet (tailored to my situation/ cultivation system)
3	Not interested (or this is not/does not seen to be 'good farming')
4	Not affordable (due to high upfront costs)
5	Do not see future profit benefit (or I am afraid to lose yields)
6	I am too old (to change)
7	Too complicated to understand its use (not compatible with current skills and knowledge)
8	Too complicated to work with it/not user friendly
9	The technology/practice is not compatible with existing technology/ machinery/ equipment in my farm

10	The guarantee of long term efficiency of the technologies/practices is limited
11	Limited guarantee of (technical) assistance when asked/needed
12	Very complicated procedures (slow, lengthy or opaque processes - re: planning, licensing, permissions, etc.)
13	Do not have time to search, consider, apply for, and implement such technology/ practice
14	Other (please specify):

63 What would be the main reasons/incentives/motivation to apply such a practice? Multiple answers possible.

63.1 subsidy or other financial incentive [Yes=1, No=2]
63.2 sharing costs with others [Yes=1, No=2]
63.3 getting training/support on how to use it [Yes=1, No=2]
63.4 Other (please specify) __________________ [Yes=1, No=2]

64 Have you seen other farmers using any such practice on his/her farm? [Yes= number No=0]

a. Yes (which ________________ **continue with QUESTION65**)
b. Yes (which ________________ **continue with QUESTION65**)
c. Yes (which ________________ **continue with QUESTION65**)
No (**continue with QUESTION66)**

65 (**Only if "yes" was chosen in QUESTION 64**): Did this raise your interest in any such practice(s)? [Yes= number No=0]

65.1 Yes (which one:________________)
65.2Yes (which one:________________)
65.3Yes (which one:________________

Farmer's attitudes regarding *information seeking on innovations*

66 How often do you visit agricultural fairs, field days/demonstrations, or exhibitions?

1. More than once a year
2. Once a year
3. Less than once a year
4. Never

67 Which were the **three most important sources of information** in which you sought out information, *last year*, in relation to **renewable energy production and energy saving technologies/ practices**?

67.1 First most important __________________

67.2 Second most important _________________

67.3 Third most important __________________

MEMO (possible answers to Q67):

1	None
2	Professional press (e.g. farmer association magazines, journals)
3	Scientific journal/press
4	Advertisement
5	Exhibitions or trade fair
6	Seminars or workshop
7	Demonstration
8	Internet
9	Social media
10	Farmer discussion group
11	Other farmers (not including discussion group)
12	Advisor contact (public/cooperative)
13	Advisor contact (private)
14	Other:

68 **Please rank each of the following characteristics** of **renewable energy production and energy saving technologies/ practices** that would make them more **relevant to farmers' needs (1 = not at all crucial ;5 = very crucial**)

1	Easy to use	1	2	3	4	5
2	Easy to install	1	2	3	4	5
3	Show economic benefits right away	1	2	3	4	5
4	Reduction of environmental hazards	1	2	3	4	5
5	Reasonable price	1	2	3	4	5
6	Technical support	1	2	3	4	5
7	Compatible with existing machinery/equipment	1	2	3	4	5
8	Long-term reliability	1	2	3	4	5
9	Operator safety	1	2	3	4	5
10	Other (please specify)	1	2	3	4	5

Farmer's opinions about technology, in general.

(1=Strongly Disagree, 2=Disagree, 3=Agree, 4=Strongly Agree)

69 Technology can improve farming.	1	2	3	4
70 Technology can help farmers comply with regulations (e.g. CAP Greening).	1	2	3	4
71 Technology can support farmers' work recognition by the public.	1	2	3	4

Farmer's Innovativeness

72 Do you like to experiment on your farm, i.e. trying new technology or practices on the farm before you adopt it at full scale?
1. Yes – by myself
2. Yes – with other farmers
3. Yes – with advisers or researchers
4. No

In the next few questions, you will be asked if you disagree or agree with the following statements.
(1=Strongly Disagree, 2=Disagree, 3=neutral 4=Agree, 5=Strongly Agree)

73 In general, I am the first in my social circle of friends and relatives to ***know*** about new machinery/technology.	1	2	3	4	5
74 In general, I am among the first of my friends and relatives to ***buy*** new machinery/technology.	1	2	3	4	5
75 Usability and user-friendliness are very important to me when I buy new things.	1	2	3	4	5
76 I wait to buy new things, until I know others have positive experiences with it.	1	2	3	4	5
77 I prefer to have some experience with something before I buy it.	1	2	3	4	5
78 Even if I am interested, I wouldn't buy if my (social) environment would be negative on it.	1	2	3	4	5
79 In general, when making farm decisions, I don't like taking risks.	1	2	3	4	5

80 What kind of incentives would you like to see in future policies to facilitate the acquisition of renewable energy production and energy-saving technologies/practices?

____

____

Farmer/

farm manager

81 Age: ___ years old

82 Gender:
1. Male
2. Female

83 What is the highest level of education you completed?

1. Elementary (approximately 4-7 years of general education)
2. Secondary school (approximately 8-12 years of general education)
3. Technical school and/or apprenticeship (approximately 2-4 years follow-up after (Lower) secondary school)
4. University (any level, Bachelor, Master, or PhD)
5. Other: ________________________

84 Is farming/farm management your primary occupation? [Yes=1, No=2]
- Yes (full-time)
- No (part-time)

85 For how long have you been a farmer/farm manager? (years ____________)

86 Is there a farm successor or someone who will inherit and/or take over the farm?
- Yes
- No
- Not relevant (not a family farm)

87 Why did you become a farmer?
1. Tradition (family, farm inherited)
2. Profession of choice
3. No other choice
4. Other (please specify) ____________________________
5. Not relevant (farm manager)

88 How would you rank your satisfaction with farming/farm management?
1. Very unsatisfied
2. Unsatisfied
3. Satisfied
4. Very satisfied

89 Do you **hold** a **Green/Farming Certificate**?
Yes/Duration of training (in months) ______
No = 0

90 Do you use the Internet?
1. Yes, every day
2. Yes, sometimes within the week
3. Yes but not very often (a few times per month)
4. Rarely
5. Not at all

91 How would you rate your information technology skills (5 = excellent, 1 = very poor, 0 = none) ____

92 Do you participate in any farmers' cooperative/association/union, etc.?

1. Yes
2. No
3. Not relevant (cooperative farm)

93 Any other comments you would like to make with regard to the topics discussed?

II. Experts interview guide

To whom it should be addressed:

Expert groups:

1. Research: Universities, Research Institutes, Universities of Applied Science

2. Industry: Experts in companies (CEOs, managers, technical experts)

3. Practice: Agricultural advisors (agronomists, consultants, public/private agricultural extension services), representatives of agricultural cooperatives/associations, etc.

Data Collection:

The number of interviewed experts is *at least 5* (academics, researchers, industry representatives, advisors, and possibly (but not necessarily) farmer representative of farmer-based organisation)

The expert interviews will be conducted face-to face or via Skype, etc.

Use of voice recorder, after the agreement by the interviewee.

Recordings will be transcribed and main points translated into English.

1. Introduction

Description of organization

- Could you briefly describe your organisation? (Main activity/activities, date of establishment, different levels of organisation (international, national, regional, local), total number of staff)

Description of the interviewee

- Could you briefly describe your career and training background?
- What is the RES field that you have expertise in?

2. Questionnaire

1) What are the main challenges facing European agriculture nowadays and in the future?

2) What is the role of RES and energy-saving practices in overcoming these challenges?

3) What is the role of policy, economic, social and environmental pressures in driving farmers to adopt/ use RES and energy-saving practices?

- What are the environmental pressures for using RES and energy-saving practices?
- What are the policy (EU regulations, national/regional legislation, incentives/subsidies, etc.) pressures for using RES (and energy-saving practices)?
- What are the economic pressures for using RES (and energy-saving practices)?
- What are the social pressures for using RES and energy-saving practices? (Are there social values/social pressure that force farmers towards a more environmental friendly/ energy-saving agriculture? If yes which? How strong influence do you believe that these have in farmers' decision making?)

4) What are, according **to your opinion**, the advantages/ disadvantages for a farmer to use RES and energy-saving practices?

5) Can you comment on the situation of RES and energy-saving practices adoption and use in your country? (If you are aware: How does it compare to other EU Member States?)

6) What are the main **farmers' motivation and criteria** for which currently they use RES (and energy-saving practices) on their farms?

7) What are the major/distinctive personal and farm characteristics of farmers who adopt RES and energy-saving practices? (i.e. are there personal factors, life-stage of farm family as well as farm-specific factors, such as cropping system, size, location/ altitude, etc., on top of policy, social, economic, environmental pressures, etc.)?

8) What are the reasons/barriers for which farmers do not adopt RES and energy-saving practices?

9) How are farmers' needs and demands taken into account - what is the role of farmers in the development of innovations regarding energy?

10) Are there any RES and energy-saving practices characteristics (economic, technical, etc.) which need improvement/ change so that these technologies/practices will become more relevant and affordable to farmers and thus more widely adopted?

11) Are there specific demands on farmers’ knowledge and skills regarding RES and energy-saving practices?

12) What is/ what should be the role of a) research and b) extension/advisory services in promoting RES and energy-saving practices among farmers

- What is the role and importance of research and advisory services vis-à-vis family and neighbour-level and/or other information sources?

13) What is/ what should be the role of subsidies, policies, or regulations in directing the adoption and dissemination of RES and energy-saving practices?

14) Can you please comment on the cooperation (or not) between AKIS[33] actors (policy, research, extension, farmers, industry, etc.) in RES (and energy-saving practices) development/ innovation (are there links between actors? how are decisions on technology development taken?)

a) in the assessment of farmer’s/end user’s needs (if any)?

b) in the design and production of innovations?

c) in terms of complementary actions (regulations, infrastructure, etc.)?

[33] AKIS (Agricultural Knowledge and Innovation system) is the organisation and interaction of persons, organisations and institutions who use and produce knowledge and innovation for agriculture and interrelated fields. The main players of the AKIS are: farmers/foresters, advisors, researchers, (farmer) organisations, NGOs, networks, retailers, media, services, various ministries…: they all produce and need knowledge (EU definition).

According to the GA, with reference to Task 1.3 "*Systematic and multi-perspective overview on farmers' needs, innovative ideas and interests about FEFTS*", in the first place, criteria (i.e. variables/factors which according to the literature review influence technology adoption, such as farmers' socio-demographic characteristics and farm structural indicators) will be selected in order to qualitatively group adopters and non-adopters and thus identify those who will participate in the survey. A first selection of such data, based on Eurostat 2013/2016, is presented in Appendix 4. Following, up to 50 interviews with farmers from the pre-classified groups will be conducted by the national partners, either personal or telephonic, using the preceding assessment template. Additionally, experts working on SETA will be identified, by the project partners, in each of the INNOSETA countries and out of those a number will be selected (representing different institutes/ organisations) and will be interviewed using the experts interview guide (aide memoire).

With respect to Task 1.4 "*Assessment of successful innovation processes and best practices around FEFTS*" concerning the identification and promotion of examples of successful innovation processes and best practices in FEFTS the AGRISPIN methodology (i.e. cross-visits during which the Innovation Spiral tool will be employed; see section 3.2) will be followed. As stated in the GA, eight examples of appropriate cases will be chosen by the research partners of AgroFossilFree (CERTH, AU, AUA, IUNG) in close collaboration with the rest of the consortium and studied in an interactive way in order to better understand the innovation processes at play as well as the roles and functions fulfilled by actors of the innovation system (advisors, researchers, private companies, vocational schools and other public agencies).

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Appendices

Appendix 1: Roger's generalisations

Early Versus Late Knowers of Innovations

The following generalizations summarize the results of findings regarding early knowing about an innovation:

Generalization 5-1: Earlier knowers of an innovation have more education than later knowers.

Generalization 5-2: Earlier knowers of an innovation have higher social status than later knowers.

Generalization 5-3: Earlier knowers of an innovation have more exposure to mass media channels of communication than later knowers.

Generalization 5-4: Earlier knowers of an innovation have more exposure to interpersonal channels of communication than later knowers.

Generalization 5-5: Earlier knowers of an innovation have more change agent contact than later knowers.

Generalization 5-6: Earlier knowers of an innovation have more social participation than later knowers.

Generalization 5-7: Earlier knowers of an innovation are more cosmopolite than later knowers.

Characteristics of Adopter Categories

… we summarize this diffusion research in a series of generalizations under the following headings:

socioeconomic status, (2) personality variables, and (3) communication behaviour.

Socioeconomic Characteristics

Generalization 7-2: Earlier adopters are not different from later adopters in age (note: there is inconsistent evidence about the relationship of age and innovativeness).

Generalization 7-3: Earlier adopters have more years of education than later adopters have.

Generalization 7-4: Earlier adopters are more likely to be literate than are later adopters.

Generalization 7-5: Earlier adopters have higher social status than later adopters (status is indicated by such variables as income, level of living, possession of wealth, occupational prestige, self-perceived identification with a social class, and the like).

Generalization 7-6: Earlier adopters have a greater degree of upward social mobility than later adopters (note: definitive empirical support is lacking).

Generalization 7-7: Earlier adopters have larger-sized units (farms, companies, and so on) than later adopters (Figure 7-3).

Generalization 7-8: Earlier adopters are more likely to have a commercial (rather than a subsistence) economic orientation than are later adopters.

Generalization 7-9: Earlier adopters have a more favorable attitude toward credit (borrowing money) than later adopters.

Generalization 7-10: Earlier adopters have more specialized operations than later adopters.

Personality Variables

(note: personality variables associated with innovativeness have not yet received much research attention)

Generalization 7-11: Earlier adopters have greater empathy than later adopters (empathy is the ability of an individual to project him or herself into the role of another person).

Generalization 7-12: Earlier adopters may be less dogmatic than later adopters (dogmatism is the degree to which an individual has a relatively closed belief system, that is, a set of beliefs that are strongly held).

Generalization 7-13: Earlier adopters have a greater ability to deal with abstractions than later adopters.

Generalization 7-14: Earlier adopters have greater rationality than later adopters (rationality is use of the most effective means to reach a given end).

Generalization 7-15: Earlier adopters have greater intelligence than later adopters.

Generalization 7-16: Earlier adopters have a more favourable attitude toward change than later adopters.

Generalization 7-17: Earlier adopters are more able to cope with uncertainty and risk than later adopters.

Generalization 7-18: Earlier adopters have a more favourable attitude toward education than later adopters.

Generalization 7-19: Earlier adopters have a more favourable attitude toward science than later adopters.

Generalization 7-20: Earlier adopters are less fatalistic than later adopters (fatalism is the degree to which an individual perceives a lack of ability to control his or her future).

Generalization 7-21: Earlier adopters have higher levels of achievement motivation than later adopters (achievement motivation is a social value that emphasizes a desire for excellence in order for an individual to attain a sense of personal accomplishment).

Generalization 7-22: Earlier adopters have higher aspirations (for education, occupations, and so on) than later adopters.

Communication Behaviour

Generalization 7-23: Earlier adopters have more social participation than later adopters.

Generalization 7-24: Earlier adopters are more highly interconnected in the social system than later adopters. Connectedness is the degree to which a unit is linked to other units.

Generalization 7-25: Earlier adopters are more cosmopolite than later adopters (cosmopoliteness is the degree to which an individual is oriented outside the social system.

Generalization 7-26: Earlier adopters have more change agent contact than later adopters.

Generalization 7-27: Earlier adopters have greater exposure to mass media communication channels than later adopters.

Generalization 7-28: Earlier adopters have greater exposure to interpersonal communication channels than later adopters.

Generalization 7-29: Earlier adopters seek information about innovations more actively than later adopters.

Generalization 7-30: Earlier adopters have greater knowledge of innovations than later adopters.

Generalization 7-31: Earlier adopters have a higher degree of opinion leadership than later adopters (note: this depends in part on the norms of the social system).

Generalization 7-32: Earlier adopters are more likely to belong to highly interconnected systems than are later adopters.

Appendix 2: Measures of key-constructs in TAM biomedical studies

Construct	Measurement dimensions of construct
Perceived usefulness	Useful for job (or task) Increases productivity Enhances effectiveness of job (or work) Allows tasks to be accomplished more quickly Improves job performance Makes it easier to do job/work Increases quality of care Increases quality of work Improves work efficiency Allows tasks to be done more accurately Allows tasks to be done more objectively Supports critical aspects of job Increases chance of getting a raise Allows greater control over work Enables decisions based on better evidence Improves patient care and management Not enough information on measurement
Perceived ease of use	Easy to use Clear and understandable Easy to become skillful with system Easy to get it to do what you want it to Easy to learn to operate Flexible to use/interact with Low mental effort Easy to do what I want Easy to do tasks with system Clear Understandable Does not demand much care and attention Navigation is easy Easy to remember how to perform tasks with system Not enough information on measurement
Social influence/subjective norms	Pediatricians who influence my behavior think I should use system Pediatricians who are important to me think I should use system People who influence my behavior think I should use system People who influence my clinical behavior think I should use system People who are important to me think I should use system People whose opinions I value think I should use system People who are important to my health care services think I should use system People who are important in assessing my patient care and management think I should use Senior management of hospital has been helpful Hospital supported use of system Colleagues who are important to me think I should use system Superiors at work think I should use system Subordinates at work think I should use system Not enough information on measurement
Perceived behavioral control/facilitating conditions	Have necessary resources to use system Have knowledge to use system Compatibility with other systems Availability of technical assistance Able to use system at work Able to use system for patient care and management Using system at work is wise Using system entirely under my control Not enough information on measurement

Appendix 3: Survey Participant Information Sheet and Consent Form

Survey Participant Information Sheet

AGROFOSSILFREE (Strategies and technologies to achieve a European Fossil-energy-free agriculture)

info partner researcher(s), responsible for the area:
(name)
Address for correspondence:
Email: … **Telephone:** …
Date

Dear ………………………….

Thank you for your interest in this study: **Strategies and technologies to achieve a European Fossil-energy-free agriculture**.

You are invited to participate in this project and we are required to provide a participant information sheet and consent form to inform you about the study, to convey that participation is voluntary, to explain the potential risks and benefits of participation, and to empower you to make an informed decision. You should feel free to ask us any questions you may have. If you agree to take part, we will ask you to sign a consent form. Please take as much time as you need to read it. You should only consent to take part in this study when you feel that you understand what is being asked of you and you have had enough time to think about your decision.

PURPOSE OF RESEARCH

We are undertaking this research at (partner institution) as the organization representing (country) in the larger European Horizon 2020 project **AGROFOSSILFREE** that brings together a wide range of actors across Europe. You have been contacted about this study because you are a farmer who uses energy in your everyday farming operations which is the focus of this research. Your answers will form part of our study on the use of alternative/renewable energy sources and energy saving practices throughout Europe.

AGROFOSSILFREE

The aim of **AGROFOSSILFREE** is to create a framework under which critical stakeholders will cooperate to evaluate and promote currently available fossil-energy-free strategies and technologies (FEFTS) in EU agriculture to diminish in the short term and eliminate in the long run fossil fuels use in any farming process from cradle to farm gate, while maintaining yield and quality of the end-product. Such a framework will contribute in closing the gap between the available FEFTS either commercial or from applicable research results with the everyday EU agricultural practices by promoting effective exchange of novel ideas and information between research, industry, extension and the farming community so that existing research and commercial solutions can be widely communicated, while capturing grassroots level needs and innovative ideas from the farming and related industry communities. Financing opportunities for de-fossilizing EU agriculture will be investigated and highlighted.

Why are my details important?

The more participants included in this survey the more beneficial it will be to both the agricultural sector and to relevant industries and research institutes. Your contribution is very important in increasing the understanding of farmers' needs and interests, and identifying factors influencing adoption and diffusion of FEFTS technologies and best practices.

WHAT YOU WILL DO

Your participation is entirely voluntary. If you consent to take part you will be asked to reply to a number of questions included in the **AGROFOSSILFREE** farmers' questionnaire. This questionnaire will take you around 45 minutes to complete. All information provided in the interview and surveys will be kept anonymous and strict confidentiality will be ensured.

POTENTIAL BENEFITS

The findings of this study will be presented in (country) and in Europe. As aforementioned, it is the aim of this research to promote effective exchange of novel ideas and information between research, industry, extension and the farming community so that existing research and commercial solutions can be widely communicated, while capturing grassroots level needs and innovative ideas from the farming community.

POTENTIAL RISKS

We do not foresee any negative effects arising from your participation in this study. Please understand that you are free to withdraw from participation in advance of the interview as well as to stop the interview at any stage. All information and topics discussed are confidential and the content of the discussion/questionnaire data will not be disclosed with third parties.

PRIVACY AND CONFIDENTIALITY

We will collect your name, organisation, and professional email address in case further details are necessary when analyzing the data. However, your participation in this survey will be treated anonymously and your personal data will only be kept for internal research purposes; your data and that of other persons and places mentioned in the survey and/or interview will remain confidential at all times.

In case the survey and/or interview is recorded, all electronic and recorded versions of the survey interview will be securely stored and treated anonymously. The only record of your participation in the interview will be stored in (researcher location) in a secure location for the duration of the study, in case we need to contact you again. Anonymised versions of the interview data will be shared with and analysed by **AGROFOSSILFREE** project partners.

The results of this study will be published or presented at professional meetings but the material used will not allow the identification of any of the participants in this survey, at all times.

YOUR RIGHTS TO PARTICIPATE, SAY NO, OR REQUEST MY WITHDRAWAL

Participation in this research project is completely voluntary. You have the right to say no. You may change your mind at any time or withdraw. You may choose not to answer specific questions or to stop participating at any time.

CONTACT INFORMATION FOR QUESTIONS AND CONCERNS

If you have any questions about this study, or about your role or rights as a research participant, please contact the researchers and their Data Protection Officer (DPO) at the address above.

(researcher) + (contact of the DPO of the partner's organization)

Summary

Participation in this study is based on the clear understanding that your participation is voluntary and can be withdrawn at any time. A consent form accompanies this participant information sheet. A copy of both will be provided to you. You are required to sign a copy of the consent form should you agree to participate in this study - please return one copy of the signed consent form. Thank you for considering taking part in this study.

AGROFOSSILFREE

[+ logo Partner]

Consent Form

AGROFOSSILFREE (Strategies and technologies to achieve a European Fossil-energy-free agriculture)

info partner researcher(s), responsible for the area:
(name)
Address for correspondence:
Email: … Telephone: …
Date

Please initial box

1. I confirm that I have read the participation information sheet dated (Date) for the above study and have had the opportunity to ask questions ☐

2. I confirm that I understand the information provided and have had enough time to consider the information. ☐

3. I understand that my participation is voluntary and that I am free to withdraw at any time. ☐

4. In signing this consent form I [Participant] agree to volunteer to participate in this research study being conducted by (leading partner researcher) and research colleagues. ☐

5. I agree: ☐

- to the data being audio-recorded for the purposes of data processing

and, ☐

- to the interview being archived in a digital repository subject to my name and identifying information being removed

6. I understand that I will participate in a recorded interview with the researcher on the agreed topic. ☐

7. I grant full authorization for the use of the above information on the full understanding that my participation will be kept anonymous and confidentiality will be preserved in public use of these data. ☐

8. I understand that participation is completely voluntary and that I am free to withdraw my data at any time, without giving a reason. ☐

________________	________________	________________
Participant	Date	Signature
________________	________________	________________
Researcher	Date	Signature

Appendix 4: A first approach to factors potentially affecting the adoption of innovative technologies and practices (source: EUROSTAT 2013 & 2016)

Arable crops

Includes: cereals for the production of grain (including seed), dry pulses and protein crops for the production of grain (including seed and mixtures of cereals and pulses), root crops, industrial crops, plants harvested green from arable land, fresh vegetables (including melons) and strawberries, flowers and ornamental plants (excluding nurseries), seeds and seedlings, other arable land crops, fallow land.

Table 4.1: Arable crops, number of holdings and hectares per size class category (2016)

	Arable land 2016																	
	Less than 1 ha		From 1 to 1.9 ha		From 2 to 4.9 ha		From 5 to 9.9 ha		From 10 to 19.9 ha		From 20 to 29.9 ha		From 30 to 79.9 ha		From 80 to 149.9 ha		150 ha or over	
	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares
Denmark	710	360	570	840	1.980	7.150	5.520	40.620	4.610	67.010	2.960	73.420	6.190	312.600	3.890	431.650	4.680	1.427.530
Germany	8.060	3.880	6.320	9.420	15.660	54.820	29.840	221.100	38.320	558.920	22.320	551.850	53.850	2.682.720	18.930	2.018.950	13.180	5.717.650
Ireland	1.260	600	1.240	1.810	3.460	11.900	4.030	29.460	4.020	58.330	2.220	54.520	3.150	148.760	730	75.440	320	77.470
Greece	74.130	31.720	48.630	66.280	77.880	244.240	48.630	334.700	27.980	378.670	9.110	215.860	8.710	371.980	830	82.460	180	36.340
Spain	96.910	34.910	51.220	69.910	70.900	222.070	53.490	387.390	49.260	703.410	27.400	673.460	54.380	2.664.700	22.350	2.432.950	15.750	4.274.110
Italy	122.420	58.090	129.200	180.110	179.820	566.360	110.710	779.870	80.610	1.120.410	31.640	766.970	39.690	1.812.630	7.970	843.840	3.660	1.016.760
Netherlands	2.520	1.290	2.500	3.720	6.000	20.490	7.670	57.130	7.940	115.280	4.770	117.880	8.380	397.380	1.820	191.500	550	123.500
Poland	129.530	70.890	234.810	330.430	380.550	1.223.150	243.900	1.711.280	138.180	1.891.400	40.800	985.310	39.960	1.819.820	7.800	820.430	5.400	1.952.900

Source: Eurostat, Main crops by NUTS 2 regions [EF_LAC_MAIN],

Permanent crops

Includes: Fruits, berries and nuts (excluding citrus fruits, grapes and strawberries), citrus fruits, grapes, olives, nurseries, other permanent crops including other permanent crops for human consumption.

Table 4.2: Permanent crops, number of holdings and hectares per size class category (2016)

		Permanent crops																	
		2016																	
		Less than 1 ha		From 1 to 1.9 ha		From 2 to 4.9 ha		From 5 to 9.9 ha		From 10 to 19.9 ha		From 20 to 29.9 ha		From 30 to 79.9 ha		From 80 to 149.9 ha		150 ha or over	
		Holdings	Hectares	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares
Denmark	**2016**	1.360	600	820	1.220	800	2.660	490	3.480	380	5.380	100	2.460	130	6.030	30	3.350	10	2.590
Germany	**2016**	8.290	4.080	5.690	8.030	6.140	19.990	4.180	30.740	3.420	49.130	1.100	27.000	870	38.440	90	9.440	60	15.180
Ireland	**2016**	1.230	170	30	40	50	180	40	320	30	360	10	200	10	420	0	NA	0	NA
Greece	**2016**	236.020	108.060	127.200	170.880	113.930	336.160	29.980	194.570	6.900	85.350	770	17.710	240	9.590	20	1.600	0	1.320
Spain	**2016**	110.240	51.280	126.240	172.010	170.040	543.660	91.290	640.880	53.310	732.100	16.900	408.890	19.410	886.390	3.310	354.140	1.440	359.590
Italy	**2016**	340.320	172.970	221.820	300.640	167.980	509.090	57.540	393.070	26.810	352.420	6.220	147.770	4.910	210.520	720	75.320	150	38.660
Netherlands	**2016**	1.680	770	810	1.170	1.140	3.760	830	6.010	710	10.060	250	6.050	160	6.940	20	2.250	10	1.110
Poland	**2016**	99.440	30.720	25.030	33.350	26.620	82.950	14.850	101.090	6.450	84.100	840	19.520	560	25.200	90	9.310	30	7.230

Source: Eurostat, Main permanent crops farm [EF_LPC_MAIN]

Greenhouses - Areas under glass or high accessible cover

Includes: Flowers and ornamental plants (excluding nurseries) under glass or high accessible cover, permanent crops under glass or high accessible cover, fresh vegetables (including melons) and strawberries under glass or high accessible cover

Crops under glass or high (accessible) cover refers to crops that are covered by accessible greenhouses for the whole period of growth or for the predominant part of it.

- Includes accessible greenhouses, accessible shade houses, fixed high cover (made of glass, rigid plastic or flexible plastic) and mobile high cover (made of glass, rigid plastic or flexible plastic).
- Excludes sheets of plastic laid flat on the ground, land under cloches, tunnels not accessible to persons and movable glass-covered frames.

*Source:*https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Crops_under_glass_or_high_accessible_cover

Table 4.3: Fresh vegetables under glass or high accessible cover, number of holdings and hectares per size class category (2016)

	Fresh vegetables (including melons) and strawberries - under glass or high accessible cover															
	Less than 0.10 ha		From 0.10 to 0.19 ha		From 0.20 to 0.29 ha		From 0.30 to 0.49 ha		From 0.50 to 0.69 ha		From 0.70 to 0.99 ha		From 1 to 1.9 ha		2 ha or over	
	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares
Denmark	80	0	20	0	10	0	10	0	10	10	0	0	10	10	20	80
Germany	500	20	410	50	310	60	310	100	150	80	140	110	170	210	210	1.010
Ireland	:	0	:	0	:	0	10	0	10	10	10	10	10	10	30	250
Greece	380	20	1.260	150	1.140	250	2.020	720	1.210	660	680	520	590	720	440	1.940
Spain	550	20	580	70	1.000	230	2.560	960	2.130	1.150	2.000	1.560	5.030	6.430	5.240	29.300
Italy	1.650	80	1.370	170	1.320	300	1.560	570	1.840	970	1.130	950	2.560	3.360	3.320	17.900
Netherland	80	0	60	10	60	10	80	30	80	40	110	90	250	360	610	4.380
Poland	1.610	70	1.970	240	1.330	290	1.570	550	1.110	580	710	540	1.020	1.270	500	1.630

Source: Eurostat, Under glass by NUTS 2 regions [EF_LUS_UNGLASS]

Table 4.4: Flowers and ornamental plants under glass or high accessible cover, number of holdings and hectares per size class (2016)

	Flowers and ornamental plants (excluding nurseries) - under glass or high accessible cover															
	Less than 0.10 ha		From 0.10 to 0.19 ha		From 0.20 to 0.29 ha		From 0.30 to 0.49 ha		From 0.50 to 0.69 ha		From 0.70 to 0.99 ha		From 1 to 1.9 ha		2 ha or over	
	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares
Denmark	80	0	30	0	30	10	40	10	20	10	30	20	30	40	30	150
Germany	170	10	860	110	630	140	670	230	380	210	300	230	320	390	150	480
Ireland	:	0	:	0	:	0	0	0	0	0	0	0	0	0	0	0
Greece	20	0	130	20	170	40	90	30	80	40	50	40	20	20	10	20
Spain	230	10	490	60	150	30	840	320	140	70	100	80	520	630	350	1.850
Italy	500	20	730	90	220	50	440	150	410	220	430	330	370	380	640	2.370
Netherlands	120	10	140	20	130	30	160	60	180	100	210	170	440	620	610	2.810
Poland	370	20	710	80	390	80	370	120	230	110	170	120	270	330	70	190

Source: Eurostat, Under glass by NUTS 2 regions [EF_LUS_UNGLASS]

Table 4.5: Permanent crops under glass or high accessible cover, number of holdings and hectares per size class (2016)

	Permanent crops under glass or high accessible cover															
	Less than 0.10 ha		From 0.10 to 0.19 ha		From 0.20 to 0.29 ha		From 0.30 to 0.49 ha		From 0.50 to 0.69 ha		From 0.70 to 0.99 ha		From 1 to 1.9 ha		2 ha or over	
	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares	Holdings	Hectares
Denmark	30	0	20	0	10	0	0	0	0	0	0	0	10	10	0	0
Germany	100	10	70	10	40	10	40	10	20	10	10	10	10	10	30	70
Ireland	:	0	:	0	:	0	0	0	0	0	0	0	0	0	0	0
Greece	10	0	0	0	10	0	20	0	30	10	50	10	40	40	0	0
Spain	10	0	0	0	0	0	70	20	390	180	50	40	10	20	150	510
Italy	130	0	0	0	90	20	0	0	110	50	0	0	10	10	90	300
Netherlands	10	0	10	0	10	0	20	10	10	10	20	10	20	20	10	50
Poland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Source: Eurostat, Under glass by NUTS 2 regions [EF_LUS_UNGLASS]

Table 4.6: Total number hectares for Arable crops, Permanent crops and Area under glass or high accessible cover (Greenhouses)

	Arable land	Permanent crops	Area under glass or high accessible cover
	2016		
	Hectares	Hectares	Hectares
Denmark	2.361.200	27.760	380
Germany	11.819.330	202.010	3.540
Ireland	458.290	1.690	270
Greece	1.762.250	925.230	5.250
Spain	11.462.910	4.148.960	43.540
Italy	7.145.040	2.200.440	28.310
Netherlands	1.028.170	38.120	8.830
Poland	10.805.610	393.460	6.230

Source: Eurostat

Livestock-Animal Production

Dairy cows

Table 4.7: Dairy cows. Number of heads, LSU and holdings per head size categories (2016)

	Dairy cows																				
	2016																				
	1 or 2 heads			From 3 to 9 heads			From 10 to 19 heads			From 20 to 29 heads			From 30 to 49 heads			From 50 to 99 heads			100 heads or more		
	Heads	LSU	Holdings	Heads	LSU	Holdings	Heads	LSU	Holdings	Heads	LSU	Holdings	Heads	LSU	Holdings	Heads	LSU	Holdings	Heads	LSU	Holdings
Denmark	0	0	0	30	30	10	120	120	20	280	280	20	840	840	50	8.480	8.480	240	561.880	561.880	2.830
Germany	290	290	250	3.460	3.460	1.080	27.180	27.180	3.990	60.000	60.000	5.020	181.750	181.750	9.740	592.230	592.230	18.180	3.409.570	3.409.570	30.950
Ireland	0	0	0	0	0	0	1.150	1.150	90	4.110	4.110	250	20.990	20.990	920	156.100	156.100	4.100	1.215.710	1.215.710	12.960
Greece	930	930	780	2.680	2.680	990	4.920	4.920	740	5.130	5.130	450	10.140	10.140	530	29.600	29.600	810	70.650	70.650	740
Spain	1.580	1.580	1.380	7.120	7.120	1.720	18.580	18.580	1.960	38.980	38.980	2.270	88.490	88.490	3.480	190.780	190.780	4.330	560.310	560.310	4.670
Italy	2.100	2.100	1.380	29.910	29.910	9.500	69.480	69.480	9.440	83.130	83.130	6.570	156.080	156.080	7.720	292.300	292.300	7.890	1.377.100	1.377.100	10.880
Netherlands	40	40	30	350	350	120	1.030	1.030	150	2.690	2.690	210	16.660	16.660	700	157.530	157.530	3.340	1.566.540	1.566.540	13.360
Poland	55.880	55.880	49.760	181.860	181.860	76.290	259.170	259.170	42.810	303.830	303.830	26.600	483.180	483.180	26.950	524.920	524.920	17.060	374.640	374.640	4.100

Source: Bovine animals by NUTS 2 regions [EF_LSK_BOVINE]

Bovine

Table 4.8: Live bovine animals. Number of heads, LSU and holdings per head size categories (2013)

	Live bovine animals																				
	2013																				
	1 or 2 heads			From 3 to 9 heads			From 10 to 19 heads			From 20 to 29 heads			From 30 to 49 heads			From 50 to 99 heads			100 heads or more		
	Heads	LSU	Holdings	Heads	LSU	Holdings	Heads	LSU	Holdings	Heads	LSU	Holdings	Heads	LSU	Holdings	Heads	LSU	Holdings	Heads	LSU	Holdings
Denmark	470	320	320	10.120	6.860	1.690	28.140	18.360	2.000	32.020	20.770	1.330	59.010	38.490	1.540	105.050	68.900	1.490	1.379.840	1.014.020	4.100
Germany	3.610	2.550	2.170	76.560	53.570	12.340	245.470	171.620	17.190	298.440	211.800	12.340	760.190	552.560	19.460	2.035.720	1.484.590	28.460	8.950.680	6.479.210	38.470
Ireland	3.710	2.660	2.200	87.950	60.840	14.490	257.010	176.700	18.140	336.990	230.110	13.910	731.000	498.370	18.910	1.594.070	1.104.060	22.610	3.891.920	2.799.390	21.060
Greece	4.030	2.780	2.620	18.330	12.970	3.350	33.470	23.490	2.460	37.300	26.330	1.570	67.510	49.140	1.760	166.220	120.100	2.420	293.610	211.590	1.750
Spain	15.690	11.560	10.040	108.970	80.650	20.170	190.770	143.040	13.650	234.210	178.500	9.750	498.940	377.660	12.990	1.178.640	872.370	16.620	3.549.160	2.481.680	16.330
Italy	19.270	13.060	12.120	137.360	96.430	25.240	266.310	193.810	19.730	232.810	171.660	9.830	476.850	351.470	12.600	849.850	636.820	12.260	3.722.470	2.724.280	14.180
Netherlands	1.110	790	650	16.220	11.190	2.820	33.580	22.880	2.400	39.010	26.660	1.610	91.270	64.710	2.340	421.270	324.950	5.610	3.396.770	2.352.490	14.830
Poland	178.610	147.360	121.540	757.780	547.040	147.930	922.780	669.670	67.300	817.310	608.660	34.200	1.183.240	894.020	31.540	1.154.970	876.220	17.730	874.960	654.650	4.160

Source: Eurostat, Bovine animals by NUTS 2 regions [EF_LSK_BOVINE]

Sheep

Table 4.9: Live Sheep. Number of heads, LSU and holdings per head size categories (2016)

	Live sheep																				
	2016																				
	From 1 to 9 heads			From 10 to 19 heads			From 20 to 49 heads			From 50 to 99 heads			From 100 to 199 heads			From 200 to 499 heads			500 heads or more		
	Heads	LSU	Holdings	Heads	LSU	Holdings	Heads	LSU	Holdings	Heads	LSU	Holdings	Heads	LSU	Holdings	Heads	LSU	Holdings	Heads	LSU	Holdings
Denmark	3.330	330	700	5.490	550	390	14.330	1.430	470	16.380	1.640	250	21.110	2.110	160	21.990	2.200	70	64.570	6.460	50
Germany	28.580	2.860	6.160	36.710	3.670	2.730	155.740	15.570	4.960	165.150	16.520	2.400	178.500	17.850	1.300	316.890	31.690	990	974.440	97.440	1.000
Ireland	12.980	1.300	3.320	32.110	3.210	2.170	225.800	22.580	6.630	618.010	61.800	8.480	1.197.140	119.710	8.420	1.925.390	192.540	6.330	1.128.990	112.900	1.460
Greece	79.650	7.970	17.650	152.830	15.280	11.770	430.350	43.030	14.270	942.660	94.270	13.550	2.110.360	211.040	15.150	3.507.460	350.750	12.190	1.004.320	100.430	1.440
Spain	63.770	6.380	12.880	123.940	12.390	9.270	302.960	30.300	9.480	421.260	42.130	6.000	855.890	85.590	6.200	3.103.880	310.390	9.420	10.990.470	1.099.050	10.480
Italy	40.940	4.090	8.270	89.980	9.000	6.740	254.700	25.470	8.560	442.390	44.240	6.500	1.104.640	110.460	7.690	3.156.730	315.670	10.250	1.937.160	193.720	2.640
Netherlands	9.690	970	2.080	17.380	1.740	1.240	62.170	6.220	1.930	96.220	9.620	1.380	133.430	13.340	950	198.960	19.900	660	266.060	26.610	290
Poland	19.780	1.980	5.610	18.910	1.890	1.440	36.400	3.640	1.200	47.780	4.780	690	57.290	5.730	410	49.240	4.920	160	23.970	2.400	30

Source: Eurostat, Sheep by NUTS 2 regions [EF_LSK_SHEEP]

Goats

Table 4.10: Live Goats. Number of heads, LSU and holdings per head size categories (2016)

	Live goats																							
	2016																							
	Less than 5 LSU			From 5 to 9.9 LSU			From 10 to 14.9 L			From 15 to 19.9 LSU			From 20 to 49.9 LSU			From 50 to 99.9 LSU			From 100 to 499.9 LSU			500 LSU or over		
	Heads	LSU	Holdings	Heads	LSU	Holdings	Heads	LSU	Holdings	Heads	LSU	Holdings	Heads	LSU	Holdings	Heads	LSU	Holdings	Heads	LSU	Holdings	Heads	LSU	Holdings
Denmark	960	100	160	960	100	100	370	40	40	250	30	30	5.990	600	130	2.930	290	40	1.320	130	80	240	20	40
Germany	13.810	1.380	2.020	16.290	1.630	1.430	12.710	1.270	810	11.580	1.160	910	34.770	3.480	1.880	19.200	1.920	1.060	20.860	2.090	1.150	8.870	890	70
Ireland	670	70	180	630	60	160	670	70	110	450	40	110	3.730	370	290	2.100	210	150	1.000	100	60	:	:	:
Greece	237.880	23.790	33.840	224.260	22.430	7.150	267.630	26.760	4.740	285.490	28.550	3.950	1.765.440	176.540	11.560	644.110	64.410	2.430	114.180	11.420	370	:	:	:
Spain	76.410	7.640	8.350	82.010	8.200	3.230	103.140	10.310	2.500	81.560	8.160	1.510	656.120	65.610	5.820	774.720	77.470	4.280	673.440	67.340	2.610	43.280	4.330	130
Italy	57.350	5.730	5.330	93.100	9.310	3.790	101.880	10.190	2.690	65.190	6.520	1.720	363.600	36.360	5.040	217.270	21.730	2.290	82.220	8.220	840	1.390	140	20
Netherlands	1.410	140	350	1.180	120	160	1.690	170	120	2.380	240	100	17.380	1.740	370	81.860	8.190	500	333.140	33.310	970	60.530	6.050	110
Poland	22.210	2.220	8.440	6.090	610	730	4.180	420	340	2.070	210	130	5.820	580	260	3.050	310	30	670	70	20	:	:	:

Source: Eurostat, Main livestock indicators by NUTS 2 regions [EF_LSK_MAIN]

Breeding sows

Table 4.11: Breeding sows. Number of heads, LSU and holdings per head size categories (2013)

	Breeding sows																							
	2013																							
	1 or 2 heads			From 3 to 9 heads			From 10 to 49 heads			From 50 to 99 heads			From 100 to 199 heads			From 200 to 399 heads			From 400 to 999 heads			1 000 heads or more		
	Heads	LSU	Holdings	Heads	LSU	Holdings	Heads	LSU	Holdings	Heads	LSU	Holdings	Heads	LSU	Holdings	Heads	LSU	Holdings	Heads	LSU	Holdings	Heads	LSU	Holdings
Denmark	40	20	30	80	40	50	400	200	110	340	170	30	370	190	20	610	310	20	4.690	2.340	50	1.132.490	566.250	1.570
Germany	510	250	350	2.070	1.040	850	9.780	4.890	2.040	12.620	6.310	1.230	38.930	19.460	1.420	78.010	39.000	1.430	386.770	193.390	3.130	1.637.490	818.740	4.450
Ireland	200	100	150	460	230	220	360	180	160	240	120	30	330	170	10	1.430	710	30	3.610	1.810	30	116.220	58.110	190
Greece	2.100	1.050	1.440	4.770	2.390	1.880	17.600	8.800	2.380	10.810	5.400	450	9.190	4.590	210	11.620	5.810	180	8.330	4.160	90	54.150	27.070	150
Spain	5.300	2.650	3.550	12.360	6.180	4.230	30.080	15.040	4.140	23.550	11.770	1.270	52.560	26.280	1.250	89.290	44.650	1.080	269.540	134.770	1.270	2.085.770	1.042.890	2.830
Italy	850	420	590	13.070	6.530	4.100	21.970	10.990	3.420	8.810	4.400	570	13.030	6.520	450	9.370	4.680	220	21.850	10.920	160	506.800	253.400	760
Netherlands	90	40	60	120	60	50	200	100	50	350	180	20	670	340	20	2.160	1.080	40	23.390	11.690	190	1.047.720	523.860	1.810
Poland	22.630	11.310	17.100	63.860	31.930	38.770	244.930	122.460	88.900	136.630	68.320	19.720	131.460	65.730	9.550	102.410	51.210	3.750	91.540	45.770	1.560	226.020	113.010	450

Source: Eurostat, Pig by NUTS 2 regions [EF_LSK_GPIG]

Live poultry

Table 4.12: Live poultry. Number of heads, LSU and holdings per head size categories (2016)

	Live poultry 2016																							
	Less than 5 LSU			From 5 to 9.9 LSU			From 10 to 14.9 LSU			From 15 to 19.9 LSU			From 20 to 49.9 LSU			From 50 to 99.9 LSU			From 100 to 499.9 LSU			500 LSU or over		
	Thousand heads	LSU	Holdings	Thousand heads	LSU	Holdings	Thousand heads	LSU	Holdings	Thousand heads	LSU	Holdings	Thousand heads	LSU	Holdings	Thousand heads	LSU	Holdings	Thousand heads	LSU	Holdings	Thousand heads	LSU	Holdings
Denmark	20	340	970	20	230	360	10	150	300	10	230	220	70	1.720	380	130	1.830	170	3.480	36.670	260	14.760	147.220	180
Germany	360	5.250	13.200	210	3.200	5.510	240	3.600	3.670	240	3.520	3.130	1.640	23.180	9.590	2.570	34.690	5.080	41.930	492.050	5.850	122.540	1.624.780	1.520
Ireland	20	370	1.590	20	280	990	10	190	810	10	150	640	70	1.090	2.420	210	2.810	1.400	5.180	49.760	1.110	5.540	55.470	80
Greece	3.020	36.750	147.980	270	3.460	8.760	160	2.030	4.890	110	1.390	3.760	810	9.210	8.650	1.700	16.360	1.890	12.020	95.450	830	12.300	115.760	70
Spain	680	8.970	40.440	160	2.230	6.610	160	1.730	3.920	70	960	2.420	570	5.820	6.160	4.880	38.490	3.370	76.800	654.350	4.650	119.790	1.581.020	1.230
Italy	280	3.270	4.670	170	2.690	2.090	190	2.820	1.150	30	440	600	1.360	13.600	2.360	4.950	45.050	1.280	50.440	471.890	2.150	100.610	1.391.160	1.120
Netherlands	:	70	50	:	50	20	:	50	20	10	120	20	60	670	50	450	4.890	110	22.390	242.130	930	84.420	938.150	860
Poland	10.550	165.210	378.320	1.780	28.310	49.480	940	14.750	24.060	550	8.660	14.400	1.950	28.720	29.420	5.310	60.090	5.830	69.020	710.910	4.220	108.260	1.213.490	960

Source: Main livestock indicators by NUTS 2 regions [EF_LSK_MAIN]

Table 4.13: Total number of livestock categories (in livestock units/LSU) per country (2016)

Country	Dairy cows	Total live bovine (with dairy cows)	Total live bovine (without dairy cows)	Sheep	Goats	Breeding sows	Broilers	Laying hens
	LSU	LSU	LSU	LSU	LSU	LSU	LSU	LSU
Denmark	571.640	838.030	266.390	14.720	1.300	591.670	82.220	84.610
Germany	4.274.480	6.408.370	2.133.890	185.600	13.810	1.018.470	625.080	741.600
Ireland	1.398.060	2.924.640	1.526.580	514.040	920	74.600	53.860	38.940
Greece	124.040	210.300	86.260	822.760	354.170	53.150	153.040	112.390
Spain	905.850	2.102.850	1.197.000	1.586.220	249.070	1.147.610	885.130	780.440
Italy	2.010.090	2.992.040	981.950	702.650	98.200	297.280	673.450	523.500
Netherlan	1.744.830	2.515.450	770.620	78.390	49.960	527.910	344.320	790.040
Poland	2.183.470	3.114.210	930.740	25.340	4.420	429.260	888.240	702.980

Source: Eurostat