Addressing Limits through Tracking Food

Meena Devii Muralikumar
School of Information and Computer Sciences
University of California, Irvine
Irvine, California
muralikm@uci.edu

Bonnie Nardi
School of Information and Computer Sciences
University of California, Irvine
Irvine, California
nardi@uci.edu

ABSTRACT

Tracking food along its supply chain is essential to ensuring aspects of food security such as quality and safety. Food tracking can be broadly aimed at promoting sustainable food systems. Based on the literature, we devise a preliminary framework describing how food tracking systems can be designed to promote sustainability. We present case studies of Sourcemap and Provenance, two functional platforms that support transparent tracking of products along the supply chain. We argue that such systems can be responsive to resource limits in light of the food insecurity encountered, and can complement other techniques that strive for sustainable food systems.

KEYWORDS

Food, Food tracking, sustainability, Limits

ACM Reference format:
Meena Devii Muralikumar and Bonnie Nardi. 2018. Addressing Limits through Tracking Food. In *Proceedings of LIMITS '18, Toronto, Canada, May 13-14 2018,* 9 pages.
https://doi.org/10.475/123_4

1 INTRODUCTION

Tracking has become an integral part of the food and agricultural products supply chain. Currently, the primary objectives of tracking food products—ensuring quality, food safety, fresh supply, preventing food recall, and improving supply chain and logistics management—serve business needs [14, 18]. Other stakeholders participate to a lesser extent. Government authorities, for example, are responsible for compliance with quality requirements [42]. Consumers who shop at retail stores depend on tracked data to trust (or not trust) the quality of food products they buy.

Food tracking, however, can be aimed at the broader goal of achieving sustainable practices of food production, distribution, and consumption. For example, if tracking food from farm to fork, food miles could be computed and analyzed. Food miles approximately measure the distance food travels to reach the consumer from the producer, an important measure in considering the environmental impacts of food production and consumption, including nutrition which is compromised as products age (thus using environmental inputs less wisely). Sustainability can be measured along the entire food supply chain. Tracking systems can be developed to support this function.

RFID tagging and Wireless Sensor Networks (WSN) enable collection of relevant food data. For example, in response to growing concerns about the authenticity of halal meat (prepared according to Muslim law) among consumers in Malaysia, Anir et al. proposed a real-time RFID-based system for consumers to trace its origin [13]. Further work was needed to standardize data collection across the nation before the system could be successfully implemented [13]. Golan et al. investigated traceability systems for fresh foods, grains, and cattle in the US. They studied how the private sector balances costs and benefits of ensuring quality and food safety, and optimizing supply management [26]. Collection of private sector data is a challenge that we need to consider in the implementation of food tracking systems. In many cases, data are lacking as they are not being collected or not being shared.

Though there is enough capacity in the world to produce food to feed everyone, most nations face severe food insecurity (see Figure 1) [12]. There were 795 million undernourished people in the world in 2015, and 815 million in 2016. The numbers are expected to rise to two billion by 2050 [8, 9]. Unsustainable methods of food production, distribution, and consumption are straining current capacity, feeding those who are already food secure, and leading to more waste.

In a world of limits, we need to consider how the food system can be meshed with goals of sustainability in the sense of working within physical resource constraints. Our natural resources, oceans, and forests are already degrading due to the adverse environmental impacts of human practices [9]. Climate change and global warming exacerbate the problem of managing these resources [9]. There is huge energy and water consumption involved in the processing and manufacturing of primary, intermediate, and finished food products [11]. Addressing food insecurity should not involve putting undue pressure on our lands, soil, and water to produce more food. We should promote sustainable food systems to push back on these severe environmental and ecological limits. When food production and distribution are in themselves energy intensive processes, reducing food miles wherever possible and accounting for carbon impacts will help reduce adverse impacts on global resources and waste outputs.

Clear et al. conducted a workshop to explore how HCI and ubiquitous computing can contribute to sustainable food production and consumption practices [22]. They stressed looking beyond the individual to consider all actors involved in the system, and making transparent the energy and carbon impacts of food products. Measuring carbon impacts will require intensive life cycle assessment. Two challenges are to design technologies that can collect and process information for assessment and to find the information in the first

---

LIMITS '18, May 13-14 2018, Toronto, Canada

ACM ISBN 123-4567-24-567/08/06...$15.00
https://doi.org/10.475/123_4

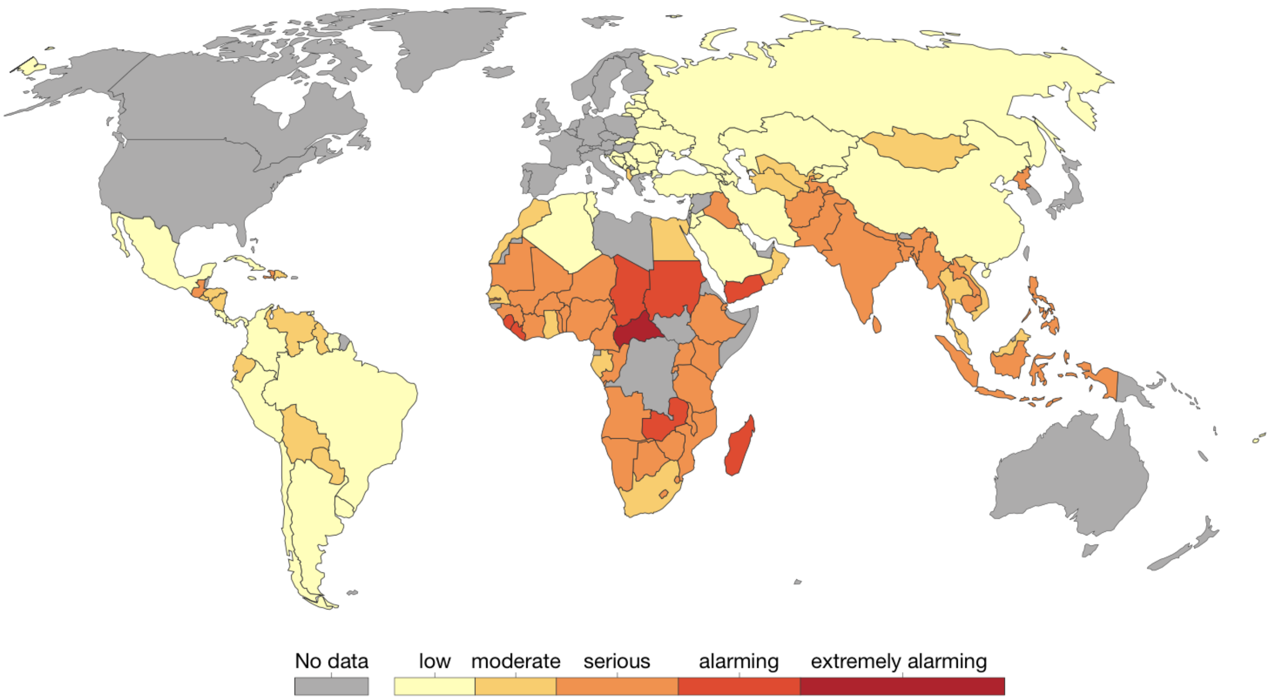

Figure 1: Mapping the Global Hunger Index (GHI) https://ourworldindata.org/hunger-and-undernourishment

place. We must get those in food production and distribution businesses to collect and share data. As seen in the Malaysian case, data must be standardized and of good quality.

In this paper, we draw from existing literature on food tracking systems and food sustainability to form a framework describing how tracking systems could be built to engender sustainability. We review some of the work done in this area and its effectiveness with respect to this framework. We have two case studies, Sourcemap and Provenance, to further illustrate the ideas.

Tracking systems have been developed for the food industry but they concentrate only on particular stages of production and distribution for specific purposes. A food tracking system for sustainability should be complete in terms of the stages it covers in the food supply chain and global impacts. Even if we transition to sustainable practices of producing some of our own food through techniques of permaculture and agroecology [36, 38, 41, 44], most of us will still want access to products such as coffee, tea, fruits, spices, sugar, herbs, and flavorings that grow only in certain places. We will want to know how the food was grown, how far it traveled, whether fair labor practices were followed, and much more. Food tracking can accomplish this.

2 BACKGROUND

In this section, we describe important aspects that can enable food tracking systems to work towards sustainability. We view them as preliminary requirements to ensure sustainability of food supply chains.

2.0.1 Trust and accountability. Norton et al. discuss how establishing trust and accountability are imperative for the sustainability of food systems [37]. All actors in the system—producers, manufacturers, distributors, retailers, and consumers—should, ideally, trust each other to act sustainably. Each should be accountable for their own practices. Norton et al. stress the need for joint responsibility of 'transparent flows of information' to cultivate trust and ensure accountability. They argue that systems promote unsustainability if they exclude the accountability of even one actor. All stages of production and consumption must be considered. This approach indicates that we need to be deliberately gathering and analyzing information across the food supply chain.

2.0.2 Information exchange. Dabbene et al. highlight how efficiency of a tracking system is dependent on the agreement of all companies to provide transparent information, which is the biggest challenge of any tracking system [24]. There is also a lack of widely accepted standards, so even companies that want to supply information do not have a rubric for doing so, making commensurability of data across products very difficult. The authors suggest creating an inter-organization communication and information system to allow for fast and efficient data exchange. They caution against considering only a snapshot of the supply chain, treating it for what it actually is, i.e., a dynamic chain constantly evolving in time. For example, the number of traceable products in the supply chain at a given time depends on the rate of production, the shelf life of foods, and the rate of consumption [24].

These challenges can be used as criteria for choosing and designing technologies that will track food products. The system should establish standards for storing and sharing information, be scalable, responsive to change, and act in real time to the extent possible.

2.0.3 *Assessing Sustainability.*

Food miles and LCA are two reliable, primary indicators for assessing the sustainability of any food system, although not the only ones. A food mile is 'the distance food travels from where it is grown or raised to where it is ultimately purchased by the consumer or other end-user' [40]. The notion of food miles originated in the early 1990s because retailers and consumers were not aware of the origins of food products [30]. There were information gaps with regard to how much distance a product travelled and the number of distributors and processors it was propagated through. Consequently, there was no scope to evaluate environmental impacts and hold anyone accountable.

Pirog et al. used Weighted Average Source Distance (WASD), a metric combining distance between producers and consumers and amount of food transported over that distance [40]. They sampled data from three local food projects in Iowa to compare conventional national systems with Iowa-based regional and local systems. They discovered that food in conventional systems travelled 1546 miles and released 5-17 times more carbon dioxide than local systems which traveled 44.6 miles. They devised recommendations for Iowa consumers, farmers, retailers, middlemen, food system scholars, and policymakers based on their study. While it is straightforward to calculate food miles for fruits and vegetables, when calculating food miles for products that consist of multiple ingredients, we need to account for each ingredient. Using the example of strawberry yogurt, the authors described steps involved in calculating Weighted Total Source Distance (WTSD), a figure which represents food miles for such a product [39].

Life Cycle Assessment (LCA) compiles inputs and outputs to evaluate potential environmental impacts of a product system throughout its life cycle [10]. This assessment has phases such as Life Cycle Inventory Analysis, Life Cycle Impact Assessment and Life Cycle Interpretation. Life Cycle Interpretation is the final phase that is used to summarize results from the previous phases and decide recommendations.

Hendrickson et al. state that conducting a complete LCA for a complex product is impossible since it involves a multitude of processes [27]. For example, an LCA for a automobile that comprises 30,000 components requires a complete list of inputs and outputs. Each of these components could be dependent on thousands of processes, directly or indirectly [27]. Delineating a boundary for a product system while doing assessment will exclude processes, lead to incorrect results, and introduce bias [27]. Though useful, the commonly used process-sum method of LCA might not always be comprehensive [47]. Other approaches such as economic input-output life cycle assessment (EIO-LCA) and Hybrid LCA are less popular but strive for a more comprehensive assessment [27, 47, 48]. Life Cycle Assessment of food products may not always be straightforward and the comprehensiveness of the assessment depends on the complexity of food supply chains and the method of life cycle assessment. Overlooking these factors might result in underestimation of the environmental impact assessed.

2.0.4 *Supporting sustainable choices.*

Iles asserts that LCA information can mobilize producers, retailers, and consumers to be more accountable and reconsider their growing, selling, and eating practices [30]. The supply sector can use food miles to inform purchasing decisions, the infrastructure sector to shorten the supply chain, and consumers to consciously buy products of fewer miles. Iles contends that shorter chains would result in quicker market reach, greater quality, and increased shelf life. Notably, he dismisses the idea of food miles being represented in a unidirectional manner where consumers will only assimilate data. He instead pushes for representations that will empower people to inspect their own consumption and question and demand accountability from the government, producers, and retailers.

Vermeir and Verbeke argue that though consumers have largely positive attitudes towards sustainable food consumption, these attitudes do not always correlate with behavior [46]. Effective representations of supply chain information and food miles can, potentially, influence consumers and help them bridge the gap. These concerns can be further criteria for the technology and user interfaces that will enable actors in the food supply chain to work towards sustainability.

3 RELATED WORK

3.1 ICT and the Food Supply Chain

Svenfelt and Zapico reviewed research in the application of Information and Communication Technologies (ICT) to sustainable food systems [43], discussing precision agriculture, smart irrigation systems, and remote sensing for monitoring plants to increase food production. Undoubtedly, these technologies can aid water and resource conservation, but they are meant for large commercial farms in developed countries. Figures indicate that though we are already producing enough food to feed the world, we are plagued by food insecurity and shortage. A more sustainable approach would be to address this gap and cultivate only as much as we need before we look at measures of increasing food production.

They point to Verdouw et al.'s information architecture that can 'virtualize' the food supply chain using IoT (Internet of Things) and Cloud Computing [45]. Verdouw et al. felt that though there is extensive research on enabling tracking of food systems using RFID and sensors, there is little on leveraging the information collected to exercise control over the supply chain to improve processes. They aimed to virtualize the food supply chain by using artificial intelligence to enact decisions. Their system executed decisions such as initiating food recall if contamination was detected or regulating temperature if there were deviations, based on certain rules and data gathered from sensors.

Taking into consideration the need for technology to be deeply integrated into the supply chain to achieve aims of sustainability, the authors defined requirements, and then designed and iteratively developed a distributed information system. They validated the system in a case study in which fish were exported from Norway, hoping to address issues of transportation caused by last minute cancellations or changes. While results showed that detecting deviations early and having real-time information were helpful in managing service and demand, an important challenge was that businesses were not very forthcoming and reluctantly shared information about their processes.

Verdouw et al. envisioned revolutionizing the food industry through such applications. For example, fish caught in open seas could be sold in a virtual auction and shipped once it reached shore, best-before dates could be dynamically decided, and so on. This system aimed for monitoring and optimization in the food supply chain to achieve food quality and safety with minimal or no human intervention. Such capabilities may not always directly induce or improve sustainability. While sustainability cannot be ensured without accounting for food quality and safety, ensuring just these aspects does not guarantee sustainability. We need to be holistic by considering all stages in the food supply chain. Fish exported or sold to manufacturers, suppliers, and retailers continue to have downstream paths which we need to track to account for sustainability.

Zapico et al.'s work explores the use of ICT in measuring, modeling, and analyzing data for carrying out environmental impact analysis, especially LCA [51]. They developed footprinted.org, to make environmental data 'open, linked and usable' using semantic web technology [50]. Each resource has a unique and permanent URI (Uniform Resource Identifier) which renders information in both machine-readable and human-readable formats. The fact sheet of the resource includes URIs to other resources if required (hence linked). The objective was to promote transparency and openness of data.

Svenfelt and Zapico acknowledge that most of the work they review addresses only parts of the problem. They stress the need for holistic approaches [43]. Sourcemap and Provenance are two initiatives that we take up as case studies to illustrate a more holistic approach to promoting sustainability in food systems. These initiatives are holistic in considering environmental and social impacts across all stages of the food supply chain, laying the ground work for sustainable food supply chains.

4 CASE STUDIES

4.1 Sourcemap

Sourcemap, developed by Leonardo Bonanni at the MIT Media Lab, is a web-based tool designed to promote sustainable design and supply chain transparency [16]. The tool supports two capabilities to meet these goals: an LCA calculator and a visualization of the supply chain on a map. Initially developed for students in an Industrial Design course to introduce them to environmental issues related to products, the tool's functionality was improved through a participatory design process that spanned over a year. The authors engaged with five small businesses to understand their use cases and gather requirements that revolved around usability, privacy and intellectual property protection, customization, and visualization for social communication. These requirements manifested in features of editors, calculators, interactive maps of the supply chain path, a parts catalogue, carbon receipts, and dashboards.

Sourcemap provides a catalogue of carbon footprint information derived from various online sources [17]. The impact of transportation is available based on the mode. Impact of using a commodity is based on industry, producer, region, or material. For a given product, the type of power generation in the locality determines the cost of using electricity or fuel to subject it to various processes. The cost of end-of-life treatments are also available by locality and material [17].

Users add materials from this catalogue to a numbered list and provide additional information about the materials' description, weight, origin, and transportation used. When an item is added to this list, the interactive map shows a bubble corresponding to that item. Clicking on the bubble gives more information about that item. In the interactive map of Hershey's chocolate shown in Figure 2, consumers can click on the bubbles to learn how different ingredients—cocoa, milk, cane sugar, and almonds—are sourced. A carbon receipt is generated for businesses by the built-in LCA calculator to identify phases in the product life cycle that contribute more towards carbon impact. The LCA calculator employs the Okala method to generate a carbon footprint for each phase in the product life cycle [17].

Figure 2: An interactive map that provides details about ingredients in Hershey's Milk Chocolate with Almonds http://open.sourcemap.com/maps/589e10c1e4bac0b357bc3d5f

Sourcemap makes distributed verification of environmental and social impact possible by enabling its users to disclose their supply chain information [17]. By adding this information to the public catalogue of sustainable processes and products, different stakeholders such as suppliers, distributors, consumers, researchers, journalists, and sustainability experts can verify the information and make sustainable decisions. Using features of Sourcemap, producers can narrate stories about their products for marketing purposes. To prevent greenwashing, Sourcemap has templates to be used for reporting supply chain information. Any changes to this template (the software is open source) leave a public record of the modifications.

Sourcemap could be used to calculate LCA of any kind of product or service. For example, one of the business participants owned a hotel, and she used the tool to track and visualize carbon impacts of her guests' travel. Two of the businesses centered around food. We will call on these examples to illustrate the use of LCA in promoting sustainable food practices.

One business owner was a butcher who reared native cattle breeds, and sold other meats from neighboring farms. He wanted to engage with his online customer base in the way he did with his walk-in customers, telling them stories about his localized production practices. For this purpose, he needed to export data about the carbon footprint of his products from Sourcemap to Facebook and post an interactive supply chain map on his online store. He insisted that this footprint take into account the carbon impact of shipping products to each consumer. It disappointed him to know that the impact of transporting the meat was much less than the impact of producing it. He still shared this finding with his customers because he believed it would encourage conversation with them and elevate the standards of his trade overall.

Another participant, a caterer, was already following sustainable practices such as obtaining most of his ingredients from local sources and maintaining a fixed location for his kitchen to avoid long travel distances. The caterer wanted printable versions of local and global maps that could be used for display on menus. The local map would show how most of his ingredients were locally sourced and the details of suppliers so that his customers could reach out to them if they themselves wanted to purchase an ingredient. The global map showed that a few of his ingredients did arrive from distant sources, which led him to reflect on his ingredients. It encouraged him to explore and replace ingredients that traveled long distances with local alternatives. Like the butcher, the caterer used the maps to encourage conversation, gain trust, and improve the standards of the restaurant business.

Though Sourcemap was started as a research project, the founders soon released it as an open source project since they believed that availability of free tools and information is instrumental to adopting sustainable practices. They built it as an extensible software application in which new calculations can be added even if they have not been invented yet. Sourcemap recognizes that the basis of any open source project is collaboration. It depends on contributions of tools and information from around the world to build itself as a source of data and supply chains that will enable global sustainable supply chain management [16]. Sourcemap is now an ongoing commercial venture as well, engaging with small businesses and farmers from the food and agriculture sectors.

4.2 Provenance

Without sufficient information about the products we buy, we end up supporting businesses that push the environmental limits of this planet and affect livelihoods of entire communities [2]. Provenance, founded in 2013 by Jessi Baker, aims to bridge this information gap by increasing transparency in supply chains, using the potential of blockchain technology and RFID [3].

4.2.1 Blockchain technology. A blockchain is a chronological set of transactions with each transaction corresponding to a block [49]. A block consists of information about the transaction, a link to the previous block in the chain, and a digital fingerprint that is used as a proof of validity for the data in that block. A blockchain typically exists in a peer-to-peer network of computers. Each computer in the network stores a copy of the blockchain and they regularly synchronize to make sure they all have the same data. Whenever a new block has to be added to the chain, the computers in the network should reach a consensus about the validity of the data in the new block. Once added, that block is permanent.

The implication of blockchain technology is that no single entity, such as a central server, has the requirement and power to vouch for the integrity of data to coordinate multiple transactions that happen on the Internet.

Recently, blockchain technology for storing information has been garnering much attention for its features of decentralization, security, and authenticity. Though it was introduced as part of the underlying mechanism for the peer-to-peer digital currency, Bitcoin, blockchains can be generalized and applied in other domains [25]. Blockchain technology does not allow for a centralized system storing all the information [3]. A decentralized, peer-to-peer architecture implies that no single organization, government, or third-party is responsible for all the data. Multiple parties are involved in adding 'blocks' of information about the products at different stages. This architecture accounts for the security, maintenance, and authenticity of the system, potentially empowering a globally applicable solution.

4.2.2 Transparent and traceable supply chains. Provenance employs an information architecture that enables chain-of-custody on the blockchain. They have a set of programs that caters to different kind of actors in the supply chain—producers, manufacturers, registrars, standards organizations, certifiers, and consumers [3].

A registration program is deployed by accreditation services to verify the real-world identity of all actors except consumers and add the identity as a record in the blockchain, thus generating blockchain-based digital identities that are available for inspection by everyone. A standards program is used for compliance requirements by certifiers. A producer typically uses a production program to create digital counterparts of primary goods and adds it to the blockchain only if the certifier successfully audits the goods using his program. Manufacturing programs digitize the transformation of input goods to intermediate or finished products. Using the blockchain warrants that specific input goods have been consumed in the process of manufacturing. One cannot simply claim to have used a source of raw materials without linking it in the blockchain. This builds a traceable supply chain.

Provenance employs RFID to track food products in real-time when they enter the blockchain. They also offer mobile applications that scan QR codes for consumers to browse information about the origin of products and the credibility of entities involved in making the end product. This will allow consumers to make sustainable decisions regarding consumption.

5 DISCUSSION

Sourcemap and Provenance use different technologies and measures to support sustainable supply chains but share similarities in terms of their holistic approach. Sourcemap could be used to calculate the LCA of any product or service. Provenance is not restricted to food supply chains. One of their case studies is a work in progress that deals with tracking cotton from its raw form to a textile to promote sustainable and biodegradable fabric [4].

The open source approach of Sourcemap indicates how globally inclusive it can be. Similarly, using blockchain technology accommodates all actors, irrespective of their geographic locations. For example, one of the pilot projects of Provenance dealt with tracking tuna fish caught in Indonesia from 'shore to plate' [5]. The usage of Sourcemap and Provenance seems scalable in terms of the different food products, geographic locations, organizations, and actors it can include in the digital food supply chain.

5.1 Trust and Accountability

Sourcemap and Provenance are not just technical data-provision platforms. Both give immense importance to weaving a story for every product using details from all stages in the supply chain. The need to share stories about the origin and history of a product with consumers to build trust was recognized, and the developers sought to connect different actors in the system to narrate these stories. The platforms recognize the social origin of sustainability concerns, and attempt to build on the ways people talk about these concerns.

Promoting open and transparent supply chains can increase accountability of actors. Providing them with tools and information to assess carbon impact can drive accountability and motivate them to switch to sustainable practices. Using a blockchain protects the integrity of data entered since one cannot go back and modify or delete information. Currently, though official authorities audit data, they are recorded either on paper or using databases [19]. They are prone to errors and inconsistencies, an issue that works in favor of corrupt, fraudulent, or unsustainable actors. There is no trail to quickly and efficiently trace information about food products. Blockchain technology can deliver both traceability and data integrity. It also allows for easier data sharing between different actors, when compared to traditional databases [19].

5.2 Privacy

Another common feature is the protection of privacy when required. We want to be transparent in supplying information about organizations, but some caution may be needed as geographic data could pinpoint fairly exact locations, revealing, for example, where farmers live [16, 37]. Sourcemap uses approximate locations for indicating origins in the supply chain map if privacy is required. Provenance allows its actors to keep identities private [3]. They contend that the information provided by these actors can still be trusted by others because without verification of identities they wouldn't be on the blockchain. While negotiating privacy concerns, it is important not to compromise on information required to ascertain a product's provenance and authenticity.

5.3 Food Sovereignty

Norton et al. call attention to how sustainability can be compromised when people lack food sovereignty [37]. Food sovereignty can be defined as 'the right of peoples and nations to create and maintain their own food systems' [33]. Small-scale farmers and workers have less control over their own production as they often sell at low prices decided by larger corporations [37]. In the tuna fish case study conducted by Provenance, the aim was not just to promote fish that had been sustainably sourced, but to ensure that they were not promoting products of slavery or illegal fishing [5]. Striving to make such practices transparent is the first step towards establishing food sovereignty.

Sourcemap's participatory design process revealed that participants sometimes depended on distant, possibly endangered, resources. Since Sourcemap accounts for LCA, the team grappled with trade-offs between being socially responsible by promoting distant resources and being environmentally responsible by reducing the travel footprint [16]. Such questions are difficult, lacking straightforward answers. Part of the value of systems such as Sourcemap is that they bring the questions to light and stimulate discussion which must always be the first line of defense.

5.4 Challenges

5.4.1 Transparency. As New points out in his article in the *Harvard Business Review*, though organizations claim to be sustainable, how they are achieving sustainability is not always transparent [35]. More consumers are holding businesses accountable for the claims they make by demanding details. New says that if consumers start seeking information, marketing and perceptions of brand value can change based on how much data is publicly available and how well claims are supported. Organizations with tools that track provenance will have an edge over others in the market, at least in theory. New highlights how even if corporations do not want to disclose data, they cannot be sure that their competitors will do the same [35]. It is possible that we could be heading towards a time when publicizing provenance data will become the norm, not the exception.

New explains how the sustainability of supply chains can be strengthened by focusing on upstream paths too [35]. For example, there are businesses that source ingredients produced from cheap or unjust labor. The businesses might be unaware of poor labor practices because they depend on suppliers to obtain these products [35]. But technologies should push everyone to be accountable by either questioning or revealing the origin of the products, including labor practices.

There are practical difficulties, however, in getting corporations to collect and reveal information about their supply chains. Even if they uphold ethical labor conditions for their workers and comply with safety requirements, they might be reluctant to reveal information because they do not want competitors to know where their products are from and prefer maintaining secrecy to retain advantage over others [1].

5.4.2 Validity. Another challenge is the validity of information corporations enter in the system [34]. The blockchain is particularly effective in creating trails and securely managing transactions of digital currency, as with Bitcoin. However, food products are not digital entities. Relying solely on the responsibility of the actors to not falsify data about food sources and processes while *entering* it in the system, is potentially a weakness. Sourcemap recognizes that its crowd-sourced verification cannot replace official authorities that conduct comprehensive audits [17]. Provenance attempts to mitigate this weakness by using the registration and standards program for accreditation and compliance.

The issue of validity comes down to how information is manually entered [34] and/or collected through sensors and uploaded. The kind of information that builds trust in a food product and acts as a testimonial cannot be collected through sensors. Important questions such as who is entering information in such systems, how it is verified, and how misuse and greenwashing are prevented, need to be addressed.

5.4.3 Environmental impact of the systems. The environmental impact of implementing these technologies is cause for concern. The hardware and infrastructure required to track food, especially in real time, will be energy intensive. High computational power is required to add transactions in the blockchain [6]. Running the cryptographic hash functions authenticating these transactions drains power [6]. There are already calls for sustainable and energy-saving blockchains that can enable its use in diverse applications [6].

Williams discusses the challenges in handling the 'rebound' effects of implementing and adopting applications for environmental benefit [47]. The rebound effect describes how, despite taking action to support sustainability, the consequences of the action counteract the benefits gained [28]. For example, energy efficient cars may encourage more driving. Such technologies should be deployed with caution, considering the higher order effects of widespread use.

The case studies of Sourcemap and Provenance are specific examples of how transparent and sustainable food supply chains can be fostered. Evaluating these systems using empirical data would help ascertain its benefits. These systems have inherent merits, but they also have challenges that should be addressed. For example, given the high environmental costs of blockchain transactions, minimizing its energy requirements is a necessary topic for research. Developing regions might not have the resources and infrastructure to build or support such technologies for food tracking. But these systems could still be useful to sustainable food systems in developing countries, especially to support low-income farmers, and should be a priority. Along with assuring food quality and safety, deliberate efforts to promote transparency, reduce environmental impact, and ensure food sovereignty should be reinforced by food tracking systems.

Sustainable methods of food production such as agroecology that restore the balance of the ecosystem [41] address issues of environmental and carbon impacts. They promote local sourcing of food, and we can be assured of its provenance. Food tracking systems, as discussed here, complement such measures. They could potentially tell stories of agroecological systems and provide LCA data, helping us fine tune sustainable food production and distribution for produce grown with agroecological methods destined for farmers markets and local grocery stores. These systems could also be useful for agroecological school garden projects, adding pedagogical value to lessons in math, science, and writing through analysis and write-up of LCA data.

It would be incorrect to conclude that the founders of Sourcemap and Provenance set out to build these frameworks for supply chains just to ensure environmentally sustainable practices. They view adoption of sustainable practices as requisite to doing business and consider how environmental sustainability fits into broader societal and economic impacts. While Provenance roots for real-time tracking of products, transparent supply chains, and empowering all actors in the system, Sourcemap promotes LCA and maps the supply chain for small businesses. Recognizing how much their products complement each other, Sourcemap and Provenance have recently decided to collaborate [7]. This collaboration might very well pave the way for robust supply chain management that engenders social and environmental sustainability in practices of food production, distribution, and consumption [7].

6 FOOD, HCI, AND CONSUMERS

The human-computer interaction community has been focusing on defining the role and contributions of HCI to sustainability in general [29]. Regarding food sustainability, workshops have been conducted to understand opportunities and challenges in designing for critical reflection of food practices, using human-computer interaction to design for human-food interactions, and ubiquitous computing technologies and HCI to cultivate and support sustainable food cultures [21, 23, 31]. The motive behind requiring food miles and LCA information available along the supply chain is to stimulate behavioral change in all actors in the system. There are several applications that incorporate techniques of persuasive design to achieve behavioral change.

Zapico et al., for instance, tried to address the difficulty in interpreting carbon dioxide information since it would not promote behavioral change otherwise [52]. They developed a site that enabled users to compare carbon impacts of different products by trying out different units. The application reported, for example, that the carbon impact of one liter of milk was equivalent to that of 1539 mobile charges. Other units included cups of tea, apples, bananas, laptops, cars, televisions, and air flights. In this application, according to Bonanni et al.'s guideline [15], issues of carbon impact were made 'visible' by using units that people could relate to. Users could compare footprints and analyze their behaviors without actually emitting carbon. This application served to help people understand the cause-effect relationship as a rehearsal for the real moments of decision-making, thus promoting 'actionable' decisions.

Kalnikaite et al. opted for a more in-situ approach while designing and developing an LED display that can be clipped to a shopping cart to scan food products with their barcode [32]. The device's graphical bars light up at different lengths based on the food miles of the product scanned. The emoticon display shows sad, neutral, and happy faces depending on the extent to which food miles are in accordance with a given social norm. Both these displays were intended to 'nudge' users towards making sustainable decisions.

Chen highlights critiques against sustainable HCI research [20] for defining sustainability too broadly while acknowledging the work of Tomlinson et al. [44] and Raghavan et al. [41]. Instead of just focusing on novel technologies, their work implements ecological practices of food production [20]. Systems that carefully consider what sustainability actually entails have better prospects for addressing the issues. The research discussed in this section can only work in addition to such broader systemic approaches.

7 CONCLUSION

Multiple factors influence implementations of sustainable supply chain food management systems in the real world. However, as we see in the case of Sourcemap and Provenance, it has already begun, albeit on a small scale. Progress has been realized by mapping problems to areas in computer science. For example, the distributed network of food systems poses issues in terms of data collection and standardization. Blockchain technology, a distributed computing system, makes a 'distributed ledger' possible. Blockchain technology can be advanced as a way to digitally transform supply chain management and account for provenance and visibility of all goods, not just food products.

It is interesting to observe how the design of a technology can enable it to navigate through complex networks of food systems to increase accountability, reflection, and awareness of all actors across all stages. This brings us a step closer to sustainable food supply chains. Over time it could potentially shift global patterns of food production and sourcing. This shift will aid attempts to ensure food security locally and complement other sustainable measures that address food security.

8 ACKNOWLEDGEMENTS

We would like to thank Lisa Nathan, Steve Easterbrook, and Kurtis Heimerl for their valuable comments and feedback.

REFERENCES

[1] 2010. When Everyone Can See Your Supply Chain. (2010). Retrieved from https://hbr.org/2010/09/when-everyone-can-see-your-sup.

[2] 2013. About | Provenance. (2013). Retrieved Feb. 3, 2018 from https://www.provenance.org/about/.

[3] 2013. Blockchain: the solution for supply chain transparency | Provenance. (2013). Retrieved Feb. 3, 2018 from https://www.provenance.org/whitepaper.

[4] 2013. Case Studies | Provenance. (2013). Retrieved Feb. 3, 2018 from https://www.provenance.org/case-studies.

[5] 2013. From shore to plate: Tracking tuna on the blockchain | Provenance. (2013). Retrieved Feb. 3, 2018 from https://www.provenance.org/tracking-tuna-on-the-blockchain.

[6] 2017. The Ridiculous Amount of Energy It Takes to Run Bitcoin - IEEE Spectrum. (September 2017). Retrieved March. 11, 2018 from https://spectrum.ieee.org/energy/policy/the-ridiculous-amount-of-energy-it-takes-to-run-bitcoin.

[7] 2017. Supply chain mapping meets blockchain tracking: Provenance partners with Sourcemap to power end-to-end, robust traceability for consumer goods — Supply Chain Mapping. (2017). Retrieved Feb. 3, 2018 from http://www.sourcemap.com/blog/2017/7/21/sourcemap-supply-chain-mapping-with-blockchain-verification.

[8] 2017. World Hunger Again On The Rise, Driven By Conflict And Climate Change, New UN Report Says | WFP | United Nations World Food Programme - Fighting Hunger Worldwide. (September 2017). Retrieved Feb. 3, 2018 from https://www.wfp.org/news/news-release/world-hunger-again-rise-driven-conflict-and-climate-change-new-un-report-says.

[9] 2018. Hunger and food security - United Nations Sustainable Development. (2018). Retrieved Feb. 3, 2018 from http://www.un.org/sustainabledevelopment/hunger/.

[10] 2018. ISO 14040:2006(en), Environmental management — Life cycle assessment — Principles and framework. (2018). Retrieved Feb. 3, 2018 from https://www.iso.org/obp/ui/#iso:std:iso:14040:ed-2:v1:en.

[11] 2018. Water, Food and Energy | UN-Water. (2018). Retrieved Feb. 7, 2018 from http://www.unwater.org/water-facts/water-food-and-energy/.

[12] 2018. What we do | FAO | Food and Agriculture Organization of the United Nations. (2018). Retrieved Feb. 7, 2018 from http://www.fao.org/about/what-we-do/en/.

[13] Norman Azah Anir, Md. Nasir Mohd Hairul Nizam, and Azmi Masliyana. 2008. RFID Tag for Halal Food Tracking in Malaysia: Users Perceptions and Opportunities. In *Proceedings of the 7th WSEAS International Conference on Telecommunications and Informatics (TELE-INFO'08)*. World Scientific and Engineering Academy and Society (WSEAS), Stevens Point, Wisconsin, USA, 87–92. http://dl.acm.org/citation.cfm?id=1404049.1404065

[14] Myo Min Aung and Yoon Seok Chang. 2014. Traceability in a food supply chain: Safety and quality perspectives. *Food control* 39 (2014), 172–184.

[15] Leonardo Bonanni, Daniela K. Busse, John C. Thomas, Eli Blevis, Marko Turpeinen, and Nuno Jardim Nunes. 2011. Visible - Actionable - Sustainable: Sustainable Interaction Design in Professional Domains. In *CHI '11 Extended Abstracts on Human Factors in Computing Systems (CHI EA '11)*. ACM, New York, NY, USA, 2413–2416. https://doi.org/10.1145/1979742.1979572

[16] Leonardo Bonanni, Matthew Hockenberry, David Zwarg, Chris Csikszentmihalyi, and Hiroshi Ishii. 2010. Small Business Applications of Sourcemap: A Web Tool for Sustainable Design and Supply Chain Transparency. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '10)*. ACM, New York, NY, USA, 937–946. https://doi.org/10.1145/1753326.1753465

[17] Leonardo Amerigo Bonanni. 2010. *Beyond transparency: Collective engagement in sustainable design*. Ph.D. Dissertation. Massachusetts Institute of Technology.

[18] Techane Bosona and Girma Gebresenbet. 2013. Food traceability as an integral part of logistics management in food and agricultural supply chain. *Food control* 33, 1 (2013), 32–48.

[19] Sylvain Charlebois. 2017. How blockchain technology could transform the food industry. (December 2017). Retrieved March. 10, 2018 from http://theconversation.com/how-blockchain-technology-could-transform-the-food-industry-89348.

[20] Jay Chen. 2016. A Strategy for Limits-aware Computing. In *Proceedings of the Second Workshop on Computing Within Limits (LIMITS '16)*. ACM, New York, NY, USA, Article 1, 6 pages. https://doi.org/10.1145/2926676.2926692

[21] Jaz Hee-jeong Choi, Conor Linehan, Rob Comber, and John McCarthy. 2012. Food for Thought: Designing for Critical Reflection on Food Practices. In *Proceedings of the Designing Interactive Systems Conference (DIS '12)*. ACM, New York, NY, USA, 793–794. https://doi.org/10.1145/2317956.2318077

[22] Adrian K. Clear, Rob Comber, Adrian Friday, Eva Ganglbauer, Mike Hazas, and Yvonne Rogers. 2013. Green Food Technology: UbiComp Opportunities for Reducing the Environmental Impacts of Food. In *Proceedings of the 2013 ACM Conference on Pervasive and Ubiquitous Computing Adjunct Publication (UbiComp '13 Adjunct)*. ACM, New York, NY, USA, 553–558. https://doi.org/10.1145/2494091.2497316

[23] Rob Comber, Eva Ganglbauer, Jaz Hee-jeong Choi, Jettie Hoonhout, Yvonne Rogers, Kenton O'Hara, and Julie Maitland. 2012. Food and Interaction Design: Designing for Food in Everyday Life. In *CHI '12 Extended Abstracts on Human Factors in Computing Systems (CHI EA '12)*. ACM, New York, NY, USA, 2767–2770. https://doi.org/10.1145/2212776.2212716

[24] Fabrizio Dabbene, Paolo Gay, and Cristina Tortia. 2014. Traceability issues in food supply chain management: A review. *Biosystems engineering* 120 (2014), 65–80.

[25] George Foroglou and Anna-Lali Tsilidou. 2015. Further applications of the blockchain. In *12th Student Conference on Managerial Science and Technology*.

[26] Elise H Golan, Barry Krissoff, Fred Kuchler, Linda Calvin, Kenneth Nelson, Gregory Price, et al. 2004. *Traceability in the US food supply: economic theory and industry studies*. Technical Report. United States Department of Agriculture, Economic Research Service.

[27] Chris T Hendrickson, Lester B Lave, and H Scott Matthews. 2006. *Environmental life cycle assessment of goods and services: an input-output approach*. Resources for the Future.

[28] Edgar G Hertwich. 2005. Consumption and the rebound effect: An industrial ecology perspective. *Journal of industrial ecology* 9, 1-2 (2005), 85–98.

[29] Elaine M. Huang, Eli Blevis, Jennifer Mankoff, Lisa P. Nathan, and Bill Tomlinson. 2009. Defining the Role of HCI in the Challenges of Sustainability. In *CHI '09 Extended Abstracts on Human Factors in Computing Systems (CHI EA '09)*. ACM, New York, NY, USA, 4827–4830. https://doi.org/10.1145/1520340.1520751

[30] Alastair Iles. 2005. Learning in sustainable agriculture: food miles and missing objects. *Environmental Values* 14, 2 (2005), 163–183.

[31] Jaz Hee jeong Choi, Marcus Foth, Gregory N. Hearn, Eli Blevis, and Tad Hirsch. 2009. Hungry 24/7? HCI design for sustainable food culture workshop. In *OZCHI 2009 : 21st Annual Conference of the Australian Computer-Human Interaction Special Interest Group (CHISIG) of the Human Factors and Ergonomics Society of Australia (HFESA)*. CHISIG, The University of Melbourne, Melbourne, Victoria. https://eprints.qut.edu.au/31087/

[32] Vaiva Kalnikaite, Yvonne Rogers, Jon Bird, Nicolas Villar, Khaled Bachour, Stephen Payne, Peter M. Todd, Johannes Schöning, Antonio Krüger, and Stefan Kreitmayer. 2011. How to Nudge in Situ: Designing Lambent Devices to Deliver Salient Information in Supermarkets. In *Proceedings of the 13th International Conference on Ubiquitous Computing (UbiComp '11)*. ACM, New York, NY, USA, 11–20. https://doi.org/10.1145/2030112.2030115

[33] Nils McCune, Peter M Rosset, Tania Cruz Salazar, Helda Morales, and Antonio Saldívar Moreno. 2017. The long road: Rural youth, farming and agroecological formación in Central America. *Mind, Culture, and Activity* 24, 3 (2017), 183–198.

[34] Jessica McKenzie. 2018. Wal-Mart and IBM want to harness blockchain to improve food safety. (February 2018). Retrieved March. 10, 2018 from https://newfoodeconomy.org/blockchain-food-traceability-walmart-ibm/.

[35] Steve New. 2010. The Transparent Supply Chain. (October 2010). Retrieved Feb. 3, 2018 from ttps://hbr.org/2010/10/the-transparent-supply-chain.

[36] Juliet Norton, Sahand Nayebaziz, Sean Burke, B. Jack Pan, and Bill Tomlinson. 2014. Plant Guild Composer: An Interactive Online System to Support Back Yard Food Production. In *CHI '14 Extended Abstracts on Human Factors in Computing Systems (CHI EA '14)*. ACM, New York, NY, USA, 523–526. https://doi.org/10.1145/2559206.2574826

[37] Juliet Norton, Ankita Raturi, Bonnie Nardi, Sebastian Prost, Samantha McDonald, Daniel Pargman, Oliver Bates, Maria Normark, Bill Tomlinson, Nico Herbig, and Lynn Dombrowski. 2017. A Grand Challenge for HCI: Food + Sustainability. *interactions* 24, 6 (Oct. 2017), 50–55. https://doi.org/10.1145/3137095

[38] Juliet Norton, Alex J Stringfellow, Joseph J LaViola Jr, Birgit Penzenstadler, and Bill Tomlinson. 2013. Plant Guild Composer: A Software System for Sustainability.. In *RE4SuSy@ RE*.

[39] Richard S Pirog and Andrew Benjamin. 2005. Calculating food miles for a multiple ingredient food product. (2005). https://lib.dr.iastate.edu/leopold_pubspapers/147/

[40] Rich S Pirog, Timothy Van Pelt, Kamyar Enshayan, and Ellen Cook. 2001. Food, Fuel, and Freeways: An Iowa perspective on how far food travels, fuel usage, and greenhouse gas emissions. (2001). https://lib.dr.iastate.edu/leopold_pubspapers/3/

[41] Barath Raghavan, Bonnie Nardi, Sarah T. Lovell, Juliet Norton, Bill Tomlinson, and Donald J. Patterson. 2016. Computational Agroecology: Sustainable Food Ecosystem Design. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '16)*. ACM, New York, NY, USA, 423–435. https://doi.org/10.1145/2851581.2892577

[42] Luis Ruiz-Garcia, G Steinberger, and M Rothmund. 2010. A model and prototype implementation for tracking and tracing agricultural batch products along the food chain. *Food control* 21, 2 (2010), 112–121.

[43] Åsa Svenfelt and Jorge Luis Zapico. 2016. Sustainable food systems with ICT?. In *4th International Conference on ICT for Sustainability (ICT4S 2016) : (Advances in Computer Science Research)*, Vol. 46. Atlantis Press, 194–201. http://www.atlantis-press.com/php/pub.php?publication=ict4s-16

[44] Bill Tomlinson, Juliet Norton, Eric PS Baumer, Marcel Pufal, and Barath Raghavan. 2015. Self-obviating systems and their application to sustainability. *iConference 2015 Proceedings* (2015).

[45] Cor N Verdouw, J Wolfert, AJM Beulens, and A Rialland. 2016. Virtualization of food supply chains with the internet of things. *Journal of Food Engineering* 176 (2016), 128–136.

[46] Iris Vermeir and Wim Verbeke. 2006. Sustainable food consumption: Exploring the consumer "attitude–behavioral intention" gap. *Journal of Agricultural and Environmental ethics* 19, 2 (2006), 169–194.

[47] Eric Williams. 2011. Environmental effects of information and communications technologies. *Nature* 479, 7373 (2011), 354.

[48] Eric D Williams, Christopher L Weber, and Troy R Hawkins. 2009. Hybrid framework for managing uncertainty in life cycle inventories. *Journal of Industrial Ecology* 13, 6 (2009), 928–944.

[49] Aaron Wright and Primavera De Filippi. 2015. Decentralized blockchain technology and the rise of lex cryptographia. (2015). https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2580664

[50] Jorge Luis Zapico, Bianca Sayan, Leonardo Bonanni, Marko Turpeinen, and Steve Young. 2011. Footprinted. org : experiences from using linked open data for environmental impact information. In *Proceedings of the 25th EnviroInfo Conference — Innovations in Sharing Environmental Observations and Information.:*.

[51] Jorge Luis Zapico Lamela. 2014. *Hacking for Sustainability*. Ph.D. Dissertation. KTHKTHKTH, Media Technology and Interaction Design, MID, Industrial Ecology, Centre for Sustainable Communications, CESC. QC 20131213.

[52] Jorge Luis Zapico Lamela, Marko Turpeinen, and Mona Guath. 2011. Kilograms or cups of tea : Comparing footprints for better CO2 understanding. *PsychNology Journal* 9, 1 (2011), 43–54. QC 20140916.