Sustainable food systems with ICT?

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***Abstract*— The food system is burdened by many and severe negative environmental and social impacts. Two of the reasons for the impacts are the increasing scale and globalisation of the food system. ICT has been put forward as a means to enhance sustainability in society, yet the potential for food systems is underexplored. In this paper we review ICT solutions for improved sustainability of food systems, which are used in practice or are discussed as potential solutions. The aim is to identify ICT solutions that can potentially enhance sustainability in the food system. We review mostly scientific literature. The ICT solutions are categorized according to four main purposes of the approach, to 1) efficiency through monitoring and assessment of environmental impact, 2) enhance transparency and traceability in the food system, 3) creating network between actors in the food chains, 4) influence and change food practices. We conclude that there is no coherent research field covering ICT in food systems. The papers reviewed are scattered over several disciplines and scientific journals. We also conclude that there is a predominance of research on monitoring of food production and transparency and traceability in the food chain. More research is needed that take on holistic approaches and include several parts of the food system. Furthermore, we would also like to see more research on what sustainable food systems could be like and how ICT could support and perhaps sometimes hinder such developments.**

***Index Terms*— ICT4S, ICT, food, agriculture, sustainability.**

I. Introduction

The food system has many merits but is also burdened with numerous environmental and social problems. Humans have transformed natural land into cropland to such an extent that it now covers about 40% of the land surface [1]. Technology, fertilizers, pesticides and energy have enabled increased food production and means to support more people with more food, but still, 842 million people, or one out of eight, do not have sufficient access to food and suffer from chronic hunger [2].

At the same time, food production and consumption have become major drivers behind environmental degradation. Major sustainability challenges related to the food system are for example climate change, e.g. [3], water scarcity [4], land use change [1], and food security for a growing population [5]. Furthermore, increasingly globalised markets have created a widening gap between production and consumption, because the two have become separated in both time and space [6]. Globalisation of trade has intensified connections over the globe, so that observed environmental problems can now have their cause and solution on the other side of the world. Current market trends can decrease the reception, understanding and communication of feedback in the production system and hinder feedback along the food chain, and make it difficult to link actors to the impacts [7], [8]. As a result, environmentally or socially concerned consumers are faced with difficulties in making the right choice of product, since there is little information available on conditions for workers, which production methods have been used and how they might affect the environment [6].

In order to be sustainable, agriculture and food systems need to be transformed and also deliver sufficient amounts of food for the growing population, e.g. [5]. In view of these great challenges, new solutions will be needed. Singh et al. [9] argue that the challenges call for multi-disciplinary innovative solutions combined with appropriate technologies, such as ICT, satellite navigation support systems or new management tools.

ICTs can produce both positive and negative impacts related to sustainability. In this paper, the positive environmental impacts are in focus. These are summarized by Sui and Rejeski [10] as dematerialization, decarbonisation, and demobilization. But ICT potentials for improved well-being [11], behavioural change [12] and for providing tools for sustainability practice [13] have also been put forward. The potential of ICT for increasing sustainability of food systems is now explored by a growing number of researchers and in practical projects. There is also a long history of using ICT in the food sector, for example for precision agriculture, tracing and tracking food products and providing information on food products [14]. The aim of this paper is to review and discuss ICT solutions for improved sustainability in food systems and to identify existing trends and possible new spaces for future research. The examples brought up are either used in practice or discussed as potential solutions in literature.

II. Method and structure

In order to identify ICT solutions that could support sustainability in the food system, we conducted a literature review of mainly peer-reviewed scientific papers, but also of non-academic projects and applications. We searched for projects and papers on the Internet and in databases such as ACM DL, Scopus and Web of Science. The review was exploratory, meaning that the search keywords were quite broad, and the papers were then read and screened for examples of ICT solutions used for improving sustainability. Search keywords both were more general such as food and ICT combined with envi-

ronment, sustainability/sustainable, sustainable food/food systems. But also more specific such as ICT and food waste.

The main emphasis was placed on environmental sustainability, and on developed countries. Hence, ICT4D was not a major focus in the selection of papers. The findings may however be relevant for all countries. The identified papers and projects that related to both ICT and food and environment or sustainability and their proposed solutions were categorised according to four main themes or categories:

- Efficiency: Monitoring, assessing and reducing environmental impacts of food production and supply chain.
- Transparency: Increasing transparency and traceability in the food system
- Connections: Creating networks (both between producers and between producers and consumers).
- Sustainable practices: Changing practices around food consumption.

These four areas have also been identified in previous discussion as key opportunities for using ICT for sustainability (See for instance [15] and [16]). We use these terms to categorise the different solutions and projects, even though some examples could be placed in several categories.

III. Efficiency

Use of information and communication technologies for increasing the efficiency of different system is one central argument when discussing the potential of ICT for enhancing sustainability [17]. This is not different in the case of food production, where ICT has been used to increase efficiency of both production and in the supply chain.

A. Efficiency in farming and food production

ICT has been used for a long time in food systems as a way of increasing resource efficiency. Even though the purpose of such measures may have been to economize, many measures can support sustainable transitions as they can decrease inputs such as fertilisers and energy, and hence also decrease outputs in the form of environmental load. One example brought up by Lehmann et al. [14] is precision agriculture, i.e. to use sensors to optimize the use of pesticides, fertilisers and water. Banhazi et al. [18] discuss ICT-controlled livestock production systems as a both cost effective method as well as one that can enhance sustainability of the intensive livestock farming. Other examples of cases include the use of ICT controlled watering system [19]. Such ICT based smart irrigation systems can both reduce water usage and carbon emissions, by combining watering schedules, with weather data and/or soil moisture and evapotranspiration sensing [20].

Zaks et al. [21] also argue that availability of data on agroecological system is a key point for ensuring sustainability, in the context of agricultural production. They review and discuss an agro ecological sensor web, with remote sensing, in situ sensors and models, all incorporated in a systematic manner. The data gathered can provide measurements on nutrients and water, soil type and fertility and meteorological indicators such as solar radiation and humidity [21]. Such a system could according to these authors enhance transparency, feed social economic and environmental data into product certification labelling, help reduce environmental impacts and increase food security. Furthermore, remote sensing and measured soil status can be used also to monitor crops to improve plant production, e.g. [22]. Raghavan et al. [23] propose "computational agroecology", in order to systematise and model agroecological data, enable interactive design of agroecosystems, and provide systems for e.g. maintenance and harvesting in order to support ecological health and food security in the long-term. Pande et al. [24] propose a new platform that should aim to overcome existing challenges to setup wireless sensor and energy efficient network at farms and thereby help execute precision agriculture. There are also small scale solutions, such as MachineryGuide[1] and Agroguía[2], that use existing smartphone devices with GPS to guide tractors during planting, spraying and harvesting, and to log data of the operations.

B. Efficiency in supply chain

Lehmann et al. [14] also bring up ICT for collecting data and information in the food supply chain, for instance discussing the use of transportation data in order to enable evaluation of the current situation in transport logistics. Sensor-based applications can be used to monitor e.g. fuel usage, speed and position for optimizing transportation processes [14]. Another example is Sourcemap, a tool that visualize supply chain information connected to the environmental impact. Sourcemap has been used for improving the efficiency and sustainability of supply chains, for instance it was used by beer brewers to analyse and improve their supply chain, calculating where a bottling facility could be located in order to reducing transportation [25]. Werdouv et al. [26] have analysed virtualization of the food chain from an Internet of Things perspective and argue that the food system can be revolutionized and enhance sustainability through monitoring, control and optimization by autonomous, self-adaptive smart systems.

Another opportunity is that coordinated food distribution systems, or e-commerce, that can potentially substitute traditional individual shopping trips by online ordering and deliveries, e.g. [27]. Downey [28] has shown that transportation costs could be significantly reduced with use of ICT purchasing systems. In contradiction to this, Williams and Tagami [29] have shown that in dense urban areas traditional retail had lower environmental impact than e-commerce. Business-to-business as well as business-to-consumer transportation need to be efficient if e-shopping is to decrease consumer travelling and improve sustainability [10]. In a study of greenhouse gas emissions (GHG) of e-grocery home delivery in Finland, the models showed that GHG emissions could be reduced, but the authors conclude that further research is needed before conclusions on whether or not online ordering and home delivery of food can decrease environmental impact can be drawn [30]. Hence it

[1] http://machineryguideapp.com

[2] https://cartodb.com/case-studies/agroguia/

seems that the environmental benefit of e-grocery systems is still uncertain.

IV. Transparency

Increasing the transparency of systems is also a key capability of ICT, which has been discuss as a possibility for sustainability [31]. This is especially relevant for food system, as there is a growing gap between producers and consumers. When feedback loops are loose and distances are large in the food system, feedback in the food chain can instead be directed through institutions on an overarching level regarding both the state of the environment, producer and consumer interests, e.g. through labelling of food items according to production conditions and environmental or social standards [6].

A. Traceability and food security

Traceability systems has become important for firms in agro-food sector in recent years, because of their need to guarantee food quality and safety, and that they comply with regulations and consumer demands. ICT can be used in this context to increase transparency of the food system and the traceability of food products. Wognum et al. [32] provide an overview of information systems in relation to improved transparency and sustainability in food supply chains. The authors suggest that a good traceability system can create potential to follow a product through the food chain, which contributes to transparency and help "(re)gaining the trust of consumers in food safety and quality" [32], p67. ICT solutions brought up by Wognum et al. [32] are for example e-tools to support environmental reporting by actors in the food chain, that can be used to exchange data and provide input for e.g. LCAs and to enhance traceability through the food chain. Regarding environmental reporting (such as Environmental Product Declarations, EPDs) the authors discuss that it can create transparency when all environmental reports of actors in a food supply chain is collected/provided and can be compared. However, such concerted action does not yet happen according to the authors. Regarding traceability through the food chain, only some ICT applications exist so far, for instance using electronically readable devices, such as RFID ear-tags on cattle, to improve traceability of meat [32].

Current systems mainly use traceability for allowing to find the origin of problems and facilitating call-backs, but they could also become a tool for improvements and provide potential impact on guidelines and regulations [32]. One concrete example provided is Farmingnet[3], a web-based information system that provides online feedback to farmers on the quality level of the pigs they have delivered to the slaughterhouse. This feedback is useful to the farmers because they acquire explanations for any price deductions made by the slaughterhouse due to flaws in quality and also provide opportunity for farms to benchmark themselves compared to other farms [31]. This system can provide better monitoring and control in a part of the food chain, but can potentially develop into a chain-wide information system [32]. Such systems could also be used for communicating the transparency to users, as Sourcemap, a tool for making supply chains transparent. It has been used by organizations and companies for increasing their transparency with the motto: "people have a right to know where things come from and what they're made of " [33].

Recent food security crises have revealed that international agencies and national governments have shortcomings in the capacity to monitor food security sufficiently, accurately and when it is needed [34]. Headey and Ecker [34] argue that mismeasurement of food insecurity can lead to inappropriate responses or even no response at all. They conclude that ICTs has a large role in improving the measurement of food and nutrition security, and that it can reduce the costs of data collection and also in improve the timeliness of data. These authors do not, however, suggest any specific solution for how to achieve this.

B. Environmental Impact assessment

Life cycle assessment, LCA, is brought up by several authors in discussions of ICT as an opportunity to enhance sustainability [11], [16], [32]. LCA is a methodology for analysing environmental impact over a product's or service's whole life cycle. LCA cannot in itself be labelled as an ICT opportunity, but new technologies can improve how the environmental impact can be calculated, by allowing bottom-up data gathering using crowdsourcing or sensors, adding real-time capabilities and allowing customization of variables in an interactive way[16]. In the case of food, existing data from the supply chain can be used for calculating the environmental impact of a specific product with high-granularity, for instance a tomato produced in a non-heated greenhouse, using organic methods, that grew in Spain and was sold in Sweden. The aforementioned Sourcemap is a practical example of this, in one of the use cases, Sourcemap was used by restaurant owners for first calculating and then communicating how the ingredients in their menu were sourced and the environmental impact [25].

Other examples are Eaternity[4], a project in Switzerland looking at how to leverage existing LCA data for improving carbon footprint calculation of food products for facilitating decision making and behavioural change; and Foodprint[5], a browser plugin that adds carbon footprint information to recipes in the major Swedish recipe sites.

V. Connecting

Connecting and creating networks between different actors are also benefits of ICT that can provide opportunities for increasing sustainability in general [15]. This is also valid in the field of food production and consumption, where internet is being used for re-connecting consumers with farmers, and creating knowledge networks between food producers.

A. Connecting farmers and consumers

As discussed above, the globalisation of the food system has created a system in which urban food consumers depend upon distant agroecosystems for their food supply, and not their

[3] http://www.farmingnet.nl/

[4] http://www.eaternity.org/app/

[5] http://foodprint.nu/

local ones [6]. It has been suggested by several authors that local production provided for local consumption can increase awareness about food production and its effect on the environment. O'Hara and Stagl for example [35], argue that to bring together urban citizens, who has limited potential to observe how their food is produced, with farmers can establish a relationship of trust between the two parts. Svenfelt and Carlsson-Kanyama [36] studied a Stockholm farmers market and found that face to face relationships with the producers made the consumers feel trust and confident in the quality and sustainability of the food. ICT can be used for augmenting the farmers market experience [37], or to establish and empower such trust relationships with the use of technology.

In such a context, internet technologies can provide new affordances for how producers can connect and distribute their products directly with the consumers. This reduction of the distance with consumers is interesting for small and medium sized organic farmers that can provide an added value to the produce and communicate better the quality and sustainability aspects [38]. Community supported agriculture (CSA) operations are embracing internet as a way to communicate and organize the distribution and planning of their produce, for instance using websites such as Local Harvest or their software CSAware[6] to manage membership, orders and delivery. There are several other services such as Local Harvest[7] that aim to make visible local producers, such as Gårdsnära[8] (Close to farm), a Swedish site that maps farms and local food producers, and Foodtrade[9], an UK site that aims to connect producers and consumers and create peer to peer food networks, for instance providing solutions for dealing with produce surpluses to avoid food waste.

Finally, ICT is also used for facilitating new ways of retailing, for example Full Circle Farm[10] in US and Ekolådan[11] in Sweden, which offer subscription based deliveries of organic vegetables and fruit. Börjesson Rivera et al. [27] discuss e-commerce and particularly e-retailing of food as having bearing on sustainability because it can potentially enhance transparency and sharing of knowledge. Murphy [39] does however take on a critical perspective towards e-commerce of groceries and its hidden geography. He argues that with e-commerce, the material effects and the real work in the food chain occurs largely unseen by consumers, and thereby becomes hidden and seemingly immaterial when the food just shows up at the doorstep. This could potentially enlarge the distance between production and consumption.

B. Knowledge networks.

ICT can also be used for connecting small scale and urban farmers. This type of small scale organic food production relies more on knowledge and labour than on automation and machines. The use of ICT for efficiency and solutions such as sensor networks are not what is needed by these users according to Odom [40], but their focus is more on using technology for creating interaction spaces and sharing knowledge. These communities of practice use internet as a way of sharing knowledge and expertise, both as a local scale, but also as a way to communicate on a global scale. Internet is also used as a way of creating communities and building interaction and knowledge sharing spaces [41]. Examples of how technology is being used to facilitate community and build networks, are different services looking at providing access to land, one main problem for prospective farmers and urban gardeners. Landshare[12] is a web application, started by sustainable food advocate Hugh Fearnley-Whittingstall, based in UK that connects people that wants land to grow food with landowners that wants to share part of their land. Yards to Gardens[13] is a local website in Minneapolis with a similar idea, connecting available land with people wanting to grow food, but that also includes listing of organic matter to compost and gardens tools to share. Farada Vis [42] used open data to visualize waiting lists for allotments in the UK and explores the use of open data for facilitating allotment access.

Another area of research that has looked at how ICT can empower small-scale farmers is ICT4D (ICT for development). Addressing issues such as improved connectivity between developed and developing countries, increased availability of open-source applications, emergence of global software and platform services can according to McLaren et al. [43] allow for collaboration to address real problems of food security and development. One concrete example is the e-Sourcebook developed by the World Bank. The e-Sourcebook[14] provides according to the website practitioners with lessons learned, guiding principles, and examples and case studies on applying ICT in agriculture in poor rural areas.

VI. CHANGED PRACTICES

The use of ICT for changing everyday practices is a main topic of research in ICT4S and specially in sustainable human-computer interaction, where up to 70% of the research is on changing behaviour/practices through eco-feedback, persuasive technologies and ambient awareness [44]. This includes using ICT for making environmental information, such as electricity use, visible for providing feedback [12], and using persuasive techniques such as competition, goal setting, social comparisons, self monitoring, praise, etc., to change behaviour towards sustainability [45]. While much of this research has focused on electricity and energy, there is a growing interest in the area of sustainable food [46]–[48].

Researchers have been looking at the possibilities of increasing sustainability by using technology to help changing

[6] http://www.csaware.com/
[7] http://www.localharvest.org/
[8] http://www.gardsnara.se/
[9] http://www.foodtrade.com/
[10] http://www.fullcircle.com/
[11] http://ekoladan.se

[12] http://www.landshare.net/
[13] http://www.y2g.org/
[14] http://www.ictinagriculture.org/content/ict-agriculture-sourcebook

users food behaviour, wanting to close the intention-behaviour gap existing between the attitudes and values around sustainable food consumption and the actual consumption practices [49]. Examples of efforts include using technology for visualizing the carbon footprint of food [50] and food-miles [51]. An especially interesting topic of research is the reduction of food waste in households [52], as it is estimated that around one third of food produced is thrown away [53]. ICT has been used as a way of making this waste visible. For instance Ganglbauer et al. [54] created an intervention where a camera was installed in the fridge in different households to record food use and stimulate reflection. In another study, Thieme et al. [55] present an augmented waste bin that takes pictures of the waste disposed and upload them to an application to motivate reflection on the users waste practices. Farr-Wharton et al. [56] present another prototype that aims to reduce food waste by increasing the knowledge and awareness of the existing food stock at home. EcoPanel is a visualization that presents users with detailed information about their food purchases with focus on how much organic food the users buy, both with up-to-date information and long term historical data [57].

This focus on individual behavioural change has been criticized in sustainable HCI in general [58] suggesting that it is not possible to put the responsibility in individual actions without taking into account the social, economical and cultural context. Davies [48] discusses that ICT solutions related to food production and consumption that are developed in isolation from the everyday practices and realities of users run the risk of hindering rather than forwarding possibilities for sustainable transitions. Davies [48] argues that here is a need for more research and development of ICT approaches, but that takes on more nuanced approaches to understand the practices of eating, what the challenges of attaining sustainable eating can be and what successful solutions might be. Ganglbauer et al. [54] discusses these complexities in the case of food waste, arguing that the food waste is not only a discrete action from individuals but part of complex of integrated practices such as cooking and shopping, which are also shaped by existing social and economic structures.

VII. Discussion and conclusions

To become sustainable current food systems have to be transformed quite radically. Information and communication technologies can be a part of this transformation, by providing new ways of measuring, visualizing, communicating and connecting.

This paper has explored some existing ICT solutions in this area but we do not claim to have done a complete review, because 1) the main source we used was scientific papers and the Internet, and 2) the data is scattered over many research fields and journals and not easy to grasp. The papers included in the review are scattered over several different scientific fields and journals.

Foley et al. [5] bring up solutions for sustainable food systems regarding for example improved crop yields, increased agricultural resource efficiency, and increased food delivery by shifting diets and reducing waste. These themes are also mirrored in the reviewed papers, but the bulk of the sources found have emphasis on two main categories. Firstly, how ICT can be used for increasing resource efficiency, and secondly the use of ICT for increasing transparency and traceability in the food system. These themes are perhaps dominating because they are of major interest also for the producers and the process industry in order to economise and save resources.

Other themes can rather be characterized as emerging, relating to for example ICT solutions for creating food networks. Strategies for providing locally produced food for local consumption has been on the sustainability agenda for several years, but it seems that the use of ICT for developing and scaling up such systems has quite recently emerged on the research agenda. There are several projects looking at how ICT can be used for connecting producers and consumers in new ways for promoting smaller scale local production, and creating solutions for connecting communities of practice for small scale organic production and for sharing knowledge and resources.

Another emerging topic is ICT for changed social practices. Some of the reviewed suggestions for solutions deal with food waste, which is a challenge emphasised by Foley et al. [5]. Also, some solutions deal with the use of ICT for understanding and changing behaviour, for instance by providing relevant information and making food practices visible for enabling reflection.

The way ICT is used in the solutions found can be related to the Visible-actionable-sustainable ideas of Bonanni et al. [59]. As a way to make the food system and its environmental impacts “visible” (sensing, visualizing, documenting, traceability, etc.), as a way of making it “actionable” (optimization, reflection, decision-making, etc.) for making it more sustainable (less resources used, better impact management, behavioural change, etc.).

A. Research needs in ICT4S

Based on the review, some conclusions on research needs and research questions than can be addressed in the ICT4S field can be drawn. For example, the dietary concerns stressed as a major challenge by Foley et al. [5] are currently not in focus. For example, red meat has been known for a long time to have large climate impact, e.g. [60], and ICT could perhaps have potential sustainable transitions and support vegetarian diets.

Another aspect that could be explored further is the use of precision agriculture approaches with a more explicit sustainability goal. Much of the technology developed is used as a way of reducing resource use, such as fertilizer, pesticides and water, based on data from different sensors, to tailor amounts to current needs and differences between parts of the same field, instead of on guessing and applying the same amount to whole areas. This reduction has positive environmental impacts, but as with other efficiency measures, there are risks of rebound effects, particularly if the goal of the technology is only to decrease costs. There are also possibilities for exploring the use of sensors and detailed data for explicitly making food production more sustainable, for instance working with increasing biodiversity or increasing carbon sequestration, that have not been in focus thus far.

What seems also to be missing in the literature are solutions or projects that take on a holistic approach, that address both production practices, feedback and communication in the food chain and consumer behaviour. In the same line of argument, Deffluant et al. [11] discuss that research approaches to address sustainable and equitable food systems need to address the complexity and the relationships between the components of the system. I.e. both biophysical resources, resource-use demands of food processors and retailers, and consumer behaviour [11]. This does not have to imply however, that one comprehensive ICT tool should be developed in order to cover all aspects, but rather that ICT opportunities should be tried out and assessed with regard to all the links in the food chain. Otherwise there may be a risk that changes and sustainability gains in one part of the system induces counteracting changes in another part. One example being that the simplicity of e-grocery induces increased consumption, that offsets the gains and worsens the situation [27].

B. Need for holistic approaches

We argue that society needs to develop sustainable food systems, because we are currently undermining the very basis for our own livelihood in the long-term and at the same time we are damage to people in the present due to working conditions and health risks. But what is, or what can sustainable food systems be? These questions may need to be answered before it can be determined what role ICT could have in strengthening or supporting such a development. Most studies that we have reviewed do not reflect upon this but describe possible solutions in a sustainability context. Borch [61] is an exception and the author describes a vision for sustainable agriculture based on workshops, but the ICT part based on this vision is not very developed. An even more proactive approach could be to explore scenarios of possible sustainable food systems and then explore the role of ICT in those futures. This way, both potential enforcement of the problems, including second order effects, as well as contributing to the solutions and thus promoting sustainable development can be explored.

These are some exciting new topics and important research needs. The challenges of achieving a more sustainable food system will require transformative work, and the capabilities of ICT for making the invisible visible and of allowing the creation of networks for collaboration and sharing knowledge and resources can be a piece of the puzzle.

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