TOWARD A DIGITAL ECOSYSTEM FOR SUSTAINABILITY

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Abstract

Environmental sustainability is one of the main challenges that the public and private sectors, and civil society need to address together. Information systems that provide data and insights into the status of the environment are considered valuable to better handle sustainability concerns. In addition, digital technologies are changing the dynamics of interaction within business environments, making the concept of digital business ecosystem highly relevant. Despite these premises, few studies on sustainability take an information systems (IS) perspective, and Green IS research has rarely been conducted from an ecosystem perspective. Therefore, in addressing these gaps we qualitatively analyze the Norwegian aquaculture ecosystem and extend the ecosystem literature by providing a conceptual framework of a digital business ecosystem for sustainability. The proposed framework can also assist organizations in developing and using information systems to manage sustainability concerns.

Keywords: digital business ecosystem; environmental sustainability; digital technologies; information systems

1. INTRODUCTION AND MOTIVATION

Environmental sustainability is among one of the main challenges of the 21st century, and it is globally receiving increasing attention from governments, consumers, organizations, and society in general (Ziegler et al., 2013) which are all concerned about how to make the world a better place (Malhotra et al., 2013). Overexploitation of resources, and the way they are being utilized, is affecting the environment, often toward a point of no return (Sarkis et al., 2013). Sustainability has a broad scope, which is far beyond the reach of a single company (Watson et al., 2010). Thus, the United Nations (UN) 2030 Agenda stresses the relevance of a collective, cooperative approach, based on national and global partnerships (Bergman et al., 2017; Guerra and Brito Lourenço, 2018; United Nations General Assembly, 2015).

It is broadly acknowledged that digital technology can play a pivotal role in building sustainable business and society (Elliot, 2011; Malhotra et al., 2013; Olson, 2008), and it has been claimed that "it is difficult to imagine solutions to environmental challenges without a substantial IS component" (Gholami et al., 2016, p. 522). Digital technologies have also affected how firms collaborate and compete within their business environment (Nischak et al., 2017; Senyo et al., 2019), making organizational borders blurred, and a digital business ecosystem perspective more relevant. However, Green Information Systems (Green IS) research has rarely been conducted from the ecosystem perspective (Sasaki, 2018). Sustainability studies in the field are scant (Gholami et al., 2016; Watson et al., 2010) and are proceeding slowly in relation to the real needs of society.

This paper contributes to filling these gaps, and at the same time, extends the construct of the digital business ecosystem when the overarching aim is to jointly achieve a sustainable environment. The following research questions guided the study:

- How can we conceptualize a digital business ecosystem for sustainability?
- How can companies develop and use Information Systems to tackle sustainability?

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To answer these questions, our paper is based on a qualitative analysis of the Norwegian aquaculture ecosystem where environmental issues are severe, and companies are willing to use digital technologies extensively. We focus on the actors, their interrelations, sustainability concerns, the technologies, and the overall impacts on the main environmental issues. By combining these insights with the ecosystem literature, we conceptualize a digital business ecosystem for sustainability. The proposed framework provides an extension of the theoretical construct of the digital business ecosystem (Nischak et al., 2017), where the overarching aim is to achieve sustainable environment, and a managerial tool for practitioners. The paper is organized as follows. First, we present the theoretical background of the study. Second, we describe the research setting and method. Third, we provide our analysis and findings, and discuss how we developed the framework. Fourth, we discuss how the findings extend the literature on digital business ecosystem and how organizations can apply the framework. Last, we conclude with limitations and directions for further research.

2. DIGITAL ECOSYSTEM FOR SUSTAINABILITY

The business ecosystem perspective has become increasingly popular in literature and in the business scenario because of the growing importance of digital technologies (Yoo et al., 2010) that have affected the way companies interact within their business environment. The term ecosystem originated theoretically within biology where it was defined as “a dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit” (United Nations, 1992). From biology, the term was brought to the field of strategic management by the seminal work of Moore (1993) on the basis that companies do not operate in isolation but affect and are affected by other companies that operate within and outside the firm’s industry. Thus, a company’s success depends on several as well as distributed entities, such as suppliers, partners, customers, and competitors, and their interrelationships (Iansiti and Levien, 2004).

Although a common agreed-upon definition is still missing, both in practice and in theory, the ecosystem approach has allowed to comprehend many new processes from the increasingly complex relationships among organizations (Gratacap et al., 2017). In a world where boundaries are blurring, and where digital technologies enable and facilitate business contacts among companies that can be located virtually wherever, the business ecosystem perspective has become more pervasive to describe and analyze interdependent organizations and activities. Recently, a literature review of ecosystems and information systems, which analyzed 42 relevant peer-reviewed articles, emphasized the importance of considering the following three components when looking at a digital business ecosystem: actors, resources, and value exchange (Nischak et al., 2017). Moreover, this work provided a new definition for a business ecosystem calling it “digital” because digital technologies are considered a fundamental element of the ecosystem whose lack would result in an obstacle toward its existence or evolution (Nischak et al., 2017).

Digital technologies are also believed to have a pivotal role in addressing environmental sustainability (Elliot, 2011; Gholami et al., 2016; Malhotra et al., 2013; Olson, 2008), especially technologies that assess the status of the environment (Gholami et al., 2016). Sustainability has been defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs, and it comprises environmental, social, and economic aspects (World Commission on Environment and Development, 1987). Sustainability has a wide scope which is far beyond the possibility of a single organization (Watson et al., 2010), a feature that was stressed by the Sustainability Development Goals launched in 2015 by the UN that highlight the importance of a collective approach and of partnerships at the national and international levels (United Nations General Assembly, 2015).

This makes it clear why a digital business ecosystem perspective can be relevant in research focused on sustainability. However, an ecosystem perspective is rare in Green IS studies.

3. METHOD

To conceptualize a digital business ecosystem for sustainability, we qualitatively analyzed the Norwegian aquaculture ecosystem in terms of the actors, their interrelations, sustainability concerns, the technologies, and the overall impacts on the main environmental issues. We selected aquaculture as the setting for several reasons. First, it is experiencing severe sustainability concerns. Second, aquaculture is a good example of an ecosystem where actors (both private and public) interact and exchange resources to achieve a sustainable environment for the ecosystem as a whole. Several initiatives have been launched to enhance collaboration among actors. Third, investment is increasing in digital technologies to overcome sustainability problems.

3.1 Research setting

Aquaculture refers to the farming in water of animals (e.g., fish, mollusks, crustaceans) and aquatic plants (e.g., seaweed). Aquaculture and fisheries have been major sources of food, employment, and economic benefit globally. In the past, the wealth of living aquatic resources was taken for granted, but by the late 1980s, it became evident that such uncontrolled exploitation of resources could no longer be tolerated (United Nations Conference on Trade and Development, 2018): New management approaches for aquatic resources were required. Therefore, several initiatives were put in place. For instance, in 1995, the Food and Agriculture Organization of the UN (FAO) Code of Conduct for Responsible Fisheries set principles and international standards of behavior to preserve and effectively manage living aquatic resources, respecting the ecosystem and biodiversity. Recently, in 2015, the 17 interlinked sustainable developments goals adopted by UN state members stressed the relevance of a collective, inclusive journey and a cooperative approach, also based on national and global partnerships (Bergman et al., 2017; Guerra and Brito Lourenço, 2018; United Nations General Assembly, 2015). Goal 14 “Life Below Water” aims at conserving and using the oceans, seas, and marine resources in a sustainable way for sustainable development.

This study focused on the Norwegian aquaculture ecosystem. Norway is the second largest seafood exporter globally due to a long coastline of clear and cold water and a healthy climate. For several generations, Norway has profited from rich fish deposits along the country’s long coasts. Moreover, knowledge about the sea has increased, and technology has evolved over time leading to a strong seafood tradition. Although there have been benefits in terms of job creation and contribution to the gross domestic product (GDP), aquaculture has its dark side, and its growth has affected the environment. For instance, salmon production affects wild salmon populations and sea trout populations, other species such as shrimp and cod, and the seabed due to pollution (Olaussen, 2018). That is why the aquaculture ecosystem represents an interesting setting for this research.

3.2 Data collection

This paper is based on several data sources: literature on digital business ecosystem and sustainability, interviews, and archival data. An initial literature review allowed us to understand what was known or unknown about the topic we wanted to investigate. We focused on articles about digital business ecosystem and Green IS. Interviews are our main data source. We interviewed managers in several companies and organizations within the ecosystem of interest. Interviews were conducted following purposeful sampling (Marshall, 1996), interviewing actors who could provide relevant and useful information because of their involvement in technological and sustainability aspects. We interviewed representatives from the major players in Norwegian aquaculture (Lerøy, Mowi, and Grieg Seafood), with managerial roles in digitalization and a broad overview of their whole organization, an innovation manager at the NCE Seafood Innovation Cluster, who is the project manager for a data lake initiative called Aquacloud, and a technology supplier (IBM). This provides a variety of viewpoints. Semi-structured interviews were chosen to allow the subjects to talk freely about the topic of interest, to share their own experiences and elaborate about how they perceive and interpret different situations and events (Johannessen et al., 2016), and to allow us to ask additional questions depending on what arose during the conversation (Saunders et al., 2016). The interviewees were informed that the interviews would be a data source for research conducted at our university, and their participation was voluntary. To stay focused on the topic, the interviews were based on a guideline. They lasted around one hour and were recorded and transcribed.

Archival data consisted mainly of aquaculture companies’ sustainability reports (e.g., of Mowi, Grieg Seafood, etc.), official and government reports and websites (e.g., from the government, the Norwegian

Food Safety Authority, etc.), consultants' reports (e.g., PwC and EY), and other websites. Examining archival data gave us a better understanding of how production is organized within aquaculture, insight into the regulations, as well as companies' actions toward sustainability. The data sources and their use are presented in table 1.

Data source	**Type of data**	**Use in analysis**
Interviews	Six semi-structured interviews	Understand the participants' perception about sustainability challenges, and how digital technologies and collaboration can help face them.
Archival data	Reports from companies, research institutes, consultancies, and governments. Sustainability reports. Websites	Understand the aquaculture ecosystem, its sustainability challenges, and present and future focus areas. Used to triangulate interview data.

Table 1. Data sources and their use

3.3 Data analysis

The data analysis did not follow a tabula rasa approach. Instead, the analysis was influenced by the research question, relevant literature, and the data (Belk et al., 2013). For the first research question, we followed a mixed coding approach (Miles et al., 2014). At first, we analyzed the data through provisional coding. The provisional coding approach begins with a "'start list' of researcher-generated codes" (Miles et al., 2014, p. 11) defined before the data collection. We followed this approach because we aimed to build on previous research, and specifically on the Nischak et al.'s (2017) conceptualization. The first list of codes consisted of Actors, Resources (Digital and Non-Digital), and Value Exchange. Over time, we revised the list (Miles et al., 2014; Saldaña, 2013) and added subcodes based on what we found in the data. New emerging codes allowed us to cover additional elements (concerns and impacts) compared to Nischak et al.'s (2017) conceptualization, whereas subcoding allowed a more detailed and richer analysis (Saldaña, 2013). Table 2 gives an overview of the codes and quotes and/or text passage.

Topic	**Provisional codes**	**Final codes and subcodes**	**A text passage or quote**
Players in the ecosystem	Actors	Actors	We have an open dialogue with all official authorities where we operate and collaborate on all aspects. We welcome their efforts to enforce regulations and engage in constructive dialogue – Grieg Seafood, Integrated Sustainability Report (2019, p. 38)
Resources	Resources -Non-digital resources -Digital resources	Non-digital resources, Digital resources (subcodes based on purpose of resources: data capture; data aggregation; data analysis)	*The big advantage to Norway is the ocean currents, incredible amount of water is moved up the Norwegian coast* – Informant #4 [non-digital resources] *For example, there are more and more environmental sensors in each cage, they measure temperature, oxygen, current, solidity* – Informant #2 [digital resources, data capture]
Value exchange	Value exchange	Value exchange	Our goal is to transition the aquaculture industry from ad hoc decision-making based on heuristics and intuition, to real-time informed decisions backed by AI insights and IoT connectivity. This transition has the potential to greatly reduce operational costs while enhancing fish health and ensuring

			sustainability – Fearghal O'Donncha, IBM Research in IBM (2019, p. 54)
Sustainability	-	Sustainability impacts (subcodes based on their breadth: local sustainability impacts; global sustainability impacts)	In case sea lice treatments are needed, we must find the correct balance between the welfare of our fish and the potential impact on the local environment, and avoid parasite resistance to existing treatments – Grieg Seafood (2019, p. 56) [local sustainability impacts] *Although the soy we use is not from the Amazon, it is related to the Amazon problem* (deforestation) – Informant #4 [global sustainability impacts]
Sustainability	-	Concerns (subcodes as issues – problems to solve/address; pressures – constraints)	*(…) salmon lice. It is the downside to sustainability in aquaculture, that is our big problem* – Informant #4 [issues] *They (investors) will not put their money in companies that pollute. And then we must be able to document that we are as green and sustainable as we claim to be* – Informant #2 [pressures] We expect our suppliers to be certified by globally recognized schemes e.g. IFFO RS, Pro Terra and GMP+ that uphold high standards for raw material sourcing, manufacture and transport – Mowi (2019, p. 122) [pressures]

Table 2. Provisional codes and subcodes used in data analysis

Thus, the data analysis focused on identifying the actors involved in the aquaculture ecosystem, and on the digital and non-digital resources exchanged in their activities. Then, we mapped each resource to the value it could bring in terms of innovation, information, or products/services (Kaiser et al., 2019; Nischak et al., 2017), resulting in identification of the generated value exchange. In addition, we linked each resource and value exchange to the concern(s) they could address or solve, and subsequently to the impact(s) they could have on the ecosystem at the local and global levels. This analysis provided an understanding of the relationships among the ecosystem components. For the second research question, we stayed closer to the data. We focused on understanding how the informants were using technologies and what aspects were important to develop information systems that can actually aid greater sustainability. No provisional coding was used. However, we retained some of the codes defined in the analysis for addressing the first question (e.g., data capture, data aggregation, data analysis). Other important aspects emerged from the data, such as data protection, data amount and availability, and data standardization.

4. FINDINGS: THE ECOSYSTEM

In this section, to describe the Norwegian aquaculture ecosystem, we rely on the recommendation of Nischak et al.'s (2017) that "emphasizing a specific ecosystem aspect is legitimate, but always needs a simultaneous consideration of the remaining components, too, in order to remain consistent with the ecosystem construct" (p. 14). Therefore, the first finding is a summary of the relevant actors, resources shared, and value exchange derived from the analysis of the data and Nischak et al.'s (2017) ecosystem conceptualization. These results are summarized in table 3. To get a holistic ecosystem, we included not only producers but also other entities operating in different private industries and public entities which are all involved in sustainability. Then, we describe the additional elements (concerns and impacts) of the proposed conceptual framework (mentioned in section 3).

Actors

Aquaculture production is carried out in all phases of the organisms' life cycles starting with egg breeding and fertilization, through the nurturing of fry to smoltification, and finally, with the stocking of organisms in the sea for further processing (EY, 2017; Regjeringen.no, 2005). It is common to refer to the various actors according to where in the production cycle they operate and by their end-product, for example, salmon and trout or mussels (Regjeringen.no, 2005).

Actors in production are divided into egg and spawn producers, smolt producers, and sea farming entities (which is the largest). In each sub-segment, there are specialized stand-alone companies but also crossover ownerships between the sub-segments (EY, 2017). In addition, three different groups of service providers are present: those who provide technical solutions (e.g., cages, sea lice treatments and software, well boats), those who provide biological or pharmaceutical raw materials, such as feed and vaccines, and those who provide distribution services, such as transport of harvestable fish to processing plants and processed fish to consumers.

Actors in processing are divided into two groups, those who provide slaughtering and gutting, and those who provide fileting, filet trimming, portioning, smoking, and packaging. Processing is sometimes conducted by the salmon producers or by individual entities, which may also operate in other industries.

Other key actors in the aquaculture industry are the authorities that regulate the industry production through the issue of licenses, administrative decisions that state the rights (e.g., of producing specific species, in a specific quantity and at specific sites), and the obligations of the license holder.

<table>
<tr><th colspan="2">Resources</th><th>Actors involved in resource exchanges</th><th>Value exchange</th></tr>
<tr><td rowspan="3">Non-digital</td><td>Rich deposit of fish and long coastline</td><td>Nature and Producers</td><td>Good raw material and Favorable production conditions</td></tr>
<tr><td>Raw and pharmaceutical material</td><td>Biotech suppliers and Producers</td><td>Fish growth, Feeding, and Health treatments</td></tr>
<tr><td>Licensing/Traffic lights system</td><td>Policy makers and Producers</td><td>Production regulation and Prevention of sea lice spreading</td></tr>
<tr><td rowspan="8">Digital</td><td>Sensors</td><td rowspan="8">Tech suppliers and Producers</td><td>Automate environmental measurements, Feeding process monitoring, Work remotization, and Improved decision-making process</td></tr>
<tr><td>Live cameras</td><td>Cage surveillance and inspection, Fish eating pattern monitoring, and Feeding process monitoring</td></tr>
<tr><td>Drones</td><td>Cage inspection and Fish eating pattern monitoring</td></tr>
<tr><td>Localization devices</td><td>Feed process monitoring</td></tr>
<tr><td>Optical delousing with laser</td><td>Fighting and preventing sea lice over time</td></tr>
<tr><td>Databases</td><td>Storage of data</td></tr>
<tr><td>Management systems</td><td>Reporting systems (summaries and interpretation of production data)</td></tr>
<tr><td>AI and big data</td><td>Analysis of a huge amount of data and Prediction models generation</td></tr>
</table>

Table 3. Overview of the Norwegian aquaculture ecosystem based on Nischak et al. (2017)

Resources

Multiple kinds of resources can be found in the aquaculture ecosystem. We divide the resources into non-digital resources and digital resources. Among non-digital resources, there are the rich deposits of fish and a long coastline offered by nature to the producers. Interacting with biological suppliers, producers can access raw material as feed and pharmaceutical materials as vaccines. Other non-digital resources are involved in the interaction between producers and the government: the licensing system that provides the licensees with the rights and the obligations to operate, as well as the more recent traffic lights system that divides Norway into 13 production zones.

Several kinds of digital resources are used in the Norwegian aquaculture ecosystem and are found in the interaction between producers and technological suppliers. These digital resources are used to create awareness or make sense of what is going on in the cages at the present and in the future, to improve the decision-making process, and to streamline operations. These resources can be grouped based on their purpose: data capture (e.g., sensors, cameras, drones, and localization devices), data aggregation (e.g., software as management system), and data analysis (e.g., artificial intelligence and big data).

Value exchange

Value exchange comes in different forms: innovation, information, and products or services (Kaiser et al., 2019; Nischak et al., 2017). The non-digital resources from nature give Norway a head start in aquaculture, whereas the raw and pharmaceutical materials allow for fish growth and treatments against or toward fish diseases. Licenses and the zone system permit and regulate production by adjusting the amount of production depending on the spread of sea lice and of other diseases. The Norwegian Food Safety Authority has set an upper limit for salmon lice in farms that must not exceed an average of 0.5 adult female lice per fish in the facility at any time (Mattilsynet.no, 2020). Licenses also promote the spread of technology when they are assigned for innovative projects, and they require that the technology developed is shared for the benefit of the entire industry (EY, 2017). Thus, non-digital resources create a value exchange especially related to products or services and sometimes, innovation.

The value exchange arising from digital resources is mainly in the form of data and information. Overall, these technologies may allow remote work, reduce manual operations, optimize the feeding process, assess the status of the environment for a better decision-making process, and inspect and monitor the cages. One informant (#4) stated: "Digitalization is linked to streamlining what we do." Specifically, sensors collect and transmit data continuously to the feeding centers of the companies' management systems. Sensors can be used on a diesel generator and on feed pumps, and to measure environmental parameters related to the cages (e.g., temperature, oxygen, salinity in the water). Thus, sensors allow to automate measurements that were previously done manually, assuring more accuracy and precision, and they allow for enhanced decision-making processes. Cameras, both over- and underwater, are used for surveillance purposes, for example, to capture important observations related to the health, behavior, and eating patterns of the fish. Overwater cameras are especially useful when the weather conditions prevent access to the facilities and are used to monitor the plants. Underwater drones are mainly used to inspect the cages (e.g., to detect a hole in the net) and to inspect the fish's eating patterns. An informant (#2) explained: "The drones can help us know more about what's going on in the cage, which will be positive both on sustainability, fish health, economy, environment, and everything." The optical delousing system, which is not yet widespread, shoots laser beams to kill the sea lice attached to the fish and prevents the parasites from reappearing. Localization devices (e.g., FishFinder), based on technology used for finding new oilfields, help identify the movements of the fish in the net through echoes and represent valid help in the feeding process to stop releasing feed when the fish is satiated, thus avoiding feed waste and its spread in the environment. Software, as management systems, provides summaries and statistics of production data that can be used for the decision-making process, whereas databases permit data archival. Artificial intelligence and big data analytics analyze the huge amount of data captured by the devices mentioned above, as well as make forecasts.

Joint use of these technologies assures the highest potential for sustainability concerns. This is what is happening in the ecosystem analyzed. The NCE Seafood Innovation Cluster is leading a synergic approach across technologies and actors through the data lake initiative Aquacloud launched in 2017. Fostering collaboration is key, because "all operate in the same bathtub. When it comes to fish health, then what you do in your own company is just a small part of the overall picture. Therefore, it will almost not have a value if your neighbor doing something completely different" (Informant #4). This also makes evident that the big picture and the idea of being involved in an ecosystem are present in the analyzed setting. Figure 1 gives an overview of how technologies are combined, and how the data they provide can be valuable individually or for more companies in the aquaculture ecosystem.

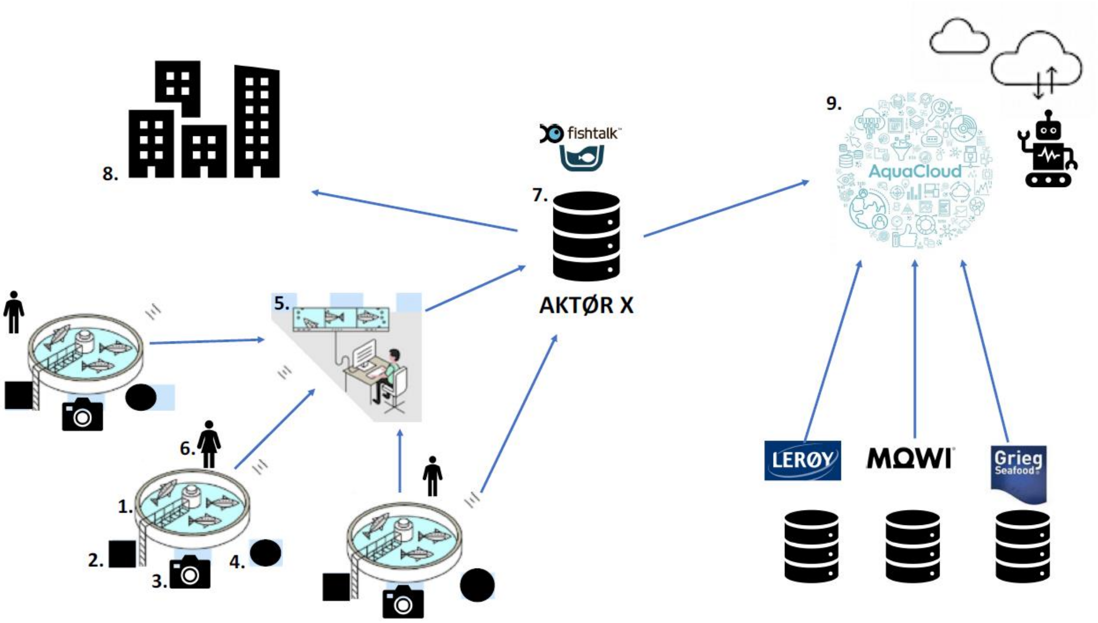

Figure 1. Jointly usage of digital technologies in Norwegian aquaculture

The cages (1) are equipped with sensors (2), cameras (3), and underwater drones (4). Sensors transmit data continuously to land, onshore feeding centers (5), or the companies' management systems (5). This data can be used to optimize the feeding process (e.g., to reduce the amount of feed released in the cages to match the fish appetite) or to adjust the conditions in the cages for optimal fish welfare. Data can be read manually by employees (6), and it is sent to local computer systems (e.g., Mercatus and Fishtalk) where data about operations is entered. Data is stored in the companies' databases (7). Thus, it is available for management and employees (8) for analysis and as the basis for decision-making to optimize operations and make them more sustainable. Data from the database of one actor (7) may be combined with data from other actors' databases, and all go together into a common data lake called Aquacloud (9). Aquacloud is a big data project (it owns data from more than half of the industry) that uses artificial intelligence to gain insight into and situational understanding of life in cages. Data collection and processing are performed by IBM. The data is mainly obtained by members' databases – retrieving it via software (e.g., Fishtalk), by open data sources (e.g., Barentswatch) that allow to get non-members' data, and by the contribution of other actors such as the Marine or the Veterinary Institute. Thus, analyses can be performed on rich data using artificial intelligence to create prediction models that will be the basis for more proactive, effective, and timing decisions, to increase sustainability. Figure 2 shows an example of a prediction model for the spread of sea lice on the West Coast. The forecasts (available for two weeks ahead) are presented at two levels: area and cage. Areas are marked with different colors depending on how the parasite affects the wild salmon in those areas. Green indicates areas where the situation is considered acceptable, yellow moderate, and red unacceptable. If a facility is located in a yellow or red area, breeders will take immediate actions to reduce the infection and avoid larger outbreaks.

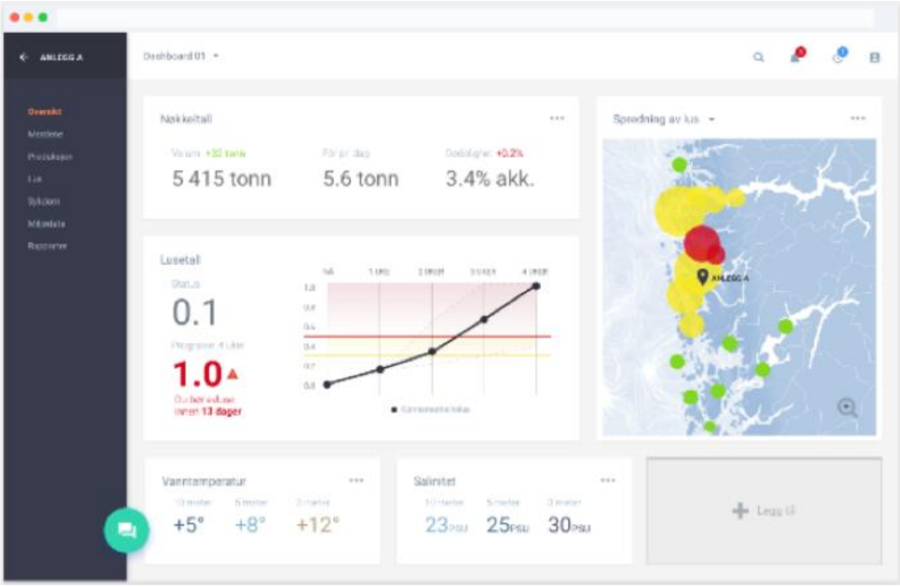

Figure 2. A prediction model for sea lice (Illustration borrowed with permission from the NCE Seafood Innovation Cluster)

The Aquacloud initiative makes it clear that to address sustainability concerns properly technologies may serve several purposes: data capture allows data collection; data aggregation summarizes the gathered data and provides a base for statistical analysis; and data analysis includes data cleaning, transforming, and modeling to extract useful information for the business decision-making process. The initiative also stresses the need for collective and coordinated efforts to unlock the technology potential to ensure that the usage of technology is aligned with societal needs (Herweijer and Waughray, 2019).

Environmental concerns and impacts

Salmon lice, disease and mortality due to salmon lice or viral diseases, escapes, and feedings are Norwegian aquaculture's biggest concerns. Salmon lice is considered the largest challenge (Institute of Marine Research, 2020) as it threatens the life and welfare of farmed and wild salmon (Olaussen, 2018; Tveterås, 2002): An annual loss of 50,000 adult wild salmon was estimated from 2010 to 2014 (PwC, 2017). Sea lice is a natural parasite that eats salmon skin, mucus, and blood, causing wounds that result in impaired health and death. It increases when the salmon host number increases. Reducing the number of lice per salmon is fundamental for the ecosystem. This concern can be addressed through the following: 1) non-digital resources as traffic lights that prevent the spread of the parasite by regulating the production, and as vaccines and other treatments; 2) digital resources as cameras that allow to see what is going on in the cages or as the optical delousing systems that shoot the parasite without impairing fish health. Addressing this concern affects the environment, for instance, positive impacts in terms of better fish health and more sustainable production.

Lice treatments are partly responsible for fish escapes, which cause crossbreeds (Olaussen, 2018) and loss of production and profit for farmers (Tveterås, 2002). Fish escapes are also a consequence of the inadequate technical state of the installation, poor inspection, absent control systems, and salmon farmers' incompetence or errors (Regjeringen.no, 2009). Digital resources such as cameras and drones can help the ecosystem avoid environmental impacts due to the spread of diseases and parasites generated by the escapes.

Another problem is the high increase in feed usage compared to the static global supply of fish meal and oil. To date, the adoption of plant oil has been the solution, but plant oil has low levels of omega 3, and its production comes from plants that could be used for human consumption. Therefore, there is an urgent need to find new sustainable feeding sources (PwC, 2017). In addition, feed is released into the cages based on experience, resulting in an undigested amount in the cages that contaminates the environment, together with chemical treatments used against parasites, and feces due to the high fish density inside the cages (Olaussen, 2018). Digital technologies (e.g., sensors) are central resources for addressing these challenges

(PwC, 2017) and reducing the environmental impacts in terms of contamination. This is also evident from the words of two informants: “We try to understand better how we affect the environment around us” (#4), and “then this camera system can report to the feeding system and it will stop. You will get much better feed utilization which in turn gives less feed waste which will again be an important bit toward the environment as well” (#2).

5. DISCUSSION

The first research question addressed is: How can we conceptualize a digital business ecosystem for sustainability? By reviewing the literature and by analyzing our data, we gained an understanding of how the Norwegian aquaculture ecosystem works. Our first contribution is the conceptualization of a digital business ecosystem for sustainability that consists of five components: actors, resources, value exchange, concerns, and impacts. We present this conceptualization in figure 3.

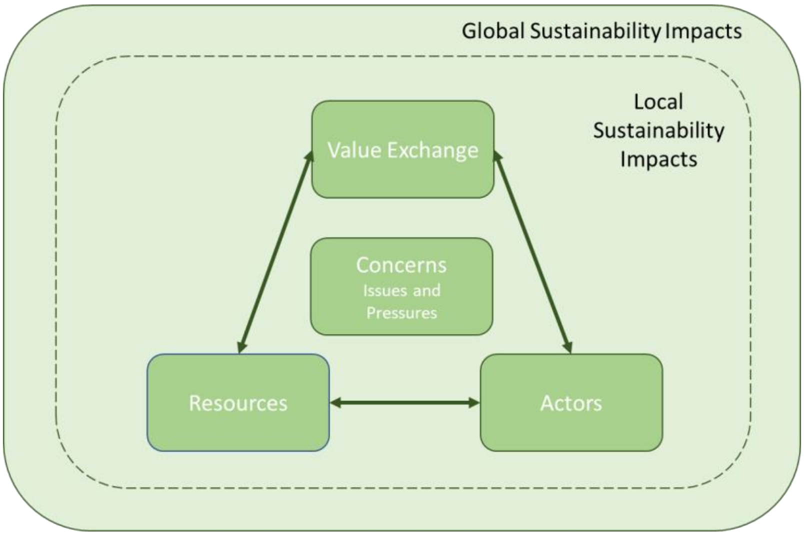

Figure 3. A digital business ecosystem for sustainability

Figure 3 highlights that the triad Actors-Resources-Value Exchange does not operate in a vacuum. Instead, it operates by considering the concerns that can act as issues to address (e.g., fighting salmon lice) or as pressures that, for instance, may constrain or affect operations (e.g., pressure from civil society for a more sustainable world, pressure from a producer on a supplier that must achieve a certain level of quality and acquire certification, pressure from investors that do not want to put money in companies that pollute). Moreover, the interactions within the triad result in impacts on the ecosystem at narrow and broad levels. In this paper, these are referred to as local sustainability impacts and global sustainability impacts (e.g., biodiversity and climate change), respectively. To explain this further, every flow in one direction generates another flow that can have a reverse or a totally different direction. For instance, if the interaction between a technological supplier and a producer is considered, the former provides digital technologies (resources) to the latter that monitor feeding (value exchange). This monitoring generates other value in the form of no unnecessary feed within the cage that would become sludge and waste. This represents a local impact on sustainability. A global impact, in this case, would be related to how this reduction in feed waste affects sustainability at the larger level: The feed contains soy that comes from the Amazon rainforest; thus, the correct amount of feed in the cages would lessen destruction and deforestation of land and reduce the emissions due to transportation of the soy. Obviously, it is not always possible to fully separate the sustainability impacts into local and global levels. Thus, in the proposed conceptualization, a dashed line separates the two. However, when sustainability is the overarching aim of an ecosystem, each value exchange from the resources shared among actors must be seen in terms of the concerns it can address and in terms of the impacts it can generate. As shown by the data analysis, concerns represent the starting point of action, the trigger for an exchange and its value to arise, which then result in impacts. Therefore, when sustainability is the overarching aim of an ecosystem, the conceptualization in terms of actors, resources, and value exchange (Nischak et al., 2017) is too narrow. The proposed model provides an extension of

Nischak et al.'s (2017) conceptualization and offers an integration between Green IS and the ecosystem perspective that has been rare so far (Sasaki, 2018).

The analysis allows us to point out something more. We suggest that the definition of a digital business ecosystem provided by Nischak et al. (2017) may be misleading sometimes when looking at sustainability. Their definition states "a digital business ecosystem is a flexible combination of heterogeneous actors, interacting co-opetitively by fundamentally drawing on a shared set of digital resources in conjunction with non-digital resources driven by the underlying perception that engaging in joint value creation increases individual chances of survival and growth" (Nischak et al., 2017, p. 13). For Nischak et al. (2017), an ecosystem typically has a certain degree of openness that allows for a flexible member base. In the analysis of the Norwegian aquaculture ecosystem, production is heavily constrained by the licensing system to safeguard the environment and to reach optimal usage of the coastline, meaning that the actors involved in the production are not free to join the ecosystem on their own. Combining the individual licenses with general regulations is believed to ensure that the requirements for industry players are predictable. Currently, there are 1366 licenses in Norway (Statistisk sentralbyrå, 2020), and authorities have restricted the issuance of new licenses (Vinding et al., 2019) because of marine garbage, overfishing, and ocean and coastal zone deterioration (Dalsmo, 2018). The number of licenses is also limited because they are expensive and time-consuming to acquire. Thus, our setting makes it evident that a digital business ecosystem for sustainability is not as flexible and open as Nischak et al.'s (2017) conceptualization indicates. In accordance with their definition, we believe co-opetition is the logic of interaction that best describes how the different actors relate to each other to pursue sustainability. However, another type of logic may be considered. For example, looking at a producer and a public actor, or a producer and a consumer, there could be a logic of *adaptation* that refers to a situation in which environmental pressures force a species to adapt to local conditions (see a description of Alfred Wallace's ideas in Larson, 2004; Bowler and Morus, 2010). An example of adaptation is a situation where producers may do something to retain their market position because of constraints imposed by authorities, international standards, or pressure from the end consumers.

On a practical level, we argue that the proposed conceptualization can help organizations understand their ecosystem. Table 4 provides a template to map the relevant components of a *digital business ecosystem for sustainability*.

Resources		Actors involved in resource exchanges	Value exchange	Local sustainability concerns and impacts	Global sustainability concerns and impacts
Non-digital					
Digital					

Table 4. Mapping a digital business ecosystem for sustainability

Mapping their own ecosystem will raise companies' awareness of the breadth of sustainability, which is beyond the reach of a single company (Watson et al., 2010) in terms of expertise and resources. It also shows that thinking in terms of participating within a value chain is not likely when the final aim is sustainability. Therefore, this template is especially valuable for companies operating in traditional industries that consider themselves involved in or controlling a value chain (Kaiser et al., 2019; Weill and Woerner, 2015).

Returning to the second question, how can companies develop and use Information Systems to tackle sustainability?, the reviewed Green IS literature (Elliot, 2011; Gholami et al., 2016; Malhotra et al., 2013; Olson, 2008) has acknowledged the key role of IS for sustainability because they can provide data that is fundamental to improve decision-making processes. Based on that, and our analysis of the Aquacloud initiative (see figure 1), we suggest the following steps (see figure 4) to develop Information Systems for sustainability.

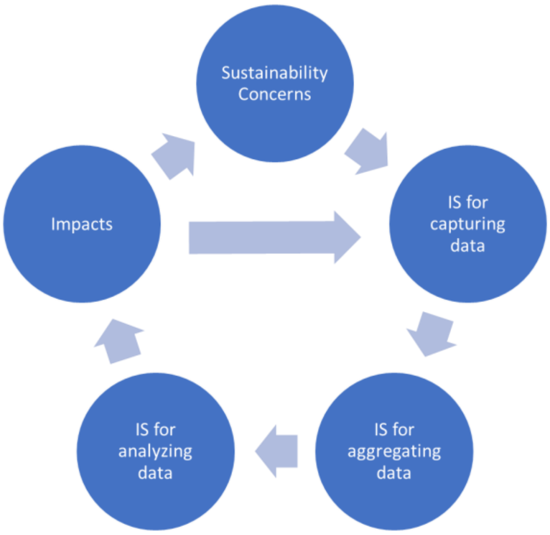

Figure 4. Developing Information Systems for sustainability

First, starting from sustainability concerns, companies need to gather more data about their current situation by developing and using technologies such as sensors, cameras, and drones. Second, to extract insights and value from data, companies need to rely on IS that aggregate data in the form of summaries and statistics (e.g., through management systems). This would constitute the base for a better decision-making process that can be further enhanced through IS (e.g., AI and big data) that analyze huge amounts of data and provide—through algorithms—forecasts for possible future scenarios. Last, the actions taken based on data and information generated by these steps will result in impacts that must be measured, and that may also imply (new) concerns to address. Therefore, continuous monitoring is needed. Overall, this clearly resonates with Gholami et al. (2016) who claim: "one needs more and better quality data are to assess the state of the environment, make appropriate decisions to ameliorate identified problems, and analyze the efficacy of the different initiatives" (p. 522). Furthermore, as these steps (would most probably) imply collective efforts (e.g., as the Aquacloud project in the Norwegian aquaculture ecosystem shows), we also acknowledge that this is not a straightforward path, because the number and availability of data, data standardization, and data protection must be guaranteed to increase willingness to join an initiative or an ecosystem (Kaiser et al., 2019). In addition, this makes clear that to develop IS for sustainability, different technologies with different purposes must be integrated. This study also shows how information systems can be used to operate at a greater sustainable level and thus, it adds some pieces to knowledge about IS usage in transformations toward sustainability (Seidel et al., 2013).

6. CONCLUSION

In response to a call in the literature to conduct more studies about sustainability from an information systems perspective (Gholami et al., 2016), and to address the gap related to Green IS research from an ecosystem perspective (Sasaki, 2018), we investigated the following research questions: How can we conceptualize a digital business ecosystem for sustainability? How can companies develop and use Information Systems to tackle sustainability? To address these questions, we reviewed Green IS and the digital ecosystem literature. Then, we analyzed the Norwegian aquaculture ecosystem through interviews and archival data to obtain a holistic picture of this ecosystem in terms of its actors, resources, and value exchange (Nischak et al., 2017). We then conceptualized a digital business ecosystem for sustainability that expands the triad actors-resources-value exchange to consider concerns and impacts, and that integrates Green IS and ecosystem studies. Moreover, these findings provide a tool for practitioners to map and visualize their own ecosystem, which will help them switch from the narrower perspective of a value chain to the broader perspective of an ecosystem where value is created from collective endeavors and interdependence. Finally, the findings emphasize the important role of information systems in data capture, data aggregation, and data analysis when the overarching aim is sustainability, and provide organizations with a cyclic process to follow for designing, developing, and using IS for sustainability.

This study has limitations. First, although sustainability challenges are severe in aquaculture, we examined only one ecosystem among the possible others that may be investigated. However, this framework should be consistent in other settings where regulations are in place, thus affecting the closeness of the ecosystem. Future research may investigate other ecosystems in which digital technologies are in place from a sustainability perspective.

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