

THE TWIN TRANSITION: PROMISE AND PERIL?

Lessons learned from empirical studies of digitalization and sustainability in energy, oil and gas, aquaculture, maritime shipping, transport, and textiles



INTRODUCTION

By Tuukka Mäkitie, Mari Wardeberg & Jens Hanson, Department of Technology Management, SINTEF Digital & Taran Thune, Center for technology, innovation and culture, University of Oslo

The intersection of digitalization and sustainability transitions, or the “twin transitions”, is gaining attention. There's optimism and expectations among policymakers, industry players, and researchers that digitalization could aid sustainability efforts. “Twin transition” must be understood primarily as a European policy concept, and there's a notable lack of clarity regarding the concept of twin transition, and more generally, the role of digital technologies in fostering or supporting sustainability transitions. Notably, digital solutions as general-purpose technologies are pervasive and complex in their impact on shaping human practices, and uncertain *ex ante* in their sustainability effects.

Meanwhile, existing analyses of twin transitions have been found to often adopt a technology-optimistic and deterministic approach to sustainability effects (Mouthaan et al, 2023). More nuanced understanding of twin transition is necessary, including in terms of adopting a more systemic understanding of digital innovations in the sustainability context, and their unintended and unexpected effects.

Of course, not everything about digital innovation is sustainable. Examples include data centers' significant carbon emissions, and the environmental impact of cryptocurrencies, as well as possible social exclusion due to a digital divide (Sareen,

2021). Moreover, when understanding sustainability transitions as fundamental shifts in the patterns of production and consumption towards sustainability (e.g., from fossil fuels to renewable energy, from linear production and consumption to circular economy), it has been noted that digital innovations typically contribute to optimizing existing production and consumption patterns (e.g., more efficient production) (Mäkitie et al., 2020). Thus, while many digital innovations aiming to increase efficiency may reduce emissions to some extent, they may not be enough in achieving the more fundamental change required for full decarbonization by 2050. At worst, digital innovations may slow down sustainability transitions by improving the performance of existing inherently unsustainable solutions and systems, thus deepening the path dependencies that may hinder the breakthrough of sustainable innovations.

Meanwhile, it has also been recognized that digital innovations may be instrumental in enabling sustainability transitions by, for example, solving key bottlenecks related to sustainability transitions. For example, smart energy systems are necessary to solve challenges related to the high intermittency of renewable energy (securing power supply when wind or solar power is not available). Additionally, digital platforms offer opportunities for coordinating collaboration in circular value chains. By leveraging digital platforms, stakeholders may enhance the efficiency of resource utilization, minimize waste, and optimize the circulation of materials.

The discussion regarding twin transitions, or so we would argue, should thus focus on digitalization's capacity in enabling the needed *systemic changes* in reaching urgent sustainability goals, including opening new

pathways for reaching net-zero carbon emissions by 2050 (Mäkitie et al., 2023). When considering twin transitions, special attention should be dedicated to considering whether the novel digital technology promotes a direction of change of optimizing existing production and consumption patterns (e.g., based on fossil fuels), or whether it contributes to creating novel sustainable patterns (e.g., based on renewable energy). Digital technologies, such as AI, blockchain and sensors, are ultimately in themselves void of a sustainability direction – it is how actors apply these technologies that determines how digitalization may or may not contribute to sustainability transitions.

To avoid empty rhetoric about the promise and peril of digitalization for sustainability, empirical studies of twin transition pathways are necessary, addressing how digital technologies are deployed in different sectors to support sustainability. In this policy brief, the aim is to present concrete examples of twin transition processes from empirical studies from different industries and sectors in Norway.

RESEARCH ON TWIN TRANSITIONS IN DIFFERENT SECTORS AND INDUSTRIES.

To illustrate the complexities involved in realizing the potential of twin transitions in different sectors, we invited a group of researchers who work on research on digitalization and sustainability in different sectors to share insights.

The researchers address twin transition topics from a social science and/or interdisciplinary perspective in maritime

shipping, oil and gas, textiles, electricity, mobility, and aquaculture sectors.

More specifically, we asked them to reflect on three questions:

- What are the key sustainability challenges in the sector you study and how are digital technologies applied to address these challenges?
- What are the potential synergies between digitalization and sustainability and what are important challenges to realize synergies in this sector?
- Why are social science perspectives important to understanding twin transition and what questions do you regard as particularly important to address?

DIGITALIZATION, CIRCULAR ECONOMY, AND THE PLASTIC WASTE CHALLENGE IN NORWEGIAN AQUACULTURE.

By Eli Fyhn Ullern, Department of Technology Management, SINTEF/ Department of Industrial Economics and Technology Management, Norwegian University of Science and Technology (NTNU)

The examples in this text are based on a collaborative and knowledge-building project, POCOplast (2020-2024), which focused on addressing the challenge of post-consumer plastic (PCP) waste from the aquaculture industry. Due to its advantages, such as low weight, durability, and low costs, plastics are used in nearly all components of net pens in fish farming. Many of these components comprise hard plastics suitable for recycling (Sundt et al., 2018). To give a brief overview of the volume: A previous report indicates that the aquaculture industry

employs 192,000 tonnes of plastics, with an annual waste output of up to 29,000 tonnes (Hognes & Skaar, 2017). Given the industry's anticipated growth in the coming years, there is a pressing need for innovation to ensure a more sustainable utilization of plastic derived from fossil resources. A key challenge is minimizing plastic waste production while enhancing the recycling rates of already produced plastics. Currently, only 1/3 is reused or recycled, while the rest is sent to incineration or landfill. I have therefore studied how circular economy (CE) principles, such as recycling, can be applied to a more sustainable value chain for PCP from aquaculture.

Although CE is widely recognized in policy, industry, and academia as a key to fostering more sustainable production and consumption patterns, the implementation of these solutions remains limited. Within this context, I have explored the potential synergies between green and digital to stimulate a shift from linear to circular plastic use in the industry. The challenge includes both gaining control of plastics in use and handling PCP waste as a resource after equipment reaches its end of life. Digital tracking can provide data on materials and ensure transparency throughout the value chain. This push for traceability is also driven by new regulations and the need for transparency in reporting on the use of materials, e.g., the expected implementation of extended producer responsibility for plastics in aquaculture and fisheries in 2024.

Furthermore, reliable information is needed to promote more circular resource use, especially concerning material quality and the origin of recycled plastics, particularly

when using recycled plastics as a resource back into the aquaculture industry or other industries that use recycled plastics. Given the strict quality standards for structures and components in aquaculture, such as net pens, to prevent sustainability issues like sea lice infestation and salmon escape incidents, firms in the plastic value chain are increasingly interested in exploring how digital tracking and traceability can ensure the quality of recycled plastics. However, transitioning the industry towards more sustainable resource utilization hinges on broader system changes and innovation.

Circular innovation ecosystems are often facilitated by platforms that enable actors to collectively deliver value, such as through new business models and value chains (Aarikka-Stenroos et al., 2021). This typically requires collaboration with other actors in either established or emerging value chains. For example, increasing the use of recycled PCP as a resource in new production depends on recycling companies. However, despite opportunities for more sustainable value creation, practice shows that these value chains do not develop without further facilitation. Consequently, businesses are entering the market to facilitate value chain development, notably through digital platforms. For plastics originating from aquaculture, digital platforms may play a role in facilitating the matching of supply and demand of recycled PCP across firms and sectors (Ullern, under review). An example of an initiative is AION <https://www.aion.eco/no>, which provides circularity services through its digital platform to help firms gain data and the documentation of environmental impacts throughout the plastic value chain. Given that

some sort of coordination seems necessary to make circular value chains competitive compared with their linear counterparts (Aspelund et al., 2021), these platforms may facilitate the need for data and more sustainable resource use both within firms, value chains, and ecosystems through digital tracking (Ullern, under review).

Additionally, digital tracking may help raise awareness in the industry by visualizing the use of the amounts, quality, and history of plastics, which may provide a better foundation for decision-making when using PCP as a resource in new production. However, as noted in previous studies, while digital technologies may lead to more sustainable use of resources, there is also a risk of digital technologies accelerating resource use and thus, they must be used responsibly to avoid unintended consequences (Bohnsack et al., 2022). Furthermore, although hard plastic from aquaculture is a durable material suitable for recycling, it is important to explore multiple ways of prolonging the lifetime of materials and products already in use to reduce the reliance of fossil resources. Therefore, synergies are found when digital technologies stimulate the use of more recycled plastics as a substitute for virgin materials without increasing the overall use of plastics.

A key challenge for researchers and practitioners is to critically assess how the twin transition creates value for individual actors and drives the systemic change needed to transition to CE practices across industries. EU also highlights this, e.g., through the introduction of digital passports, which aim to further stimulate transparency

further and enable more informed decisions on circularity. Norway's newly launched "Circular Economy Action Plan" similarly underscores the importance of digital information. Social science perspectives can contribute towards a deeper understanding of how sustainable resource use depends on innovation in various parts of the socio-technical system. This knowledge can help stakeholders navigate the complexities of transition processes and inform policymaking to support practical and scalable solutions. Methodologically, we may also contribute towards a better understanding of short-term and long-term implications of twin transitions, where researchers and practitioners collaboratively can address barriers and enablers, e.g., in line with the approach of Engaged Scholarship (Van de Ven, 2007). The ongoing debates on the twin transition represent an opportunity to address challenges, such as plastic waste from industry while informing decisions to limit the problem in the first place. Connecting data and materials for more sustainable value creation may be one way of driving these changes toward a CE.

TWIN TRANSITIONS IN THE ENERGY SECTOR.

By Raymond Andreas Stokke, Department of Technology Management, SINTEF

Our study focuses on twin transitions within the energy sector, particularly examining large energy companies in Norway. The exploration of twin transitions in this context is motivated by the urgency to address climate change and the potential of digital technologies to enhance energy

sustainability. The Norwegian electricity sector represents a unique case due to its already low carbon footprint and its ambitious goals for further sustainability and digitalization, such as integrating smart grids and advancing metering systems to improve efficiency and reduce energy waste.

The sustainability challenges in the energy sector revolve around reducing carbon emissions, enhancing energy efficiency, and ensuring both reliability and flexibility of energy systems amidst growing demand. Digitization emerges as a transformative tool to tackle these challenges by enabling more efficient management of energy production, distribution, and consumption. For example, the deployment of smart grids and digital metering systems in Norway aims to optimize energy use, minimize losses, and facilitate the integration of renewable energy sources. These digital solutions improve operational efficiency and empower consumers with real-time data to make informed choices about their energy consumption, resulting in reduced environmental impacts.

Twin transitions leverage both digital and environmental innovations to address sustainability challenges in the energy sector. Measures such as the integration of advanced digital technologies with renewable energy systems are good examples of this. For instance, digitally enhanced smart grids can better manage the variability and integration of renewable sources like wind and solar power, improving the resilience of the energy system. Moreover, digital platforms can facilitate peer-to-peer energy trading, allowing for more decentralized and efficient use of

renewable energy. These initiatives can potentially reshape energy systems, making them more sustainable, efficient, and responsive to changing environmental demands.

Creating synergies between digital and sustainable transitions requires overcoming significant barriers. Technological advancements need to be matched with robust digital infrastructure and cybersecurity measures. Regulatory frameworks must therefore evolve to support innovative business models and facilitate the integration of new technologies into existing energy systems.

A broader social science perspective is essential in understanding these dynamics, as it provides insights into consumer (and human) behaviours, institutional structures, and policy implications. Such a perspective helps in designing interventions that are not only technologically sound, but also aligned with sustainable development goals.

TWIN TRANSITIONS IN THE ELECTRICITY SECTOR.

By Barbro Renland Haugjord, Department of Informatics, University of Oslo

For the electricity sector there are two main challenges for the future; increase the share of electricity and decrease the share of fossil fuels in the generation of electricity. Energy use in buildings, transport, industry and for electricity production stands for over 70% of greenhouse gas emissions. The share for electricity generation alone stands for around 34%. Additionally, to ensure energy for all electrification must be accelerated. These

two challenges set the goals to increase the total amount of electricity, increase the share of renewables in the electricity mix and decrease emissions without putting excessive strain on the grid potentially leading to costly investments in grid infrastructure. Alongside these goals are the connected issues of not further increasing the energy gap, a sustainable use of scarce resources such as minerals, overall security of both physical and digital systems and a fair distribution of costs.

In the near future, the connection to other energy carriers and coordination of these will surge and for instance how heating / cooling (district or area solutions with thermal wells or pipes), gases / liquids (bio / hydrogen) can be integrated to a whole energy concept will be important.

Twin transition is one step on the way to have a more holistic understanding of the interconnectedness of the challenges we are facing and possible solutions to these.

There are numerous green and digital initiatives within the electricity sector. Many of these involve other sectors as electricity is an enabler for the transitions in other sectors and other initiatives are confined to the inner workings of the sector. Pertinent sectors are transport and buildings as these consume a large share of energy and electricity and have potential for both storage and flexibility in their consumption.

Creating synergy requires aligning the aims for the green and digital to create a desired goal. This alignment process is required for a diverse set of actors from individuals to states and international agencies such as the EU in their legislation. In our research we

have looked at what is required for one company to enable multi-dimensional sustainability by aligning environmental, social, and economic dimensions of sustainability. Their efforts to create more sustainable solutions went beyond the boundaries of their physical presence and into prompting sustainability within their digital ecosystem, their IoT production, manual nudging of and automated energy efficiency solutions for their consumers. Accessing all the required IoT devices is vital and a three-fold strategy of data-sourcing was employed.

A rephrasing of the physical challenge in terms that the digital can unlock synergistic solutions. Our research shows how the multiplatform ecosystem was built to integrate all relevant IoT sources from previously siloed IoTs within for instance heating, EV charging, lighting, and PV production. To make the data from the different IoTs “talk” about energy efficiency a mediation of data between the IoT source and the ecosystem use was necessary. The temperature of the water heater needed translation into energy capacity terms and connected to the hourly prices of the electricity market to become meaningful for energy efficiency measures. Digitalization is no more magic than what it is set out to solve and the correct questions must be asked to enable right solutions.

To understand what it takes to pivot technology to access the potential for sustainability and unbundle the “magic” of tech. Avoiding siloed solutions is important to create a twin transition and a broad view with societal perspectives is important to unpack implications and connections. The goals of

the electricity sector are set on a societal level but implementation of connected IoTs are at consumption and production level. The level of saturation required to balance all levels of electricity production, storage and consumption can put further strain on the earth's scarce resources if a mindful approach is not taken as to what is a sufficient level of digitalization.

To enable a twin transition requires a multitude of data matching the issue at hand both in what it represents and the granularity it represents it, a deployment fit to the users, and a wide enough scope to gather the necessary actors involved. Researching with a wide lens enables a vision to see this whole in a way to gain necessary insights.

TWIN TRANSITION IN THE MARITIME SHIPPING INDUSTRY.

By Margunn Aanestad, Raissa Pershina, Ole Hanseth, Department of Informatics, University of Oslo

The maritime shipping industry accounts for 3% of global GHG emissions. While long-term transition efforts are oriented to alternative fuels, short-term avenues to cut GHG emissions are through optimization strategies where the use of digital technologies helps reducing fuel consumption.

Relevant digital innovations that are applied to this problem involves advanced analysis on real time and historical data can generate sustainability gains through e.g., improving vessels' operational efficiency, choosing more optimal routes between destinations, and through utilizing the global fleet's

capacity more efficiently. Some concrete data-centric innovations that are developed include:

Optimize operational efficiency: The Kongsberg Energy Management System (EMS) collects data from various sources onboard a vessel, including engines, propulsion systems, and deck machinery. This enables crew members to optimize operations by identifying and remedying inefficiencies. The system also enables detailed fleet and vessel analysis. Robotic technologies such as Kongsberg's HullSkater cleans ships' hull from fouling and reduces friction and drag, which is claimed to help reduce fuel consumption by up to 15 %.

Predictive Maintenance. Predictive maintenance in the maritime shipping industry harnesses diverse data types, including sensor data from various ship systems, historical records, environmental (weather) conditions, and operational data, to foresee and mitigate potential equipment failures. AI models analyse this data to predict such failures before they occur.

Route optimization. Digital tools can identify the most efficient shipping routes, considering factors such as vessel characteristics, fuel consumption, traffic data, ocean and weather data (e.g. wave heights), port conditions and traffic. This optimization leads to reduced operational costs and lower environmental impact. For instance, StormGeo suggest a route and optimal speed, and utilize real time data from sensors onboard the vessel to update these recommendations.

Efficient Cargo Handling and Management. AI-powered robotics and automation systems

can enable rapid loading/unloading of containers, significantly reducing delays, and optimizing terminal operations. Furthermore, AI-driven algorithms play a crucial role in maximizing cargo stowage efficiency, ensuring optimal use of space, and minimizing the likelihood of damage during transportation. These technologies also assist with optimization of other processes that happen in ports (e.g. port call optimization, traffic management etc.).

General and industry-specific barriers:

Adopting data-centric innovations tend to face several (general) barriers, such as a) data accessibility, quality and integration issues, b) establishing trust and collaboration in data sharing, and c) complex, resource-intensive digital transformation processes in a traditionally conservative sector.

The need for

sociotechnical/interdisciplinary research:

The development and adoption of data-centric innovations necessitate an integrated understanding of business and organizational aspects together with technological and regulatory challenges. The sector represents a complex constellation of international, regional, and local actors, digital platforms and regulations that must be accounted for. Also, a recognition that drivers for more transparency also instigates counter-forces of data manipulation and obfuscation. Thus a broad interdisciplinary perspective is crucial to understand the dynamics of the transition process.

TWIN TRANSITIONS IN THE TRANSPORT SECTOR.

By Jørgen Aarhaug, Transport Research Institute

I study twin transitions related to mobility. More specifically I have studied the combination of digitalisation and electrification related to different modes of transport (i.e. private car, public transport, e-scooters, taxis/ridehailing, e-bikes and ferries).

Digitalisation is promoted by two hugely different agendas one focused on reducing the barriers to the use of specific services as a means to promote a sustainability transition, the other focused on making money. Although both these agendas have many similar properties in terms of technologies used, usually apps to increase use of a particular service (such as public transport, e-scooters, taxis or charging) they are in conflict. Digitalisation facilitated innovations are typically suited to provide better information on the available services. This can help overcome information induced barriers preventing use or it creates new markets. Digitalisation facilitated technologies can reduce the barriers towards public transport use, or EV adoption, but it does not alter the underlying properties related to the use of energy and space of the modes in question. An electric car is still a car, and public transport still follows lines and schedules. Reducing barriers tend to increase the use of transport and as a consequence induced externalities, such as emissions, accident risk and space consumption. On the one hand society needs digitalisation to reduce the consumption of energy and space intensive transport, on the other hand digitalisation

reduce the barriers to consuming energy and space.

Twin transitions as a concept may help highlight the complexities of the processes at hand. There are many studies focusing on developing a technology (often an app) that is supposed to solve “everything.” It seldom does. The issues at hand, changing how society moves, is complex and cannot be easily solved by a technological solution. Better technologies may both be part of a solution and make the problem worse. The transitions need to happen in parallel.

To increase mobility can be both utility maximizing and economically profitable. However, it acts against a sustainability transition. The fundamental issues are not linked to the efficiency or environmental impact at a sector level. Rather, it is a systemic failure at system level. We consume too much of the wrong things. It is not a technical issue, it is a societal or organisational issue. Digitalisation (and technological progress) improve efficiency, but as long as people desire to move, this is likely to result in increased negative externalities from the consumption of mobility, and detrimental consequences for the environment, unless organisational changes are made to utilise these gains to reduce the negative impact of mobility. This is not the same as saying that mobility has to be avoided, rather that decisions need to be made continuously in order to ensure that the gains from digitalisation does not result in a deeper lock-in in an unsustainable mobility pattern. The important challenges are in the realm of social science not technology, (but technological progress can help).

TWIN TRANSITION IN THE TEXTILE SECTOR.

By Signe Davidson, Centre for technology, innovation and culture, University of Oslo

I study twin transitions in the textile sector. I look at the development of a digital product passport technology specific for textiles. The digital product passport is a key tool in the EU’s 2022 Strategy for Sustainable and Circular Textiles. Through regulations, the digital product passport for textiles is becoming mandatory for businesses of a certain scale by 2027. We therefore see the development of a digital technology in an industry not usually through of as very tech savvy, driven by sustainability goals and strategies. There are also other examples of digital technologies emerging in the textile sector in response to the sustainability push; blockchain technology for sharing of data, the use of artificial intelligence in the design process, repair-oriented customer service systems and modern resale platforms.

The textile sector is highly pollutive and resource intensive. In fact, it ranks second on the list of polluting industries, only beaten by the oil and gas industry. The sustainability issues are a result of social dynamics and consumption patterns as well as today’s manufacturing processes and textile waste management. A transition of the sector requires change along the whole supply chain, both upstream and downstream. This involves for instance improved material inputs, improved working conditions in manufacturing, design for durability and reparations, new business models in sales (i.e. rental, repair services), technologies for material recycling (mechanical or chemical) and separate textile waste collection. In addition, it is vital that we reduce the

quantity of textiles consumed. A transition away from the fast fashion mindset in the general population is therefore also necessary, often envisioned through the introduction of circular economy principles, closing the loop on textiles.

This larger supply chain transition is at the core of what the EU is trying to achieve. The digital product passport is a digital tool that is linked to most parts of the textiles supply chain through enhanced information requirements from the textile producers. The main goals of the digital product passport are:

- Enhancing sustainable product
- Extending product lifetimes, optimizing product use, and providing new business opportunities to economic actors through circular value retention and extraction
- Supporting consumers in making sustainable choices
- Enabling the transition to the circular economy by boosting materials and energy efficiency
- Supporting authorities to verify compliance.

Digital technologies are often framed as the way forward in dealing with today's unsustainable regimes. Digital technologies have the potential to close the realization gap between theory and practice of the circular economy concept. Often, digital technologies require less material input, enable data sharing and big data, and enhance transparency. Used in the right way, these qualities can greatly benefit the sector transition. This is especially relevant in the case of sustainability-driven digital

technology development, such as the digital product passport. These technologies are designed for the sole purpose of addressing sustainability issues. Studying the synergies between digitalization and sustainability in these cases can reveal important dynamics for the twin transition to succeed.

At the same time, while digitalization has the *potential* to create positive change, it is not a given. There are many examples of the opposite. System and societal change is highly complex. As evident from the textile case, you can develop digital technologies that will have no real impact unless the social norms also change. Therefore, studying digitalization and sustainability together is important to ensure that these two development paths align.

As mentioned, in the case of the textile sector, the social and physical challenges are closely intertwined. The issue of sustainability in textiles is complex and has implications across the whole value chain. It has both deep-rooted environmental and social dimensions. As mentioned previously, one of the most fundamental challenges of the textile industry is the pattern of overconsumption. One clear benefit of the social science perspectives in studying this case is therefore the assessment of both these dimensions in the research. Studying one without acknowledging the impact of the other can result in ineffective outcomes. This also applies to policy work and company initiatives. A wider perspective is necessary to successfully tackle the complexity of the challenges ahead.

TWIN TRANSITIONS IN THE OIL AND GAS SECTOR.

*By Katja Maria Hydle and Hannah Schupfer,
Department of Informatics, University of Oslo*

Digital platforms have become increasingly present across a variety of industries, including heavy-asset industries, such as oil and gas (O&G). We have explored how digital platforms contribute to sustainability, focusing on actors and ecosystems that revolve around digital platforms for O&G being responsible for a large amount of emissions. To reduce greenhouse gas emissions, it is important that companies dominating carbon-intensive industries, such as O&G, change behavior while accounting for and reducing the actual emissions. Since over 70% of the global greenhouse gas emissions come from the energy sector, it is imperative for O&G companies to divest from conventional, dirty technologies and engage in green and more sustainable solutions.

For technological innovation and development, oil companies are largely dependent on innovations from suppliers and entrepreneurial companies for digital transformation, industrial platform ecosystems and energy efficiency tools. Industrial digital platforms connect IoT-enabled facilities and machines, collect data from equipment, operations and processes and provide platform services such as integrated work management, predictive maintenance, autonomous services, and overview of remote operations.

Twin transition for O&G companies, involves using solutions on digital platforms to reduce emissions and thus become more sustainable. We have followed a digital platform, the

creation of different solutions for O&G companies, and we found different forms of solutions. One is indirect sustainability effects, by using the digital platform for efficiency gains and optimization. The other is direct sustainability effects, where platform applications are made to address sustainability challenges, using solutions for reporting, and accounting the emissions.

The synergies between the digital and the sustainable, is using digital platforms and data to first report and second reduce emissions. This twin transition between digital platforms, use of data and sustainability reporting and possible reduction is imperative to understand in a social science perspective to expose the industry development and to inform policy makers of possible important actions.

Although O&G companies discursively commit to a divestment from fossil fuels, and the digital platforms solutions to report and reduce emissions, twin transition still relies on individual companies' action. Thus, this stresses the need of policy makers to lead the twin transition through concrete policies, direct regulations, and binding requirements on limiting emissions and the economic support for green technologies.

LESSONS LEARNED AND NEW QUESTIONS

The above examples of scholarship open various insights into promising avenues where digital innovations may contribute to establishing more sustainable patterns of production and consumption: sustainability

transitions. As discussed by these snippets of research, digital solutions as general-purpose technologies have the potential to increase sustainability in all central sectors of the society: energy, food, mobility, and clothing. The examples also showed that, currently, the opportunity for twin transitions typically lies in reducing the consumption of materials and energy by changing how the societal needs may be met with smaller impact on the physical environment.

The presented research has also shown that digital innovations' potential to increase sustainability hinges on their ability to lead to system changes in the patterns of production and consumption. Thus, the challenges related to twin transitions are often socio-technical and systemic in nature, expanding far from the confines of the technology itself, into the ability of facilitating change processes in the surrounding systems, consisting of networks of firms, users and regulators, rules and norms, business models, infrastructure, and practices. In other words, it is the actors who must realize the sustainability benefits by creating novel practices and business models for the novel solutions, push for regulatory changes, create markets, develop, and diffuse knowledge, and so on. In the meantime, actors are faced with various challenges, such as mismatches with prevailing rules of the sector, and other sources of inertia for change.

The above analyses also show that digital innovations' contribution to sustainability can be merely incremental, meaning, that the change is limited to optimizing existing production and consumption patterns, as shown by the oil and gas case. Meanwhile,

and illustrated by the mobility example, digitalization may also lead to outright negative consequences for sustainability.

Finally, however, digital innovation may also possess the potential of providing means to solve critical bottlenecks in the more fundamental transitions towards sustainability, for example by reducing the challenge of intermittent renewable energy through smart electricity system and helping to transform the linear production and consumption patterns into circular ones. Such examples of differences highlight the need to be mindful that digital solutions effects to sustainability transitions are not pre-determined, but subject to how actors may choose to empower and deploy digital solutions (see Figure 1).

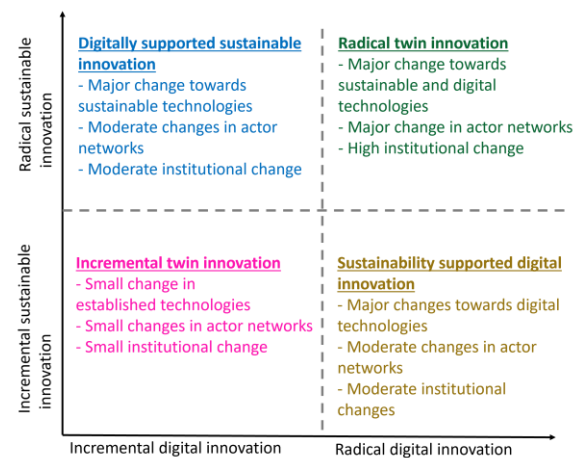


Figure 1 Different modes of couplings between digital and sustainable innovations (Mäkitie et al., 2023).

Given that the studied solutions in this research note are yet in their early stages, it is yet unclear whether the studied digital technologies lead to significant emission reductions or fundamental structural changes in the studied sector.

Moreover, little attention has yet been paid to assessing e.g. the increased energy needs and emissions related to computing, and whether such externalities offset the intended positive consequences. Therefore, to pursue twin transitions, it is necessary for researchers, managers, and policymakers alike to continue to monitor whether digital innovations indeed lead to more sustainable production and consumption systems, or “only”, towards more digital ones.

REFERENCES

Aarikka-Stenroos, L., Ritala, P., & Thomas, L. D. (2021). Circular economy ecosystems: A typology, definitions, and implications. *Research handbook of sustainability agency*, 260-276.

Aspelund, A., Olsen, M. F., & Michelsen, O. (2021). Simultaneous adoption of circular innovations: a challenge for rapid growth of the circular economy. In *Research Handbook of Innovation for a Circular Economy* (pp. 160-173). Edward Elgar Publishing.

Bohnsack, R., Bidmon, C. M., & Pinkse, J. (2022). Sustainability in the digital age: Intended and unintended consequences of digital technologies for sustainable development. Wiley.

Hognes, E. S., & Skaar, C. (2017). *Avfallshåndtering fra sjøbasert havbruk*.

Makitie, T. et al. (2020) Greener and smarter? Transformations in five Norwegian industrial sector. https://ntnuopen.ntnu.no/ntnu-xmlui/bitstream/handle/11250/2723268/M%C3%A4kitie+et+al+2020_INTRANSIT+RS1+report.pdf?sequence=1

Mouthaan, Matthijs; Koen Frenken, Laura Piscicelli, Taneli Vaskelainen, (2023): Systemic sustainability effects of contemporary

digitalization: A scoping review and research agenda, *Futures*, Volume 149,

Mäkitie, Tuukka; Jens Hanson, Sigrid Damman, Mari Wardeberg, (2023) Digital innovation's contribution to sustainability transitions, *Technology in Society*, Volume 73, 2023,

Sareen, Siddharth (201): Digitalisation and social inclusion in multi-scalar smart energy transitions, *Energy Research & Social Science*, Volume 81, 2021,

Sundt, P., Briedis, R., Olav, S., Erlend, S., Johnsen, H. R., & Schulze, P.-E. (2018). Rapport for Miljødirektoratet. Underlag for å utrede produsentansvarsordning for fisker- og akvakulturnæringen. <https://www.miljodirektoratet.no/publikasjoner/2018/mai-2018/underlag-for-a-utrede-produsent-ansvarsordning-for-fiskeri--og-akvakulturnaringen/>

Ullern, Eli Fyhn (under review in a journal). Unpacking complementarities in circular economy innovation ecosystems: the case of industrial plastic waste from the Norwegian aquaculture industry.

Van de Ven, A. H. (2007). *Engaged scholarship: A guide for organizational and social research*. Oxford University Press on Demand.