Industry 4.0 in Finland: Towards Twin Transition

Iqra Khan\textsuperscript{a}, Osmo Kauppila\textsuperscript{a,b}, Jukka Majava\textsuperscript{a}, Marko Jurmu\textsuperscript{c}, Jan Olaf Blech\textsuperscript{d}, Elina Annanperä\textsuperscript{e}, Marko Jurvansuu\textsuperscript{c}, and Susanna Pirttikangas\textsuperscript{f}

\textsuperscript{a}Industrial Engineering and Management, University of Oulu, Oulu, Finland
\textsuperscript{b}Quality Technology and Logistics, Luleå University of Technology, Luleå, Sweden
\textsuperscript{c}VTT Technical Research Centre of Finland Ltd., Oulu, Finland
\textsuperscript{d}Department of Electrical Engineering and Automation, Aalto University, Espoo, Finland
\textsuperscript{e}M3S Research Unit, University of Oulu, Oulu, Finland
\textsuperscript{f}Center for Ubiquitous Computing, University of Oulu, Finland

In the global rankings of digitalisation and Industry 4.0 maturity, Finland constantly places among the frontrunners. This study examines the path Finland has taken to reach the forefront, the drivers, and the current challenges and future opportunities related to Industry 4.0 and digitalisation. This analysis is based on extensive experience in Industry 4.0-related ecosystem projects, policy documentation and previous research. As Finland focuses on the export of high-value-added products and services, the early adoption of new technologies is vital and thus a key driver. Moreover, the national culture of innovation, R&D and triple helix collaboration have driven Industry 4.0 implementation along with a highly skilled workforce. However, multiple barriers hindering full Industry 4.0 utilisation still exist, including SMEs’ hesitation to digitalise due to insufficient support mechanisms, an aging population and the difficulty in finding single-source solutions. Respective future opportunities were found in areas such as smart sustainable manufacturing and ecosystems, enhanced SME involvement, lifelong learning and platform economy. Currently, Finland is moving from digitalisation towards a twin transition and sustainable ecosystem-to-ecosystem collaboration. Practical early-stage examples of implementing this policy include the AI 4.0 and the Sustainable Industry X supercluster initiatives.

Keywords: Industry 4.0; Finland; digitalization; sustainability; twin transition; drivers; barriers; opportunities

Introduction and Country Background

As the European Union’s (EU) leader in digitalization performance (DESI 2020, DESI 2019) and its most sparsely populated nation, Finland is a Nordic country of 5.5 million inhabitants, with few political risks, high-end infrastructure and good quality logistics (Kaivo-Oja \textit{et al.} 2018). Finland is amongst the leaders in many global rankings, such as PISA (Schleicher 2019), anti-corruption (Transparency International 2020), happiness (Helliwell \textit{et al.} 2020) and innovation (Cornell University \textit{et al.} 2020).

In Industry 4.0 rankings, Finland also ranks near the top. Castelo-Branco \textit{et al.} (2019) place Finland as a leader alongside the Netherlands in Industry 4.0 readiness in manufacturing in the EU. Atik and Ünlü (2019) rank Finland second in Europe in Industry 4.0 performance. Additionally, Sung (2018) investigated global Industry 4.0 competitiveness based on UBS (2016), WEF (2016) and IMD (2017) and ranked Finland second behind Singapore.
The Finnish industry is based on high-value-added export-oriented manufacturing (Cifolilli and Muscio 2018) due to its small domestic market and price competition not being an option. To remain competitive, Finnish manufacturers need to be flexible, reliable and able to provide state-of-the-art technology (Kaivo-Oja et al. 2018). Examples of export companies in Finland include Stora Enso (wood and paper products), Kemira (chemicals), Wartsila (marine, power), Neste (oil products), Nokia (information and communications technology), KONE (escalators), SSAB (steel products), ABB (robotics, power) and Ponsse (forest harvesters). Recently, the Finnish game industry has had success stories as well, such as Rovio (Angry Birds) and SuperCell (Clash of Clans).

Regarding exports, in 2005, nearly 86% of Finnish exports were industrial goods, but the share of services is currently 33% (Confederation of Finnish Industries 2020). Still, most exports are physical products. In 2019, the total goods exported were worth 64.8 billion euros with 2% annual growth, while the service exports totalled 31.7 billion euros in 2019 with 17% annual growth (Confederation of Finnish Industries 2020). The Finnish industry depends on its international supplier base, with more than 80% of intermediate goods and components coming from abroad (Ali-Yrkkö and Kuusi 2020).

The Finnish economy has fluctuated between periods of growth and turmoil due to events such as the collapse of Eastern trade accompanied by a financial crisis (1990–1993), a global financial crisis (2007–2009) and the collapse of Nokia’s production (2007–2011). The shift towards digitalisation could be seen to have started in the mid-1990s, when the value added in the electronics and electrical products sector exceeded both the wood and paper and machinery and equipment sectors. In recent years, between 2015 and 2020, the GDP has steadily grown (Statistics Finland), and there is also evidence of manufacturing jobs being reshored to Finland lately (Kaivo-Oja et al. 2018).

**Digitalisation Policy in Finland**

Digitalisation and Industry 4.0 under the term “Industrial Internet” can be found in policy documents from the era of the Katainen and Stubb governments (2011–2015). In Finland, strategizing pre-set visions and plans for the Industry 4.0 transition was the first step on the roadmap of Industry 4.0. For example, the governmental program of 2011 proffered the introduction of intelligent solutions in all sectors of society and the creation of intelligent strategies for each of the ministries (Prime Minister’s Office 2011). In the Industrial Competitiveness Approach (Känkänen et al. 2013), ICT is recognised as not only a support function but a ‘bloodline’ for the manufacturing industry.

Further development by the Ministry of Employment and the Economy ([MEE] 2014) has involved creating the prerequisites and support for the Industrial Internet's implementation. The report presented actions for promoting digitalisation as a value creator of industrial manufacturing for the MEE itself, for the Finnish Funding Agency for Technology and Innovation (Tekes – an activator and funder of business, higher education and research institutions’ R&D projects), for the Ministry of Transport and Communications and for the Ministry of Education. Following this trend, in 2014, the Prime Minister’s Office commissioned an assessment on the challenges and opportunities of the “Finnish Industrial Internet” (Ailisto et al. 2015). The results were reported in 2015, and another set of recommendations were suggested.

The Sipilä government’s (2015–2019) program (Prime Minister’s Office 2015) presented
a new strategy that focused on the digitalisation of public services and the creation of a growth environment. This led to the second phase on the Industry 4.0 roadmap, which emphasised the adoption of new technologies and solutions development by fostering a culture of experimentation. One action point of the programme was to establish a governmental program for the Internet of Things. Later on, in 2017, AI was promoted to a strategic spearhead, and a roadmap for integrating AI into the Finnish society and businesses was created (MEE 2019). Ecosystem thinking also became visible in the national policy and was prominently featured in the governmental action plan for 2018–2019 (Finnish Government 2018). This can be viewed as the third step of Industry 4.0 implementation in Finland – ecosystemic collaboration and data-driven value creation.

The Rinne (2019) and the current Marin (2019–) governmental programs (Finnish Government 2019a, 2019b) advocated for a switch to sustainability, inclusiveness and carbon-neutrality. Ecosystemic thinking has also been strongly featured (e.g., “Ecosystems will be the engines of sustainable growth” [Finnish Government 2019a, 2019b]). The Research, Development and Innovation Roadmap (Ministry of Education 2020) lists three strategic development targets: competence, a new partnership model and an innovative public sector. A key figure in operationalising the strategy is Business Finland (former Tekes), and their programs and terminology provide insight on how Industry 4.0 has been interpreted in Finland. Their policy is also transitioning towards sustainability through “Sustainable Manufacturing Finland” (Mattila 2020). This programme shares the “twin transition” ideology of the EU’s Green Deal, and implies promoting digitalisation – especially through a platform economy, AI and data-driven business models – while simultaneously increasing the sustainability of the business in terms of a circular economy, lowered carbon emissions and inclusion. This fourth step of the progression can be called “Sustainable Industry 4.0 ecosystems.”

It should be noted that despite Finland being on the forefront of digitalisation, there has not been a national definition for Industry 4.0. “Industrial Internet” made a somewhat brief appearance in the mid-2010s, but it was soon superseded by digitalisation and individual areas of Industry 4.0, such as IoT and AI. Following, Kaivo-Oja et al. (2017) published a definition: Industry 4.0 in Finland is implemented through high-end automation and digitization processes by using advanced electronics and information technologies. To summarise how this has taken place, Figure 1 illustrates key developments in the national Industry 4.0 strategy in Finland.
Methodology

To conduct more thorough investigations of drivers, barriers and future opportunities for Finnish Industry 4.0 implementation, a framework of these three dimensions was first created based on a literature review of the subject. The most relevant literature sources identified include Türkes et al. (2019), Stentoft et al. (2019), Rajput and Singh (2019), Moeuf et al. (2020), Müller and Voigt (2018), Kamblea et al. (2018) and Horváth and Szabó (2019). An initial search was constructed using the search strings “Industry 4.0 in Finland” and “Drivers, barriers and opportunities of Industry 4.0” in Google Scholar. After that, the best papers and reports specifically relevant to the Finnish context were included in the study. The contents of the papers and reports were carefully reviewed, and Industry 4.0-based barriers, drivers and opportunities were handpicked using the identified documents.

Subsequently, each individual item’s relevance to Finland was analysed based on existing policies and research. This was complemented by the authors’ expertise on the topic that was gained, for example, from conducting several research projects, such as Reboot IoT Factory (2018–2021). The project is one the first pilot projects in the Finnish digitalisation program Reboot IoT Finland, which aims to facilitate the digital transformation of Finnish manufacturing. Table 1 presents the drivers, barriers and opportunities in order by their perceived relevance to the Finnish context, explained in the sections below.

Table 1. Drivers, barriers and opportunities of Industry 4.0 in Finland.

| Drivers                        | Barriers                                                | Opportunities                                           |
|--------------------------------|---------------------------------------------------------|---------------------------------------------------------|
| High market competition        | Single source solutions for unique needs are difficult to find | Growing global markets                                   |
| National infrastructure that supports Industry 4.0 | SMEs lacking monetary and strategic support               | Competitive advantage through smart and sustainable manufacturing |
| Culture of innovation and R&D | SMEs hesitance to digitalise their operations | Involving SMEs to create new innovations in business ecosystems |
|--------------------------------|-----------------------------------------------|---------------------------------------------------------------|
| Highly skilled workforce      | Aging population, less potential employees with new skills | Societies as innovation platforms |
| Culture of triple helix collaboration | Issues related to data security, ownership and trust in digital ecosystems | Collaboration platforms for industrial symbiosis, value creation networks and business ecosystems |
| Business model innovation    | Lack of methodological approaches, such as best-practice-examples, toolsets and distilled information | Sustainable business models, organizations, processes and products |

**Industry 4.0 Drivers in Finland**

Changes in economic and social life conditions have led to reliance on modern digital technologies signifying high-tech strategies and innovations as the underlying factors of Industry 4.0 and its development (Türkes *et al.* 2019). The Finnish manufacturing industry has initiated digitalisation processes to increase productivity, which is required for competency in the global market and retaining the industry in Finland. The industry has become a part of the ‘new globalization’ trend the world has been facing since 1990 (Ali-Yrkkö *et al.* 2017).

Currently, Finnish factories are in very close competition with their global counterparts. High labour and logistics costs have resulted in decreased cost competitiveness. The total logistics costs of Finnish manufacturing firms are approximately 14% of the turnover, whereas in Swiss manufacturing firms, they are approximately 8%. The difference is partly attributable to the long transportation distance to export markets (Solakivi *et al.* 2018). To beat the global competition, the Finnish manufacturing industry relocated their activities and tasks to locations abroad to optimise their efficiency and the reconfiguration of their value-chains (Kaivo-Oja *et al.* 2018). Because the global markets are becoming more heterogenous over time, a growing number of competing companies opting for technological advancements have abruptly made it essential for Finnish companies to reduce their time-to-market rates, to be amongst the first movers and to gain a decisive advantage over their competitors by increasing their innovation capability, productivity and efficiency.

Political support from different actors in Finland has played a vital role in shaping the Industry 4.0-based economic development in the information and telecommunications and healthcare and engineering sectors. With this support, Finland has been able to provide the necessary modern and robust infrastructure to support digitalisation. Connectivity is targeted through immense 5G initiatives that aim to serve an extensive range of sectors, such as connected automobility, e-health and energy management. Furthermore, the infrastructure supports the use of advanced digital technologies, such as AI, IoT, CPS and big data in general. More specifically, Finland has been marked as the most advanced country to uptake cloud services (DESI 2020).
The general aim of Industry 4.0 is to eradicate the boundaries between the digital and the physical world, acquiring highly skilled Industry 4.0 human operators for the accurate exchange of information between intelligent support systems, supported by their robust aids and capabilities (Schmidt et al. 2015). In Finland, such production systems support the digitization of production units by successful human-robot collaboration, thereby building smart and intelligent factories with multiplied efficiency levels in terms of monitoring and supervision support systems, digital computing systems, virtual trainings and decision support systems. A highly educated workforce/human capital in terms of digitally skilled labour and ICT specialists has supported Finland in becoming a digitalisation leader (DESI2020). This has been further reinforced by the Finnish national curriculum (2016), which includes coding and programming from the very beginning of students’ school education. For example, sixth-grade students studying handicrafts learn to embed automation as a part of their product, whereas students studying mathematics learn to solve problems in a graphical programming environment. Furthermore, in secondary school (grades 7–9), they learn how to use their skills to produce digital work individually and in a collaborative environment.

Finland has a tradition of research–business collaboration, and around 70% of large businesses collaborate on innovation with higher education or research institutions (OECD 2013a, 2017). While the percentage of large businesses collaborating with research and higher education institutions is the highest in the world, the SME portion is only ranked fourth, following after Great Britain, Belgium and Austria. Collaboration between companies and research organisations produces new Industry 4.0-based innovations and operators in the ‘factory of the future’ (Isabel et al. 2019). Successful collaborations have presented key innovations together with smart technologies based on CPS, IoT, cloud computing, big data and 3D printing, leading to increased efficiency and competitiveness.

Industry 4.0 has established digitalisation trends that vary from country to country. While the digitalisation policies of Germany and Japan have focused primarily on product quality (Türkes et al. 2019), the US and China have emphasised efficient product delivery and cutting the costs, respectively (Urciuoli et al. 2013; Müller and Daeschle 2018; Zhu and Geng 2013). Large businesses in Finland have developed their business models based on new product and service offerings and the simplification of smart products based on quality. Finnish manufacturers distinguish themselves based on the reliability and flexibility they offer in the regional balancing of their value chains (Kaivo-Oja et al. 2018). This allows Finnish manufacturers to synchronise their operations with all the stakeholders in the value-chain and to precisely be more responsive to customer needs. Additionally, strong customer orientation, flexibility and state-of-the-art technologies have resulted in the dynamic capabilities needed for Industry 4.0 development (Xu et al. 2018). In summary, the high process digitalisation of the country is based on high-end governmental financial support, an educated workforce, technological innovation and close industry–research collaborations.

**Industry 4.0 Barriers in Finland**

The Finnish industry is characterised more by customised offerings, which makes it hard to find off-the-shelf/single-source solutions. To find holistic solutions, companies need the competence to define their own needs and collaborate with the SMEs to provide expanded solutions. Subsequently, without the large budget required for SMEs to match
big corporations, it becomes a huge challenge for SMEs to achieve visibility, thereby making it difficult to be competitive and seen as valuable for strategic partnership.

Finland lacks the culture and resources for later-stage venture capital investments compared to many other countries (Saarikoski et al. 2014), which hinders its SMEs’ growth in international markets. Furthermore, while the start-up culture itself is quite strong, there is a lack of start-ups oriented towards manufacturing industry innovation. In addition to venture capital, SMEs, particularly microenterprises, are under-represented in government support for companies. For instance, micro and small enterprises only represent 6.2% and 22%, respectively, of subsidy receivers (Statistics Finland 2020). Additionally, regarding Industry 4.0, digitalisation money might not be targeted towards manufacturing.

Digitalisation requires investments in new technologies, such as artificial intelligence, digital twins, advanced robotics and virtual reality. The field of new technologies is very wide and disperse, often without standards. However, even if the technology sounds lucrative, it is often hard to estimate the business benefits it can provide. Even large companies do not have enough resources to identify, evaluate, test and pilot all digitalisation solutions to gain their full benefits. Testing is required to achieve confidence in actual large-scale investments and deployment, and change management is required throughout the organisation while processes become more autonomous. For SMEs and mid-cap size manufacturing, which comprise most Finnish exports, the challenge is even more severe. The profitable digitalisation solutions identified by the forerunner companies would have to be scaled down to typically low-volume SME production. Additionally, the investment level needs to be lower for new technology in SMEs, as they may lack digital expertise.

Finland has experienced a natural decrease in population growth leading to a lack of young people for future the technological development (Santos et al. 2017), creating a gap between the skills of traditional factory workers and the new skills needed on the job. This is significant, as a Deloitte study has predicted that technology will likely create more jobs in the manufacturing industry (Wellener et al. 2020), posing a challenge for procuring skilled and motivated labour for the industry in Finland. Thus, as production costs are high in Finland and most likely will stay that way, the level of automation and optimisation of production processes must be under constant development to keep the competitive edge.

Despite a well-established digital ecosystem, the country still needs substantial investment from companies in data security and protection standards. Further, the companies need to understand data security laws and standardisation issues related to digital strategy and working with machines (Wang et al. 2015). These issues can be further tackled by offering new incentive initiatives and funding programs. Another shortcoming stems from the legal and contractual uncertainties in using certain technologies; however, these can be solved by developing and adopting legal frameworks about big data collection, data privacy and data security.

Finally, companies joining in implementing Industry 4.0 lack best-practice examples from successful organizations. Sharing methodological toolkits in the ecosystems will thereby create enormous opportunities for start-ups and SMEs in terms of providing a baseline for strategic and market orientations, exemplifying business operations (Sahi et
al. 2020). Thus, while Finland is still striving to offer large-scale digitalisation solutions in the manufacturing industry as a country with both strong ICT and manufacturing verticals, it could do much more.

**Industry 4.0 Opportunities in Finland**

Industry 4.0 linked with high-level digitalization has created the opportunity for Finnish companies to join global value chains and understand the diversity of different industrial branches, their economic geography and their supply chain implementation strategies (Ailisto et al. 2015). As a result, this kind of multi-dimensional global understanding will help Finnish companies to attract job markets and foreign direct investments. Finland’s strengths as a pilot plant site due to its low collaboration barrier, the availability of technology and its highly skilled workforce should be further harnessed.

Industry 4.0 has and continues to transform the definition and skills required for workers. Active learning, analytical thinking, innovation, programming, critical thinking, co-creation, networking and complex problem-solving skills, emotional intelligence, reasoning and system analysis will be essential qualities for the industrial workforce (The National Academies of Science 2017). The education curriculum and systems must evolve to support the lifelong learning of blue collar workers and white collar workers as well as to attract individuals to counter the labour shortage in the manufacturing industry. To ensure the rapid reskilling of society, agile education is required to ensure that companies can leverage novel solutions.

Previously, SMEs in Finland have lagged behind in adopting Industry 4.0 due to multiple factors, such as lack of resources compared to larger companies and a lower degree of initiative to apply the technologies within their business networks (Stentoft et al. 2019). However, SMEs and start-ups are now seen as tools for enhancing the strategic and operative performance of the traditional companies (Ailisto et al. 2015). Ecosystem collaboration projects and the growth of a start-up scene that fosters the creation of more Industry 4.0-oriented start-ups has resulted in companies such as Meluta (acoustic and vibroacoustic measurements) and Visual Components (3D manufacturing simulation). However, even though SMEs are involved in Industry 4.0 implementation as technology and solution providers, the level of SMEs’ Industry 4.0 maturity in absorptive capacity and knowledge acquisitions (Müller et al. 2020) could be further improved.

The value created based on Industry 4.0 and digitalization in Finland has utilised smart components, sensors, data sharing standards and interfaces building autonomous and integrative architectures. Currently, it is necessary to focus on the interconnected systems forming trusted and collaborative networks, thus creating a need for innovative societies. These platforms and ecosystems based on innovative societies are seizing new opportunities in building new strategic and operative business capabilities to integrate processes, structures, visions, information systems, data and competencies through active experience sharing (Kaivo-oja et al. 2017). In addition, cross-company collaborations for exchanging smart data, resources, products and materials form value-creating networks, offering new opportunities for industrial symbiosis and thus creating ways for closed-loop product lifecycles through efficient coordination (Schuh et al. 2014). In an attempt to capture further value, Finland is currently in the stage of moving past ecosystemic collaboration into collaboration between ecosystems.
Another major global disruptor of late has been platform economy, with giants such as Google or Amazon aggressively utilising the ‘winner takes all’ dynamic to capture the B2C market in digital services. To address these developments, the EU has devised the European Data Strategy, which established a regulatory framework for handling and utilising data in business value creation. It specifically assesses value capturing in the emerging B2B platform economy based on data sharing between companies, organisations and the public sector. Implementations of the data strategy include the International Data Spaces (IDS) and GAIA-X architectures, which aim for a federated architecture of services for B2B data sharing and value creation. At the close of 2020, GAIA-X has also been emerging in Finland. The Finnish hub is forming, and the first GAIA-X members have included VTT, SITRA, CSC and the Vastuu Group. The potential for cross-vertical data sharing in the Industry 4.0 verticals has been recognised. However, use cases are still few, and opportunities are more unclear in contrast to some of the other verticals moving forward in the EU, such as mobility-as-a-service and healthcare. Nevertheless, Finland has the prerequisites in place and has profiled itself along with the Netherlands as one of the frontrunners in charting opportunities arising from GAIA-X (Vahti 2020).

Moreover, the technological advancements and inclinations based on Industry 4.0 require companies to transform from a linear to a circular economy and forge a path towards sustainability (Rajput and Singh 2019). Manufacturing companies in Finland are also striving to attain sustainable operations and achieve circular economy principles. Exploring the opportunities created by the technological revolution, companies are transforming their supply chains by generating a vast amount of data concerning raw materials, waste monitoring, energy consumption, closed loop supply chains and assessments of real-time information (Geissdoerfer et al. 2017). In a nutshell, if companies rightfully use the opportunities provided by Industry 4.0, they can successfully develop sustainability-based business models, thereby maintaining a balance between economic, environmental and social aspects (Rajput and Singh 2019).

Discussion and Conclusion

Throughout the 2010s, digitalization has been recognised as a key factor of Finland’s global competitiveness, and the elements of Industry 4.0 have been quite successfully implemented through consistent national policy. This has been supported by a high level of education and the development of a supporting national infrastructure (OECD 2017). The traditions of a collaborative and trust-based business environment, triple helix collaboration, and a strong culture of experimentation, rapid testing and innovation have advanced Industry 4.0 implementation (Ailisto et al. 2015, Schuh et al. 2014). Moreover, high levels of R&D investments and a transition to innovation ecosystem-based thinking for value creation (Finnish Government 2018) helped Finland to reach its current position as one of the global front-runners of Industry 4.0 maturity in 2019 (Atik and Ünlü 2019; Castelo-Branco et al. 2019).

However, areas of improvement and barriers to implementation have been recognised. Finland’s population is one of the oldest in Europe and is rapidly aging (Finnish Institute for Health and Welfare 2020), causing serious concerns for recruiting a workforce with an up-to-date set of skills. While major companies are advancing in digitalisation, the knowledge is not always disseminated throughout their supply networks. In the manufacturing sector and within SMEs, there is still room for the implementation of
Industry 4.0 tools, particularly related to analytics, as noted by Mittal et al. (2020). Improving digital skills in SMEs is also a key objective in the national AI 4.0 programme launched in late 2020 (MEE 2020).

The focus on high-value-adding niche markets indicates that implementing off-the-shelf solutions is often impossible, resulting in higher costs and lead times in the implementation of digital solutions. This contributes to another barrier of Industry 4.0 implementation, as costs are often assessed as high compared to the benefits. This holds particularly true for SMEs, and the barriers of lack of expertise as well as unwillingness to commit to a long-term Industry 4.0 strategy or to invest in technology that could soon be obsolete (Moeuf et al. 2020) can be recognised in Finnish SMEs as well.

Many future opportunities can be recognised regarding the current twin transition towards digitalisation and sustainability. With the ecosystem thinking that has already been established, a current initiative to harness the knowledge and innovation created across vertical clusters aims to establish a national “supercluster” or an “ecosystem of ecosystems” to nationally coordinate these activities. This Sustainable Industry X (SIX) initiative (Figure 2) aims to integrate existing clusters and ecosystems, the best practices, national and EU policies, industry and stakeholder needs and triple helix collaboration. It is currently in an early start-up phase, but if successful, it could boost national competitiveness and support the goals of sustainable manufacturing in the near future.

**Figure 2. Initiative for establishing a national industry program SIX.**

Other future opportunities can be found within the current ecosystem collaboration models. Many of these initiatives are project-based, and they operate based on public funding. The challenge of sustaining them after the funding period has passed has not been fully solved. Furthermore, finding more explicit value propositions from research to industry and vice versa could support the creation of partnerships spanning beyond public funding of ecosystem collaboration projects. Moreover, active information sharing and working together could establish a basis of trust and more sustainable collaboration. The research community is also responsible for finding these new management qualities and practices (Horvath and Szabo 2019).
This leads to another future challenge for increasing SME participation in these innovation ecosystems, both as solution providers and solution utilisers. Due to their limited resources and ability to take risks, SMEs need implementation support to exploit and to explore Industry 4.0 opportunities, as observed by Müller et al. (2020). Future opportunities also exist within the platform and data economies. Last, to counter the issues stemming from the aging population and the shifting required skillset, all parties of the triple helix have to find ways to further promote lifelong learning and to quickly adapt to the changing requirements of workforce competences (Isabel et al. 2019).

Overall, as a society, Finland has remained at the forefront of digitalization for some time now, which has also enabled Finnish industries to successfully adopt and develop Industry 4.0 solutions and new operating models. However, structural characteristics of the society, such as the aging population and high labour cost, indicate that keeping on top of global trends and technological change remains necessary for Finland to remain globally competitive. How to adapt and stay on the forefront of innovation remains a primary concern, as sustainability and circular-economy-based operating models are becoming a new standard in global business.

References
Ailisto, H., Mäntylä, M., Seppälä, T., Collin, J., Halén, M., Juhanko, J., Jurvansuu, M., Koivisto, R., Kortelainen H., Simons, M., Tuominen, M. and Uusitalo, T., 2015. Finland - The Silicon Valley of Industrial Internet. Publications of the Government's analysis, assessment and research activities.
Ali-Yrkkö, J., Lehmus, M., Rouvinen, P., and Vihriälä, V., 2017. Riding the wave: Finland in the changing tides of globalisation. Helsinki: Research Institute of the Finnish Economy – ETLA.
Ali-Yrkkö, J., and Kuusi, T., 2020. Korona-sokki talouteen - Missä määrin Suomi on riippuvainen ulkomaisista arvoketjuista? [Corona-shock Hits the Economy – To What Extent Finland Is Dependent on Global Value Chains?]. ETLA Muistio [online], 87. Available from: https://pub.etla.fi/ETLA-Muistio-Brief-87.pdf [Accessed 09 December 2020].
Atik, H., and Ünlü, F., 2019. The Measurement of Industry 4.0 Performance through Industry 4.0 Index: An Empirical Investigation for Turkey and European Countries. Procedia Computer Science, 158, 852–860. Available from: https://doi.org/10.1016/j.procs.2019.09.123 [Accessed 09 December 2020].
Business Finland, 2018. Digitaalisen alustatalouden tiekartasto [Roadmap for a digital platform economy]. Available from: https://www.businessfinland.fi/globalassets/julkaisut/alustatalouden_tiekartasto_web_x.pdf [Accessed 09 December 2020].
Castelo-Branco, I., Cruz-Jesus, F., and Oliveira, T., 2019. Assessing Industry 4.0 readiness in manufacturing: Evidence for the European Union. *Computers in Industry*, 107, 22–32. Available from: https://doi.org/10.1016/j.compind.2019.01.007 [Accessed 09 December 2020].

Ciffolilli, A., and Muscio, A., 2018. Industry 4.0: national and regional comparative advantages in key enabling technologies. *European Planning Studies*, 26 (12), 2323–2343. Available from: https://doi.org/10.1080/09654313.2018.1529145 [Accessed 09 December 2020].

Confederation of Finnish Industries, 2020. Ulkomaankauppa [Foreign Trade]. Available from: https://ek.fi/tutkittua-tietoa/tietoa-suomen-taloudesta/ulkomaankauppa/ [Accessed 24 November 2020].

Cornell University, INSEAD, and WIPO, 2020. *The Global Innovation Index 2020: Who Will Finance Innovation?* Ithaca, Fontainebleau, and Geneva. WIPO. Available from: https://www.wipo.int/edocs/pubdocs/en/wipo_pub_gii_2020.pdf [Accessed 09 December 2020].

Finnish Government, 2018. *Finland, a land of solutions: Government action plan 2018-2019*. Publications of the Finnish Government, 29.

Finnish Government, 2019a. *Programme of Prime Minister Antti Rinne's Government 6 June 2019: Inclusive and competent Finland - a socially, economically and ecologically sustainable society*. Publications of the Finnish Government, 25.

Finnish Government, 2019b. *Programme of Prime Minister Sanna Marin's Government 6 June 2019: Inclusive and competent Finland - a socially, economically and ecologically sustainable society*. Publications of the Finnish Government, 33, 228.

Finnish Government, 2020. *The National Roadmap for Research, Development and Innovation*. Available from: https://minedu.fi/en/rdi-roadmap [Accessed 09 December 2020].

Finnish Institute for Health and Welfare, 2020. *Ageing policy*. Available from https://thl.fi/en/web/ageing/ageing-policy [Accessed 3 December 2020].

Geissdoerfer, M., Savaget, P., Bocken, N.M., and Hultink, E.J., 2017. The circular economy: a new sustainability paradigm? *Journal of Cleaner Production*, 143, 757–768. Available from: https://doi.org/10.1016/j.jclepro.2016.12.048 [Accessed 09 December 2020].
Helliwell, J.F., Layard, R., Sachs, J., and De Neve, J-E., eds., 2020. *World Happiness Report 2020*. New York: Sustainable Development Solutions Network.

Horváth, D., and Szabó, R.Z., 2019. Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities? *Technological Forecasting and Social Change*, 146, 119–132. Available from: https://doi.org/10.1016/j.techfore.2019.05.021 [Accessed 09 December 2020].

IMD, 2017. IMD World Digital Competitiveness Ranking. Lausanne: IMD Switzerland.

Isabel, C., Cruz-Jesus, F., and Oliveira, T., 2019. Assessing Industry 4.0 readiness in manufacturing: Evidence for the European Union. *Computers in Industry*, 107, 22–32. Available from: https://doi.org/10.1016/j.compind.2019.01.007 [Accessed 09 December 2020].

Kaivo-Oja, J., Knudsen, M.S., and Lauraeus, T., 2018. Reimagining Finland as a manufacturing base: the nearshoring potential of Finland in an industry 4.0 perspective. *Business management and education*, 16, 65–80. Available from: https://doi.org/10.3846/bme.2018.2480 [Accessed 09 December 2020].

Kamble, S.S., Gunasekaran, A., and Sharma, R., 2018. Analysis of the driving and dependence power of barriers to adopt industry 4.0 in Indian manufacturing industry. *Computers in Industry*, 101, 107–119. Available from: https://doi.org/10.1016/j.compind.2018.06.004 [Accessed 09 December 2020].

Känkänen, J., Lindroos, P., and Myllylä, M., 2013. Elinkeino- ja teollisuuspolitiitten linjaus - Suomen talouskasvun eväitä 2010-luvulla [Industrial Competitiveness Approach. Means to guarantee economic growth in Finland in the 2010s]. *MEE Publications: Innovation*.

Mattila, T., 2020. *The pressures for renewal in the manufacturing industry are intensifying - is a "twin transition" possible?* [Blog post]. Available from: https://www.businessfinland.fi/en/whats-new/blogs/2020/the-pressures-for-renewal-in-the-manufacturing-industry-are-intensifying [Accessed 09 December 2020].

Ministry of Economic Affairs and Employment, 2020. Artificial Intelligence 4.0 programme to speed up digitalisation of business [Press release]. Available from: https://valtioneuvosto.fi/en/-/1410877/artificial-intelligence-4.0-programme-to-speed-up-digitalisation-of-business [Accessed 13 November 2020].
Ministry of Employment and the Economy, 2014. Teollisuus osana elinvoimaita elinkeinorakennetta. [Industry as a Vital Occupational Structure. Global trends in industry, Finland's industrial situation and the checkmarks for renewable Finnish Industry]. MEE Publications: Innovation.

Ministry of Employment and the Economy, 2015. Palvelutalouden murros ja digitalisaatio - Suomen kasvun mahdollisuuDET. [Service economy revolution and digitalization - Finland's Growth Potential]. MEE Publications: Innovation.

Ministry of Employment and the Economy, 2019. Edelläkävijänä tekoälyaikaan: Tekoälyohjelman loppuraportti 2019. [Towards the AI age as a front runner: the final report of the AI programme 2019]. MEE Publications.

Ministry of Finance, 2020. Digitalisaation edistämisen ohjelman 2020-2023: Toimintasuunnitelma 2020 [Programme for advancing digitalization 2020-2023: Action plan 2020]. Available from:
https://vm.fi/documents/10623/1464506/Digitalisaation+edist%C3%A4misen+ohjelman+toimintasuunnitelma/5cd124e3-ec59-2fcb-79e0-a501f7ec404c/Digitalisaation+edist%C3%A4misen+ohjelman+toimintasuunnitelma.pdf [Accessed 09 December 2020].

Mittal, S., Khan, M.A., Purohit, J.K., Menon, K., Romero, D., and Wuest, T., 2020. A smart manufacturing adoption framework for SMEs. International Journal of Production Research, 58 (5), 1555–1573. Available from:
https://doi.org/10.1080/00207543.2019.1661540 [Accessed 09 December 2020].

Moeuf, A., Lamouri, S., Pellerin, R., Tamayo-Giraldo, S., Tobon-Valencia, E., and Eburdy, R., 2020. Identification of critical success factors, risks and opportunities of Industry 4.0 in SMEs. International Journal of Production Research, 58 (5), 1384–1400. Available from:
https://doi.org/10.1080/00207543.2019.1636323 [Accessed 09 December 2020].

Müller, J. M., Buliga, O., and Voigt, K. I., 2020. The role of absorptive capacity and innovation strategy in the design of industry 4.0 business Models-A comparison between SMEs and large enterprises. European Management Journal. Available from: https://doi.org/10.1016/j.emj.2020.01.002 [Accessed 09 December 2020].

Müller, J.M., and Voigt, K.I., 2018. Sustainable industrial value creation in SMEs: A comparison between industry 4.0 and made in China 2025. International Journal of Precision Engineering and Manufacturing-Green Technology, 5 (5),
Müller, J.M., and Daeschle, S., 2018. Business Model Innovation of Industry 4.0 Solution Providers towards Customer Process Innovation. *Processes*, 6, 260. Available from: https://doi.org/10.3390/pr6120260 [Accessed 09 December 2020].

OECD, 2013. *Regions and Innovation: Collaborating Across Borders*. Paris: Organisation for Economic Cooperation and Development.

OECD, 2017. *OECD Science, Technology and Industry Scoreboard 2017: The digital transformation*. Paris: OECD Publishing. Available from: https://doi.org/10.1787/9789264268821-en [Accessed 09 December 2020].

Official Statistics of Finland, 2019. Statistics on business subsidies [online]. Helsinki: Statistics Finland. Available from: http://www.stat.fi/til/yrtt/2019/yrtt_2019_2020-08-14_tie_001_en.html [Accessed: 26 November 2020].

Prime Minister's Office, 2011. *Programme of Prime Minister Jyrki Katainen's government*. Helsinki: Ministry of Finance.

Prime Minister's Office, 2015. *Ratkaisujen Suomi: Pääministeri Juha Sipilän hallituksen strateginen ohjelma* [Finland of Solutions: a strategy programme of Prime Minister Juha Sipilä’s government]. Helsinki: Prime Minister’s Office.

Schmidt, R., Möhring, M., Härting, R.C., Reichstein, C., Neumaier, P., and Jozinović, P., 2015. Industry 4.0-potentials for creating smart products: empirical research results, June. In: *International Conference on Business Information Systems*, 16–27 Cham. Springer. Available from: https://doi.org/10.1007/978-3-319-19027-3_2 [Accessed 09 December 2020].

Rajput, S., and Singh, S.P., 2019. Industry 4.0 – challenges to implement circular economy. *Benchmarking: An International Journal*. Available from: https://doi.org/10.1108/BIJ-12-2018-0430 [Accessed 09 December 2020].

Saarikoski, M., Roine, P., Ruohonena, J., Halonen, A., Sulin, J., and Lebret, H., 2014. *Evaluation of Finnish Industry Investment Ltd*. Publications of the Ministry of Employment and the Economy.

Sahi, G.K., Gupta, M.C., and Cheng, T.C.E., 2020. The effects of strategic orientation on operational ambidexterity: a study of Indian SMEs in the industry 4.0 era.
International Journal of Production Economics. Available from:
https://doi.org/10.1016/j.ijpe.2019.05.014 [Accessed 09 December 2020].

Santos, C., Mehrsai, A., Barros, A.C., Araújo, M., and Ares, E., 2017. Towards Industry 4.0: An overview of European strategic roadmaps. Procedia Manufacturing, 13, 972–979. Available from: https://doi.org/10.1016/j.promfg.2017.09.093 [Accessed 09 December 2020].

Schuh, G., Potente, T., Wesch-Potente, C., Weber, A.R., and Prote, J.-P., 2014. Collaboration mechanisms to increase productivity in the context of Industry 4.0. Procedia CIRP, 19, 51–56. Available from: https://doi.org/10.1016/j.procir.2014.05.016 [Accessed 09 December 2020].

Schleicher, A., 2019. PISA 2018: Insights and Interpretations. OECD.

Solakivi, T., Hofmann, E., Töyli, J., and Ojala, L., 2018. The performance of logistics service providers and the logistics costs of shippers: a comparative study of Finland and Switzerland. International Journal of Logistics Research and Applications, 21 (4), 444–463.

Stentoft, J., Jensen, K.W., Philipsen, K., and Haug, A., 2019. Drivers and barriers for Industry 4.0 readiness and practice: a SME perspective with empirical evidence. Proceedings of the 52nd Hawaii International Conference on System Sciences. Available from: https://doi.org/10.24251/HICSS.2019.619 [Accessed 09 December 2020].

Sung, T.K., 2018. Industry 4.0: a Korea perspective. Technological forecasting and social change, 132, 40–45. Available from: https://doi.org/10.1016/j.techfore.2017.11.005 [Accessed 09 December 2020].

Transparency International, 2020. Corruption Perceptions Index 2019. Available from: http://www.transparency.org/cpi [Accessed 09 December 2020].

Türkeş, M.C., Oncioiu, I., Aslam, H.D., Marin-Pantelescu, A., Topor, D.I., and Căpuşneanu, S., 2019. Drivers and barriers in using industry 4.0: a perspective of SMEs in Romania. Processes, 7 (3), 153. Available from: https://doi.org/10.3390/pr7030153 [Accessed 09 December 2020].

UBS, 2016. Extreme automation and connectivity: The global, regional, and investment implications of the Fourth Industrial Revolution. UBS White Paper for the World Economic Forum Annual Meeting.

Urciuoli, L., Hintsa, J., and Ahokas, J., 2013. Drivers and barriers affecting usage of e-Customs-A global survey with customs administrations using multivariate
analysis techniques. Government Information Quarterly, 30 (4), 473–485. Available from: https://doi.org/10.1016/j.giq.2013.06.001 [Accessed 09 December 2020].

Vahti, J., 2020. Sitra mukaan Euroopan digitulevaisuutta rakentavan GAIA-X-projektiin [Sitra joins the GAIA-X project shaping Europe's digital future]. Available from https://www.sitra.fi/uutiset/sitra-mukaan-euroopan-digitulevaisuutta-rakentava-gaia-x-projektiin/ [Accessed 09 December 2020].

Wang, H., Osen, O.L., Li, G., Li, W., Dai, H.N., and Zeng, W., 2015. Big data and industrial internet of things for the maritime industry in northwestern Norway. In: Proceedings of the TENCON 2015-2015 IEEE Region 10 Conference, 1–4 November 2015 Macao, China. 1–5.

Wellener, P., Dollar, P., Ashton, H., Monck, L., and Hussain, A., 2020. The future of work in manufacturing: what will jobs looks like in the digital era? Available from: https://www2.deloitte.com/us/en/insights/industry/manufacturing/future-of-work-manufacturing-jobs-in-digital-era.html [Accessed 3 December 2020].

WEF, 2016. The Global Information Technology Report 2016: Innovating in the Digital Economy. The Global Information Technology Report.

Xu, L.D., Xu, E.L., and Li, L., 2018. Industry 4.0: State of the art and future trends. International Journal of Production Research, 56 (8), 2941–2962. Available from: https://doi.org/10.1080/00207543.2018.1444806 [Accessed 09 December 2020].

Zhu, Q., and Geng, Y., 2013. Drivers and barriers of extended supply chain practices for energy saving and emission reduction among Chinese manufacturers. Journal of Cleaner Production, 40, 6–12. Available from: https://doi.org/10.1016/j.jclepro.2010.09.017 [Accessed 09 December 2020].