Next Generation Decision Support Systems for Farmers: Sustainable Agriculture through Sustainable IT

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Abstract: The core of many changes towards a more sustainable agriculture is the individual decision-maker. The decisions of each farmer have impacts on sustainability and are made in a complex world of contradictious interests and values. Agricultural decision support systems (AgriDSS) will be a major contributor in the realization of a viable farm economy with less negative environmental impact, but it must not only provide current and relevant information. Current DSSs available to farmers, advisors, experts, and policy makers are not used to their full potential. One reason is that they fail to capture the actual needs of the farmers and to understand their decision-making in practice. They are not adapted to the high complexity characterizing sustainable land use decision-making. Among farmers the acceptance of these systems are low, partly because existing DSS are based on what scientists and system developers consider as necessary. As a result, new linkages and better understanding between different stakeholders in agriculture has to be improved. The user-centred design (UCD) approach can answer the core of the identified problems of most DSSs, because it put the farmers' experience in focus and involve them early and continuously in the design process.

In this paper we discuss next generation's AgriDSS which are useful and useable for farmers and other stakeholders. By introducing theories from UCD, illustrated by the Swedish case of implementing Precision Agriculture, we show what is needed to make new technologies contribute to resilient farms and farming systems. We argue that there is a dual link between environmental sustainability and information systems (IS) addressing both *sustainability through design* – how IS can be used to promote more sustainable behaviours, and *sustainability in design* – how sustainability can be the governing principle of the design of the information systems themselves.

Consequently, the next generation's AgriDSS must simultaneously enable stakeholders to get access to the best knowledge available, and at the same time involve them in the process of developing the user interface design. To use existing and future information efficiently, participatory approaches are therefore crucial and need to be a part of transition towards sustainable agriculture.

Keywords: farmer´s decision-making, farmer participation, decision support system, sustainable land use, sustainable IT

Failures and success factors in AgriDSS

At the very core of a societal transition towards sustainability is the individual decision-maker. An increased awareness, knowledge, participation, and capacity are keys to sustainable development of agriculture. It is the farmer that will take both strategic and operative decisions that bridge between theory and practice, and balancing the desirable with the feasible. Information systems (IS) will be a major contributor in the realization of a sustainable development, yet the role of IS as both an actor and a solution within sustainability is receiving only limited attention in current research generally (Melville, 2010; Korte et al., 2012), and specifically within agriculture (but see Aubert et al., 2012). To bridge the gap mentioned above and to tackle the challenges and complexity of a sustainable development of modern agriculture (social, ecological, economical, and technological), the farmers need agricultural decision support systems (AgriDSS) that not only provide current and relevant knowledge, but are also tailored to the farmers' needs (Leeuwis, 2004).

Currently, the main efforts of bridging the gap within today's Swedish agricultural knowledge and innovation system include implementing new advisory concepts, re-organizing extension, and developing DSS. However, current DSSs available to farmers are not used to their full potential and are not adapted to the trade-offs and high complexity characterizing sustainable agriculture and relevant decision-making processes on different scales. The uptake and acceptance of these systems are low, partly because existing DSS are based on what scientists and system developers consider as necessary decision support, but in reality they fail to capture the actual needs of the farmers in practice (e.g. McCown, 2002; 2005; Parker & Sinclair, 2001; Öhlmér, 2001: Öhlmér et al., 1998). One explanation for this is that common technology acceptance models fail to take public resources, such as the environment, into account when analyzing the adoption of information systems (Melville, 2010). Additional identified failure factors of AgriDSSs are, for example, lack of confidence, validity, poor user interface design, low adaptability, and the fear of replacing advisors (e.g. McCown, 2002; Parker & Sinclair, 2001). Parker & Sinclair (2001), for example, point out that a DSS is a useful tool for the ongoing transfer of scientific knowledge and "best practices" within the field of agriculture, claiming that the single unifying predictor of success or failure of a DSS is the extent to which users are involved and participate in design and development processes. Recently, Jakku and Thorburn (2010) as well as Meensel et al. (2012) stress the importance of participatory approaches for the successful development of AgriDSSs as well as the role and relevance of social learning in the stakeholders involved in the participatory AgriDSS development process.

In addition, the agricultural sector is supposed to fulfill several goals and societal values simultaneously; producing food, fiber and energy, reaching environmental goals, preserving and developing cultural heritage, and recreational values, etc., while at the same time being economically viable on a long-term basis. No single actor can manage these challenges themselves, why there is a need for an increased collaboration between farmers, and other actors, in order to reach objectives especially on a collective level. New linkages between stakeholders are needed in order to manage the challenges facing modern agriculture. Participatory AgriDSS must therefore take the collaborative dimension and potential of farmers' decision-making into account. Comparing urban development with rural and agricultural development in Sweden today, the access to and implementation of adapted DSS differs. In sustainable rural planning, collaborative learning and decision-making where modern DSS are applied, is almost non-existing (Ljung et al, 2014).

In other words, the lack of a user-centred design (UCD) and participatory design (PD) approaches is the core of the identified problems of most DSSs. The above mentioned authors stress the importance of an active user involvement approach as the major success factor for delivering AgriDSSs that have a significant uptake by intended users, and therefore can have a substantial impact on the quality of farmers' individual and collective decision-making. The proposed research approach is user-centred and emphasizes participatory design for the development of an AgriDSS for farmers. Hence, the shortcomings of today's AgriDSSs are a consequence of a lack of understanding of farmers' decision-making in practice as well as their actual needs. These shortcomings need to be addressed in order to accomplish next generation's AgriDSS that considerably facilitates future sustainable agriculture in general and farmers' decisions in particular.

In this paper we discuss next generation's AgriDSS which are useful and useable for farmers and other stakeholders. We argue that there is a dual link between environmental sustainability and information systems (IS) addressing both *sustainability through design* – how IS can be used to promote more sustainable behaviours, and *sustainability in design* – how sustainability can be the governing principle of the design of the information systems themselves. The remainder of this paper is structured as follows. The following section provides some conceptual background, motivations and empirical illustration on sustainable IT and sustainable decision support systems, framing and addressing the work discussed in this paper. The paper ends with a summary and discussion of the work presented here and proposes some future research trends.

Sustainable IT and sustainable decision support systems

Sustainable development was initially defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987). In terms of the design and implementation of sustainable IT solutions, this definition has been reinterpreted to address current challenges. A sustainable IS is characterized by longevity, simplicity, accessibility, responsiveness, and adaptability, among others (Misund & Høiber, 2003).

A DSS is a computer-based IS that supports either a single decision-maker or a group of decision-makers in making more effective decisions when dealing with unstructured or semi-structured problems. The DSS supports one or more activities in a decision process in order to complement and 'support' decision-makers rather than to replace them. Furthermore, a DSS can either support the decision-maker in an on-going decision situation or it can prepare the decision-maker to perform better in the future through decision training (Alenljung, 2008). The benefits of using a DSS are that it can improve individual productivity, improve decision quality and problem solving, as well as facilitate interpersonal communication. It can also improve decision-making skills and increase organizational control (e.g. Power, 2002; Turban et al., 2007).

The development and deployment of future sustainable agriculture requires acquisition, application and adaptation of knowledge, with the support of appropriate IT. In this paper, we directly acknowledge the dual link between environmental sustainability and IS by addressing both *sustainability through design* – how IS can be used to promote more sustainable behaviors, and *sustainability in design* – how sustainability can be the governing principle of the design of the information systems themselves (Hanks et al., 2008). To account for this need for sustainability in future deployments, *sustainable information systems* (SIS) have been put forward as a new direction within IS research. SIS adapt to their environment, involve relevant stakeholders, and support knowledge creation, evaluation and application (Maruster et al., 2008).

Experiences from Precision Agriculture

The implementation of Precision Agriculture (PA) technologies can exemplify the challenges described. The technological development in PA is accelerating, while a broad implementation and practical use of the new technologies has shown to be much slower. During the late 1990s the nitrogen sensor (Yara N-Sensor) was introduced on the Swedish market. Few farmers embraced the technology quickly, while the majority of farmers, advisers as well as the authorities have remained passive, despite a continuous promotion of the technology in the farming press, through courses, fairs and various venues. As a technology the N-sensor not normally reduces the amount of fertilizer, but it distributes the fertilizer after the crop needs, increasing nitrogen efficiency and reduces nitrogen leaching. The most important potential benefit of N-sensor has growers where crop quality and payment is strongly linked to the nitrogen content, such as malting barley and bread wheat or where soil mineralization ability varies greatly for example due to high manure supply or variation in soil type. N-sensor also provides increased harvest and a more even protein content. The technology thus has both environmental and economic benefits for both farmers and society.

Different assisted steering systems, such as auto steering, were introduced on the Swedish market in the early 2000s. Systems for auto steering or guiding systems helps the driver to steer straight in the field. Thus, the driver can devote more time to the work of the tractor or the combine harvester performance. The decrease of overlaps reduces energy consumption and makes work faster. The interest from farmers has been big from the beginning and the technology became popular directly after being launched. Today, many new tractors are prepared for mounting of auto steering directly into the control system.

In none of the two cases the technology has been aided by advisory services or specific support from authorities. Any farmer knows that the harvest in a field varies. Therefore, the usefulness of the N-sensor theoretically should be no problem to understand if one trusts the sensor’s function. Farmers also understand that site-specific fertilizing give higher yields, more consistent quality and reduced risk of leaching. At the same time the benefit of the N-sensor is difficult to see in practice if one has not historically had problems with crop lodging. Many farmers also perceive that using the N-sensor implies more work and if you buy the service of someone else. It will be slightly more expensive than doing it yourself with existing machines. In fact, not even in special crops where varied fertilization has been shown to provide a direct added value, the technology has had a broader impact.

When compared to the N-sensor, using a steering system also requires new technological knowledge by the farmer. The difference between the two systems is that they demand a slightly different decision making. The N-Sensor requires data input of expected yield and fertilizer need at the reference site, while the steering system only requires a decision concerning the distance to the next track. A steering system in a tractor or harvester has a few obvious pedagogical benefits compared to the N-sensor in understanding the environmental and economic consequences, in the immediate effect that can be experienced while driving the tractor. Straight lines, and the avoidance of double runs or missing rows are obvious and immediate results. The farmer's immediate sense of advantage of the technologies thus differs.

The question is what is possible to achieve if introducing new ways of developing these technologies in the context of a sustainable AgriDSS.

Sustainable Human-Computer Interaction and Sustainable Interaction Design

We argue that the design of IS and DSS needs to be user-centred, since humans undergo activities in a context and the varieties in people’s context make the design of interactive systems challenging. The field of Human-Computer Interaction (HCI) is characterized as; “…a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them” (The ACM SIGCHI group, 1992). User-centred design (UCD) is an approach within HCI and interaction design to IS design aiming to develop and adapt the system based on the users’ needs, rather than forcing the users to change their behavior to accommodate to the system (e.g. Hartson & Pyla, 2012; Rogers et al., 2011). Similarly, a more radical approach to UCD is the “Scandinavian model” of participatory design (PD) emerging within the system development field among a group of Scandinavian researchers who focused on the democratization of working life (Marti & Bannon, 2009). PD as a design approach is characterized as attempting to actively engage all users and stakeholders (they all are seen as equal partners) in the design process in order to achieve that the product designed fulfills their needs and is useful. PD stresses the importance of processes and procedures of design and is more responsive to their stakeholders’ and users' cultural, emotional, and way of working practices and being in the world (see e.g. Bjerknes et al., 1987). In sum, both UCD and PD approaches have the vision to insuring high usability, i.e. adapting the system to the end users’ and stakeholders’ needs and goals, the possibility of reaching satisfied users and IS success increases significantly. The four central principles of UCD process are to obtain a clear understanding of the intended *people*, the *activities*, *context of use* and the *technologies* (PACT), to design the graphical user interface based on the users' actual needs, to ensure active involvement of users during the whole development process, and to integrate UCD with other development activities (Benyon, 2011). In farming, the people are the farmers and other stakeholders that undertake activities in the contexts of agriculture, and in many cases they use different kinds of technology to run a farm, and designing technology that is usable and useful in the agricultural domain is a demanding challenge.

IS research offers a large amount of interesting user participation research, showing user involvement to be a critical factor in successfully developing an IS (Harris & Weistroffer 2009). One identified reason for failure in IS implementation is the lack of communication between users and developers (Hartwick & Barki 2001). The result of employing an UCD approach when designing and developing a IS is a more efficient, satisfying, and usable experience for the user, which is likely to increase user acceptance and confidence of the system. The final IS is not an end in itself; rather the system is a *means* towards the end of providing good usability and user experience, and for supporting the actual tasks for the intended users (Hartson & Pyla, 2012; Rogers et al., 2011). Computer-based DSS are a good example of this; DSS can be very effective when dealing with unstructured or semi-structured problems (Alenljung, 2008) and sustainable DSS can combine the potential of DSS with the adaptability needed within the agriculture domain. Importantly, sustainable DSS can only be utilized to their fullest potential as long as usability does not suffer and they work properly for different users in varying situations and contexts (Rogers et al., 2011).Some recent successful examples of the PACT principles and active user-involvement in the design process of AgriDSSs are, for example, the work by Jakku and Thorburn (2010) as well as Van Meensel et al. (2012). Jakku and Thorburn (2010) highlight the importance of involving stakeholders as active participants throughout the whole development process. A central issue in their paper is the changed view on the agricultural innovation process, stressing the importance of viewing agricultural innovations as complex interactive processes of co-learning and negotiation, in which social learning practices are fostered. An AgriDSS can function as a "discussion tool", facilitating the dialogue between different key stakeholders within agriculture, such as farmers, scientists, advisors, and extension officers.

Van Meensel et al (2012) point out that agriDSSs have previously failed to fulfil the intended expectations, and their uptake have been poor. Some identified reasons for the low adaption rate are that some AgriDSSs are too complex, terminology and functions are not adapted and irrelevant to the intended users and their activities, and the often mentioned gap between science and practice within agriculture. Decision-making in pig farming is considered as a typical case of the simultaneously improvement of productivity and the effort to reduce environmental pressure, primarily produced by nutrient emissions (Van Meensel et al., 2012). Van Menseel et al. (2012) identify some success factors in the participatory development approach of a DSS named Pigs2win. The aim of Pigs2win was to develop a DSS that is scientifically sound, usable in practice, and supported by the pig sector in the actual region. Critical success factors that affected the Pigs2win project include, flexibility, perceived usefulness, accessibility, credibility, maintenance and adaptability, and focus on the intended users. Central issues for the success of the participatory approach during the whole development process are (1) selection of appropriate stakeholders and high level of transparency to the stakeholders, (2) constructive collaboration among stakeholders, which resulted in active involvement and a consensus of common goals for the DSS, and (3) a flexibility in the development process, respecting the available time and scope, but accepting adaptation during the process and not following a priori detailed road map (Menseel et al., 2012). As a result of using a participatory process, the stakeholders identified 14 outcomes that the DSS should be able to handle properly, which then were implemented in 12 features in

Pigs2win. The result is a DSS that allows for identifying farm-specific suboptimal KPIs (key performance indicators), and assessing aggregate economic and environmental effects of improving these KPIs. The authors stress that the DSS does not provide any direct advice on what concrete decision to make. This means, the actual decision is left for the intended user (advisor) to do, but the DSS provides information on the KPIs that is useful in supporting the activities of pig farming via technological support. Generally speaking participatory approaches and social learning processes share some common characteristics; stressing the importance to understand the contexts in which the activities take place, getting to know the people involved, establishing a dialogue of mutual sharing of different perspectives, and working together to reach common goals.

AgriDSS, HCI and everyday practice

Applying this to the design of sustainable AgriDSSs, the question is how a digital artifact can be designed such that users will prefer sustainable behaviors to unsustainable ones (Blevis, 2007). As pointed out by Pierce et al. (2013) environmental sustainability has established itself as a mainstream concern for HCI since Blevis's (2007) seminal paper in 2007. Since then, HCI researchers have begun to recognize that the complexity and apparent uncontrollability of working towards sustainability offers serious challenges to the current and traditional HCI approaches to solve problems. Contrary, Pierce et al. stress that this should not be faced as a problem at first glance. Instead, it could be considered as an opportunity to understand the limits of HCI as currently constituted and as a way forward to further development and possibilities for the field of HCI. Hanks et al., (2008) point out the importance of sustainability for design, focusing on Sustainable Interaction Design (SID) which is the perspective that sustainability can and should have a central focus within HCI. The importance of considering sustainability within interaction design was put forward by Blevis (2007) and the focus in SID has since then centered on the link between environmental sustainability and interactive technologies by addressing both *sustainability through design* – how IS can be used to promote more sustainable behaviors, and *sustainability in design* – how sustainability can be the governing principle of the design of the information systems themselves (Hanks et al., 2008). However, Hanks et al. (2008) stress that it should be unavoidable for interaction designers to consider not only the interactive products themselves from a perspective of environmental effects, but also the contexts of use and design for cultural alteration that can affect more sustainable human attitudes and behaviors. According to Pierce et al. (2013) one recently identified methodological limitation is the overwhelming dependence in HCI research on individuals as the unit of analysis for design, development and evaluation.

To date, the majority of work in sustainable HCI has focused on how to change individuals' attitudes and behaviors to become less resource-intensive and be more aware of environmental and sustainability issues. This way of research has drawn mainly on theories and concepts from social psychology and behavioral economics (Pierce et al., 2013). Instead, as they point out, recent work within sustainable HCI offers an alternative approach to sustainable HCI by shifting the unit of analysis from *individual action to everyday practice*. They highlight that this shift of focus, to consider organizations and reorganizations of shared activities and routines rather than individual behaviours and general social values and norms, results in looking beyond isolated interactions between humans and computers and instead view them as necessary ingredients of *practice* rather than simply something that humans interact with (Pierce et al., 2013). As a consequence of this suggested practice-oriented approach to HCI, there is a need to seriously consider other forms of materiality other than interactive technologies and computers. Taking *practice* as the unit of analysis, it offers HCI researchers new ways to investigate the dynamics of (un)sustainability, generating understandings of the interactions between humans and other material artefacts that more fully capture the complexity of everyday practices as they are enacted and change over time (Pierce et al., 2013). As pointed out by Watson's commentary of the special issue on practice-oriented approaches to sustainable HCI (in DiSalvo, Redström & Watson, 2013) to consider different aspects of the potential relationship between practice theories and the role of design and HCI in creating future changes in everyday life that can contribute to a socio-technical change towards better and greater sustainability. It should be noted, however, that "theories of practice" refers to a diversity of approaches and draws on fields such as anthropology, sociology, cultural studies, and philosophy (Pierce et al., 2013). They, for example, span from viewing practice within the routine and seemingly mundane activities of everyday life, incorporating great consideration of the social, cultural and material contexts in which these contexts are situated to emphasizing the simultaneously social and material nature of practice, viewing practice as socially, materially and technically constituted or mediated arrays of activity and meaning (Pierce et al., 2013).

Next generation's AgriDSS for sustainable agriculture

Already in 1998, Öhlmér et al. (1998) demonstrated the need to revise the study of decision-making of farmers toward more naturalistic decision-making models. Surprisingly, very few ethnographic empirical studies of farmers' decision-making processes have been carried out. It follows that very limited natural inquiry on agricultural decision support with a focus on sustainable resource management in the field has been conducted, although it has been suggested that performing longitudinal case studies would be a more suitable approach to investigate farmers' complex decision-making processes in agriculture and being-in-the-world (Grey et al., 2009). We need a better understanding on how decisions are made, of both operational and strategic nature in agriculture, but also an ability to move such an understanding into practical applications and recommendations in the context of new, emerging technologies as part of a sustainable AgriDSS. Different actors, such as farmers, advisors, scientists, suppliers, and policy makers, all contribute to the development of today's agriculture. The question is how the different sources of information that actors' bring in to the process, can supplement and support each other, which conflicts exist, and how today's agricultural knowledge and innovation system (AKIS) needs to be changed in order to better fit the challenges facing industrialized agriculture. Without doubt a central part of a new AKIS is an AgriDSS that can facilitate the management of sustainability issues on farm and landscape level simultaneously. Future AgriDSS must fulfill the demands set up by a SIS (sustainable information system) in order to be perceived as relevant, feasible, and practical. Developing new AgriDSS, and in this process integrating the best available technologies such as N-sensor, traffic guidance systems, etc., is necessary in collaborative learning and decision-making process.

An AgriDSS that supports a sustainable development of today's agriculture needs to be sustainable in itself. It must be adaptable, flexible, and user-centred. Additionally it must support farmers and policy makers in the continuous monitoring of the effects of sustainable practices within agriculture. Enabling an ever growing possibility to gather production and environmental data through new technologies enables farmers and other actors to make more informed decisions, but it will also make it possible to evaluate the consequences of taken actions and policies in an early stage of implementation.

There is an increased focus on the need for a social learning perspective in both IS, AgriDSS, and sustainable agriculture in general. Social learning has the potential to be the common ground in future, integrated initiatives. In this paper we have argued that to reach existing potentials, when developing and implementing new technologies in agriculture and trying to improve both environmental performance and farm viability, we must change our approach and integrate the different instruments in a joint collaborative process of learning and decision making.

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